

# **DEVELOPMENT OF AN ONLINE PLANNING TOOL FOR DESIGNING TERRACE LAYOUTS**

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at the University of Missouri**

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**In Partial Fulfillment  
of the Requirements for the Degree  
Master of Science**

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**by**

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**DEVELOPMENT OF AN ONLINE PLANNING TOOL FOR  
DESIGNING TERRACE LAYOUTS**

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# DEVELOPMENT OF AN ONLINE PLANNING TOOL FOR DESIGNING TERRACE LAYOUTS

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## ABSTRACT

A web-based conservation planning tool for terrace layouts was created by modifying a terrace location program (TERLOC), developed originally by Sudduth and Gregory (1982) and revised by Ghidey et al. (1992). Development of a terrace system is complicated by the time-intensive manual layout process, which can take up to 50% of the total design time. TERLOC is a conservation planning tool designed to locate terrace layouts using digital elevation data and minimal user input. The use of TERLOC enables users to automate the terrace layout procedure, potentially saving time and money in the terrace design process. The main goal of this research project was to develop a web-based conservation planning tool for designing terrace layouts. The tool was made for public use by NRCS, land developers, and land owners. Availability of the program was greatly enhanced by integrating the program to an online ArcGIS interface. Multiple help menus and automated drawing and uploading tools increased input efficiency and TERLOC's ease of use. Existing design procedures were modified to accommodate a range of field conditions. These modifications included adjusting the minimum radius of curvature for smoothing contour lines, reducing step size for linear based intersection routines, and the addition of an internal detection of field orientation. These adjustments enhanced layout results for fields with irregular boundaries, topography, and orientation.

In addition to program modifications, additional design options were included: variable terrace spacing, channel grade adjustments to meet non-erosive velocities, underground outlet selection, interconnecting outlet design, and the option for multiple key terraces. These new features provide TERLOC, and its users, with a means of selecting the best layout design based on conservation, cost, and farmability. Analysis of TERLOC and its output was performed by comparing the program layout results to manually located terraces. The program results were found to be similar to the manual terrace layout results, where fields with large drainage areas were most similar. Terrace number, general trend, shape, and length were the features with the most similarities. Terrace spacing was found to differ the most, with the program spacing typically larger than the manual result. Finally, the software quality of TERLOC was analyzed qualitatively and quantitatively. The presence of specific user and overall software requirements in TERLOC were found to increase program performance and utility.

# CHAPTER 1

## INTRODUCTION TO DEVELOPMENT OF AN ONLINE PLANNING TOOL FOR DESIGNING TERRACE LAYOUTS

### 1.1 TERRACES- DEFINITION AND IMPACT

Terracing is a conservation practice used to decrease erosion by water. Terraces are specifically used for erosion control due to concentrated flow over a long slope length. A broad channel is constructed across the slope of a field to decrease the field length and to allow sediment to settle from runoff water (Schwab et al., 1993). These structures help cropland from exceeding average annual soil loss and improve the quality of water leaving the field. Terraces are well suited for land capability classes II, III, and IV. These classes represent farmable land with good soil quality where slopes are over 2% and moderate to very severe erosion may occur. The land capability classes were developed through land and soil surveys by the staff of Soil Conservation Service (SCS), now known as the USDA-Natural Resources Conservation Service (NRCS) (Helms, 1992). The land capability classes are described in Table 1.1 (Das, 2009).

Terraces are not suitable for fields with coarse or very coarse soil texture or slopes greater than 12%. Therefore, Classes V, VI, VII, and VIII, which are non-farmable land, are not suited for terrace development.

Terracing can be a costly investment which does restrict farming procedures. Therefore terracing should only be used for the conditions listed above and when other conservation practices such as conservation tillage, contour farming, or strip cropping do

not provide adequate erosion control. Fields with extreme gully erosion typically fall into this category.

Table 1.1 Land Capability Classes

<b>Class</b>	<b>Limitations</b>	<b>Slope %</b>	<b>Soil Characteristics</b>
I	SC; Little to no erosion	0-1	Deep, productive soils
II	SC; Moderate soil erosion	1-3	Moderate depth; productive soils
III	SC; Severe erosion	3-5	Moderate soil fertility
IV	SC; Very severe erosion	5-8	Good soil quality
V	NSC; Little to no erosion hazard	8-12	Too wet or rocky
VI	NSC; Severe erosion and climate	12-18	Shallow depth, rocky, or too wet
VII	NSC; Very severe erosion and climate	18-25	Shallow depth, rocky, or too wet
VIII	NSC; Very severe erosion and climate; unusable	>25	Shallow depth, rocky, or too wet

SC= Suitable for cultivation; NSC= Not suitable for cultivation

A 2007 national study performed by the USDA-NRCS found that 40 million hectares (99 million acres) of all cropland is eroding above the soil loss tolerance rate, T (USDA-NRCS, 2009). The T-value can be described as the “maximum rate of annual soil loss that can occur and still provide productive crop yields economically and indefinitely” (Carlson, 1986). The 40 million hectares (99 million acres) of all cropland area eroding above T in 2007 decreased from 68.4 million hectares (169 million acres) in 1982. Conservation practices, including terracing, contributed to this decrease. Factors including conservation practices have decreased soil erosion on U.S. cropland by 43% between 1982 and 2007 (USDA-NRCS, 2009).

## **1.2 TERRACING IN THE 21<sup>ST</sup> CENTURY**

Terracing remains a useful management practice in modern conservation planning. In 2008, the NRCS reported installation of 8.8 million meters (29 million feet) of terraces on a national level, 63% of which were installed in the central states of Iowa, Kansas, Missouri, and Nebraska (R. Purcell, personal communication, April 21, 2009). Within the last several decades, few changes have been made to the terrace design procedure. Traditional equations and methods for terrace design, some originating in the 1930s, continue to be used to this day. Two of the most influential changes to terrace systems came with the introduction of parallel terraces and underground outlets. These two developments, occurring in the 1950s and 1960s, allowed for more farmable terrace designs (Sudduth and Gregory, 1982). Terrace installation of parallel-underground outlet systems rapidly increased in the late 1960s (Forsythe and Pasley, 1969). In fact, by the 1970s, parallel terraces with steep, grassed back slopes became widespread (Fangmeier et al., 2006). These systems continue to provide farmable layouts and are still prevalent today.

Terracing changes within the last 30 years can be attributed to changes in technology and farming equipment. Technology has modified agriculture practices in general through precision farming. Precision farming utilizes new technologies such as global positioning systems (GPS) and geographic information systems (GIS). These technologies operate to provide spatial data to assist land owners in optimizing management practices. Stafford (2000) describes how this technology introduces new pressures to apply spatial precision to all field operations. Spatial precision requirements

then increase the need for field efficiency, thus increasing the demand for farmable terrace layouts.

This same modern technology has enhanced the terrace design process. Surveying and topographic maps were traditionally used to locate terraces. While this practice is still used today, the development of high-resolution digital elevation models (DEMs) has assisted in making initial plans (Fangmeier et al., 2006). Other forms of digital elevation data may be obtained through Light Detection and Radar (LiDAR) or Real Time Kinematic (RTK) GPS equipment used in precision farming. Computer programs directed towards conservation planning have also played a large role in terracing and will be discussed later in the chapter.

In addition to technology changes, machine size and row width affect terrace procedures. Today, 76-cm (30- inch) row widths are common, with eight-to 12-row corn heads and 12-to 24-row planters. Curvature of terraces within the field may hinder equipment use due to the turning radius of the equipment. As Hunt (2001) describes, soil conservation practices like terraces are the “most important modifier of time-efficient field patterns.” Therefore extra consideration should be taken to design terraces that maintain efficient field patterns. The general layout must provide long, gentle curves for maximum maneuverability. Spacing must be optimized to also allow for the fewest, equal number of turns within the field.

Future changes in technology and equipment are expected to have an even greater impact on terracing. No matter what changes occur however, the goal of a terrace system

remains the same: “to produce a cost-efficient and easy-to-farm system that meets the owner’s preferences” (Schottman and White, 1993).

### 1.3 TERRACE CLASSIFICATION

Terraces may be classified in one of four ways: alignment, cross section, grade, or outlet type. The alignment types are either nonparallel or parallel. The nonparallel alignment is typically on a constant grade and follows the contour of the field, while the parallel alignment requires equal spacing between terraces.

Multiple options are available for a terrace cross section. These options consist of broadbase (Figure 1.1), conservation bench (Figure 1.2), steep-backslope (Figure 1.3), narrow-base (Figure 1.4), bench (Figure 1.5), and ridgeless-channel (Figure 1.6).

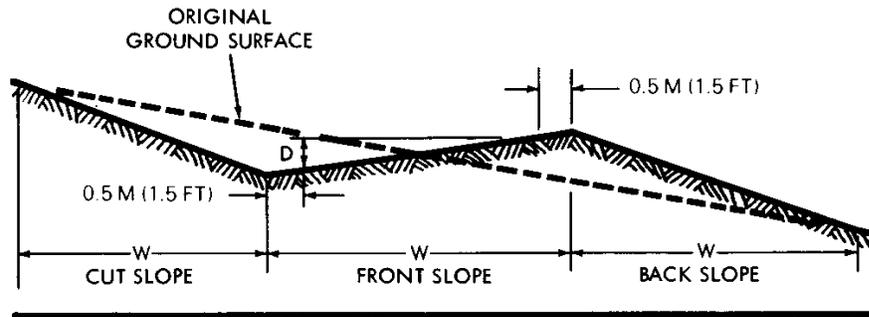


Figure 1.1. Broadbase terrace cross section (ASAE, 2009)

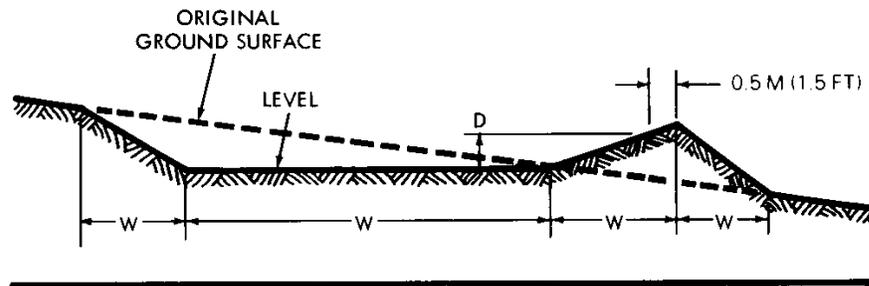


Figure 1.2. Conservation bench terrace cross section (ASAE, 2009)

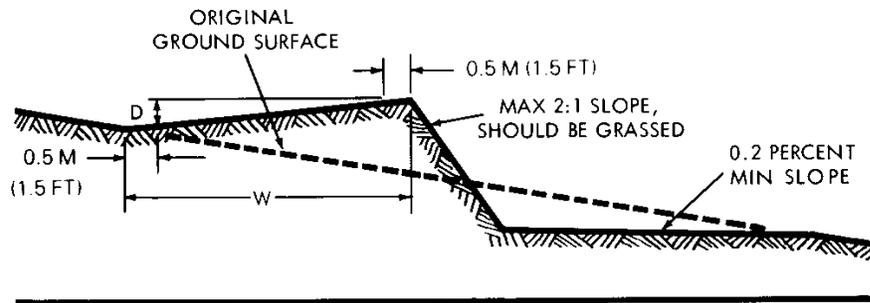


Figure 1.3. Steep-backslope terrace cross section (ASAE, 2009)

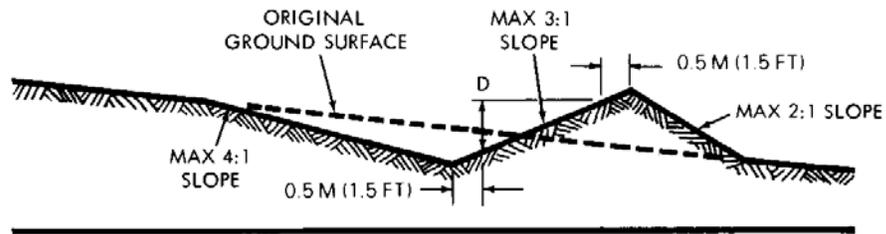


Figure 1.4. Narrow-base terrace cross section (ASAE, 2009)

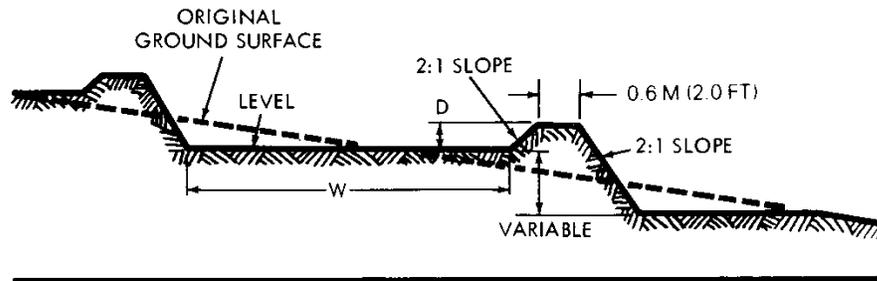


Figure 1.5. Bench terrace cross section (ASAE, 2009)

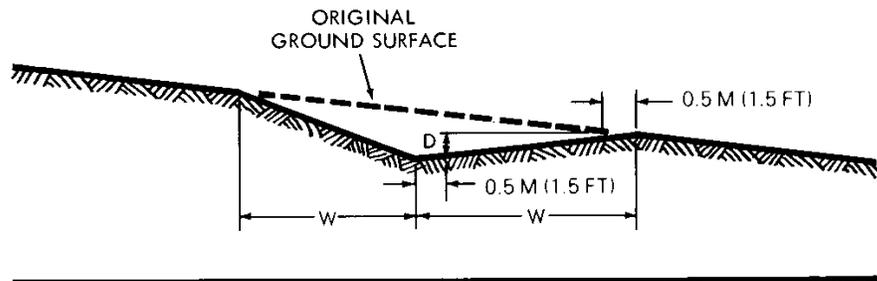


Figure 1.6. Ridgeless-channel terrace cross section (ASAE, 2009)

Grade classification consists of graded or level. Graded terraces drain runoff water towards a specified outlet at a nonerosive velocity (Fangmeier et al., 2006). Level terraces are not graded and are usually used for water retention and conservation. Outlet classification of terraces include blocked, vegetated, piped, or any combination. The blocked outlet involves a system in which all water must infiltrate into the channel. Vegetated and piped outlets remove water from the channel at a specified grade.

#### **1.4 DESIGNING TERRACES BASED ON FARMABILITY**

Many steps and procedures go into developing a terrace system. Terraces that are more farmable are more likely to be “accepted and maintained by the farmer” (Tollner, 2002). Therefore, when designing a terrace system the farmability components should be considered. These components include access roads, optimal spacing, farmable cross sections and a parallel layout (Tollner, 2002). Outlet selection and terrace location are the first steps in terrace development. Typical outlet types include grassed waterways and underground pipe outlets (UGO). Grassed waterways are commonly used due to their low cost; however, UGOs are more adaptable when the system is parallel or located on complex topography. To increase farmability, access roads into and out of the field are essential. Waterways should be positioned so that the farmer can have access to one side of the field boundary. Keeping one area open for the farmer eliminates damage to the waterway from equipment passage. Terraces may be located following outlet selection. The topmost terrace is typically laid out first (Schwab et al., 1993). Subsequent terraces are laid out based on topography, farmability, and erosion control. Spacing between terraces is calculated to reduce the field length to meet soil loss tolerance criteria.

Spacing is also selected with consideration of limiting non-erosive channel velocities. Wider spacing increases total drainage area, thus total runoff the channel will need to handle. A narrower spacing may need to be chosen to ensure channel velocities remain non-erosive. Large farm equipment can damage existing crops or the terrace itself if inadequate terrace spacing is used. Therefore, spacing may be altered by 10% to allow even turns for prevention of crop and terrace damage (USDA-NRCS, 2010). The NRCS recommends using the Universal Soil Loss Equation (USLE), or the Revised USLE (i.e. RUSLE), to determine spacing.

The USLE is an empirical equation designed to “predict longtime soil loss in runoff from specific field areas in specified cropping and management systems” (Wischmeier and Smith, 1978). The empirical nature of this equation is attributed to the complexity of erosion and transport mechanisms, as well as physical and management factors of the particular area. These factors make up the USLE equation, shown in Equation 1.1.

Equation 1.1 can then be rearranged to solve for the slope length factor using an acceptable soil loss rate, typically 5 to 11 Mg/ha/yr (2 to 5 tons/acre/yr) (Tollner, 2002).

$$A = RKLSCP \quad (1.1)$$

where,

A=average annual soil loss (Mg/ha/yr),

R=rainfall and runoff erosivity index for a geographic location (MJ-mm/ha-h-yr),

K=erodibility factor(metric tons-ha-h/ha-MJ-mm),

LS=slope length and steepness factor (dimensionless),

C=cover management factor (dimensionless),

P=conservation practice factor (dimensionless).

Wischmeier and Smith (1978) note that considerable fluctuation of these variables may be seen from storm to storm; however, over time these values average out.

The K factor in Equation 1.1 describes soil erodibility for specific soils under a unit plot condition: 22m length with uniform 9% slope in continuous fallow, tilled up and down the slope (Wischmeier and Smith, 1978). It describes what makes some soils more erodible than others. Factors that influence erodibility of a soil include texture, organic matter, structure, and permeability. Soils with high silt or fine sand percentage, low organic matter percentage, poor structure, or slow infiltration rates are typically more susceptible to erosion. Other factors affecting overall soil loss are accounted for in the remaining factors in Equation 1.1.

The USLE estimates interrill and rill erosion. Interrill erosion may be described as splash and sheet erosion. It describes the soil detachment from raindrop impact as well as uniform soil removal and transport in thin layers from sheet or overland flow. Rill erosion is described as detachment and transport of soil by concentrated flows. The LS,

slope length and steepness factors, may be adjusted to account for rilling that occurs due to runoff accumulation and greater erosive energy on long, steep slopes. McCool et al. (1989) developed methods for calculating the LS factor for conditions where rill and interrill erosion were equal and where rill erosion is greater than or less than interrill erosion. The USLE does not account for gully or channel erosion, which is soil detachment and transport by larger concentrated flows that cannot be removed through tillage operations. The USDA-Agriculture Research Service developed a model to improve the erosion prediction procedure. The Water Erosion Prediction Project (WEPP) (USDA-ARS, 2010) was developed as a physically based model to account for interrill and rill erosion as well as gully and stream erosion (scouring only) (Flanagan et al., 2007). While WEPP is a much more detailed model that does account for gully erosion, it still only provides estimations of soil loss. In addition, the model requires extensive data input to predict soil loss which would make solving for the terrace spacing very difficult.

Terrace spacing can also be calculated using the vertical interval method in Equation 1.2,

$$VI = Xs + Y \quad (1.2)$$

where,

VI=vertical interval between consecutive terraces (m),

X= constant for geographical location,

s=land slope (m/100m),

Y=constant based on soil erodibility, cropping systems, and crop management.

The equation is based on erosive rainfall and uses generalized geographic, soil erodibility, cropping systems, and crop management system values in the X and Y constants, respectively. Specific X and Y values may be found in the ASAE terrace standards (ASAE, 2009). Terrace spacing, or horizontal interval (HI) can be calculated by dividing the vertical interval by the land slope. This value can then be rounded to an interval of the equipment width to provide maximum farmability between terraces.

Terrace cross sections are designed after the terrace spacing and layout are determined. A terrace cross section should have farmable side slopes, provide adequate capacity, and be economically feasible (Schwab et al., 1993). To create a farmable cross section, a slope no steeper than 5:1 (i.e. horizontal to vertical) should be used (USDA-NRCS, 2010 Code 600). Cross section options include rectangular, triangular, parabolic, and trapezoidal. The parabolic most closely resembles a natural channel; however, the trapezoidal and triangular cross sections tend to become parabolic from channel flow, deposition, and erosion (Schwab et al., 1993). The channel capacity, or water depth, may be solved by rearranging Manning's equation to solve for the hydraulic radius. To provide adequate capacity for runoff volume, a terrace channel must be designed to handle a 10-year, 24-hour storm (ASAE, 2009).

In order to ensure proper drainage of runoff water in the terrace channel, terrace grade must be considered. Erosive velocities in the channel bed may be prevented by calculating the maximum allowable slope. The average velocity can be chosen based on maximum permissible, nonerosive velocities as given in the NRCS standard.

Channel grade can then be solved for using Manning's equation and the continuity equation as shown below:

$$Q/A = V = R^{2/3}S^{1/2}/n \quad (1.3)$$

where,

Q=cross sectional runoff flow rate (m<sup>3</sup>/s),

A=cross sectional area (m<sup>2</sup>),

V= cross-sectional average velocity (m/s),

R=hydraulic radius (Cross sectional Area/Cross sectional Perimeter) (m),

S= channel slope (m),

n=Manning's roughness coefficient (dimensionless).

Typically, parallel terrace layouts are more desirable than conventional, constant grade layouts since equal spacing is achieved down the entire terrace. A conventional layout is designed where terraces are placed with respect to the contour lines. This layout potentially introduces varied terrace spacing, which makes equipment maneuvering difficult due to sharp curves and point rows. Point rows decrease the farming efficiency and may cause damage to crop or the terrace itself. Steichen and Powell (1985) showed that it takes about 20% more time to farm the nonparallel system than a parallel system. Thus, when feasible, a parallel layout should be utilized.

## **1.5 TERRACE LAYOUTS—A COMPLEX PROCEDURE**

As one of the first steps of the terrace design process, a suitable layout selection is imperative for the success of the terrace system. A terrace layout is the actual placement, or location, of terraces within the field. The layout selection has many

components, with importance on the farmability of the system. The complexity of choosing the layout explains why terrace layouts are the most time consuming component of the design process. A study done by the Missouri NRCS found that for a 3600 m (12,000 ft) long broad based terrace, 50% of the total development time was spent on laying out the terrace (R. Purcell, personal communication, April 21, 2009). Time spent on terrace location for one field limits time and labor spent on other terrace systems. A loss of funds may be experienced for local Soil and Water Conservation Districts due to delays in completing a terrace design (Gantzer et al., 2008). Complex topography or steep slopes may increase these losses. Not only is this an inefficient process from a monetary perspective, but also from a conservation implementation perspective.

Terrace layouts are performed manually by a field technician with experience in layouts and surveying (Wittmuss, 1988). The procedure requires field time for the technician to stake out points along terraces using topographic maps, a laser level, or other surveying equipment. The steps completed for a manual terrace layout are summarized below:

1. Establish boundaries for water flow including the ridge line (high points in field), streams, and gullies.
2. Establish additional boundaries including roads, property lines, and fence lines.
3. Using these boundaries determine the terrace area within the field.
4. Start with the first, uppermost, terrace. Space the terrace from the ridge line (or previous terrace) according to the terrace spacing procedures listed above.
5. Mark the first terrace point at the desired spacing with a stake or flag.

6. Using a laser level or other surveying equipment, find the next terrace point that provides the desired channel grade. Stake this point with another flag.
7. Continue staking terrace points in 15m (50 ft) intervals to an outlet and then until the terrace extends to the boundary of the terrace area.
8. Repeat steps 4-7 for downhill terraces.
9. Stakes may be altered slightly to provide a parallel layout.

Even with modern technology including GPS, a terrace layout may take up to a full day to complete. Furthermore, this process is completed for a single terrace layout. If the original layout is not acceptable, additional time and money must be spent to complete an alternative layout.

Research and development on ways to improve terrace design and layouts using computers began decades ago. These computer programs, and other developments, are important for promoting the construction of terrace systems, and also for more efficient use of cost-share dollars for terraces.

## **1.6 COMPUTER ASSISTANCE AND DIGITAL DESIGNS**

Beginning in the late 1960s, computers were used to aid in terrace design. One of the first programs was written by Forsythe and Pasley (1969) and was designed to calculate cuts and fills, earthwork quantities, and storage volume. As the basis for future programs, this technology allowed engineers to determine total costs and volumes, and compare multiple design options. This program was followed with detailed research on computer terrace programs through the 1980s and 1990s. Increased use of computers during this time period was made possible by the drop in computer price, making the

technology more available to the public. Ryu and Hunt (1981) developed a program to get a more accurate measurement of cut and fill values for parallel terraces by basing calculations on earthwork equipment capabilities. Both the Forysthe and Pasley (1969) program and the Ryu and Hunt (1981) program allowed users to compare cut and fill values based on price and volume to determine the best design option. Neither program, however, actually determined the location of terraces and outlets within the field. The technicians were still required to perform manual layouts in the field. In addition, the user had to manually enter elevations from a field survey into the program. It may have taken some technicians longer to enter all the data than to do the computations by hand. A program named TERLOC (Terrace Location Program) was developed by Sudduth and Gregory (1982) to provide actual horizontal and vertical (x,y,z) coordinates of terraces. The program utilized digital topographic information given by contour maps, along with user input. Digital contour maps provide all the elevation information for the field and eliminate the need for manual data entry. Wittmuss (1988) estimated that utilizing elevation maps cut layout time in half. A detailed flow chart of the procedures utilized in TERLOC is shown in Appendix A. The development of TERLOC introduced a comparison tool and a tool for the planning process. Additions of cut and fill procedures and varying channel grades were later made by Ghidney et al. (1992). Other layout programs were introduced including the Terrace Design Program for NRCS (Keep, 1989), and the Johnson and Holly (1992) program called TERPS (Terraces for Erosion and Runoff: A Program Simulation). The Keep (1989) program required manual data entry and was limited to designing terrace cross sections. An updated version of this

program is still used in Missouri NRCS field offices. Other states, such as Iowa, have similar terrace cross section design programs. TERPS included several new additions to terrace layout design including usage of soil maps for further time reduction in calculating terrace spacing (Ghidey et al., 1992). This addition was important as it calculated spacing that would reduce soil loss quantities instead of choosing spacing based on equipment width and vertical intervals.

Terrace planning in the office has become a popular practice that is used in terrace designs today. As discussed above, there are several programs and methods available, any of which provide time savings and methods of comparing conservation and farmability.

The development of computer software has introduced many standards and guidelines for developing successful programs. User requirements are defined as items the software is “expected to provide and the constraints under which it must operate” (Sommerville, 2004). Keep (1989) lists requirements for NRCS engineering software:

- Ease of use
- Utilization of NRCS design procedures
- Availability of program on current office equipment
- Multiple trial design alternatives
- Printable final output for producers.

Sommerville (2004) also notes that the quality of a program is not only measured by the services provided, but also by the following characteristics:

- Maintainability-Easily adaptable to future needs
- Dependability- Reliable, safe, and secure
- Efficiency- Responsive, adequate speed and memory usage
- Usability- Easy to use interface with appropriate documentation.

These attributes combined with the user requirements contribute to a well designed program.

## **1.7 SUMMARY & PROBLEM STATEMENT**

Terracing is a conservation practice that is still used in modern engineering to conserve soil and water resources. Technology and equipment changes within the last several decades have modified the terrace design process and require further consideration of the farmability of a terrace system to meet land owner needs. Terrace layouts are the most influential factor affecting farmability. Terrace layouts also are the most time consuming process of a terrace design. Therefore, computer programs could be useful to assist in the terrace layout process to reduce time and labor spent on single layouts. All terrace programs previously discussed provide some degree of automated data entry and quick computation. The current drawback is that programs were established for basic, straightforward field designs. Complex fields with varying topography present issues such as “improper terrace location” (Sudduth and Gregory, 1982), improper channel grade, or even program crashing. All the terrace programs lacked certain details as well. The earlier programs did not provide terrace layouts, and required the manual entry of elevation data. TERLOC lacked spacing computations based on soil loss, and optimization of earthwork options. The terrace spacing and layout in

TERPS proved to be difficult to achieve, and unsuccessful at times (Holly, 1989). In addition, none of the programs possessed all the software requirement characteristics listed above. This was largely because the programs' development predated the establishment of these software requirements. However, few changes have been made within the last few decades to update or modify these programs.

The need exists for a comprehensive terrace layout program that can optimize cost, conservation, and farmability. The program should meet software requirements, work for various field conditions, and provide optimal layouts with an emphasis on farmability. A comprehensive terrace layout program will expedite the planning process. More importantly, it will allow NRCS staff, as well as land owners and contractors, to design an optimal terrace layout more rapidly and efficiently.

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## **CHAPTER 2**

### **STUDY OBJECTIVES**

The overall goal for this project was to provide a web-based conservation planning tool for terrace layouts. The tool was to be made for public use by the Natural Resources Conservation Service (NRCS), land developers, and land owners. This was accomplished through amendments to a terrace location program, TERLOC (Terrace Location Program), developed by Sudduth and Gregory (1982) and revised by Ghidey et al. (1992). Specific goals for the revised terrace planning tool were to work for various field conditions, provide optimal, farmable layouts, and meet software requirements.

These goals were met through the following objectives:

- Integrate the terrace location program with a web-based Internet Map Server (IMS) interface,
- Modify the conventional and parallel layout design procedures,
- Integrate additional spacing, channel grade, engineering parameters for optimal terrace results.

## 2.1 REFERENCES

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## **CHAPTER 3**

# **TERRACE LAYOUTS FOR COMPLEX FIELDS USING A TERRACE LOCATION PROGRAM**

### **3.1 ABSTRACT**

This project focused on modifying a terrace location program, TERLOC (Terrace Location Program), to operate for multiple field types. Modifications to TERLOC were completed to accommodate complex field features such as irregular field boundaries, topography, and orientation. These main modifications included program integration into a web-interface, reduction in minimum smoothing radius and step size for intersection routines, and internal detection of field orientation. The modifications to TERLOC were demonstrated to assist the development of terrace layouts for six sample fields with complex field characteristics.

### **3.2 INTRODUCTION**

Locating a terrace system can be a time consuming procedure. Hours, even days may be spent surveying the field, staking terrace points, and consulting with the landowner. Terraces are a method of controlling soil loss, specifically the concentrated flows of rill and gully erosion over a long slope length. Multiple terraces are designed at intervals down a field that sufficiently reduce the slope length to meet soil loss criteria. For this reason terrace placement, thus the layout procedure is a key component of design. Due to limited time and money allocations, field technicians typically only have time to complete a single layout for a field.

A terrace location program, TERLOC, was developed by Sudduth (1981) to support the terrace layout procedure. The program also sought to provide alternative layout options for a field. TERLOC operations were based on lines and linear functions. Terrace layouts were derived from contour lines and other line-based input including outlets, divides, ridgelines, and field boundaries. A flowchart of the program procedure is shown in Appendix A. Unlike other terrace programs, (Forsythe and Pasley, 1969; Ryu and Hunt, 1981; Keep, 1989; Holly, 1989), TERLOC provided a means of utilizing digital contour data instead of entering the data manually. Curve fitting and intersection routines were then used to process and analyze contour lines to locate terrace points. The final program output supplied a conventional, constant grade terrace option, a smoothed conventional option, and multiple parallel options.

The drawback for TERLOC was its use required a local copy of the program. In other words, to run the program on a given computer, the user would need a form of the program on a disc or other device for local installation. A FORTRAN compiler was also needed to process the program. Use on other computers was noted as a potential problem due to the internal output routines (Sudduth, 1981). Technology at the time of TERLOC's development limited program testing for a wide variety of fields. The original program was tested for three sample fields (Sudduth, 1981), and two additional data sets in future work (Ghidey, 1990). Potential problems were noted for fields with more complex features (Sudduth, 1981); however, extensive field testing was not within the scope of the project due to limited processing speed. Both Sudduth (1981) and Ghidey (1990) recommended future research for a wide range of fields.

Complex fields are most time consuming, and in fact, terrace layout design for these fields may be ruled out due to layout complications. These fields would benefit the most from a terrace layout program. Advances in technology and processing speed over the last several decades now make it possible to quickly test multiple fields and even larger input files. These changes enable further testing and analysis within TERLOC.

### **3.3 OBJECTIVES**

The objective for this project was to amend a terrace location program developed by Sudduth and Gregory (1982) and revised by Ghidey et al. (1992). The main goal of this project was to broaden the program's ability to handle various types of field characteristics including:

- Field location,
- Irregular field boundaries,
- Fields with irregular or complex contour lines,
- Irregular field orientation.

### **3.4 MATERIALS**

The hardware utilized for this project was an X86-based PC with a 2992 Mhz processor. The terrace layout program was written in FORTRAN and additions were made using Intel® Fortran Compiler Version 10.1.011 and Microsoft Visual Studio 2008. Additional software utilized for this project includes:

- Sql Server 2000 with service pack 3 (Delaney, 2000)—Enterprise Edition 64 MB minimum, 128 MB recommended,
- ESRI ArcIMS 9.3 with service pack 3 (ESRI, 2004),
- Ogr2Ogr freeware (<http://www.gdal.org/ogr2ogr.html>),
- AspTreeview freeware (<http://aspwebsolution.com/articles/coder4life/treeview/asp/index.htm>).

The following programming languages were also used for the online modifications:

Active Server Pages, JavaScript, Visual Basic Script, and Window Script.

## **3.5 METHODOLOGY**

### **3.5.1 INTEGRATION WITH A WEB-BASED APPLICATION**

The first step was to create an internet accessible program, using TERLOC, to upload field data for any field. This step was implemented with assistance from the staff of the Center for Applied Research and Environmental Systems (CARES) at <http://cares.missouri.edu/about/facility.aspx> (CARES, 2010). ArcIMS 9.3 was utilized to provide an interactive interface and to display various layers of data. The web-based program allowed for contour data, in the form of real world topographic coordinates, to be submitted as input and output. Specifically, GIS shapefiles (a spatial data format) were uploaded as user input. The interface was developed to accept a certain type of shapefile:

- Zipped, or compressed, file format (.zip),
- No spaces within the file name,
- Universal Transverse Mercator (UTM) coordinate system projection,
- UTM Zone 15,
- Metric Units,
- Contents: A “CONTOUR” attribute field containing contour elevations.

Custom JavaScript and Active Server Pages (ASP) were used to develop the overall program and to incorporate TERLOC into the interface. The new web-based tool was placed on the Cooperative Soil Survey server at <http://www.soilsurvey.org>. Figure 3.1 illustrates the program’s main screen.

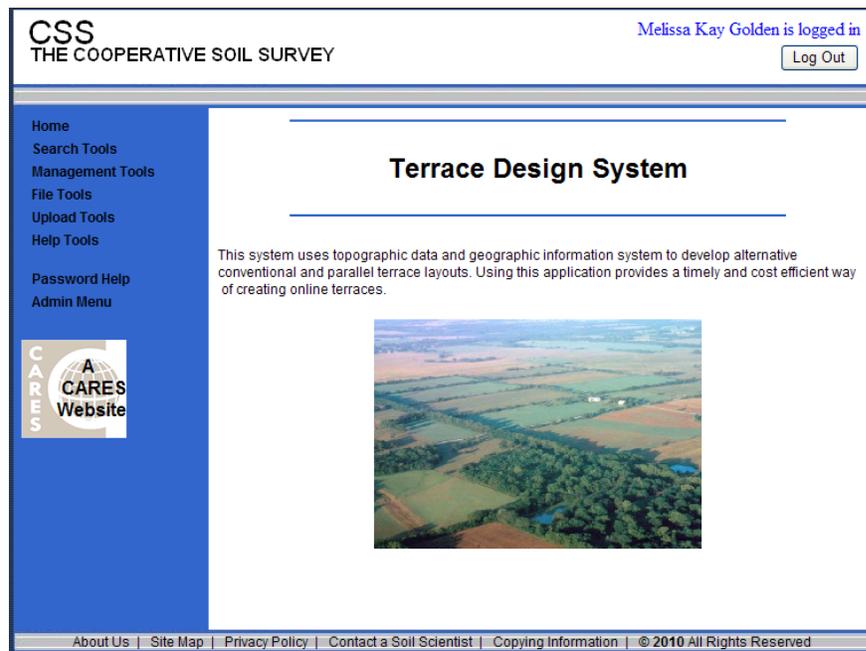


Figure 3.1. TERLOC Web-Interface Homepage (<http://www.soilsurvey.org/tools/terrace/main.asp>).

An interactive mapping window and the TERLOC input menu are accessible through the main page. Users can then select any field, upload and enter field data, and run the terrace location program.

### **3.5.2 MODIFY DESIGN PROCEDURES**

Another step for this project was to make modifications to the original TERLOC code to facilitate efficient program operation for complex field conditions: irregular field topography, boundaries, and orientation. Modifications were made through custom FORTRAN code additions to specific routines within TERLOC. These modifications are explained in the following sections.

#### ***3.5.2.1 Terrace Double-Backing Modification***

The first modification was in locating terrace points for fields with irregular contour lines. These fields experience issues with terrace double-backing after a terrace point has been projected. Terrace double-backing can be described as the terrace reversing direction towards previously laid out terrace points. Figure 3.2 illustrates some examples.

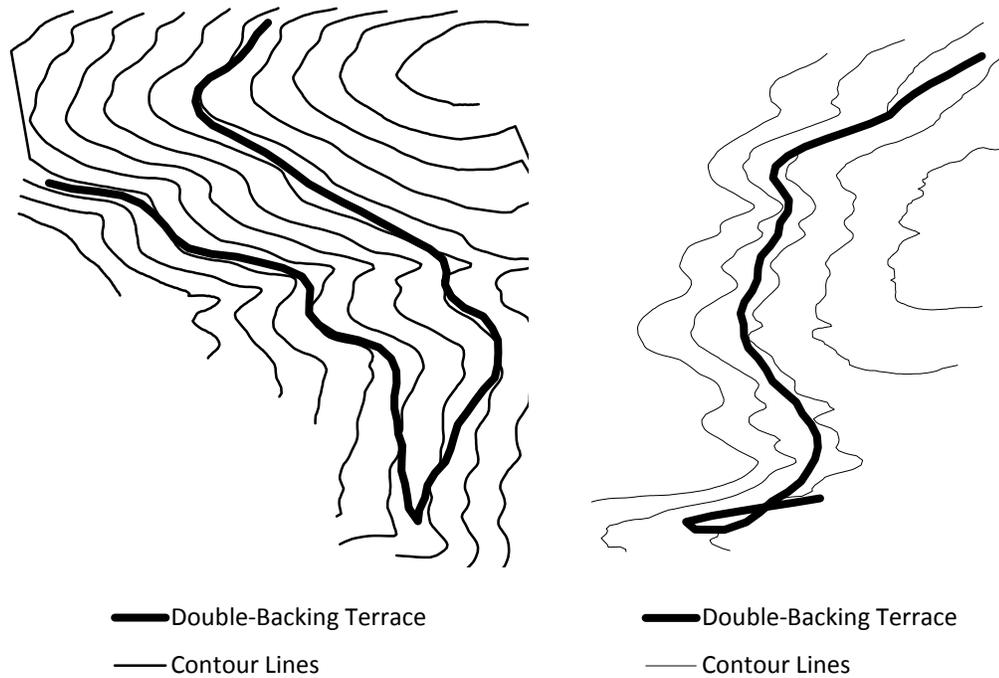


Figure 3.2. Examples of fields with irregular contours that experience terrace double-backing.

The double-backing problem lies within a routine called NCINT. This routine finds intersections of adjacent contour lines and lines normal to a terrace. The intersections are used to interpolate new terrace points. Terrace double-backing is a result of incorrect intersection location.

The original TERLOC code includes a verification that an initial terrace point does not double back. A new point is projected from the terrace line using NCINT. The new terrace point is saved with the assumption that it is moving in the correct direction. The projection routine may find incorrect intersections when dealing with irregular-shaped contours, as described by Sudduth (1981).

Two steps were needed to reduce double-backing for complex contours. First, a check for double-backing written by Sudduth (1981) was used to flag backwards movement on a terrace. This check compared distances between the last three terrace points. Second, if double-backing occurred, the default 15 meter (50 foot) step size along the contour was reduced and the NCINT routine was rerun.

### ***3.5.2.2 Intersection Routine (NCINT) Modification***

The intersection routine, NCINT, required additional changes to improve consistency for fields with highly-variable contours. The routine iterates along the contour line to find a minimum distance. If the minimum distance is passed, the routine reverses direction and reduces the step size to find the correct point. Upon reversal to the previous point, the same, or very similar, distance is recorded. The subroutine sometimes mistakenly records this point as the point of minimum distance, since the difference between these distances is less than the threshold value of 0.6 meters (2 feet). To eliminate false minimums, a check was included to rule out insignificant changes in distance. Change was considered insignificant, thus false, if the difference was less than 0.003 meters (0.01 feet).

When the routine could not converge to an intersection point at the new contour, the routine used an interpolation procedure to find a new starting point. The following equation (3.1) was originally used:

$$TNX = TNX + (TNX - TBX) * 400/D \quad (3.1)$$

where,

TNX=new point,

TBX=old point,

D=distance between new and old point.

In this equation, the point is moved beyond the current point instead of interpolating between the current and previous point. Thus, the sign was changed so that the newest point would fall between the two points as shown in Equation 3.2:

$$TNX = TNX - (TNX - TBX) * 400/D \quad (3.2)$$

### ***3.5.2.3 Terrace Length Limitation and Boundary Check Modification***

TERLOC continues locating terraces in a field until it can no longer find points of correct elevation above the bottom portion of the field boundary. Fields with irregular boundaries and lengths may allow the program to start a new terrace too close to the bottom of the field. Only a small portion of terrace is then located. One or two terrace points fall inside the boundary, while one portion of the short terrace does not. A terrace length and boundary check for projected terrace points was added to exclude terraces too short for practical purpose. The boundary check procedure operates by finding the relationship between a point and a polygon, the field boundary (Sudduth, 1981). The terrace length restriction was also incorporated into the routine for designing parallel terraces, PARALLEL.

#### ***3.5.2.4 Contour Radius of Curvature Modification***

Contour lines are an essential input for the layout of terraces. Contour lines may exhibit excess curvature, demonstrating areas with steep elevation changes such as major gullies. Excess curvature in a contour line also affects the functionality of curve fitting routines in TERLOC, making them less stable (Sudduth, 1981). A contour line smoothing procedure developed by Sudduth (1981) is used to reduce excess curvature by altering contour lines that do not meet the minimum allowable radius of curvature. Line smoothing alterations can be justified by the fact that these areas of steep elevation change would be filled during terrace site preparation. Sudduth (1981) noted that a minimum radius of curvature of 31 meters (100 feet) proved to be most successful. An analysis of contour lines and radii of curvature was performed to determine which minimum radius is appropriate for modern field practices. Three different minimum radii of curvature, 7.6, 15, and 31 meters (25, 50, and 100 feet) were inserted into the smoothing routine and compared.

#### ***3.5.2.5 Line intersection: Step Size Modification***

An intersection routine, FIND\_INTER, is used within TERLOC to locate intersections of outlets and divides with contours or terraces. These intersection calculations are essential for determining terrace location. The routine procedure includes stepping along the two lines to locate a point of minimum distance. The step size was originally set to be half of the length of the shortest line. If a point of minimum distance was passed, and not within the error threshold, the stepping direction would be reversed, and step size would be reduced. In most situations, this procedure was

successful at locating the correct minimum distance. Irregular lines, however, can lead to false minimums, thus incorrect intersections (Sudduth, 1981). To increase reliable routine output, modification of the routine step size was required. Input lines were examined to determine which step size would be most appropriate to reduce errors in intersections.

#### ***3.5.2.6 Terrace Line Ordering for Parallel Layouts***

The routine to design parallel layouts, PARALLEL, requires points along all terraces to be numbered starting from the same side of a field. Likewise, a routine for altering terrace channel grade requires terraces to start on the same side as the first outlet. The conventional terraces passed to these routines are not necessarily in the correct order. Thus a terrace line ordering routine, LINE\_ORDER, was developed with assistance from the staff of the Center for Applied Research and Environmental Systems (CARES). The routine used a reference point to find the starting, or zero, end of a terrace. The line ordering routine steps were as follows:

1. Starting with terrace 1, use the high point (or first outlet point) as the original reference point (RP).
2. Compare distance from the RP to both ends of the terrace.
3. The end closest to the RP is labeled as the zero end of terrace.
4. Renumber if necessary by copying terrace points backwards into a new array.
5. Repeat steps 2-4 for remaining terraces. Use the zero end of the previous terrace as the reference point.

This routine was successful at numbering all terraces from the same side. The routine was not consistent, however, at numbering them with respect to a reference point.

Fields in which the reference point was almost equidistance from both terrace ends were the main cause for routine instability. Figures 3.3 and 3.4 illustrate such fields.

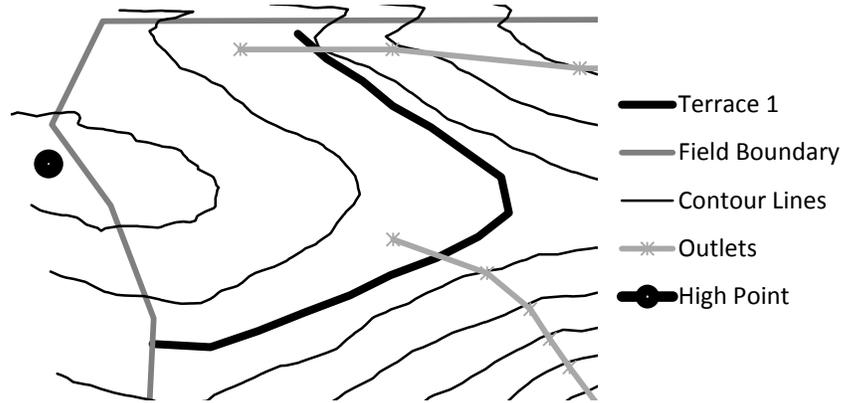


Figure 3.3. An example of a field with terrace endpoints almost equidistance from the highpoint.

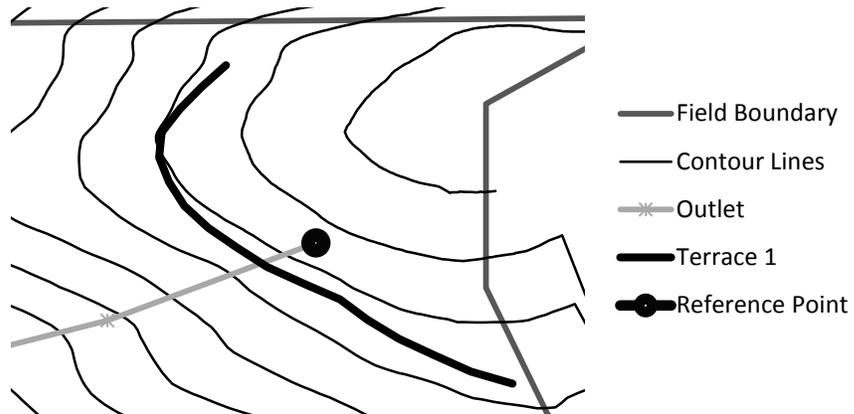


Figure 3.4. An example of a field with terrace endpoints almost equidistance from outlet starting point.

The LINE\_ORDER procedure was modified to properly number terraces with respect to a reference point regardless of field orientation. The new version located the starting side of the field by comparing all terrace endpoints to the reference point. The

end with the smallest average distance was chosen as the correct starting side and terraces were renumbered as needed.

### 3.5.2.7 *Parallel Layout Orientation Modification*

Field orientation also affects parallel terrace layouts. Parallel terrace points are found using Equations 3.3 and 3.4:

$$TPX=PS*\text{Cos}(\Theta)+PCX, \quad (3.3)$$

$$TPY=PS*\text{Sin}(\Theta)+PCY, \quad (3.4)$$

where,

TPX= X coordinate for the parallel terrace point,

TPY= Y coordinate for the parallel terrace point,

PS=spacing and directional value,

$\Theta$ = angle normal to the key terrace,

PCX and PCY = X and Y coordinates of a point on the key terrace.

The parallel spacing variable describes not only the parallel horizontal spacing, but also whether the parallel terrace should be uphill (+) or downhill (-) from the key, or reference, terrace. The key terrace is used as the reference terrace in which all other terraces in the field are located parallel to it. Ghidey (1987, 1990) made corrections for layouts that were producing incorrect parallel terrace positions due to sign reversal of the key terrace slope. Theta values were incorrect, causing parallel terraces to mistakenly cross over a key terrace. Ghidey's correction eliminated incorrect theta calculations; however, placement of entire parallel systems still proved to be a problem. Fields that were not oriented with the high point at the north-, or top-, most side placed entire

parallel terraces on the incorrect side of the key terrace. Figure 3.5 displays examples of these fields.

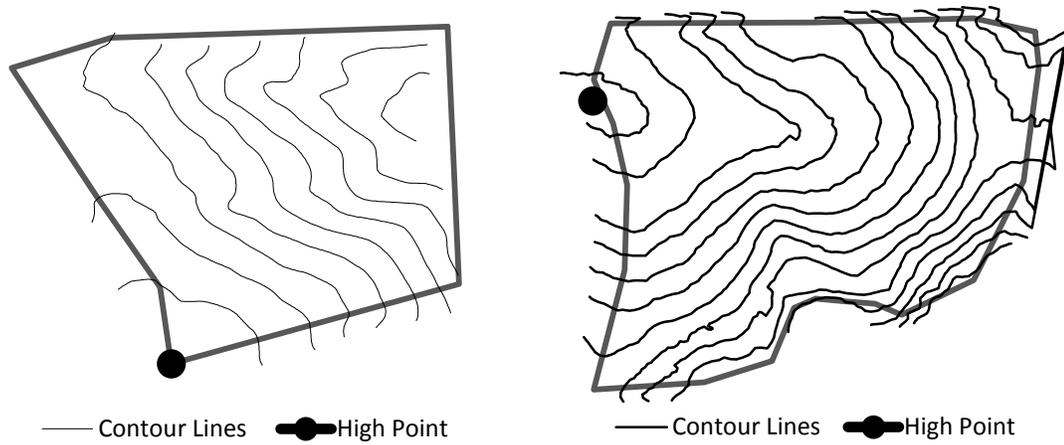


Figure 3.5. Examples of fields in which the high point is not oriented at the Northern-most side of the field.

For fields with orientation similar to Figure 3.5, the PS variable sign is incorrect, producing inverted layouts. This is because the coordinate system for each field is developed with (0, 0) at the bottom left corner. Values for X and Y increase from left to right and from bottom to top, respectively. Figure 3.6 demonstrates how the downhill terraces should not possess smaller values of X and Y as indicated by a negative PS value. Rather, the downhill terrace should actually be to the right, or in a positive direction from the key terrace. Figure 3.7 shows how original PS values are relevant for fields where the high point is at the upper portion of the field boundary.

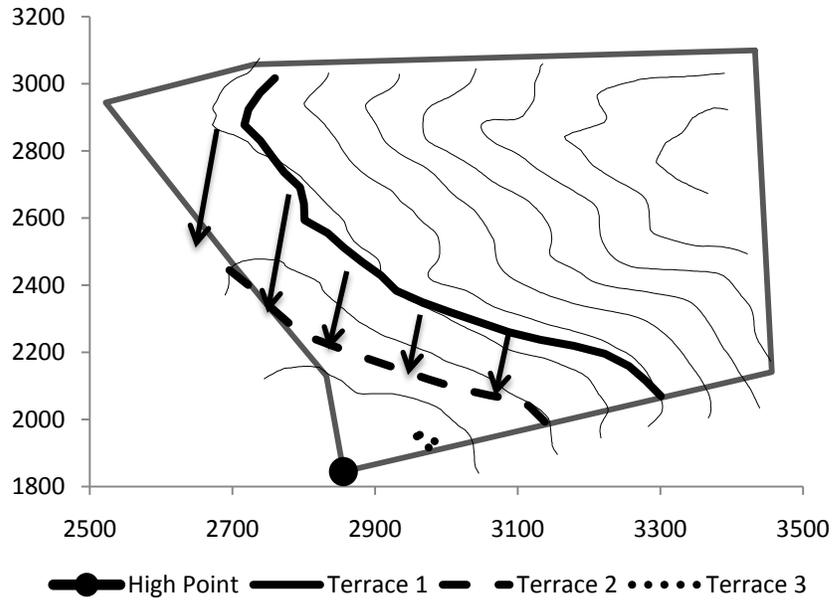


Figure 3.6. An example of inverted terrace layout for key terrace 1. PS spacing signs are incorrectly assigned as -180 for terrace 2 and -360 for terrace 3.

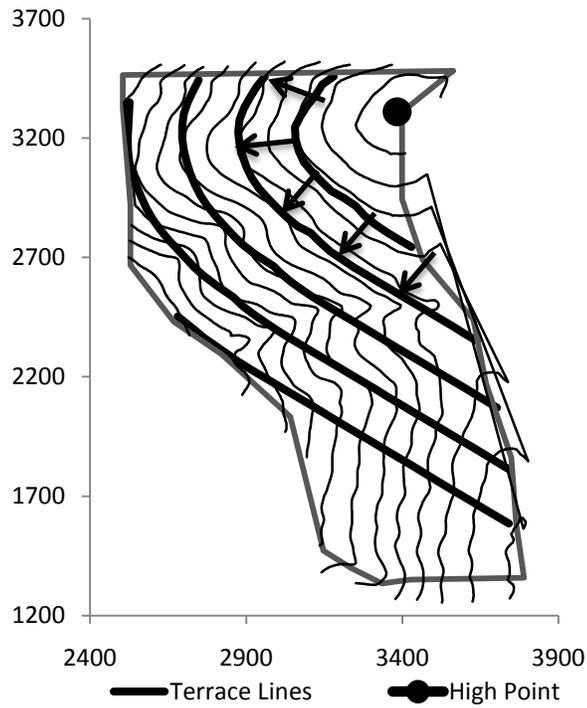


Figure 3.7. An example of correct terrace layouts for key terrace 1. Original negative sign of PS produces correct layouts for this field orientation.

Modifications were made to the PARALLEL routine to accommodate fields of any orientation. The new steps are performed for the first key terrace and listed below:

1. Measure distance from the first key terrace to the high point.
2. Measure distance from new terrace points to the high point.
3. If the new terrace points are closer to the high point (oriented incorrectly), change PS sign value for all key terraces.
4. Recalculate parallel terraces.

## **3.6 RESULTS AND DISCUSSION**

### **3.6.1 INTEGRATION TO A WEB-BASED APPLICATION**

The web-interface tool was developed with a robust menu to input required user data, create terrace layouts, and review or edit results for any field. The program interface options allow a user to locate a field based on several different characteristics.

Users can select a field location based on:

- Project Name
- Project Area
- County
- City
- Latitude & Longitude
- Township, Range, Section.

Figure 3.8 illustrates these options.

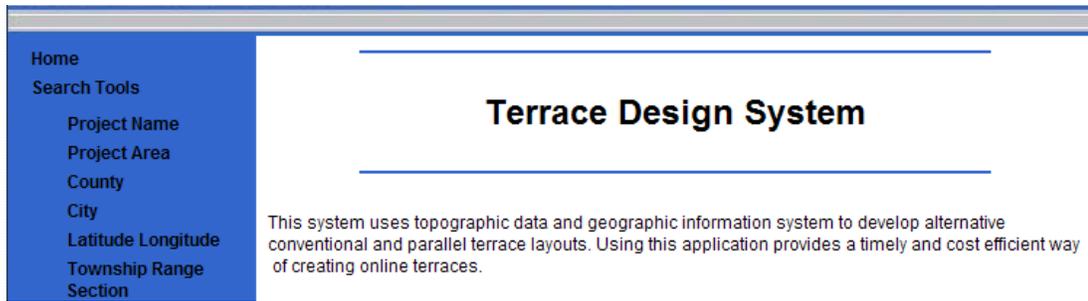


Figure 3.8. TERLOC web-interface search tool options (<http://www.soilsurvey.org/tools/terrace/main.asp>).

All options are a method of quickly locating and zooming to a field location. Depending on the method of search, the user may need to zoom or pan in the mapping window to locate a field. Aerial photography from 2007 and 2009 are provided as a visual reference. The following steps are used to upload field contour data once the field is properly located within the mapping window.

1. Click on “Add New” under Contour Information (Figure 3.9) in the interface menu.



Figure 3.9. Contour upload on TERLOC web-interface (<http://www.soilsurvey.org/tools/terrace/main.asp>).

2. Click “Browse” in the Contour Upload Menu (Figure 3.10).



Figure 3.10. TERLOC Contour upload menu (<http://www.soilsurvey.org/tools/terrace/main.asp>).

3. Select the zipped file containing the GIS shapefile for the field.

4. Select “Upload file” and return to the mapping window.

The contour data will appear in the interface menu as shown in Figure 3.11. The resulting uploaded contours are shown in Figure 3.12.

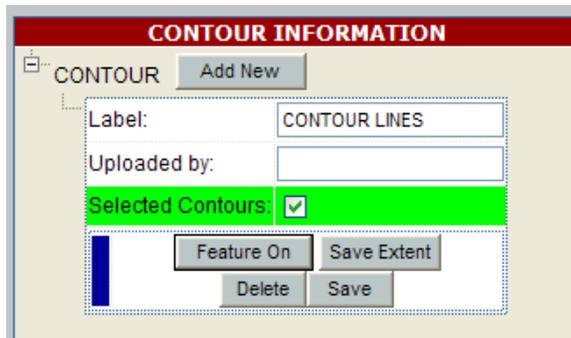


Figure 3.11. TERLOC uploaded contour data menu (<http://www.soilsurvey.org/tools/terrace/main.asp>).

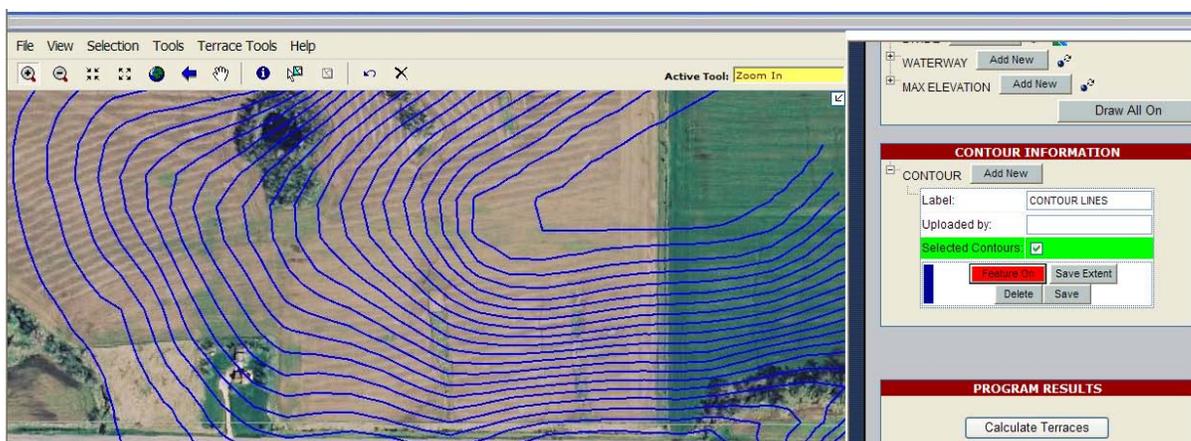


Figure 3.12. TERLOC web-interface displaying uploaded field contours (<http://www.soilsurvey.org/tools/terrace/main.asp>).

Field contour data are essential input for calculating terrace layouts. The upload contours feature allows any field to be uploaded and run through the terrace location program. A maximum file size of 50 megabytes provides ample space for even the largest fields. A future limit of 150 megabytes will be introduced as technology advances.

As mentioned in the methodology, contour data coordinate projection is presently limited by the CARES restriction to Zone 15. This restriction limits contour data to within this zone. Zone 15 includes most of Arkansas, Iowa, Minnesota, Missouri, Louisiana, and small portions of Kansas, Oklahoma, Texas, and Wisconsin. These areas are located within the central region, which in 2008 accounted for 91% of total terrace installation (R. Purcell, personal communication, April 21, 2009). In addition, interface layers including aerial photography, soil data, and other supplemental data provided, are restricted to a full extent of the Missouri state line (Figure 3.13).

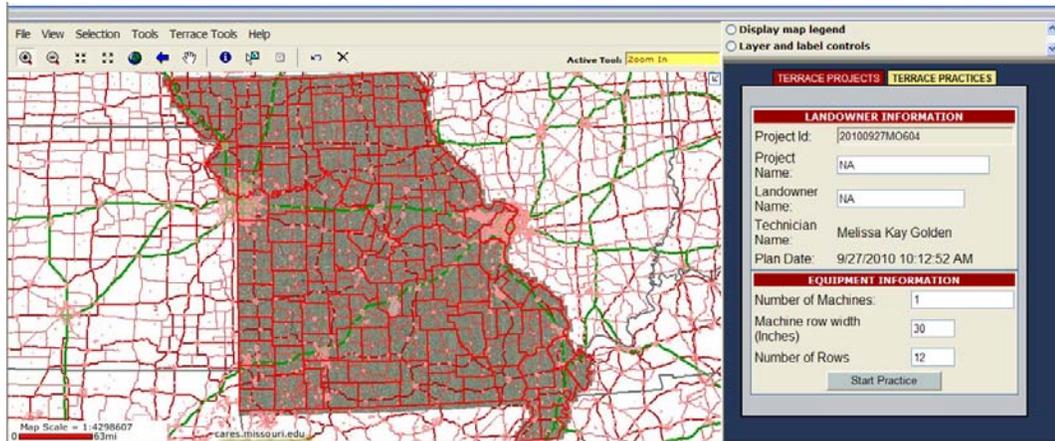


Figure 3.13. The mapping window on the TERLOC web-interface zoomed to full extent (<http://www.soilsurvey.org/tools/terrace/main.asp>).

The supplemental layers are not currently necessary for running the terrace layout program. These layers do however offer visual analysis for locating or comparing field data.

### 3.6.2 MODIFICATION OF DESIGN PROCEDURES

#### 3.6.2.1 Terrace Double-Backing

Terrace double-backing results before and after modifications are shown below in Figures 3.14 and 3.15.

In Figure 3.14, the curvature and irregular arrangement of two adjacent contours causes terrace one to double-back. It also demonstrates how terrace double-backing can affect downhill terrace layouts. The double-backed portion of terrace one is used to locate the first point for terrace two. This portion is further uphill than the rest of the terrace, causing terrace two to be spaced too close to the first terrace.

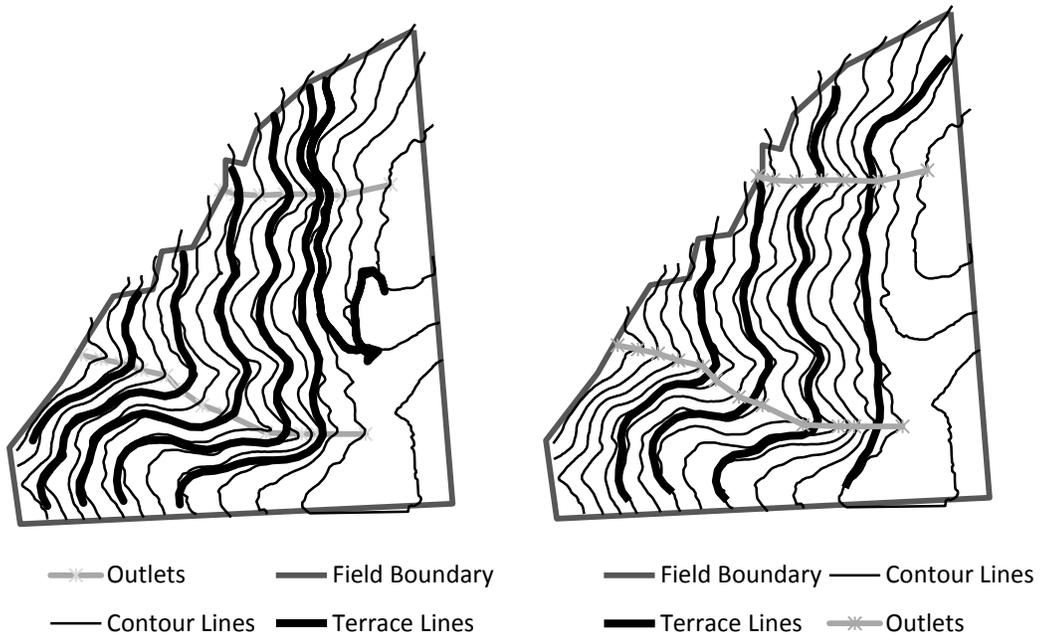


Figure 3.14 & 3.15. (3.14). MO402—Terrace layout with double-backing.  
 (3.15). MO402—Terrace Layout with double-backing modifications.

Figure 3.15 illustrates how the modifications benefit not only the double-backing terrace, but the layout as a whole. Terrace double-backing results for an additional field are shown in Figures 3.16 and 3.17.

Figure 3.16 illustrates how contour line curvature at an outlet can also cause a terrace layout to double-back. Terrace two double-backs across the entire field at a constant grade. Downhill terraces are spaced with the correct portion of the terrace and are spaced correctly.

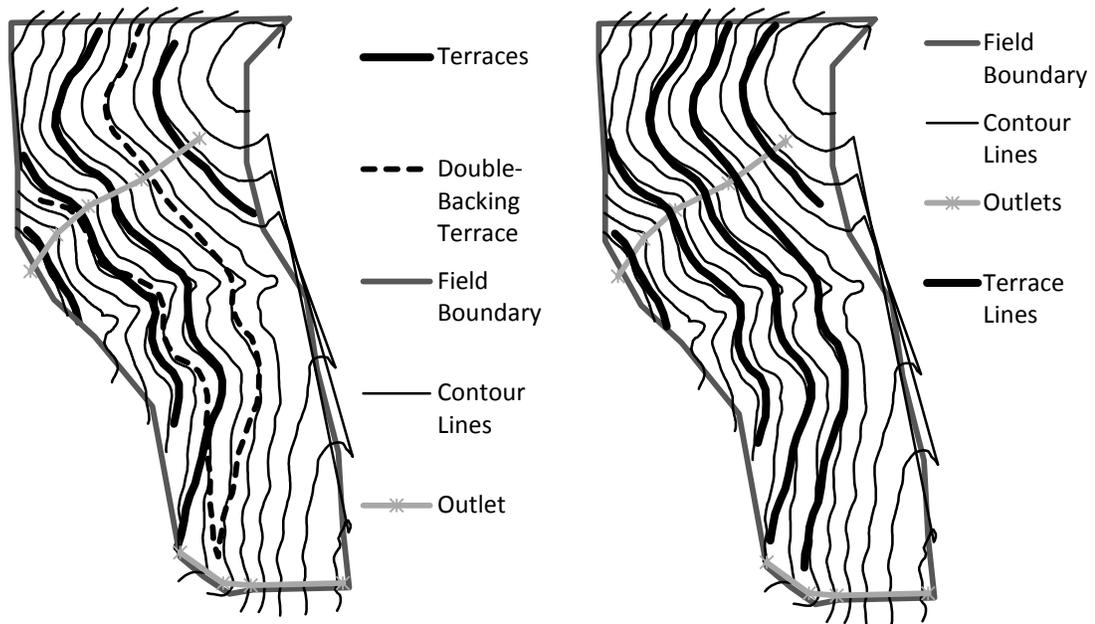


Figure 3.16 & 3.17. (3.16) MO574—Terrace layout with double-backing.  
 (3.17). MO574—Terrace Layout with double-backing modification.

Layouts after modifications to NCINT do not possess double-backing terraces as shown in Figures 3.15 and 3.17. These figures demonstrate how smaller step size enhanced the intersection routine's ability to locate the correct initial minimum distance. Decreasing the step size by half has proved to be most successful. As a result, the routine was more likely to converge to the correct intersection point rather than a local minimum.

### ***3.6.2.2 Terrace Length Limitation and Boundary Check***

An example of a short, out-of-bounds terrace is shown in Figure B1. The final terrace has one point inside and a second point outside the boundary. The final point outside the boundary is erroneously saved since terrace projected points are not verified

to be within the field boundary. None of the terrace points should be used, as they fall too close to the bottom field boundary.

The boundary and length check were both utilized to obtain the results in Figure B2. The boundary check eliminates points outside the boundary to be added. Remaining point(s) are then too short to qualify as a practical terrace and are discarded. A minimum restrictive length of 3 data points proved to be most successful. Spacing between points is currently set to 15 meters (50 feet), thus a minimum restrictive length of 31 meters (100 feet) was used. This distance was chosen due to current program restrictions in the parallel routine. It requires terraces to have at least 3 data points, or 31 meters (100 feet) in length. The minimum length requirement was then set to this shortest possible distance to allow the parallel routine to function properly. From a farmability or practical perspective, even the 31 meters (100 feet) restriction may be too short. However, this distance still allows terraces to be short enough to help avoid excessive discharge flows. Shorter terraces also allow for more channel slope variations.

### ***3.6.2.3 Contour radius of curvature***

Contour smoothing results proved the amount of field alterations increased directly with an increase in radius of curvature. The smallest, 7.6 m (25 ft) radius (Figure C1) proved to alter the original contours the least, while the 31 m (100 ft) radius (Figure C3) modified contours the most. As shown in Figure C3, the 31 m (100 ft) radius requires almost a complete field reconstruction. Cuts and fills up to 1.2 m (4 ft) are needed throughout the entire field. Site preparation typically consists of limited field work for economical and practical reasons. Thus, the amount of smoothing from the 31

m (100 ft) radius of curvature proved to be unrealistic. The 15 m (50 ft) (Figure C2) and 7.6 m (25 ft) (Figure C1) radii provide much less smoothing, thus require less earthwork. The 7.6 m (25 ft) radius, in Figure C1, however, still includes sharp curvature even after smoothing. Its use in the program significantly reduces the stability of curve fitting routines, causing the program to crash or produce erroneous output. The 15 m (50 ft) radius of curvature, however, provides practical smoothing without generalizing too much field data. It has also proved to work successfully for multiple fields.

#### ***3.6.2.4 Line intersection: Step Size Reduction***

A visual comparison of contour, terrace, and outlet and divide lines is shown in Appendix D. As shown in Figures D1 and D2, line irregularities are most commonly found with field contours, or from terrace lines derived from irregular contours. These lines have more curvature and lack uniformity throughout the field length. While terraces are spaced at similar widths, their shape and length uphill may differ from terraces downhill. Unlike contours and terraces, outlet and divide lines are user-drawn and lack excess curvature. The source of false minimums then can be related to contour and terrace lines. Reduction of step size should then be focused on distances down these lines rather than an outlet or divide. Spacing between contour points is not uniform, and can be smaller than one foot. Step sizes in the range of a few feet are not efficient with contour and terrace lengths reaching up to and over 305 m (1000 feet) long. Spacing between terrace points, however, are typically 15 m (50 ft). Step size less than this value would not improve results for terraces lines. Therefore, a default step size of 15 m (50 ft)

was incorporated for the FIND\_INT routine. This new value proved to be most successful at finding correct line intersections.

### 3.6.2.5 Terrace Line Ordering

Figure 3.18 demonstrates the effectiveness of the original version of LINE\_ORDER. All four terraces are numbered with the starting, or zero, end at the bottom portion of the field. With outlet one as the reference point, the routine fails to number terraces with the starting point on the upper end nearest outlet one. Routines within the program would not function properly and produce less than desirable output with this numbering system.

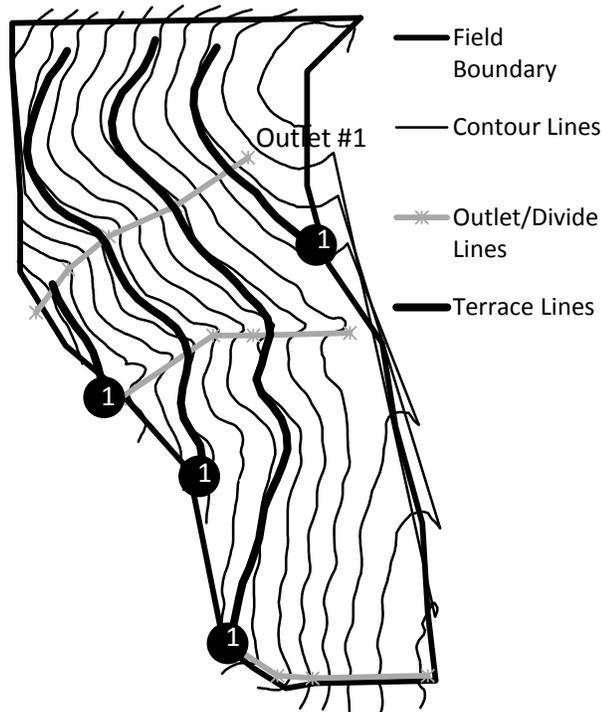


Figure 3.18. An example of terrace line numbering without respect to the first outlet.

Adjustments to LINE\_ORDER help to ensure the terraces are numbered with respect to the reference point, outlet 1 (Figure 3.19). Original routine functions are not sacrificed with these modifications, as the figure shows the points all start on the same, upper end of the field.

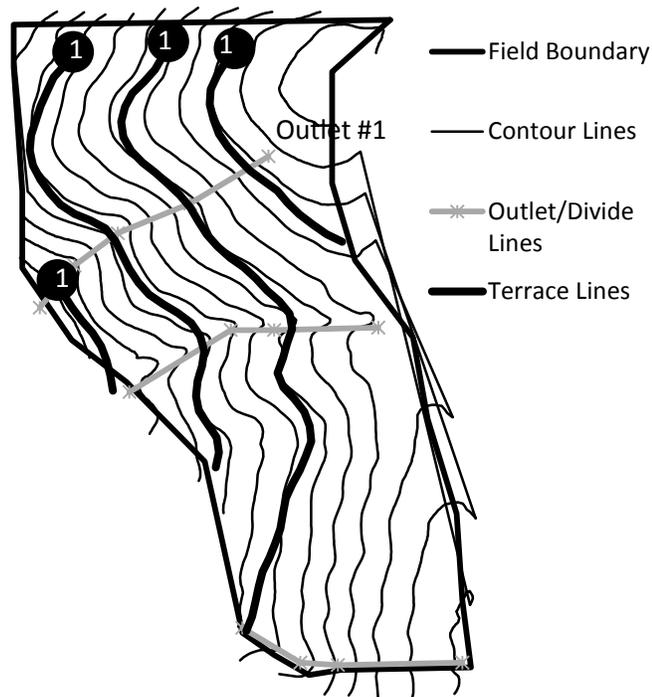


Figure 3.19. An example of terrace line numbering with respect to the first outlet.

### 3.6.2.6 Parallel Layout Orientation

Incorrect parallel layout resulting from irregular field orientation is shown in Figures E1-E3. For key terrace one (Figure E1), terrace two and three are downhill, resulting in a negative PS value. Since the negative X and Y direction are actually the uphill direction, terraces two and three are incorrectly positioned above key terrace one.

Upon first glance, the key terrace two layout (Figure E2) appears to be correct. The terraces uphill and downhill from key terrace two are in the correct field positions. Spacing from key terrace two is 54.9 meters (180 feet) for both terraces. The only difference then is to note that terrace one is actually downhill, while terrace three is the uppermost terrace. This is again due to incorrect PS signs. The key terrace three results (Figure E3) show the same sign issue. However, the important note here is that a lack of contour data beyond the lower boundary causes terrace one to be incorrectly laid out. Figures E7 through E9 show similar incorrect layout results for a field with different orientation. The key terrace one (Figure E7) layout is the exception. The layout is correctly oriented due to an internal inversion of PS when no terrace points are being located. However, this inverted value was not transferred to the remaining key terrace layouts as seen in Figures E8 and E9.

Adjustments to the parallel routine modified PS signs if field orientation was irregular. Figures E4-E6 and Figures E10-E13 illustrate the changes to parallel layouts. The modifications not only invert the original PS signs, they also transfer the new sign values to all key terrace layouts to reflect the field orientation. As shown in Figure E5, after modifications the layout looks identical to the incorrect version in Figure E2. However, the terraces are placed in the correct order with respect to the key terrace. This example proves the PS variable was the cause for this issue. It emphasizes that the theta value in Equations 3.3 and 3.4 is working correctly, and did not influence incorrect placement of entire terrace layouts. The modifications assist in offering proper terrace coverage and eliminate layout errors due to faulty placement.

## **3.7 CONCLUSION**

### ***3.7.1 Summary***

The ability for a terrace location program to handle multiple types of fields is an important aspect from a usability perspective. First, the program was updated to input data for any field. Integration to an online interface facilitated accessibility and provided a means of uploading field data regardless of field size or location. Modifications were also made to provide additional support for various field types. Fields with irregular boundaries, contour lines, and orientation prove to affect layout procedures in TERLOC. Erroneous output and program crashing caused by these field characteristics make terrace layouts difficult to develop. Irregular field boundaries and length affected presence of downhill terraces and their length. Incorporating practical length limitations and a boundary check provided more practical results for the sample field. A 15 m (50 ft) radius of curvature proved to be the optimal radius for smoothing. It provided a more realistic estimation of field preparation while maintaining sufficient contour smoothing. Decreasing step size for intersection routines proved to increase program stability for the sample fields with irregular contours. The most successful step size was found to be related to the line intervals. Finally, internal routine procedures were incorporated to recognize the orientation of a field. This reduced inverted parallel layouts, providing functional alternative layouts for sample fields. Overall, the modifications reduced program errors for more complex fields.

### **3.7.2 Future Research**

The modifications made for handling various fields do have limitations that should be followed up with further research:

- The TERLOC mapping window is limited to the state of Missouri. In addition, contour uploading options are limited to Zone 15. Future work should be conducted to accommodate nationwide zones. Further research may also be focused on obtaining supplemental data such as aerial photography and soils data on a nationwide scale.
- Portions of a field may be left un-terraced for some fields with irregular boundaries. The boundary is used as an execution point, ceasing terrace layout once crossed. If a boundary is irregular, a terrace may cross the boundary temporarily, but should continue in another portion of the field. Further research should be conducted on terrace layouts for irregular boundaries.

### 3.8 REFERENCES

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## **CHAPTER 4**

# **OPTIMIZING RESULTS FROM TERRACE LOCATION PROGRAM**

### **4.1 ABSTRACT**

TERLOC (Terrace Location Program), a terrace layout program, was modified to include additional design options for an optimal layout selection. The additions were: varied terrace spacing, channel grade modifications, underground outlet selection, split stream design, and multiple key terraces. The new additions enhance the program's ability to handle various fields, provide additional layout designs, and help improve results for maximum conservation and farmability, while limiting costs. These changes provide an overall comprehensive planning tool that allows the user to select the best layout design from multiple alternatives.

### **4.2 INTRODUCTION**

Soil erosion by water accounts for 960 million tons of soil loss per year on U.S. cropland (USDA-NRCS, 2009). While soil loss has decreased over time with implementation of various soil conservation measures, 40 million hectares (99 million acres) of cropland are still eroding above soil loss tolerance levels (USDA-NRCS, 2009). Terraces are an effective means of reducing soil erosion and help restore prime cropland. Terraces decrease the land slope length, reducing displacement energy of overland flow. Erosion, specifically rill and gully erosion, may be reduced up to 60% as a result (Sudduth and Gregory, 1982). Additionally, water quality leaving a terraced field may

be improved as some studies have found that terraces reduce sediment yields by over 50% (Yang, 2009) and up to 95% (Wischmeier and Smith, 1978).

The increase in computer technology in the last several decades has popularized planning tools for conservation. Designed to provide time and cost savings, these tools assist engineers and technicians to quickly evaluate a problem and develop a solution. Terrace design programs emerged in the 1970s. Many programs, (Forsythe and Pasley 1969; Ryu and Hunt 1981; and Keep, 1989) were aimed at terrace cross-section design and optimizing earthwork volumes and costs. These programs were limited by time consuming manual data entry. Furthermore, prior to running these programs, terrace layouts had to be performed manually in the field. Sudduth (1981) and Holly (1989) addressed this issue with the development of programs focused on locating terraces within a field. The program developed by Sudduth (1981), called TERLOC (Terrace Location Program), provided a more comprehensive program with more reliable output. Further research on this program was done by Ghidey (1987, 1990) to design terrace channel profiles and estimate required volume of earthwork. The program utilized digital topographic data as well as user input of field and equipment data. A flowchart of the TERLOC logic and procedures is shown in Appendix A. Output from the program included conventional terraces, smoothed conventional terraces, as well as parallel layouts.

TERLOC was designed to provide a method of saving time and money for designing terrace layouts; however, the program was limited. The main limitation noted by Sudduth and Gregory (1982) was the lack of additional design data to provide an

analysis for best layout design based not only on conservation, but also on farmability and cost. Ghidey, et al. (1992) conducted research on adding earthwork and channel design calculations into TERLOC. The earthwork amendments were not incorporated in the overall program; instead focus was placed on improved layout methods. The channel grade procedure has been redone to make it consistent with the new layout procedures for terrace smoothing. Supplemental data for a design analysis such as terrace spacing, optimal outlet selection, and multiple key terrace selection are important additions needed to permit the user to balance advantages and disadvantages of each terrace layout. With these data, an optimal solution may be selected to solve erosion issues while meeting land owner requirements and promoting improved land use.

### **4.3 OBJECTIVES**

The goal of this project was to incorporate additional engineering design considerations to provide a best design analysis for a terrace location program, TERLOC, developed by Sudduth and Gregory (1982) and revised by Ghidey et al. (1992). The additions provided the terrace location program with optimal terrace results for conservation planning. Results with special consideration of conservation, farmability, and cost were desired. This objective was met through the following program additions:

- Varied terrace spacing,
- Verification of adequate channel grade,
- Optimal outlet selection,
- Multiple key terraces.

## **4.4 MATERIALS**

The hardware utilized for this project was an X86-based PC with a 2992 Mhz processor. The terrace layout program was written in FORTRAN and additions were made using Intel® Fortran Compiler Version 10.1.011 and Microsoft Visual Studio 2008.

Additional software utilized for this project includes:

- Sql Server 2000 with service pack 3 (Delaney, 2000)—Enterprise Edition 64 MB minimum, 128 MB recommended,
- ESRI ArcIMS 9.3 with service pack 3 (ESRI, 2004),
- Ogr2Ogr freeware (<http://www.gdal.org/ogr2ogr.html>),
- AspTreeview freeware (<http://aspwebsolution.com/articles/coder4life/treeview/asp/index.htm>).

The following programming languages were also used for the online modifications:

Active Server Pages, JavaScript, Visual Basic Script, and Window Script.

## **4.5 METHODOLOGY**

### **4.5.1 VARIABLE TERRACE SPACING TO MEET SOIL LOSS TOLERANCE**

TERLOC calculates terrace spacing using the Vertical Interval Method. This method uses generalized geographic and rainfall energy values to account for soil loss, and a site specific land slope value. The NRCS recommends restrictions for maximum terrace spacing to verify that soil loss criteria are met. Therefore, a variable spacing technique was added to determine the final spacing between terraces. The program initially calculated a theoretical spacing, HI, with the Vertical Interval Method. In Missouri, 36.6 to 54.9- meter (120 to 180 -foot) spacing is regarded as the minimum and respective maximum allowable spacing for most fields (USDA-NRCS Code 600, 2010a).

The initial HI value was then compared and altered using the spacing consideration logic in Table 4.1.

Table 4.1. Horizontal Interval Adjustments for Conventional Terrace Layouts

<i>Calculated Horizontal Interval<sup>1</sup> m (ft)</i>	<i>Adjusted Horizontal Interval m (ft)</i>
<36.6 (120)	36.6(120)
36.6(120)<HI>54.9(180)	HI
>54.9(180)	54.9(180)

<sup>1</sup> Using the Vertical Interval Method

These modifications transferred to the parallel layout as well. Parallel spacing was calculated using the original horizontal interval. The final spacing was rounded to a multiple of the equipment width. Previously, for 9.1 meter (30 foot) machinery, spacing from 9.1 to 183 meters (30 feet to 600 feet) were available options. Modifications to the original, conventional horizontal interval eliminate inappropriate spacing options. The original horizontal spacing falls between 36.6 and 54.9 meters (120 and 180 feet), thus all parallel layouts were rounded to 36.6, 45.7, or 54.9 meters (120, 150, or 180 feet) for 9.1 meter (30 foot) machinery.

#### **4.5.2 TERRACE CHANNEL GRADE FOR NON-EROSIVE VELOCITIES**

The original terrace layout was constructed with a constant grade of 0.4%. While it is currently a constant value, this value can be made a user specified option. After a conventional layout was completed, the terrace lines were smoothed to minimize areas

with sharp curvature which could hinder farm operations. An example of terrace line smoothing is displayed in Figure 4.1.

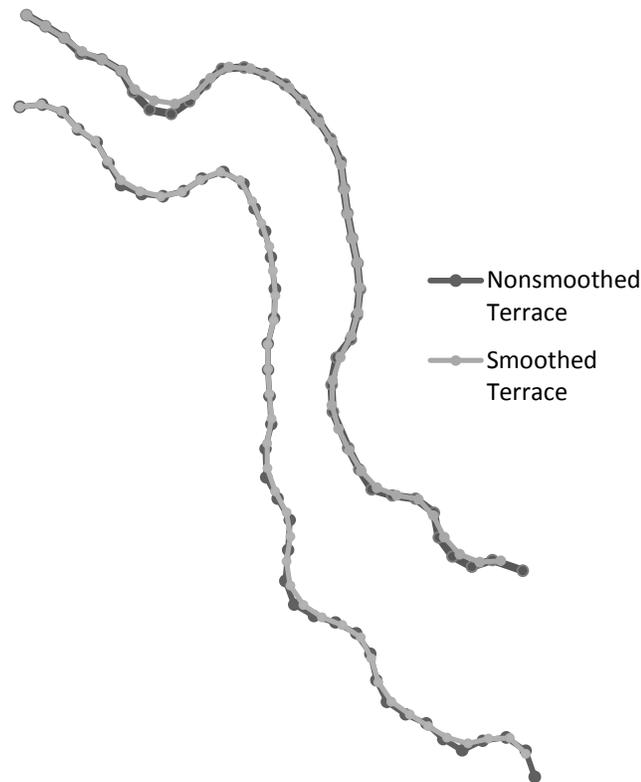


Figure 4.1. An example of the terrace smoothing procedure results.

While line smoothing represents an increase in farmability of the terrace system, it may alter the coordinates, hence elevation and original constant grade. Figures G1-G15 illustrate the effects of line smoothing on terrace cross sections. Maintaining a nonerosive velocity in a terrace channel is an essential component for providing a stable terrace design according to the USDA-NRCS (2010a) terrace standard. The terrace channel must also maintain a slope steep enough to provide drainage to an outlet without

ponding. A channel slope routine was developed using Manning's equation to check the modified terrace channel, as shown in Equation 4.1:

$$V = \phi R^{\frac{2}{3}} S^{\frac{1}{2}} / n \quad (4.1)$$

where,

$\phi = 1$  m/s or 1.486ft/sec,

$V =$  cross-sectional average velocity (m/s, ft/sec),

$R =$ hydraulic radius (cross sectional area/cross sectional perimeter) (m/ft),

$S =$  channel slope (m/m, ft/ft),

$n =$ Manning's roughness coefficient (dimensionless).

Soil erodibility must be known to determine the nonerosive cross-sectional velocity needed in the channel. The USDA-NRCS (2010a) terrace standard provides a relationship for soil erodibility and maximum permissible velocity:

$V = 0.46$  m/s (1.5 fps) for erosive soils,

$V = 0.61$  m/s (2 fps) for moderately-erosive soils,

$V = 0.76$  m/s (2.5fps) for erosion-resistant soils.

A fixed velocity of 0.61 m/s (2 feet per second) for moderately erosive soils was used within the routine. The hydraulic radius in Equation 4.1 was solved based on a trapezoidal cross section as shown in Equation 4.2:

$$R = A/p = (B + ZD^2)/[B + 2D(\sqrt{(Z^2 + 1)})] \quad (4.2)$$

where,

B= bottom width of channel (m, ft),

D= water depth in channel (m, ft),

Z= side slope ratio (dimensionless).

Manning's equation was combined with the continuity equation and rearranged to solve for maximum slope. Plugging in the hydraulic radius equation yielded Equation 4.3 for maximum slope:

$$Max\ Slope = \frac{\varphi_3^{\frac{2}{3}}(V^{\frac{8}{3}}N^2(B+(2D(\sqrt{Z^2+1})))^{\frac{4}{3}}}{\varphi^2(BD+(ZD^2))^{\frac{2}{3}}(\varphi_2*A*P*C)^{\frac{2}{3}}} \quad (4.3)$$

where,

$\varphi=1$ (Metric), 1.486(English),

$\varphi_2=0.0028$  (Metric), 1(English),

$\varphi_3=10,000$  m<sup>2</sup>/ha, 43,560 ft<sup>2</sup>/ac,

A=drainage area (m<sup>2</sup>, ft<sup>2</sup>),

P=Rainfall intensity (mm/hr, in/hr),

C=Runoff coefficient (dimensionless).

Variable assumptions were made based on Missouri geography, topography, and soils. The side slope ratio was set at 10:1 and Manning's n was assumed to be 0.03 for a

vegetated channel. Rainfall intensity was set to 178 mm/h (7 in/hr), and channel bottom width was zero feet. The runoff coefficient was assumed to be 0.7, a value reflecting row crops.

Drainage area was calculated using the area originating from the previous terrace, and flowing from a divide to an outlet. For the first terrace, the high point is the origin of water. Area was calculated using Equation 4.4, the Double Meridian Distance Method for calculating the area of a polygon (Ghilani and Wolf, 2008):

$$Area = \left| \frac{1}{2} \sum_{i=1}^N (X(i) + X(i + 1)) * (Y(i + 1) - Y(i)) \right| \quad (4.4)$$

where,

Area= m<sup>2</sup>/ ft<sup>2</sup>,

X= x coordinates of boundary points,

Y=y coordinates of boundary points,

i=index point,

N=number of boundary points.

The drainage area and peak runoff rate contribute to the channel water depth. The peak runoff rate was calculated in Equation 4.5 using the Rational method:

$$Q = \varphi_2 CIA \quad (4.5)$$

where,

Q= peak runoff rate (m<sup>3</sup>/s, cfs),

C= Runoff Coefficient (0.7 for row crops),

I= Rainfall intensity (mm/hr, in/hr),

A=drainage area of field (ha, ac).

The water depth was calculated by solving the hydraulic radius equation (Equation 4.2), in combination with the continuity equation, for depth, D (Tollner, 2002).

The solution to this quadratic formula is shown in Equations 4.6 and 4.7:

$$D = \frac{-B\sqrt{V} + \sqrt{B^2V + 4QZ}}{2\sqrt{VZ}} \quad (4.6)$$

$$D = \frac{-B\sqrt{V} - \sqrt{B^2V + 4QZ}}{2\sqrt{VZ}} \quad (4.7)$$

The shallowest, non-zero value was chosen as the water depth within the channel and was used in Equation 4.3 to solve for the maximum allowable slope.

Once the maximum slope was found, the actual slope of the terrace channel was compared to that value. Slope adjustments were made in the routine via cuts in elevation. Slopes that were too steep were cut to meet the maximum allowable slope. When the slope was too flat, or was oriented in the wrong direction, a cut was made to the

minimum allowable slope of 0.1 percent. No modifications were made when minimum and maximum allowable slopes were satisfied. Cut depths and new elevations at each terrace point were recorded and supplied as output. A warning message was also displayed in the output to alert the user of excess cuts of over 1.2 meters (4 feet). All custom FORTRAN code for the channel grade modifications are shown in Appendix P.

#### **4.5.3 OPTIMAL OUTLET SELECTION—UNDERGROUND OUTLETS**

TERLOC was originally designed for any water outlet system (Sudduth, 1981). No distinction was made between underground outlets (UGO) and grassed waterways since they were only used to locate the terrace. Underground outlets have grown increasingly popular since the 1960s (Forsythe and Pasley, 1969; Fangmeier et al., 2006). In fact, most terraces installed in Missouri today are designed with an UGO system. A routine was developed to provide engineering parameters needed for development of a UGO system. At each terrace-outlet intersection, runoff volume was computed using Equation 4.5 where the variable  $I$  was the runoff depth of the design storm in meters or inches. A value of 0.14m (5.4 in) was used for Central Missouri conditions.

Runoff volume was then used to solve for both the peak runoff rate and the desired discharge rate. The peak runoff rate was determined assuming a triangular hydrograph using Equation 4.8. A 10-year-24 hour storm was used to determine peak inflow rate (Beasley et al., 1984):

$$Q_{in} = (2 * \text{Runoff Volume}) / (\varphi_4 \text{Storm Duration}) \quad (4.8)$$

where  $Q_{in}$  is in  $m^3/s$  (cfs) and  $\varphi_4 = 3660$  for Metric units and 1 for English units. The release time was set to 24 hours as well to avoid crop damage from drowning for most crop varieties. The underground outlet design discharge was calculated using this release criterion :

$$Q_o = (\text{Runoff Volume}) / (\varphi_4 \text{Release Time}) \quad (4.9)$$

where  $Q_o$  is in  $m^3/s$  (cfs). Storage volume needed to prevent overflow and crop damage was then calculated using a relationship between  $Q_o/Q_{in}$  and  $V_{storage}/V_{runoff}$  in Figure 4.2 (Beasley et al., 1984).

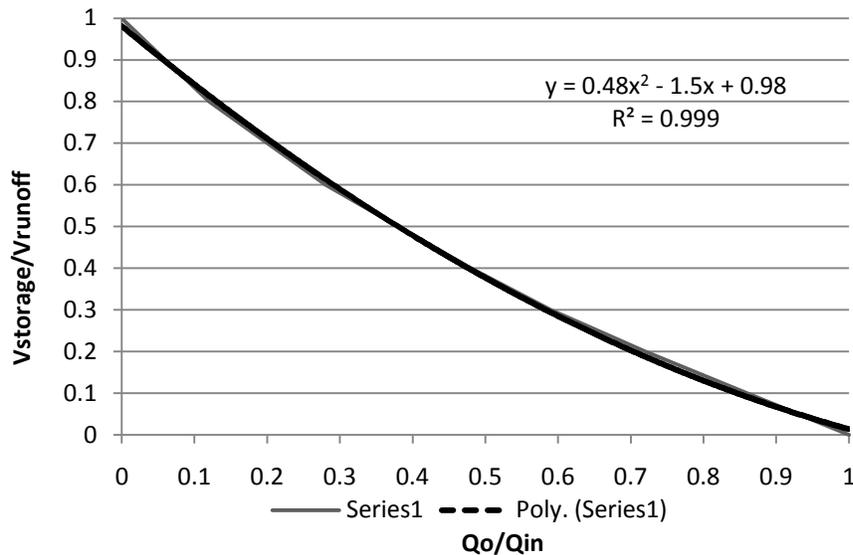


Figure 4.2. The Underground Outlet Routing Curve.

An equation for storage volume (Equation 4.10) was derived by fitting a second-degree polynomial to the Underground Outlet Routing Curve in Figure 4.2:

$$V_{storage} = \left( 0.4817 \left( \frac{Q_o}{Q_{in}} \right)^2 - 1.4491 \left( \frac{Q_o}{Q_{in}} \right) + 0.9814 \right) * V_{runoff} \quad (4.10)$$

where storage volume is in cubic meters (acre-inches).

Maximum berm height was calculated using the water depth derived in equations 4.6 and 4.7. Berm height (Equation 4.11) was solved by assuming the water surface was at a maximum of 70% of berm height (Beasley et. al, 1984):

$$B_h = D/0.7 \quad (4.11)$$

where  $B_h$ = berm height (m, ft). A freeboard of 0.15 meters (six inches) and a 10% settling factor were added for the final berm height.

Design of inlet holes (Equation 4.12) for Type I risers were derived from the orifice equation assuming 50% of the holes were plugged (USDA-NRCS Code 620, 2010b):

$$N = 2 * 0.3Q_o / (a\sqrt{B_h}) \quad (4.12)$$

where,

N=number of holes,

a=area of one filter hole (0.00065 m<sup>2</sup>, 0.00545 ft<sup>2</sup>).

An orifice plate was designed to control flow into the conduit. The orifice diameter was calculated using the orifice equation as shown in Equation 4.13:

$$D_{orifice} = \left( \frac{4}{\pi} * Q_o / (0.6 \sqrt{2g(H_1 + 0.7B_h)}) \right)^{0.5} * \varphi_5 \quad (4.13)$$

where,

$D_{orifice}$  = orifice diameter (mm, in),

$g$  = acceleration from gravity (9.81 m/s<sup>2</sup>, 32.2 ft/s<sup>2</sup>),

$H_1$  = distance from orifice plate to 1- meter (3-foot) channel bottom width (m, ft),

$\varphi_5$  = 1000 mm/m (12in/ft).

A restriction for minimum orifice diameter was set to 38 mm (1.5 inches) to prevent plugging issues (Beasley et. al, 1984). In addition, the distance from the orifice plate to the bottom 1-meter (3-foot) point was assumed to be 0.76 meters (2.5 feet). The orifice diameter was rounded to the nearest quarter inch and discharge was solved by rearranging Equation 4.13 for  $Q_o$ .

Finally, the conduit pipe diameter for full pipe flow was calculated using Manning's equation as shown in Equation 4.14:

$$D_{sealed\ pipe} = \left( \frac{3.22 * Q_o n}{\varphi \sqrt{S_p}} \right)^{3/8} * \varphi_5 \quad (4.14)$$

where,

$D_{sealed\ pipe}$  = pipe diameter (mm, in),

$S_p$  = pipe gradient (dimensionless).

Corrugated pipe ( $n=0.016$ ) with sealed joints was assumed, thus no limiting velocity was calculated. Pipe diameters were rounded to nearest whole integers and pipe discharges were calculated by rearranging Equation 4.14 to solve for  $Q_o$ . Conduit pipe size between terraces was calculated by adding all upstream discharges. Pipe restrictions were set to a minimum value of 101 mm (4 inches) and maximum value of 305 mm (12 inches). Warnings were printed to the user when outlet sections required diameters larger than 305 mm (12 inches). The warning alerted the user of the required diameter of a secondary conduit to carry the excess flow. Custom FORTRAN code for this modification is shown in Appendix P.

#### **4.5.4 OPTIMAL OUTLET SELECTION—SPLIT STREAMS**

Outlets and divides within a field are essential input that must be drawn on the user interface to assist in terrace location. TERLOC requires a divide to fall between two adjacent outlets. Providing input for fields with converging outlets then becomes difficult. For these fields the user would attempt to draw the two outlets and divide at the same exact location from the convergence point down. This method was not precise, and proved to yield incorrect results. Due to the scale of the user interface and the difficulty of drawing two or more lines exactly the same, considerable error was introduced. Figure 4.3 illustrates this user error in the original method.

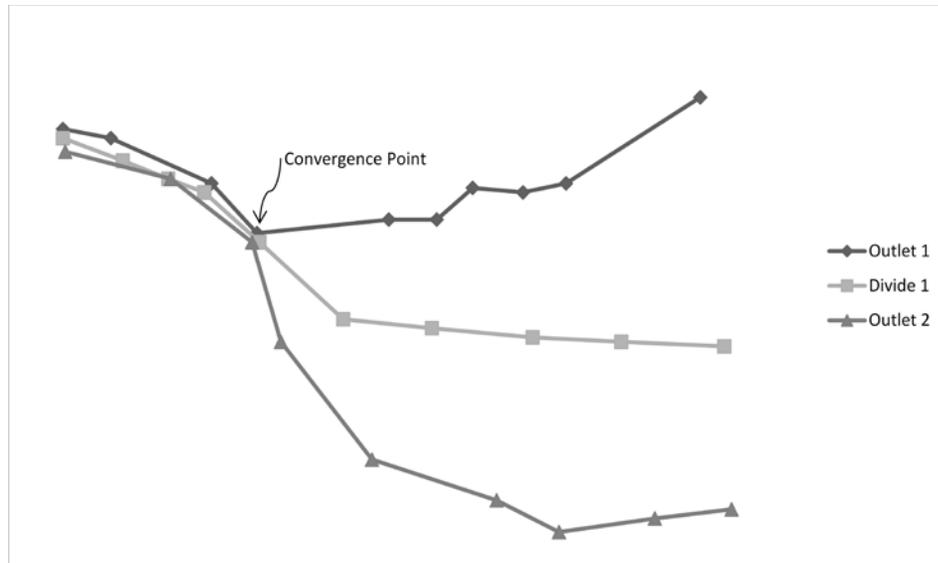


Figure 4.3. User error in drawing split streams

As shown, precise data entry on the web-interface proves to be difficult. Even if the points appear to be on top of one another on the interface, the actual coordinates may still differ. In some cases, points on the divide may not fall between the two outlets. An additional option, split or converged streams, was included in TERLOC to provide more precise input for outlet locations. This addition was implemented with the assistance of the staff of the Center for Applied Research and Environmental Systems (CARES). Modifications were made on the web-interface to provide a new method for drawing split or converged streams. Using custom JavaScript code, two dimensional arrays were manipulated to capture points from one line and store in other lines. The new method enabled the user to identify a point of confluence and indicate which points were to be shared between two outlets and the divide. ESRI ArcIMS 9.3 was used to display outlet and divide lines on the interface. The steps involved in the split stream process are listed below:

1. Draw the divide that will fall between the two outlets (Figure 4.4).



Figure 4.4. Web-Interface view of the divide (cyan) to fall between split streams. Contour line data is shown in orange (<http://www.soilsurvey.org/tools/terrace/main.asp>).

2. Draw separate portions of outlets that belong to the split stream network (Figure 4.5).

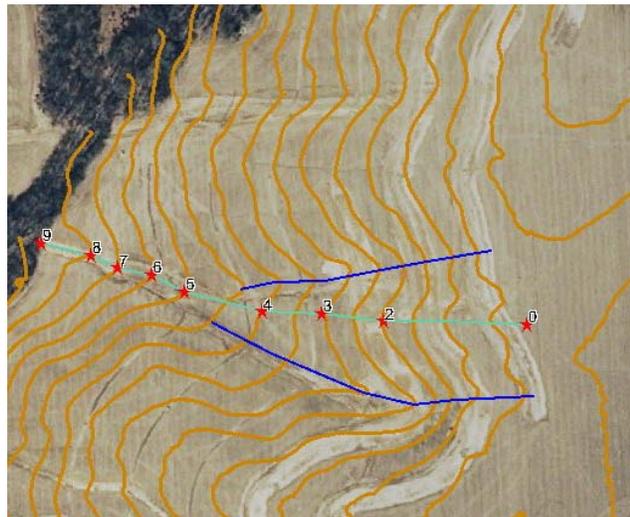


Figure 4.5. Web-interface view of separate outlets (blue) on each side of a divide (cyan). Contour line data is shown in orange (<http://www.soilsurvey.org/tools/terrace/main.asp>).

3. Select the corresponding divide and point of convergence (or separation) from the divide drop down menu (Figure 4.6).

DIVIDE Add New

Label: DIVIDE

Length (feet): 1225.795

Order Number: 1

Part of Split Stream: YES

Select an intersection point: 5 Draw Point

Feature On Label On Delete

Change Color Move Label Save

WATERWAY Add New

MAX ELEVATION Add New

Figure 4.6. Web-interface menu displaying selection of split stream convergence point (<http://www.soilsurvey.org/tools/terrace/main.asp>).

4. Select which points on the divide should be added to the outlets (Figure 4.7).

WATERWAY Add New

Label: WATERWAY

Length (feet): 627.784

Order Number: 1

Add all points to split stream: > the intersection pt. < the intersection pt.

Add to Waterway

Feature On Label On Delete

Change Color Move Label Save

Label: WATERWAY

Length (feet): 838.567

Order Number: 2

Add all points to split stream: > the intersection pt. < the intersection pt.

Add to Waterway

Feature On Label On Delete

Change Color Move Label Save

MAX ELEVATION Add New

Figure 4.7. Web-interface menu displaying selection of outlet points (<http://www.soilsurvey.org/tools/terrace/main.asp>).

For the example shown, point 5 on the divide is the point of convergence. Points five through nine should be present on both outlets as well. Thus, the interface took these points and added them to the existing outlet points. A straight line was used to connect the last drawn point on the outlet to the point of convergence.

#### 4.5.5 USE OF MULTIPLE KEY TERRACES

The parallel routine in TERLOC calculates multiple layout alternatives using each terrace as a key terrace. Figure 4.8 shows an example of the parallel option menu for a field with 3 terraces.

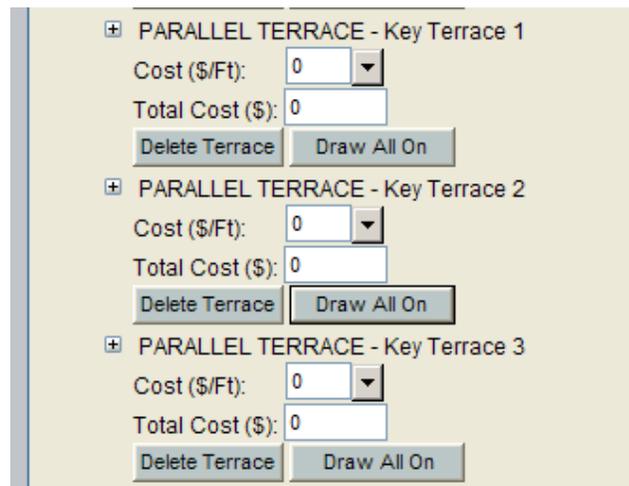


Figure 4.8. Web-interface menu displaying parallel terrace layouts (<http://www.soilsurvey.org/tools/terrace/main.asp>).

Fields with varying topography or irregular boundaries, however, may be better suited for one key terrace uphill, and another key terrace downhill. Figure 4.9 shows a field with an irregular boundary and variable topography. Figure F4 shows the original terraces to be used as key terraces.

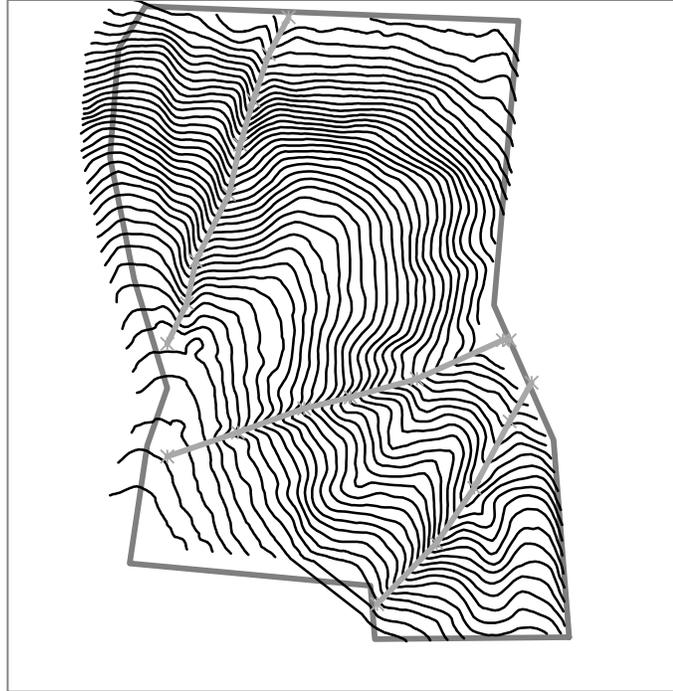


Figure 4.9. An example of a field with an irregular boundary and variable topography.

The option for multiple key terraces has been included to provide an optimal parallel layout selection. This addition was implemented by the staff of Center for Applied Research and Environmental Systems (CARES). Custom JavaScript code was used to identify each key terrace layout. ESRI ArcIMS 9.3 was used to display each parallel terrace of each layout individually. The user could then select any combination of parallel terraces from any key terrace layout option as shown in Figure 4.10.

Label:	Key Terrace 1-1	
Date:	9/15/2010 2:53:07 PM	
Length:	1150.4	
Cost (\$):	0	
<input type="checkbox"/> Feature On	<input type="checkbox"/> Label On	<input type="checkbox"/> Delete
<input type="checkbox"/> Change Color	<input type="checkbox"/> Move Label	<input type="checkbox"/> Save

Label:	Key Terrace 1-2	
Date:	9/15/2010 2:53:07 PM	
Length:	1078.5	
Cost (\$):	0	
<input type="checkbox"/> Feature On	<input type="checkbox"/> Label On	<input type="checkbox"/> Delete
<input type="checkbox"/> Change Color	<input type="checkbox"/> Move Label	<input type="checkbox"/> Save

Label:	Key Terrace 1-3	
Date:	9/15/2010 2:53:07 PM	
Length:	561.4	
Cost (\$):	0	
<input type="checkbox"/> Feature On	<input type="checkbox"/> Label On	<input type="checkbox"/> Delete
<input type="checkbox"/> Change Color	<input type="checkbox"/> Move Label	<input type="checkbox"/> Save

Figure 4.10. Web-interface menu displaying separate parallel layers for key terrace 1 (<http://www.soilsurvey.org/tools/terrace/main.asp>).

Figure 4.10 shows each parallel terrace for the key terrace 1 layout. The user can view each individual terrace by selecting “Feature On”. An overall layout may be chosen by selecting multiple parallel layouts from different key terrace layouts.

## 4.6 RESULTS AND DISCUSSION

### 4.6.1 VARIABLE TERRACE SPACING TO MEET SOIL LOSS TOLERANCE

Three fields in Missouri were examined for terrace spacing purposes: a Saline County field, and two Monroe County fields (MO433 and MO574). Figures F1-F6 and Tables F1-F3 in Appendix F compare terrace spacing and the total number of terraces before and after modifications. Figures F1, F3, and F5, as well as Tables F1-F3 illustrate how the original terrace layouts resulted in inadequate terrace spacing for soil loss

criteria. Figures F2, F4, and F6 show how the modifications decreased spacing, thus slope length. The Saline County (Figure F1) and MO574-Monroe County (Figure F5) fields exceeded the maximum allowable spacing for all terrace intervals. The final modified spacing was reduced to 54.9 meters (180 feet) and resulted in an additional terrace for both fields (Figures F2 and F6). Total terrace number for MO433-Monroe County (Figure F4) remained the same. As shown in Table F2, spacing between terraces four and five and between terraces five and six fell within the allowable range. Therefore, no changes were made. None of the fields had spacing less than 36.6 meters (120 feet). With the VI parameters used in the routine,  $X=0.6$  and  $Y=2$ , a field would need to have a land slope greater than 8% to achieve a spacing less than 36.6 meters (120 feet). Terraces are not commonly installed for fields this steep; however, it is possible to still come across such a field. The VI variables X and Y should be modified to best reflect field conditions when fields fall into a different geographic locations or changes in soil erodibility, cropping systems, or crop management systems occur. If the equation parameters are altered, spacing less than 36.6 meters (120 feet) is more likely to be achieved.

The variable spacing technique provides a balance of conservation, cost, and farmability. In the sample fields, the method resulted in some additional earthwork costs due to additional terrace construction, but this is balanced by the overall goal of soil conservation. The maximum 54.9 m (180 ft) restriction helps to insure terraces meet their original purpose: to reduce soil loss. Farmability is considered by the minimum threshold. Practical minimum spacing of 36.6 m (120 ft) accommodates a sufficient

number of turns for modern equipment. It helps keep spacing wide enough for adequate field efficiency. In addition to farmability, the minimum threshold may also reduce earthwork costs by reducing terrace numbers.

#### **4.6.2 CHANNEL GRADE VERIFICATION**

Channel grade was also tested on the three sample fields. The original, non-smoothed cross sections are shown in Appendix G. Prior to smoothing, the terrace channels have constant grades throughout their length. Figures G1-G15 demonstrate how line smoothing affects channel elevation and disrupts the original channel grade. The smoothed terrace cross section, before and after modifications, are shown in Appendix H (Figures H1-H15). Unlike the original, non-smoothed terraces, the modified channel slopes are varied. Specifically, upstream portions of the terrace channel are allowed to have steeper slopes due to less drainage area contributing to flow volume. Using variable slopes along the smoothed channel helps maintain maximum farmability without incurring extra earthwork costs. Earthwork costs are also reduced by using minimum allowable slopes in place of maximum slopes in some areas. This idea is reiterated in the cut depth Table II in Appendix I. Not only are farmability and costs optimized, but conservation is also met by providing adequate drainage within the terrace channel.

#### **4.6.3 OUTLET SELECTION—UNDERGROUND OUTLETS**

Underground outlets were designed for each of the three fields using the conventional terrace layouts. Results are shown in Tables J1-J3 in Appendix J. Berm heights for most terraces are around one foot high. This low height requirement is due to the use of a flat, farmable side slope, which results in shallow water depths. Required

conduit pipe size increases for down slope terraces as flow volume accumulates. Orifice plates are designed to control flow entering the conduit. This not only prevents downhill terraces from overflowing, it may also contribute to cost savings when compared to a system controlled by conduit (Beasley et al., 1984). Both Monroe County fields (Tables J2 and J3) require secondary conduit pipes to handle excess flow. Secondary conduits provide cost savings due to the expense of large diameter pipe. This might also provide an alert to the user to reconsider outlet placement if flow becomes too great and requires large pipe diameters. Designing additional outlets or placing outlets closer together may benefit by decreasing total pipe cost.

For MO574-Monroe County, the third UGO is not designed. Referring to the terrace layout (Figure F6) in Appendix F, the third, bottommost outlet is located at the field boundary, which no terraces actually intersect. In order to be designed, it is essential that one or more terraces cross an outlet in order for it to receive flow.

The UGO design output provides the user with additional options and information regarding outlets. UGOs in general provide maximum farmability for terrace systems that are parallel. Steeper sloping fields may be terraced using underground outlets. Due to sealed joints and no limiting velocities needed, steeper slopes may also be used within the terrace channel.

#### **4.6.4 OUTLET SELECTION—SPLIT STREAMS**

The split stream drawing method results are shown in Figure 4.11.

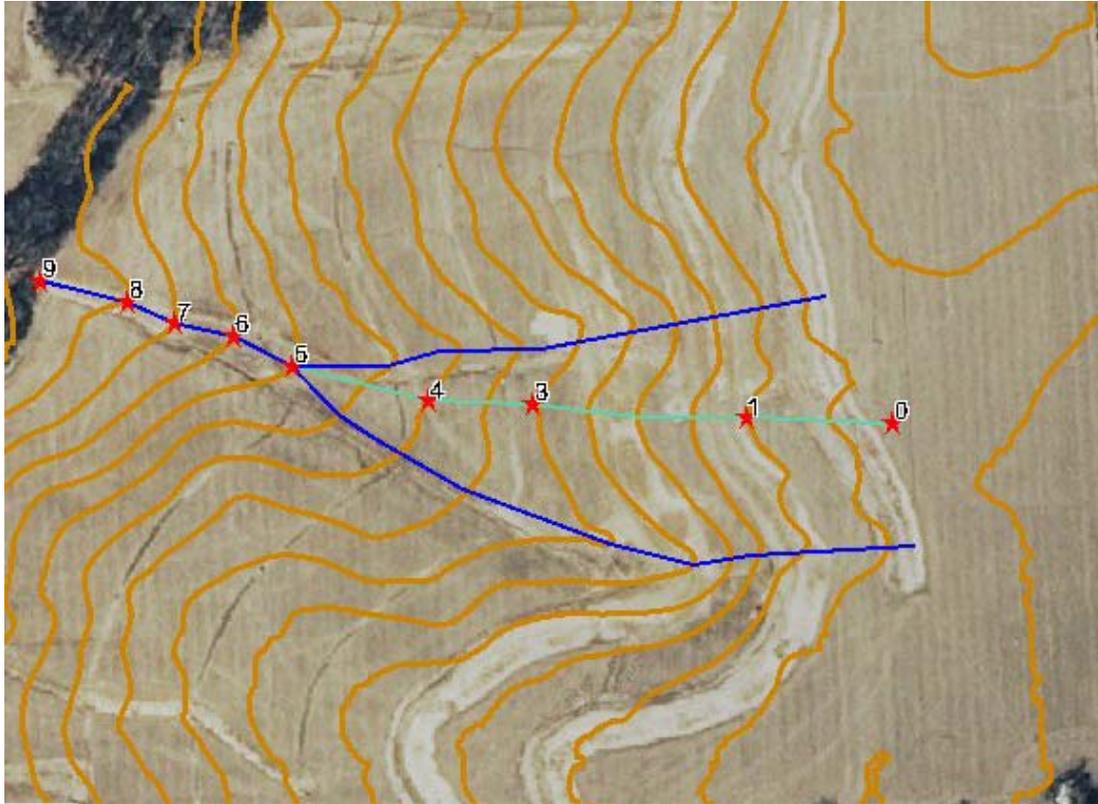


Figure 4.11. Web-Interface view of split stream results. Items in the mapping window include outlets (blue), a divide (cyan) and contour line data (orange) (<http://www.soilsurvey.org/tools/terrace/main.asp>).

As shown, the split streams are successfully joined together, yet still have the required divide in between. All three lines share identical coordinates from point five on. This increased precision provides additional ease of input, especially for fields with interconnecting outlet systems.

#### 4.6.5 USE OF MULTIPLE KEY TERRACES

Key terrace examples are shown for MO574-Monroe County (Figures K1-K4) and MO414-Platte County (Figures K5-K7) in Appendix K. Figure K1 demonstrates how key terrace 2 for Monroe County effectively represents the upper portion of the field,

while key terrace 4 (Figure K2) represents the middle portion, and key terrace 5 (Figure K3) represents the bottom portion. Similarly, Figure K5 shows key terrace 3 representing the top portion of the Platte County field and key terrace 5 (Figure K6) representing the bottom portion. No single key terrace option for either field provides an optimal layout. Separately, the key terraces cause inappropriate terrace placement or missing terraces. Combined, however, the key terraces provide additional farmability for the sample fields. Figures K4 and K7 show how the multiple key terrace selection permits the user to display multiple key terrace options on a single field. Special consideration should be taken with selecting the total number of key terraces. As shown, farmability decreases with an increase in multiple key terraces. Segments between terraces of separate key terrace options are not parallel. Each additional key terrace, NKT, results in NKT-1 nonparallel segments. The Platte County field (Figure K7) has two key terraces with one nonparallel segment between terraces three and four. The Monroe County Field (Figure K4) has three key terraces, which result in two nonparallel segments between terraces two and three, and terraces four and five. In order to provide sufficiently farmable parallel layouts, it is recommended that no more than half the total number of terraces should be used as key terraces.

#### **4.7 SUMMARY**

Additional features were integrated into TERLOC to provide the operator with tools to select the best layout design from multiple layout alternatives. These additions included: varied terrace spacing, verification of adequate channel grade, optimal outlet selection, and multiple key terraces. Varied terrace spacing and channel grade

modifications are not user-specified additions; however, both provide an internal optimization analysis. They design the appropriate spacing and channel grade for the field conditions, while balancing farmability and costs. Underground outlet selection and design, as well as split stream options and multiple key terraces, provide options for steep or complex sloping fields. These options permit user interaction and analysis on selecting an appropriate layout for a given set of conditions.

#### **4.8 LIMITATIONS AND FUTURE RESEARCH**

Limitations of the program are listed below. Future research on these topics is encouraged.

1. Terrace spacing does not use the revised Universal Soil Loss Equation (RUSLE) to calculate the slope length that would meet soil loss tolerance levels. A level of conservation is provided by restricting spacing to maximum widths. The drawback is that these values will change with different geographic locations and field characteristics. Therefore, further research should be done to incorporate a form of the USLE or revised USLE.
2. Channel grade modifications are limited to one-dimensional alterations, the elevations. Earthwork volume and cost may be reduced or eliminated, if the X and Y coordinates were moved uphill or downhill to the elevation that meets the maximum slope requirement. To provide a more sophisticated method of verifying the channel grade, a three-dimensional process should be researched.
3. Fixed equation parameters limit use of fields outside Missouri geography, topography, cropping practices, and soils. All fixed variables used in design

equations are specific to Missouri or Midwestern states. Future development should provide a means of altering variables to be specific to the field characteristics and location.

4. The UGO design is based on the following assumptions:
  - a. The orifice plate is controlling.
  - b. Conduit pipe is corrugated with sealed joints.

Further research will need to modify the design procedure to account for different design scenarios including conduit controlling or limiting velocities for non-sealed joints.

5. Outlet design is limited for only a UGO. Design of a stable vegetated waterway is not yet incorporated.

## 4.9 REFERENCES

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## **CHAPTER 5**

### **VERIFICATION AND ANALYSIS OF A TERRACE LAYOUT PROGRAM**

#### **5.1 ABSTRACT**

A terrace layout program, TERLOC (Terrace Location Program) has been developed to provide assistance in the terrace design process. Quality of the program and its output were analyzed. Program results for five sample fields were quantitatively compared to manually located terraces by terrace number, length, and average spacing. Program results were also qualitatively compared to the manual terrace results by overall terrace curvature trend and shape. TERLOC's output was verified to be similar to the manual results. Fields with larger drainage areas were actually found to be most similar to the manual layouts. Terrace number, curvature trend, shape, and length were terrace features that matched the closest. Fields with small drainage areas allow multiple layout alternatives to function properly, thus the program layouts were more likely to differ from the manual results. For any case, terrace spacing was the main cause for discrepancy between the layouts. Software quality of TERLOC was also analyzed. Program quality was found to be enhanced by the presence of specified user requirements as well as overall software requirements.

#### **5.2 INTRODUCTION TO TERLOC AND SOFTWARE QUALITY**

TERLOC is a terrace layout program developed to aid engineers, contractors, or landowners in locating terraces within a field. The program was originally developed by

Sudduth and Gregory (1982) and later revised by Ghidry et al. (1992). Terraces are a conservation practice consisting of broad channels constructed at specified intervals down the slope of a field. The goal of a terrace system is to help reduce soil loss by decreasing the slope length of a field. Fields benefitting from terracing include fields with rill or gully erosion due to long, steep slope lengths (USDA-NRCS, 2010). The process of locating terraces can be time consuming. A USDA-NRCS study in Missouri found that it takes 50% of the total terrace development time to complete the terrace layout for a 12,000 ft broadbase terrace system (R. Purcell, personal communication, April 21, 2009). The development of TERLOC improves terrace design efficiency by reducing the amount of manual calculations needed for the terrace layout process.

Setting itself apart from other programs, TERLOC requires very little user input. The required input consists of digital elevation data and field characteristics including field boundary, outlets, divides, ridgeline, and maximum point of elevation. Entry of all input was automated by Sudduth (1981) and later simplified with drawing tools in a web-interface as discussed in Chapter 3.

Once the input entry is complete and TERLOC is executed, output is displayed in a mapping window for visual analysis as well as in tabular format of a text file. Multiple layout alternatives may be viewed for selection of a best design analysis. Features within the program have been added as discussed in Chapter 4, to allow the user to select an optimal layout.

Previous versions of TERLOC have been tested on simulated and actual data sets for only a few different sample fields. Program testing has not been completed, however,

to compare the program results to manually located terrace systems. Comparison of program layout results to manually located layouts provides a method of verifying the program's use as an efficient planning tool.

Likewise, the program quality of TERLOC has not been examined. Software quality is defined as the "degree to which software possesses a desired combination of attributes." (IEEE 1061, 1992). Software should meet the general functional requirements given by the expected users. Functional requirements are the specific features or services needed within the program. Non-functional requirements must also be met (Barbacci et al., 1995). These requirements are not directly related to program functions; rather they describe the system as a whole. These requirements may include efficiency, reliability, usability, maintainability, and security. Sommerville (2004) describes non-functional requirements as more critical for system success, yielding an unusable system if not met. In addition, they are difficult to quantify due to interconnectivity with other functional and non-functional requirements (Gross and Yu, 2001). In practice, a software quality analysis consists of both qualitative measures of requirement goals as well as quantitative measures (Sommerville, 2004).

### **5.3 OBJECTIVE**

The objective for this project was to analyze and verify the quality of a terrace location program, TERLOC developed by Sudduth and Gregory (1982), revised by Ghidey et al. (1992), and further enhanced in this current project. To do this, program results for five sample fields were compared to the manual layouts completed by USDA-Natural Resources Conservation (NRCS) staff. The software quality of TERLOC was

also analyzed for functional and non-functional requirements using qualitative and quantitative metrics.

## **5.4 MATERIALS**

The hardware utilized for this project was an X86-based PC with a 2992 Mhz processor. Internet Explorer 7.0 was utilized to run the web-interface of the terrace location program. Field contour data was obtained through field surveys performed by the USDA- NRCS. Existing LiDAR data were also processed in ArcGIS by USDA- NRCS staff to obtain additional contour data. ArcMap 9.3 and Microsoft Excel were utilized for coordinate mapping and comparing results from the program and manual terrace layouts.

## **5.5 METHODS**

Five fields were chosen based on availability of digital contour data, location, and varying topography. The fields chosen were in the Missouri counties of Saline (Figure L1), Pike (Figure L2), Monroe 574 (Figure L3), Boone (Figure L4) and Monroe 566 (Figure L5). Terraces for these fields were manually located and staked by USDA NRCS field technicians and engineers. Terraces were then installed under NRCS supervision using these manual layouts. The terrace coordinates were recorded using a total station and handheld GPS equipment. The horizontal and vertical data were then uploaded into ArcGIS for comparison.

### 5.5.1 TERLOC OPERATING PROCEDURE

The program layouts were performed by accessing the terrace layout web-interface at [www.soilsurvey.org](http://www.soilsurvey.org). Access to the terrace program was protected with a user-ID and password. From the homepage, each field was located through the search tools (Figure 5.1). Once a field was selected, the TERLOC mapping window and terrace practices menu appeared (Figure 5.2).

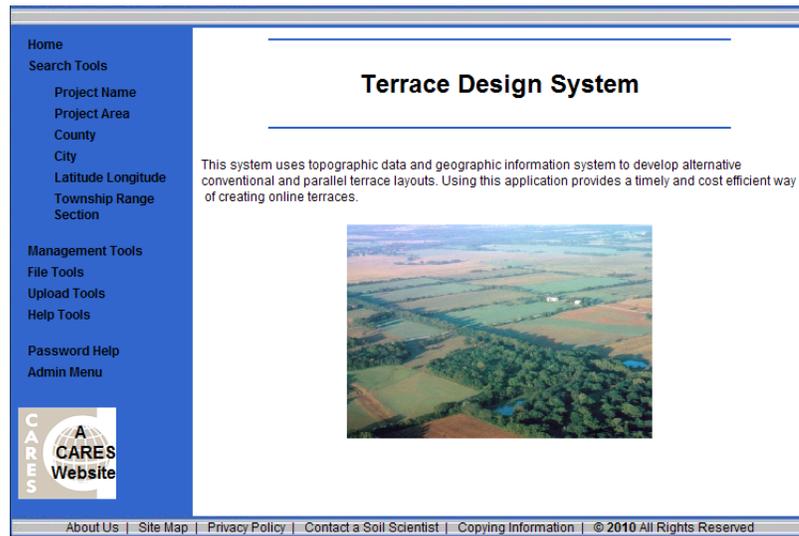


Figure 5.1. TERLOC web-interface homepage. Menus are listed on the left (<http://www.soilsurvey.org/tools/terrace/main.asp>).

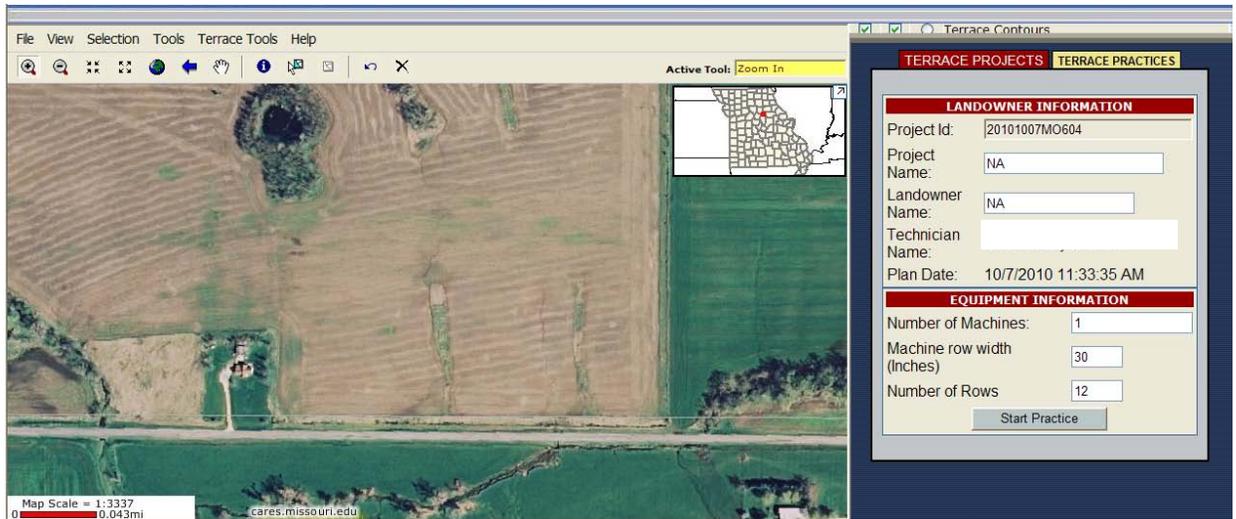


Figure 5.2. TERLOC mapping window (left) and first terrace practices menu (right) (<http://www.soilsurvey.org/tools/terrace/main.asp>).

The five fields were run through the TERLOC web-application by entering all user input, including digital elevation data, field and terrace boundary, outlets, divides, ridgeline, and maximum point of elevation. This information is entered into the mapping window (Figure 5.2) using polygon and line drawing tools. Machinery information is also entered.

The procedure to run through the TERLOC web-application is listed below:

1. Enter project name, landowner, number of machines, number of rows, and row width in inches.
2. Click “Start Practice”.
3. A new menu screen will display on the right portion of the screen (Figure 5.3).

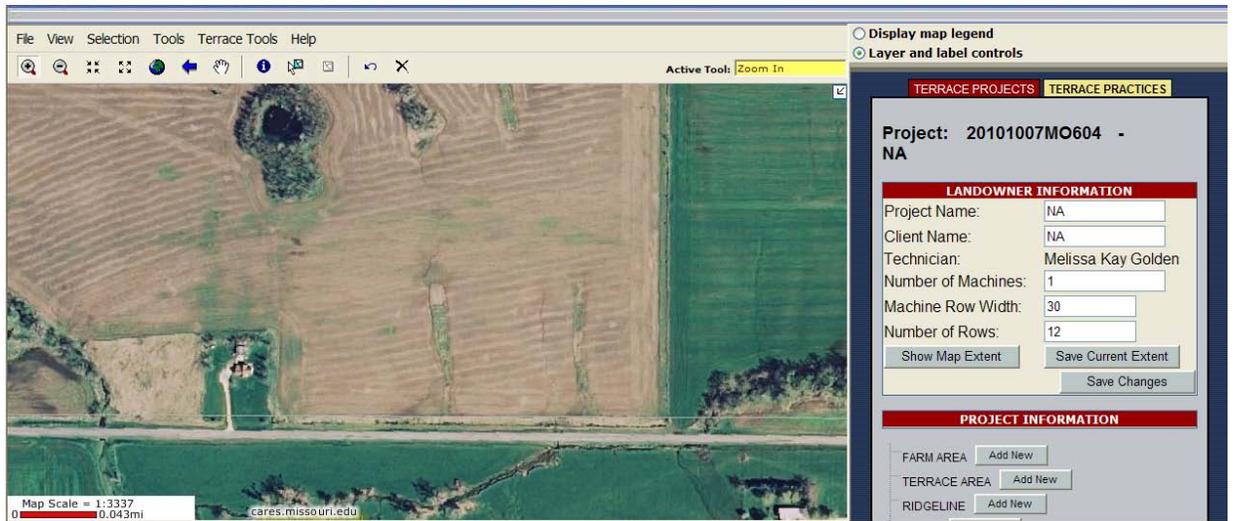


Figure 5.3. TERLOC mapping window (left) and second terrace practices menu (right) (<http://www.soilsurvey.org/tools/terrace/main.asp>).

4. Click “Add New” farm area under Project Information in the terrace practice menu.
5. A drawing tool activates and a menu (Figure 5.4) appears in the left corner of the mapping window.

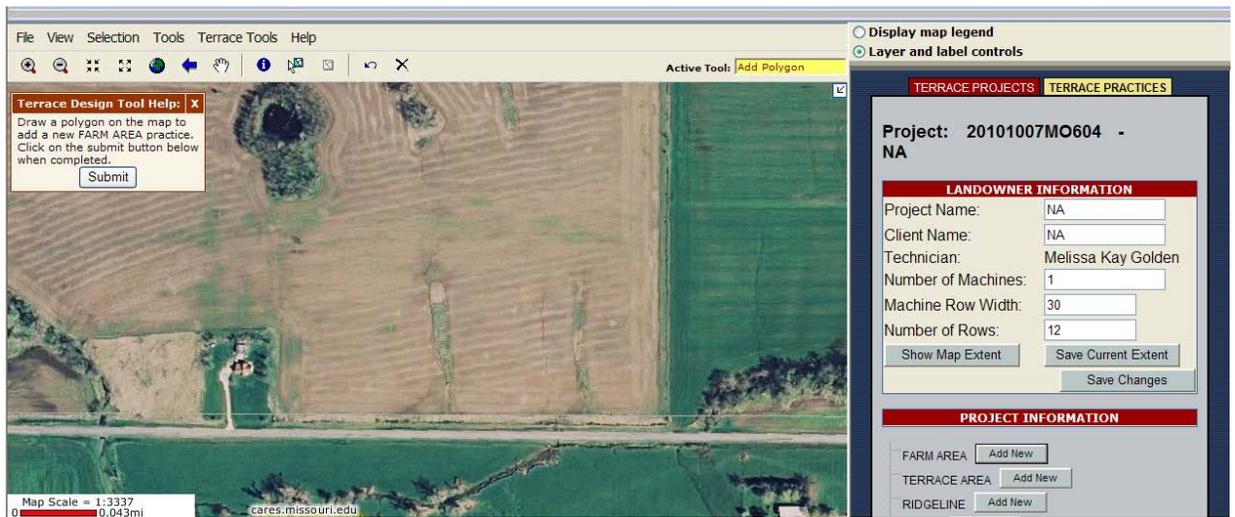


Figure 5.4. Drawing Tool Menu in TERLOC mapping window (<http://www.soilsurvey.org/tools/terrace/main.asp>).

6. Use the aerial photo in the mapping window as a reference to click the cursor and add points to the farm area boundary. Double click to complete the drawing.
7. Click “Submit” in the drawing tool menu (Figure 5.4) to add farm area to the project.
8. Click “Copy Farm” for terrace area if farm and terrace area are the same. If not, repeat steps 4-6 for the terrace area.
9. Field contour data, in a zipped ArcGIS shapefile format, may be uploaded using the “Add New” contour button and the pop-up window in Figure 5.5. (See Chapter 3 for more details)

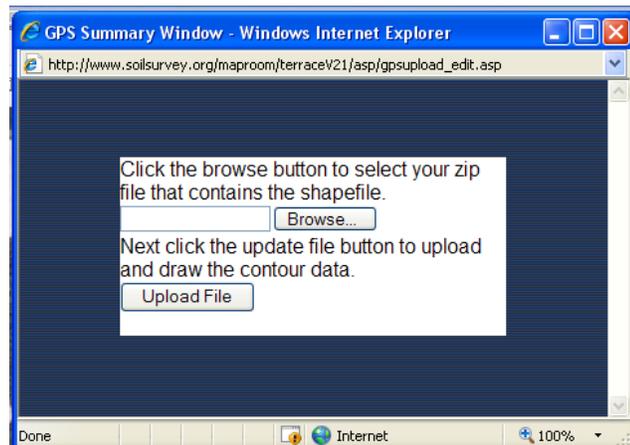


Figure 5.5. TERLOC Contour Upload Menu  
(<http://www.soilsurvey.org/tools/terrace/main.asp>).

10. Using the newly loaded contour line data, repeat steps 4-6 to draw the ridgeline, divides, and outlets (called waterways on the interface), and the maximum point of elevation.
11. Click “Calculate Terraces” under Program Results in the menu (Figure 5.6).

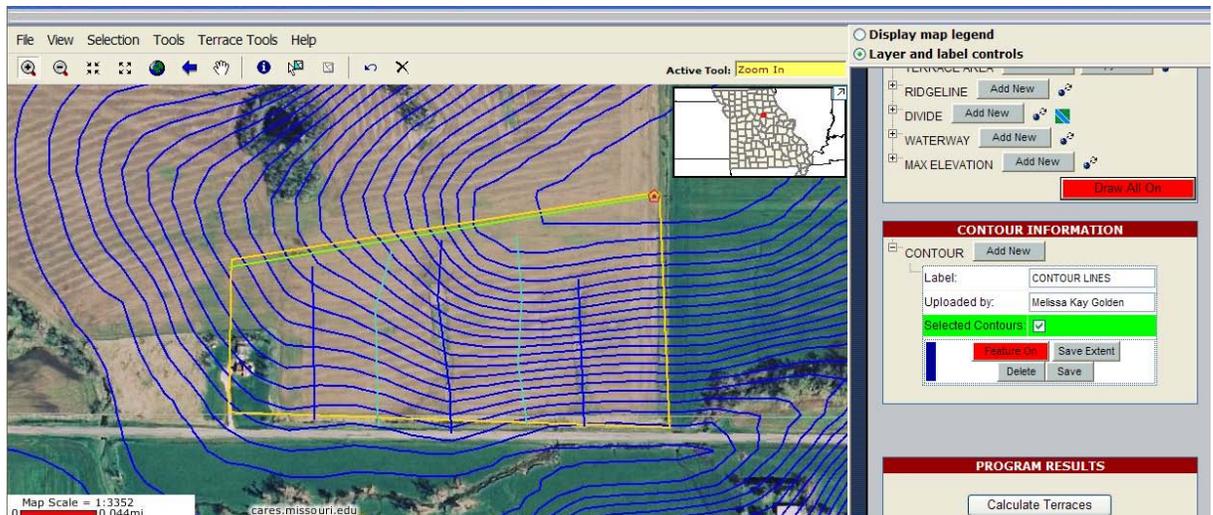


Figure 5.6. Field data drawn on TERLOC mapping window. User can click “Calculate Terraces” when user input is complete (<http://www.soilsurvey.org/tools/terrace/main.asp>).

It is important to note that the program requires outlets and divides to be entered in sequential order from left to right or from top to bottom. If either set of lines becomes out of order for any reason, or a new line needs to be inserted, the interface menu provides an “Order Number” attribute that allows the user to revise the order of the lines. Attributes of each of the input parameters can be viewed and altered in the program menu (Figure 5.7). Area, length, line color, and labels are among the features available. As described in Chapter 4 and shown in Figure 5.7, split or converged streams may be drawn for fields with interconnecting outlet systems. Terrace results were then examined in the terrace practice menu (Figure 5.8) once the web-application procedure was completed.

**PROJECT INFORMATION**

**FARM AREA** Add New

Label: FARM AREA  
 Area (acre): 13.77  
 Order Number: 1

Feature On Label On Delete  
 Change Color Move Label Save

**TERRACE AREA** Add New Copy Farm

Label: TERRACE AREA  
 Area (acre): 13.77  
 Order Number: 1

Feature On Label On Delete  
 Change Color Move Label Save

**DIVIDE** Add New

Label: DIVIDE  
 Length (feet): 539.068  
 Order Number: 1  
 Part of Split Stream:  YES  
 Select an intersection point: -- Draw Point

Feature On Label On Delete  
 Change Color Move Label Save

Label: DIVIDE  
 Length (feet): 570.882  
 Order Number: 2  
 Part of Split Stream:  YES  
 Select an intersection point: -- Draw Point

Figure 5.7. TERLOC terrace project menu view of farm area, terrace area, and divide attributes (<http://www.soilsurvey.org/tools/terrace/main.asp>).

**CONVENTIONAL TERRACE - Original**

Cost (\$/Ft): 0  
 Total Cost (\$): 0  
 Delete Terrace Draw All On

Label: Original-1  
 Date: 9/6/2010 7:40:22 AM  
 Length: 778.5  
 Cost (\$): 0

Feature On Label On Delete  
 Change Color Move Label Save

Label: Original-2  
 Date: 9/6/2010 7:40:22 AM  
 Length: 1594.5  
 Cost (\$): 0

Feature On Label On Delete  
 Change Color Move Label Save

Label: Original-3  
 Date: 9/6/2010 7:40:22 AM

Figure 5.8. TERLOC conventional terrace results for a sample field (<http://www.soilsurvey.org/tools/terrace/main.asp>).

As shown in Figure 5.8, lengths for each terrace were provided. A drop down menu can be used to select terrace type and construction cost as shown in Figure 5.9. The values in Figure 5.9 were on a per foot basis from the 2009 average cost list provided by the USDA-NRCS. Construction costs for each terrace were then displayed in the project menu as shown in Figure 5.10.

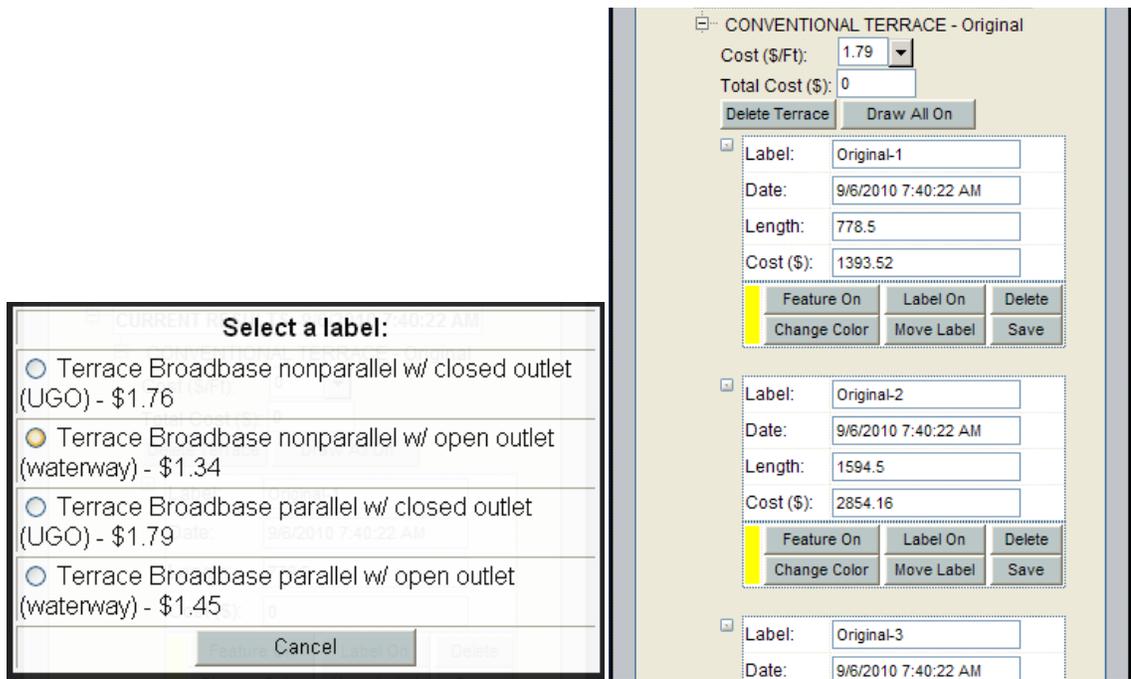


Figure 5.9 and 5.10. (5.9) TERLOC web-interface terrace cost list (per foot). (5.10). TERLOC conventional terrace results for a sample field with construction costs (<http://www.soilsurvey.org/tools/terrace/main.asp>).

The terrace report was also displayed. The report lists total terrace number, terrace coordinates, lengths, and spacing for each alternative. An excerpt from an output file is shown in Figure 5.11.

```

TERRACE 5      AVERAGE SPACING = 174.8      LENGTH = 1380.9      Number of Points = 28
COORDINATES OF TERRACE POINTS (X,Y,Z) ARE
2280.035      2068.578      719.311
2332.752      2063.800      719.130
2376.420      2038.483      718.872
2418.570      2011.229      718.745
2467.451      2000.003      718.551
2517.794      1993.639      718.366
2563.847      1971.830      718.099
2610.299      1952.902      717.917
2660.621      1941.649      718.224
2710.427      1946.022      718.295
2760.577      1938.473      718.548
2809.788      1927.634      718.793
2859.041      1918.995      718.582
2909.087      1916.962      719.494
2959.000      1912.905      719.338

```

Figure 5.11. Except of terrace report in program output. Terrace coordinates, length, and spacing are among the output provided (<http://www.soilsurvey.org/tools/terrace/main.asp>).

Also included in the terrace report was all input information, including field boundary, ridgeline, outlet, and divide coordinates as well as the outlet and divide lengths.

### 5.5.2 COMPARISON OF MANUAL TERRACE LAYOUTS WITH TERLOC PROGRAM OUTPUT

TERLOC offered multiple terrace layout options (Figure 5.12). Each option was viewed and compared, and a best layout option was chosen for each of the five sample fields.

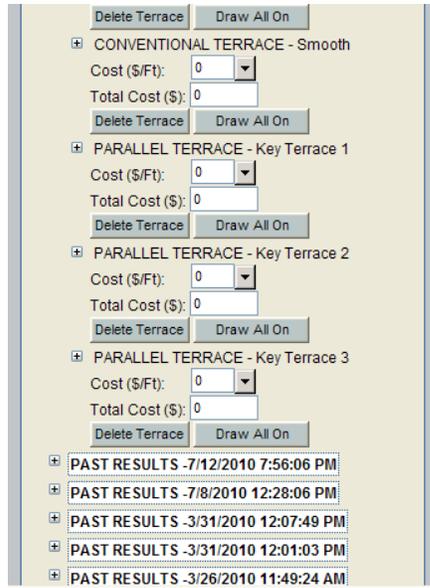


Figure 5.12. An example of multiple terrace layout options in TERLOC (<http://www.soilsurvey.org/tools/terrace/main.asp>).

### 5.5.3 ANALYSIS OF FUNCTIONAL AND NONFUNCTIONAL SOFTWARE REQUIREMENTS

A quality analysis was also performed for the terrace location program. It was analyzed based on functional and non-functional requirements. Functional requirements from NRCS, the expected users of the terrace layout program, are described by Keep (1989):

- Availability of program on current office equipment,
- Ease of use,
- Utilization of NRCS design procedures,
- Multiple trial design alternatives,
- Printable final output for producers.

The analysis also covered non-functional attributes listed by Sommerville (2004):

- Dependability- Reliable, safe, and secure,
- Usability- Easy to use interface with appropriate documentation,
- Efficiency- Responsive, adequate speed & memory usage,
- Maintainability-Easily adaptable to future needs.

Both types of requirements were analyzed either on qualitative or quantitative basis. Ease of use and usability, design alternatives, and efficiency were all quantitatively analyzed. The remaining requirements were analyzed from a qualitative perspective of goal achievement.

## **5.6 RESULTS AND DISCUSSION**

### **5.6.1 PROGRAM VERIFICATION**

The NRCS manual terrace layouts shown in Appendix M illustrate the actual alignment of the terraces constructed in the five sample fields. The layout for the 10 hectare (25 acre) Saline County field (Figure M1) contains six conventional grade terraces designed in a North-to-South pattern with terrace spacing between 36.6 and 54.9 meters (120 and 180 feet). The 19 hectare (47 acre) Pike County field (Figure M2) and 16 hectare (39 acre) Monroe (574) County field (Figure M3) consist of North-to- South patterned, parallel terraces. The Pike County field includes seven terraces, while the Monroe (574) County field contains four. The horizontal interval between the terraces for both fields is 45.7 to 54.9 meters (150 to 180 feet). Terrace lengths for all fields are shown in Table O1 having a total terrace length of 3,264 meters (10,710 feet) for the entire Saline County field , 1,747 meters (5,732 feet) for Pike County, and 1,857 meters (6,092 feet) for Monroe (574) County.

Corresponding program terrace layout results for the five sample fields are shown in Appendix N. Conventional grade layouts were selected as the best design for Saline (Figure N1), Pike (Figure N2), and Monroe (574) Counties (Figure N3). TERLOC results for these fields closely follow the manually located terraces. The layouts possess the same North-to-South orientation as the constructed layouts. Terrace spacing for the Saline program layout averaged 54.9 meters (180 feet), slightly larger than the constructed layout in some areas. Likewise, the Pike and Monroe (574) County program terraces were similarly spaced compared to the manual results, but averaged at the larger width of 54.9 meters (180 feet). Some spacing differences for the Pike and Monroe (574) County program terraces can be attributed to the conventional grade layout rather than a parallel layout.

The slopes found in Saline, Pike, and Monroe (574) Counties are between 2% and 2.5%. These slopes are flat enough to allow for a larger spacing interval when using the Vertical Interval Method. TERLOC utilizes this method, allowing for larger spacing intervals than the manual layouts. To restrict excess spacing for soil loss purposes, a variable spacing feature is also included in the program to limit spacing to a maximum average width of 54.9 meters (180 feet). This feature is described in detail in Chapter 4.

For both Saline and Pike Counties, the TERLOC layouts did not include the shorter, top-most terrace, nor the terrace at the bottom of the field as designed in the NRCS layout. The placement of the top terrace is higher than in the program layouts, and allows for an additional terrace at the bottom of the field. For the Monroe (574) County field, the program layout had a higher top terrace; therefore, TERLOC results yielded an

additional bottom terrace. These additional terraces are another cause for slight discrepancies in alignment.

Total terrace length for the program layouts was found to be shorter for both Saline and Pike fields. TERLOC layouts differ from the constructed terrace lengths by 14% (242 meters, 795 feet) for Saline County and 18% (585 meters, 1918 feet) for Pike County (Table O1). These differences are mostly due to the additional two terraces included in the constructed layouts. When excluding the 226 meters (742 feet) of additional terraces, the Saline County TERLOC layout is less than 1% (16 meters, 53 feet) off from the final constructed terrace. Excluding 486 meters (1,595 feet) of additional terraces in the Pike County, the TERLOC layout is only 3% percent (97.5 meters, 320 feet) off from the NRCS design.

Conversely, the total terrace length for the Monroe (574) County program layout was 18% (333 m, 1,903ft) longer than the manual layout. This difference was also partially caused by the additional bottom terrace. It is also caused by the shorter length of terrace 4 in the manual layout. Excluding the additional 122 meters (400 feet) of additional fifth terrace, the program layout difference is reduced to 11% (211 meters, 693 feet). Overall, the same general trend is seen in both the TERLOC program layout and the manual layouts. Figures O1, O2, and O3 illustrate the similarities by plotting both program and manual layouts on the same map.

Different results were seen with smaller, more uniform fields, such as Boone County (Figure N4) and Monroe (566) County (Figure N5). The manual layouts for these fields consist of three straight parallel lines. The Boone County field (Figure M4) is a 7

hectares (17.4 acre) field oriented East-to-West with 36.6 to 39.6 meter (120 to 130 foot) spacing. The 7.6 hectare (18.8 acre) Monroe (566) County field (Figure M5) is oriented North-to-South with spacing around 36.6 meters (120 feet). Total terrace lengths for both manual layouts were much shorter than the other sample fields with 829 meters (2,721 feet) for Boone County and 503 meters (1,650 feet) for Monroe (566) County (Table O1).

Unlike the Saline, Pike, and Monroe (574) County fields, program results for Boone and Monroe (566) Counties were considerably different from the manual layouts. Parallel layouts were chosen for both TERLOC layouts, with orientations similar to the corresponding manual layouts. In addition, the program results included the same number of terraces as the constructed. The terrace spacing, length, and overall alignment, however, were notably different. Gentle slopes again allowed the program layouts for both fields to have wider terrace spacing, averaging 54.9 meters (180 feet). The Monroe (566) County field had a field slope similar to Saline, Pike, and Monroe (574) Counties of approximately 2% to 2.5%. The Boone County field, however, was slightly steeper at 3% to 3.5%.

Both Boone and Monroe (566) fields were laid out with more linear curvature, longer terrace lengths, and flatter channel slopes than the NRCS designs. The overall alignment difference can be explained by the size and slope of these fields. Smaller drainage areas and flat slopes allow for larger maximum channel slopes, thus a wider range of horizontal placement. For these fields a variety of different alignments may all function properly. The larger spacing intervals used for the program layouts create a larger drainage area between terraces than the manual layouts. This explains the need for

flatter channel slopes, thus differing alignment in the TERLOC layouts. While both layouts are acceptable and dependent on user preference, the straight-line layout provided by the manual terrace results offers a more farmable layout. While the total terrace number was the same, the terrace curvature increased the total terrace length by 56 % (462 meters, 1,519 feet) for Boone County and 71% (359 meters, 1,179 feet) for Monroe (566) County (Table O1). Visual analysis of both manual and program layouts on the same map can be seen in Figures O4 and O5.

### **5.6.2 QUALITATIVE AND QUANTITATIVE QUALITY ANALYSIS**

Running through TERLOC's online interface and examining the program output suggests that TERLOC meets some level of all software engineering characteristics described by Sommerville (2004) and the NRCS user requirements (Keep 1989).

Availability is a key requirement that has been met with the introduction to the interactive web-interface. Any office can access the program with a modern computer and internet access. Server updates or site maintenance might limit availability. Recent updates, however, have provided TERLOC with a separate server, which is expected to decrease site interruptions. Carefully planned updates can be scheduled during limited-use hours to help reduce availability issues.

While the terrace layout program is accessible through any internet connection, its use is limited to specified users through password protection. A user-ID and password provides a level of security, or dependability, by limiting access to only qualified users. Field or site specific information may be considered personal or private data. Therefore, the password protection allows only the specified user to create, modify, or delete terrace

layout projects. Currently, users can view any field project made by another user; however, they may not modify or delete other user projects. TERLOC or any data within the program cannot be viewed without a user ID and password.

The interactive web-interface also provides ease of use, or usability, a critical aspect from a user and software perspective. Minimal user input and pop-up menus assist the user to efficiently run through the program procedure. Three different help menus are also located in the program to assist the user. The terrace drawing tool help menu shown in Figure 5.4 helps the user draw and submit input data. An overall help menu is also located at the top of the program mapping window as shown in Figure 5.13.

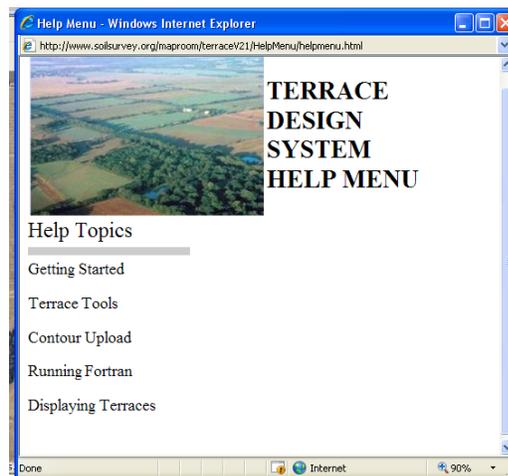


Figure 5.13. TERLOC web-interface help menu (<http://www.soilsurvey.org/tools/terrace/main.asp>).

The help menu provides the user with a step-by-step guide for operating the program. A final help menu is designed specifically for input of branched outlets, or splits streams (Figure 5.14).

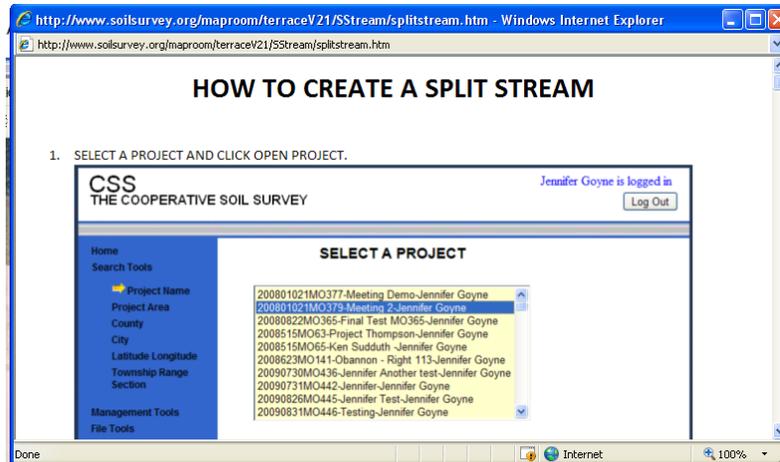


Figure 5.14. TERLOC split stream help menu (<http://www.soilsurvey.org/tools/terrace/main.asp>).

These three menus provide usability to the user by providing general guidelines for the program. Excluding the split stream menu, however, TERLOC does not list specific information regarding the input of certain features, such as the required sequential ordering of outlets and divides. In addition, the program assumes the user is familiar with technical terms relating to terracing, and has some experience with interpreting contour lines. No documentation is provided with technical definitions or contour delineation guidelines. The program does require a user to have some previous experience with field elevations, contour data, or terracing.

Program efficiency as well as improved layout design efficiency is also offered in TERLOC through rapid entry of input and execution of code. Sudduth and Gregory (1982) discuss how the automated data entry greatly increased program. A terrace layout project might take anywhere from five to fifteen minutes to complete, depending on user experience with the program. A maximum input time of 30 minutes may be required for complex fields with multiple or interconnected arrangements of outlets. This processing

speed is more than adequate when compared to the hours, if not days, required to complete a manual terrace layout. Program efficiency is met with this rapid development time. The time and efficiency is dependent and may be limited to network connection speed. A slower speed results in longer processing time, thus less efficiency. A network connection faster than a 56 Kbit/s (dial-up speed) will help reduce these problems. A broadband network connection of 4 megabit/s or faster is highly recommended for maximum performance.

As one of the primary clients for TERLOC, the program has been developed using NRCS equations and criteria listed in the Missouri NRCS terrace standard (2010). As shown in Chapters 3 and 4, terrace spacing, capacity, cross section and channel grade have all been developed using these techniques and criteria. Terrace design procedures in other states or even for other clients may differ slightly, but will require only minimal modifications due to the nationwide standard practices of terrace design.

The requirement for multiple trial alternatives and printable output are met as shown in Figures 5.11 and 5.12. A conventional, constant grade layout, a smoothed conventional layout, and multiple parallel layouts are provided for each terrace project. Therefore, up to  $N+2$  layout alternatives may be provided for any given field, where  $N$  is the total number of terraces. This value is limited to 17 since the maximum allowable terrace number is set to 15 (Sudduth and Gregory, 1982). The terrace report and mapping window allow the user to view multiple aspects of each alternative. The report itself meets the requirement for printable producer output, and the mapping window provides additional visual inspection. The report is provided as a text file and may be given to a

producer as raw data, or with some modifications may be uploaded to GPS-fitted equipment. As Chapter 4 describes, all the input and output information can be utilized to create and select a best design option based on conservation, farmability, and cost. Sommerville (2004) notes maintainability as a final software requirement. In other words, the program should be easily adaptable for future needs. TERLOC does provide maintainability in design equations by utilizing variables rather than hard-coded numbers. It also includes structured routines that provide room for future alterations. Studies performed by Banker et al. (1993), however, found that a program's maintainability will be more expensive with an increase in program or component complexity. Therefore, while modifications and new features help improve TERLOC results, they also increase program complexity and required maintenance. The introduction of the web-interface provides a perfect example. While the interface has boosted usability and efficiency, routine server and site maintenance will be needed as requirements and technology change.

Consideration of future user requirements and technological advances must also be considered as part of TERLOC's maintainability. One important consideration is conversion from a linear-based system to a grid-based system. Increased coverage of LiDAR and wide-spread use of grid-based data such as digital elevation models (DEM) contribute to this consideration. Conversion to a more modern programming language is also an important maintenance consideration. Most modern programmers work with languages such as Java, C++, or Perl. In fact, online job posting trends over the last five

years rate FORTRAN as one of the least sought after languages compared to modern languages Java, C++, Python, and Perl as shown in Figure 5.15 (Indeed.com, 2010).

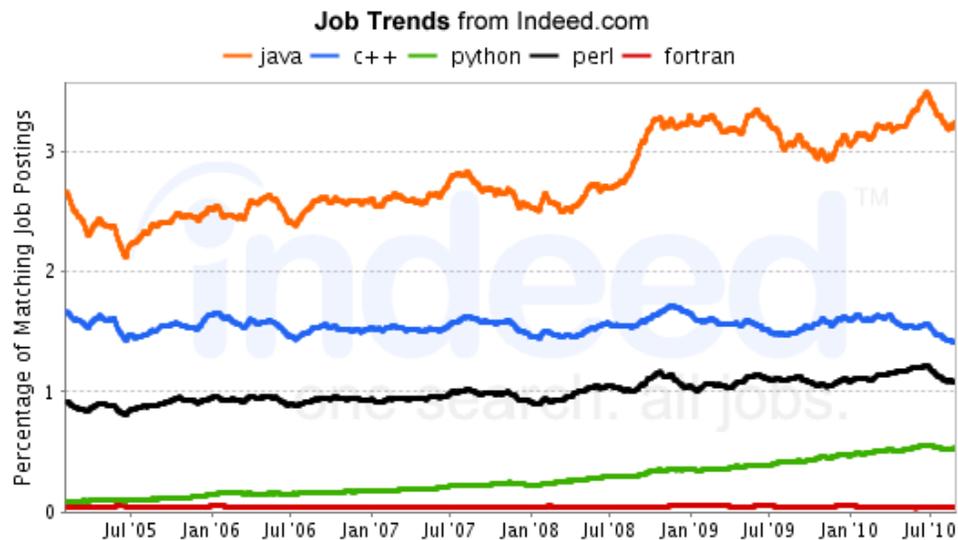


Figure 5.15.Indeed.com job posting trends from 2005-2010 for different programming languages.

Due to these trends, it may become more difficult or costly to find a skilled FORTRAN programmer to perform program updates and maintenance. Both of these considerations would require significant changes to TERLOC, but would improve the program's maintainability.

## 5.7 SUMMARY AND CONCLUSION

TERLOC program results proved to share similarities to the NRCS constructed terrace layouts for all five sample fields. Sample fields with more drainage area and less uniform slopes proved to actually follow the final constructed layout the closest. This is mostly due to limited layout possibilities for these fields, but it emphasizes how accurately TERLOC can locate terraces for even a complex field.

TERLOC results for uniform fields with small drainage areas proved to differ the most from manual results. These fields provide the most flexibility in layouts, where multiple layout options provide the same functionality. TERLOC results proved to have wider terrace spacing, but flatter channel slopes than the NRCS designed terraces.

Terrace spacing was found to be the feature that caused the most discrepancy, directly and indirectly, between the program and constructed layouts. Altering spacing values, however, is a common practice, as USDA-NRCS(2010) and ASAE(2009) both allow spacing alterations up to 10% (or greater for underground outlets) to help improve overall terrace alignment.

On a software quality basis, TERLOC offers some level of all the functional and non-functional software requirements: availability, usability, dependability, efficiency, maintainability, NRCS design procedures, multiple design alternatives, and printable output. Most of these software requirement features are a direct result of TERLOC's incorporation to a web-interface. Prior to the online version of TERLOC, requirements such as availability, dependability, and usability were not being met. A trade-off has been made by adding new features to TERLOC. New additions to the program have shown to decrease maintainability. The routines and procedures within TERLOC are structured in a format that may be easily modified for future needs.

In conclusion, for planning purposes, the TERLOC program provides close estimations for terrace placement as well as terrace cost. Verification of the program reiterates the idea that there are multiple ways to terrace a single field. TERLOC's similarities to the final constructed terraces demonstrate its use as an efficient terrace

planning tool. Quality of the program is significantly enhanced by the presence of each of the software requirements. In addition, the comprehensive program output introduces multiple uses for TERLOC. The program may be used as a planning tool to calculate drainage areas, field slopes, or estimate outlet costs using the input data, area calculations and outlet length output provided on the web-interface.

## **5.8 LIMITATIONS & FUTURE RESEARCH**

TERLOC does include limitations. Future research in the following areas is suggested for future development of the program:

- The program does not tolerate all user errors. TERLOC currently provides no explanation for faulty input data errors. Erroneous data and program crashing may result from incorrect or missing input data. Research on a routine check for user input is needed to provide a method of alerting the user when input is incorrect.
- A fully equipped, comprehensive user manual has not yet been developed for TERLOC, due to recent additions and modifications. In order to provide assistance for any level of experienced user, development of a detailed user manual is needed.
- No user acceptance testing has been performed for TERLOC. Feedback from potential users should be considered, as well as quality assurance testing for additional user requirements.
- TERLOC procedures are written to process linear elevation data. Currently, all topographic data must first be converted to contour lines. Modern elevation

data from LiDAR or other remotely sensed sources produces contour lines with excess noise. These data require careful, tedious processing. Future research should be focused on converting TERLOC to a grid-based system that can support modern elevation input such as digital elevation models, or direct GPS points.

- As mentioned above, TERLOC is written in FORTRAN, which is no longer considered a popular programming language. Maintainability of TERLOC is expected to increase with further development and conversion of the program to a modern programming language.

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## CHAPTER 6

### SUMMARY AND CONCLUSION

Designing terrace layouts can prove to be a tedious, time-consuming process that may hinder the development of additional terrace designs. The total layout procedure may take up to 50% or more of the total terrace design time. Amendments to TERLOC (Terrace Location Program) were made to provide a web-based conservation planning tool for the Natural Resources Conservation Service (NRCS), land developers, and land owners to assist with the layout design procedure.

- TERLOC was integrated to a web-based application to provide maximum availability and a means for uploading elevation data for any field.
- Reduction of smoothing radius (from 30.5 m (100 ft) to 15.2 m (50 ft)) and line step size as well as a field orientation detection feature reduced erroneous layout results and program crashing for fields with irregular field boundaries, highly variable contour lines, and atypical orientation.
- Varied terrace spacing, verification of adequate channel grade, optimal outlet selection, and multiple key terraces were all features that were added (Chapter 4) to promote optimal layouts and best design analysis.
- Program quality was enhanced by the presence of functional and non-functional software requirements:

- Availability,
  - Usability,
  - Dependability,
  - Efficiency,
  - Maintainability,
  - NRCS design procedures,
  - Multiple design alternatives,
  - Printable output.
- Analysis of the program output in comparison to manual layouts proved that TERLOC, with modifications, produces similar results to a manually located terrace system. Program results for fields with larger drainage areas, size, and length proved to be most similar to the manual layouts. Fields with smaller drainage areas allowed for more variety in layout alternatives therefore were more likely to be different from the manual layout.

The modifications of this project have broadened TERLOC's use as a terrace layout-planning tool by providing optimal layout alternatives for a wide range of fields.

Verification of the program (Chapter 5) shows that there are multiple terrace layouts that would function properly for a single field. The efficient input and rapid processing of TERLOC, along with verification of its results, emphasizes TERLOC's use as a terrace placement tool.

## CHAPTER 7

### FUTURE RESEARCH

There are several opportunities for modification and analysis of TERLOC that did not fall within the scope of this project. These research topics are listed in Chapters 3, 4, and 5. Additional opportunities for future research and analysis are listed below:

- Development of ready-to-use output. Currently, all program output is printed with a generic X, Y coordinate system set by the extent of the program screen. All terrace coordinates, then are not in a specified projection used by clients. Assigning and converting these data to a specified coordinate system will decrease processing time of output data. Developing output that can be directly uploaded to GPS equipment for field use would provide even more time savings.
- Selection of terrace cross section. No cross section type is specified for TERLOC calculations. Providing an option for different terrace cross sections may improve accuracy of design calculations.
- Additional Software Verification and Validation. Chapter 5 included a brief analysis of TERLOC's software quality. An in-depth study on TERLOC from a software engineering perspective has not been completed.
- Additional Field Testing of Program Output. Chapter 5 also compared five fields to manually located terraces. Further testing of program output as well as actual field- testing of the output will provide additional knowledge of the ability of

TERLOC. Pilot testing performed by Missouri NRCS should be considered as the next step.

## APPENDIX A: FLOWCHART OF TERLOC

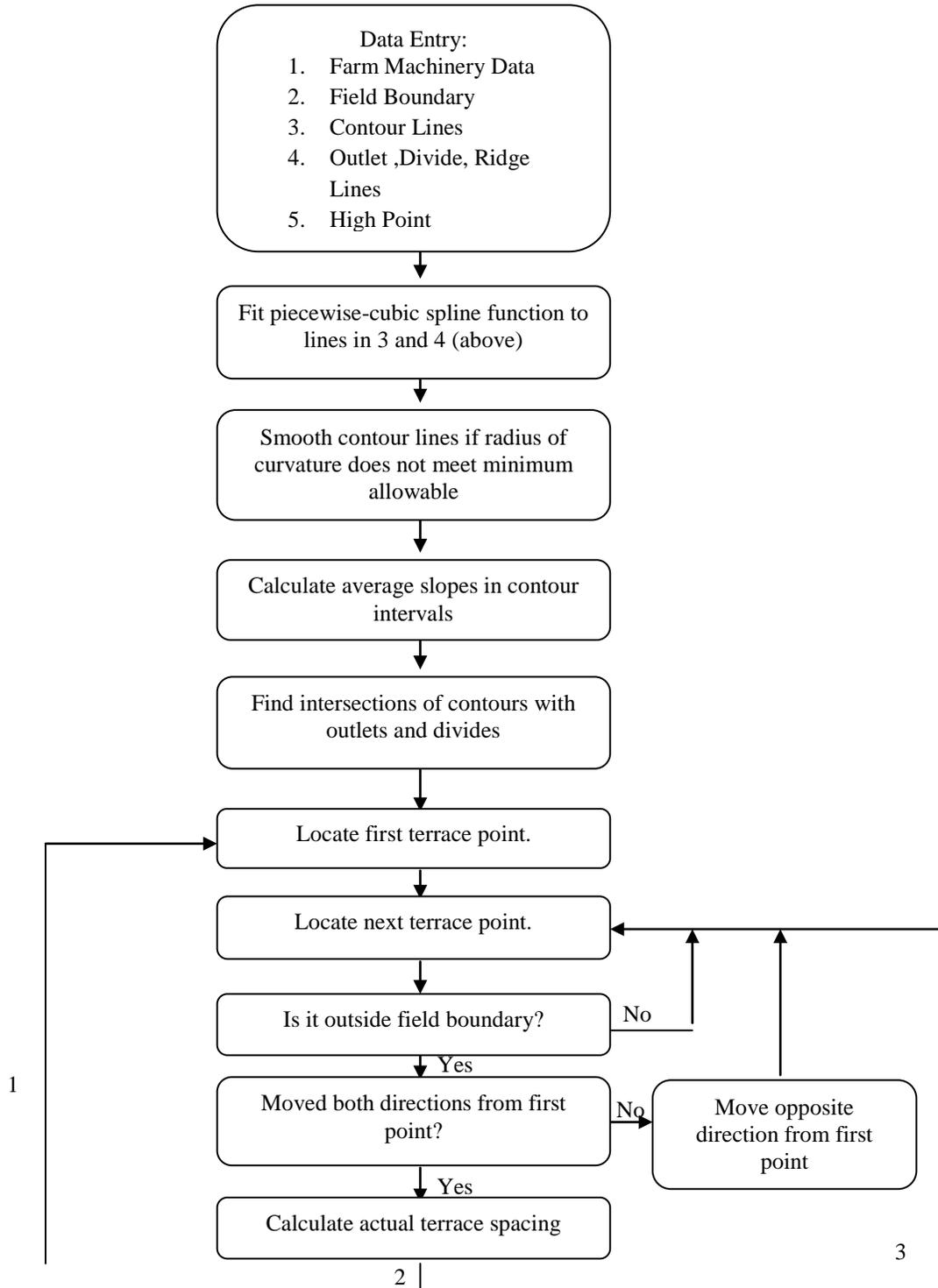


Figure A1. Flowchart of TERLOC (Sudduth, K.A.1981.Terrace Location by Computer. M.S. thesis. Columbia, Missouri: University of Missouri, Department of Agricultural Engineering.)

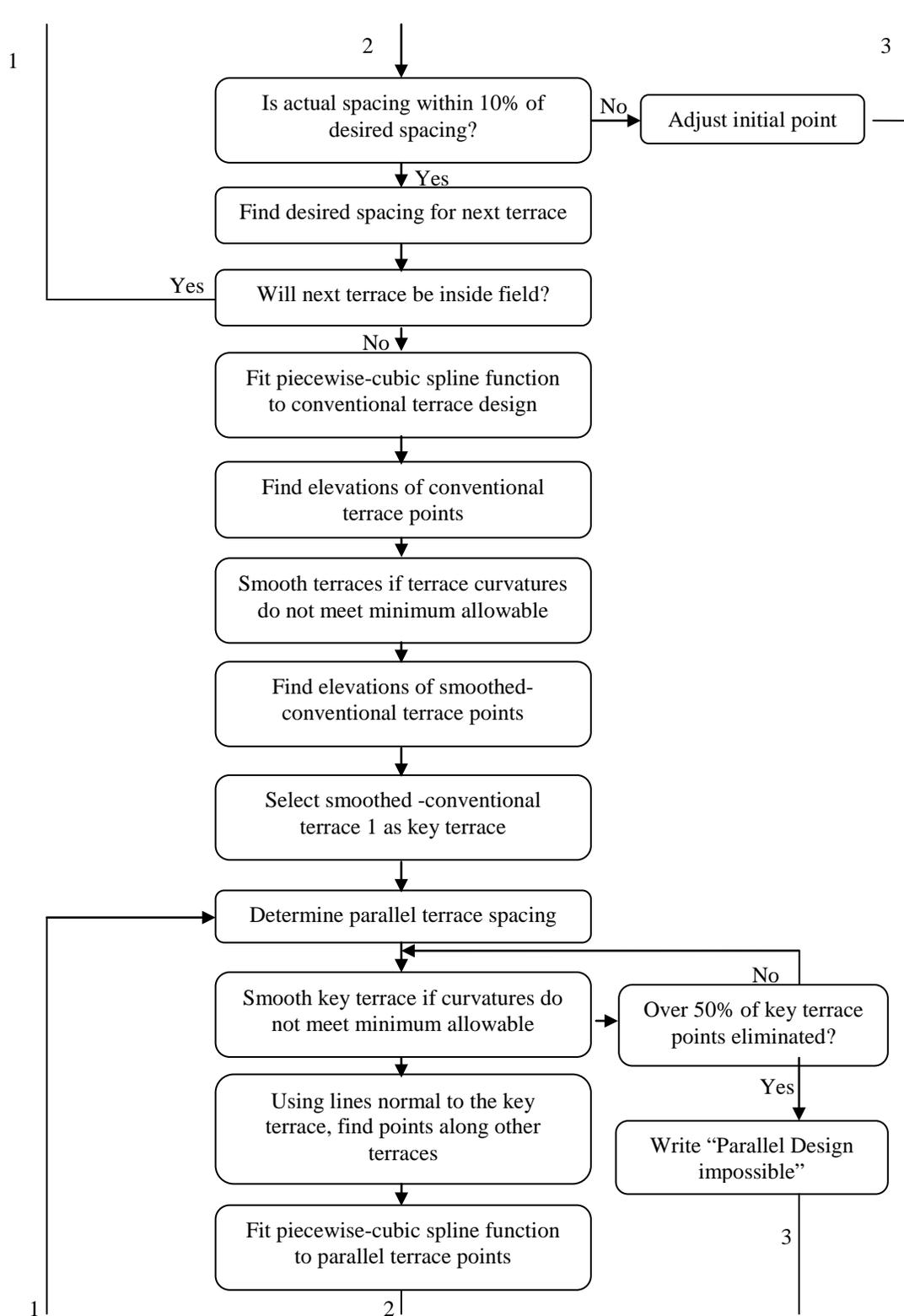


Figure A1. Cont.

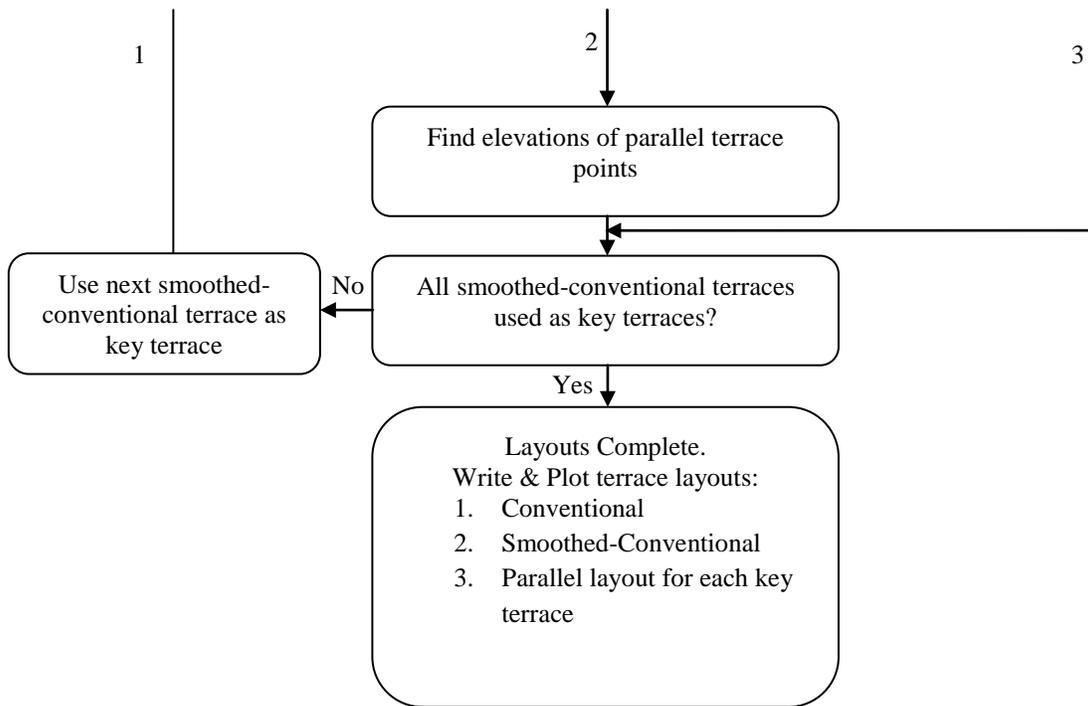


Figure A1. Cont.

**APPENDIX B: RESULTS FOR TERRACE LENGTH LIMITATION AND BOUNDARY CHECK**

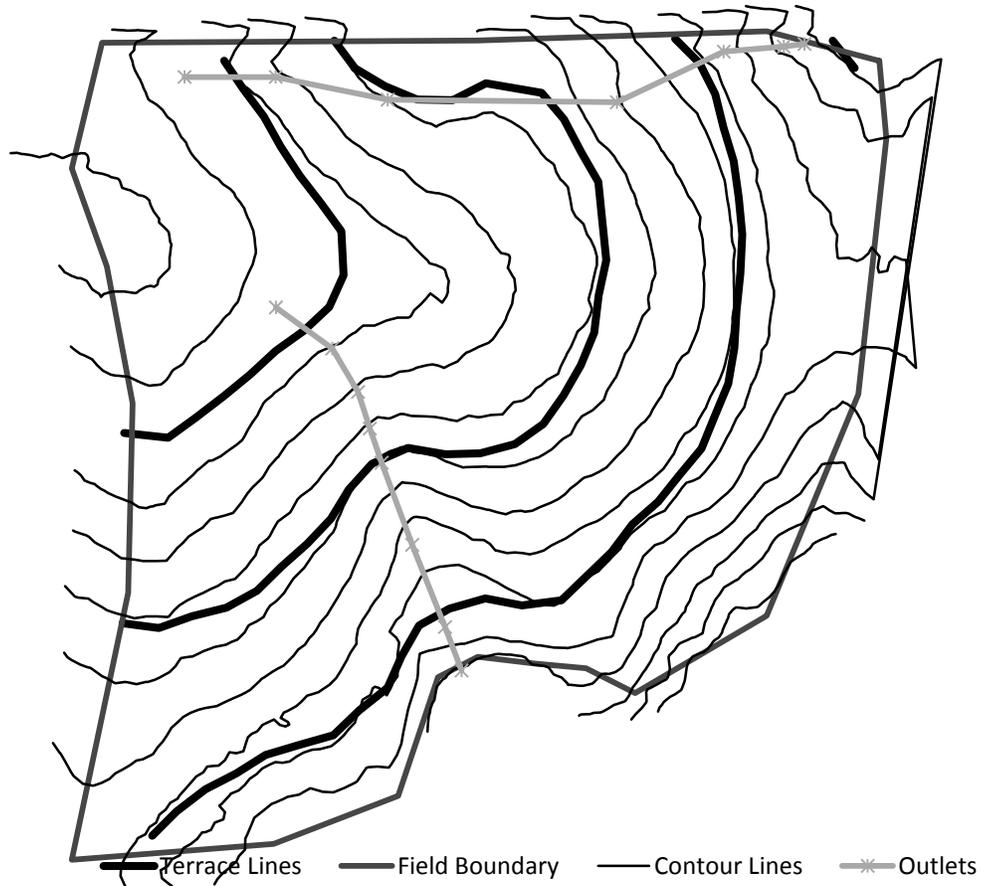


Figure B1: MO563—Terrace layout including short, out-of-bounds fourth terrace.

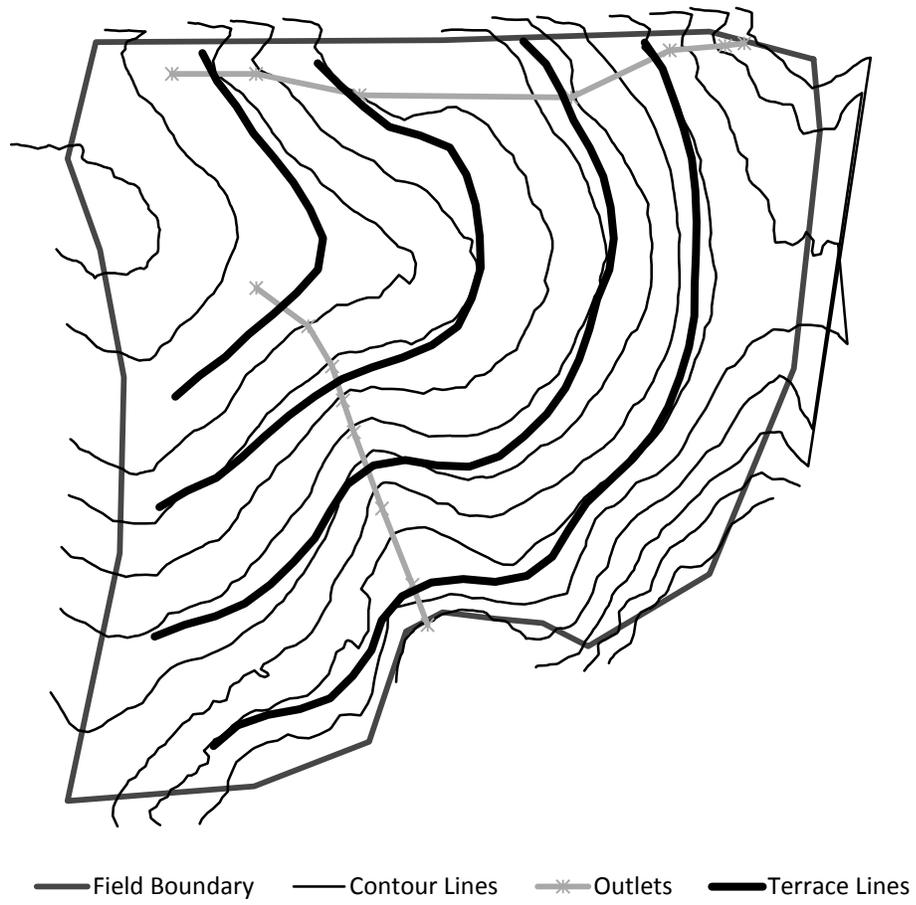


Figure B2. MO563—Terrace Layout after terrace length and boundary modifications.

## APPENDIX C: CONTOUR RADIUS OF CURVATURE SMOOTHING RESULTS

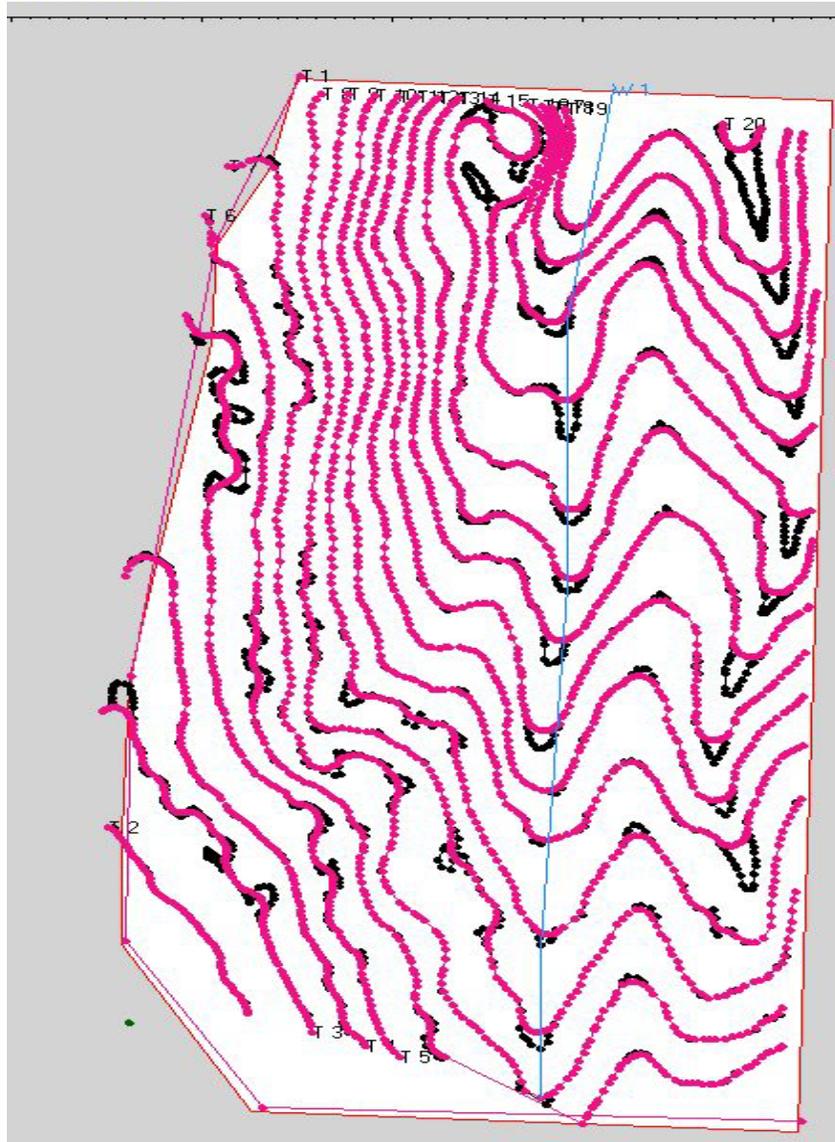


Figure C1. Non-smoothed (black) and smoothed (pink) contours (7.6 m, 25ft minimum ROC).

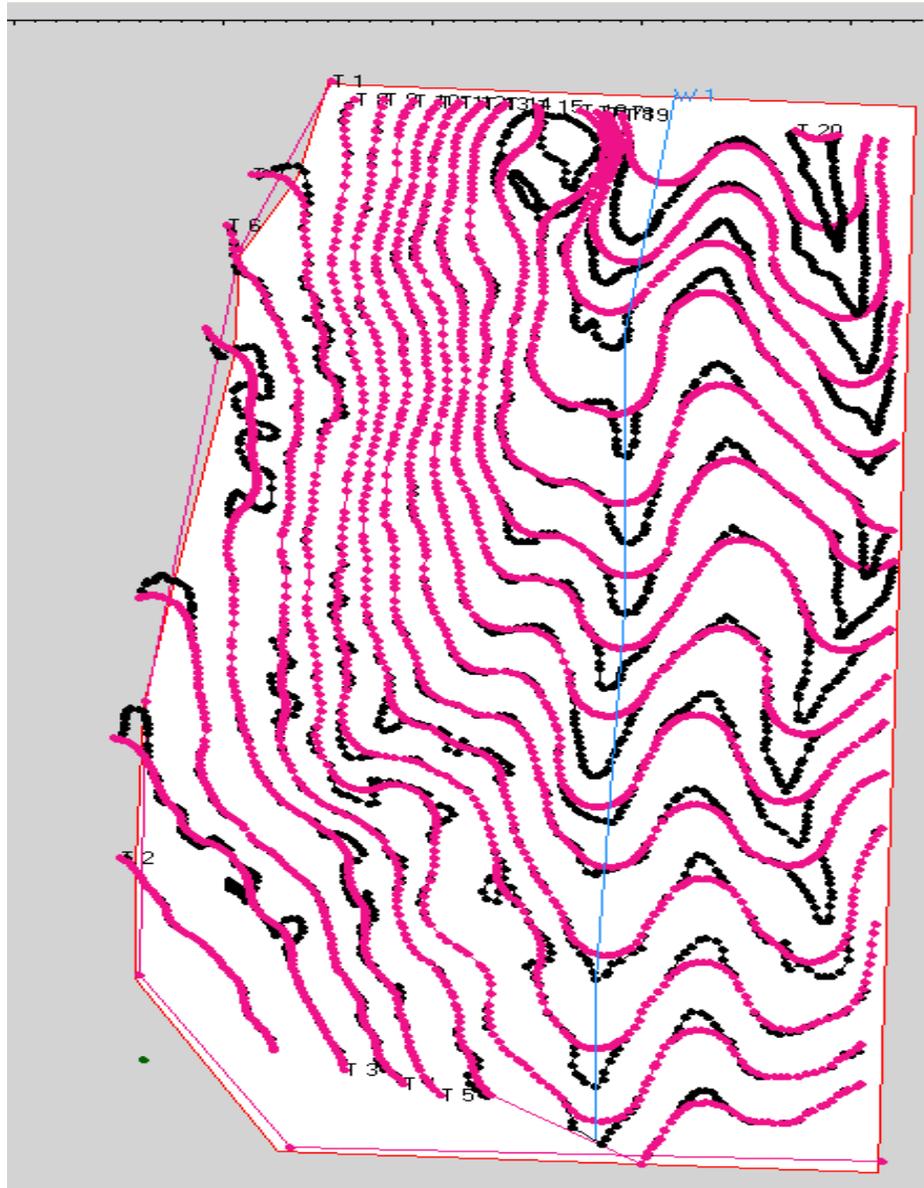


Figure C2. Non-smoothed (black) and smoothed (pink) contours (15.2 m, 50 ft minimum ROC).

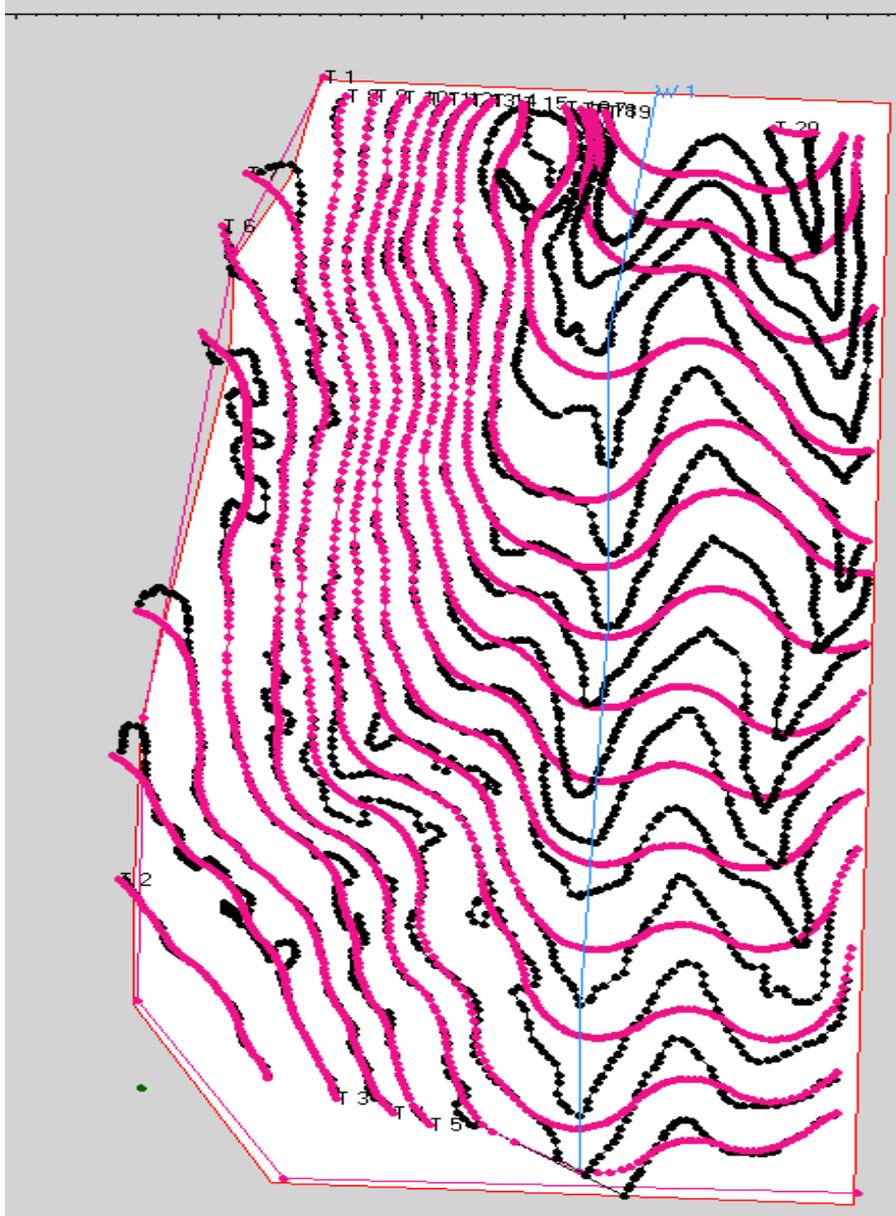


Figure C3. Non-smoothed (black) and smoothed (pink) contours (30.48 m, 100 ft minimum ROC).

## APPENDIX D: FIELD DATA COMPARISON

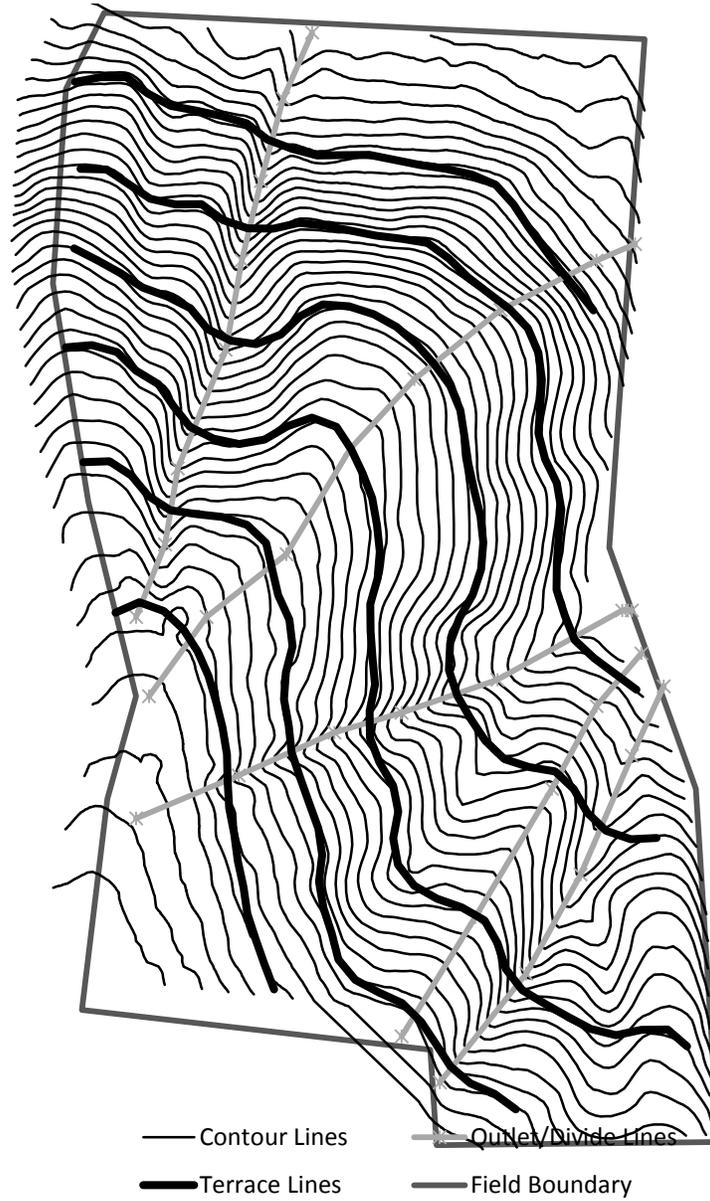


Figure D1. MO433 Field—Visual analysis of contour, terrace, outlet, and divide lines.



Figure D2. MO402 Field—Visual analysis of contour, terrace, outlet, and divide lines.

## APPENDIX E: PARALLEL TERRACE ORIENTATION MODIFICATION RESULTS

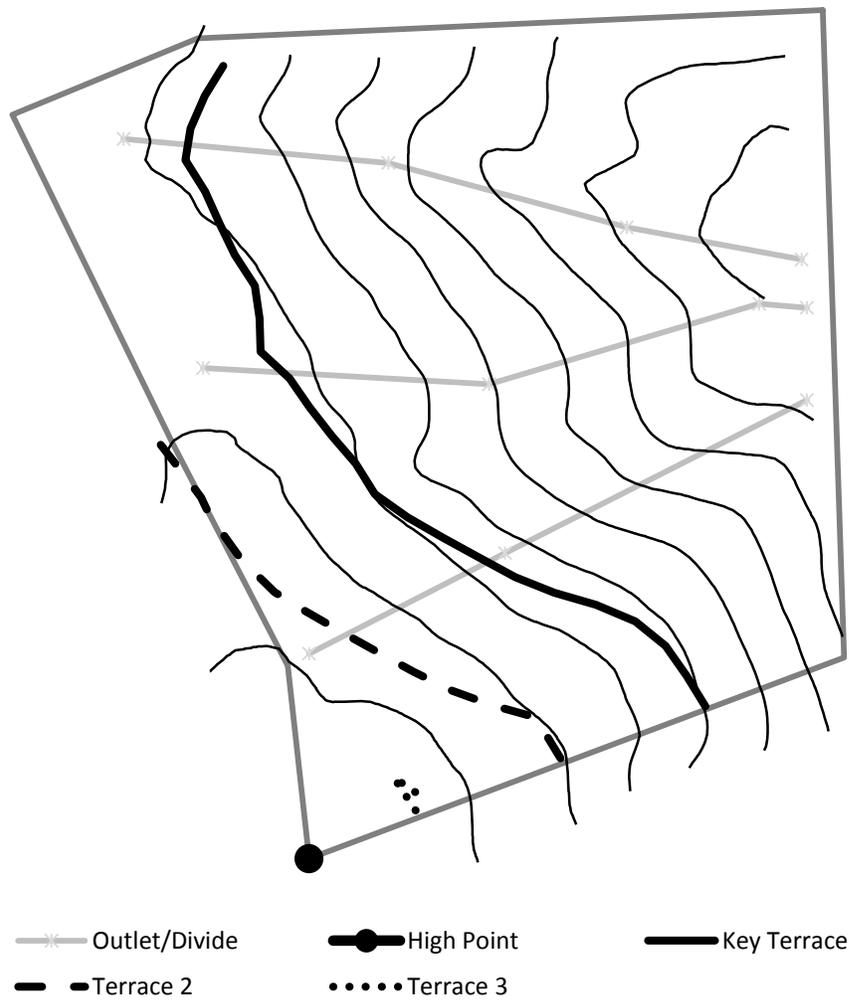


Figure E1.MO566—Key Terrace 1 layout with incorrect orientation.

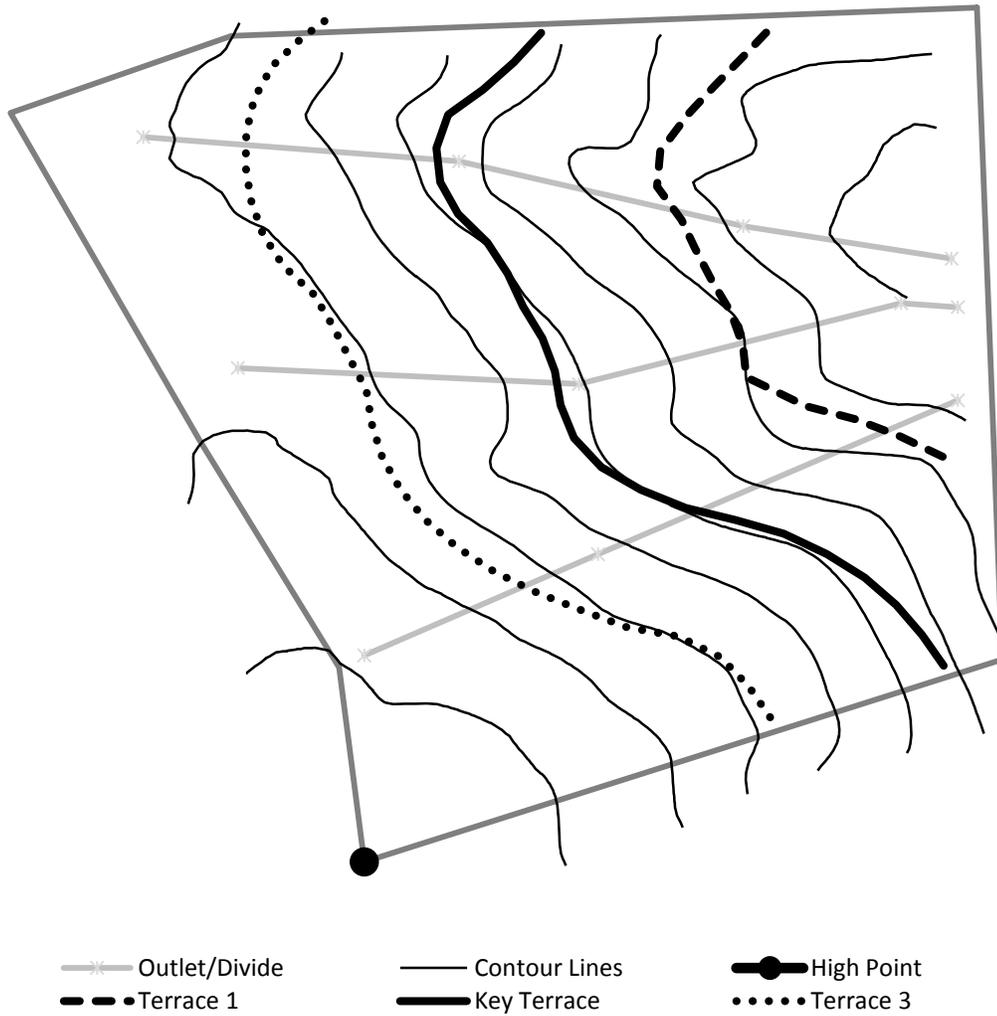


Figure E2:MO566—Key terrace 2 layout with incorrect orientation.

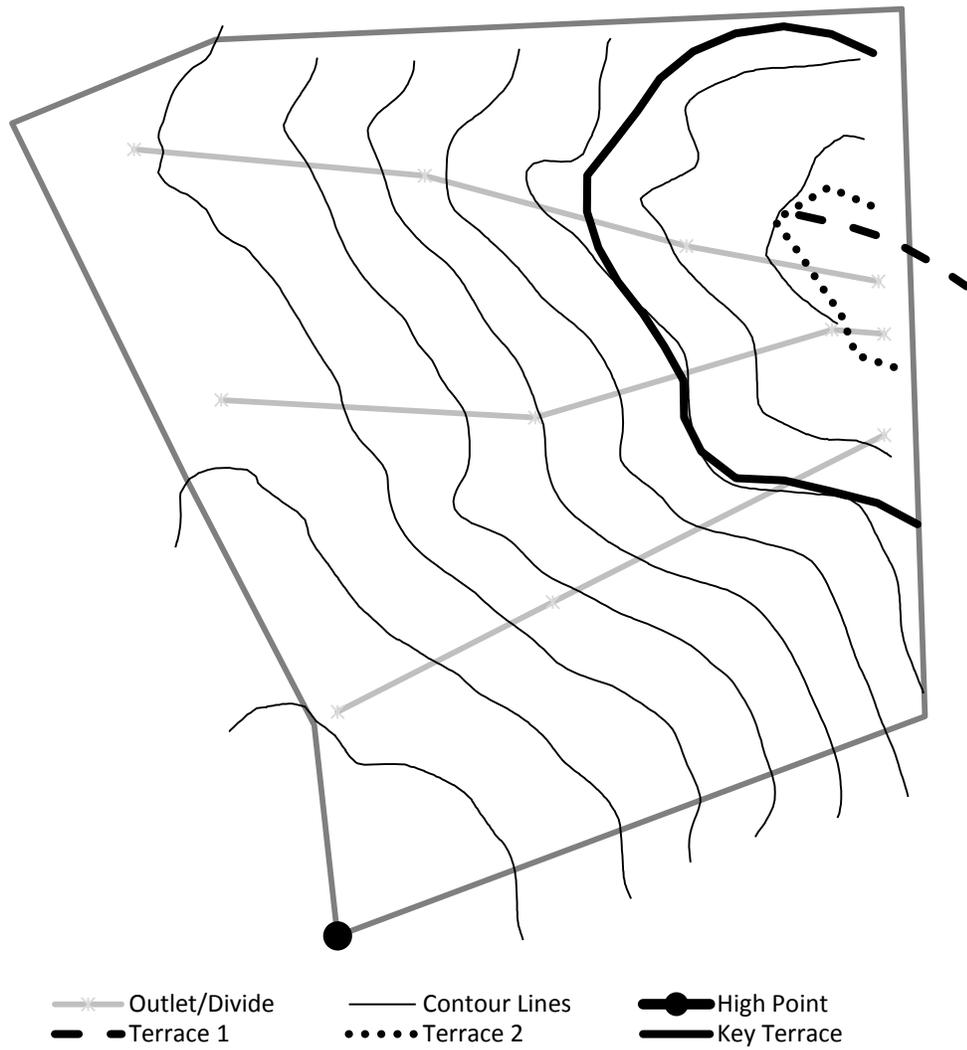
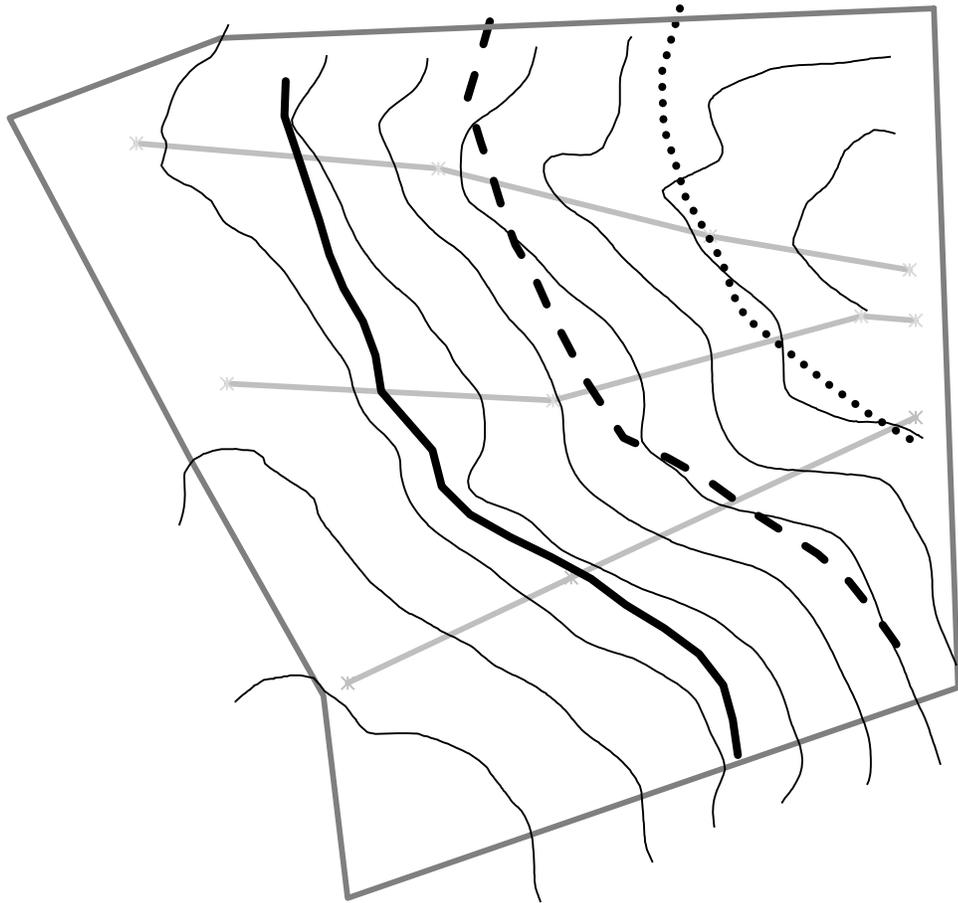


Figure E3. MO566—Key terrace 3 layout with incorrect orientation.



\*— Outlet/Divide    **—** Key Terrace    - - - Terrace 2    ••••• Terrace 3    — Contour Lines

Figure E4. MO566—Key terrace 1 modified parallel layout.

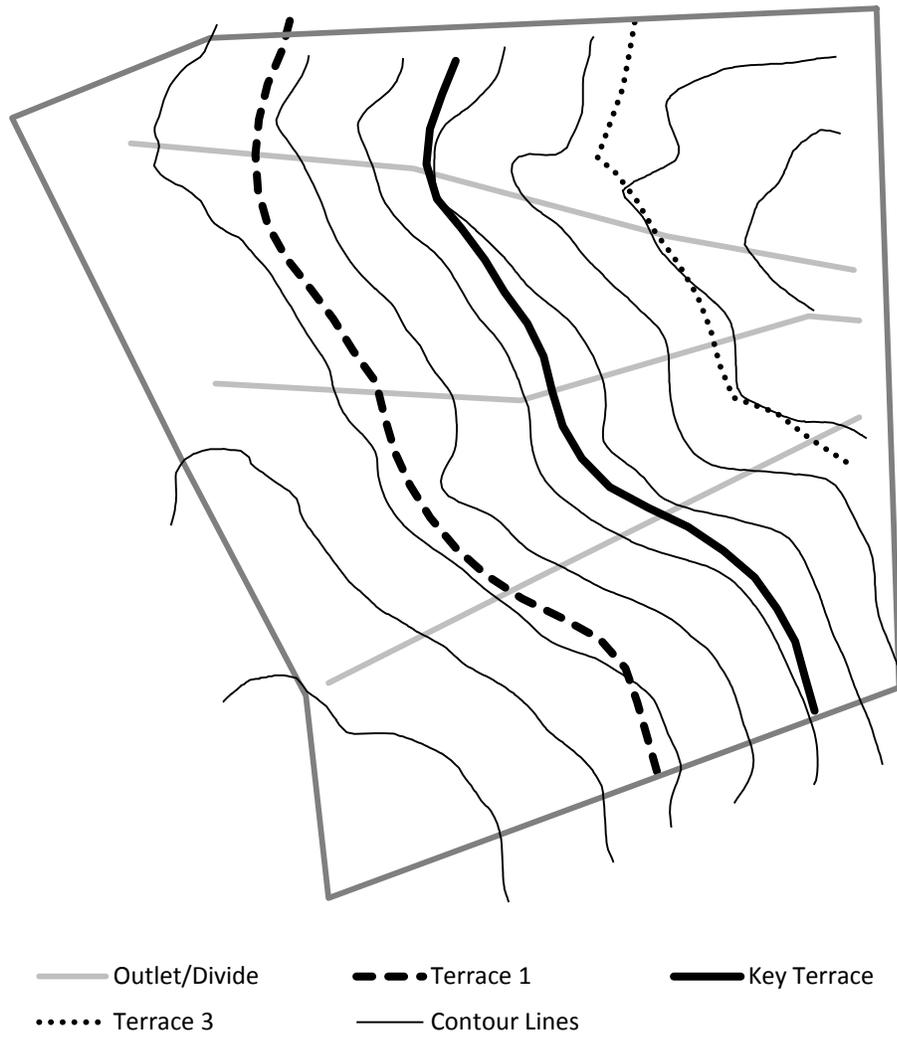


Figure E5. MO566—Key terrace 2 modified parallel layout.

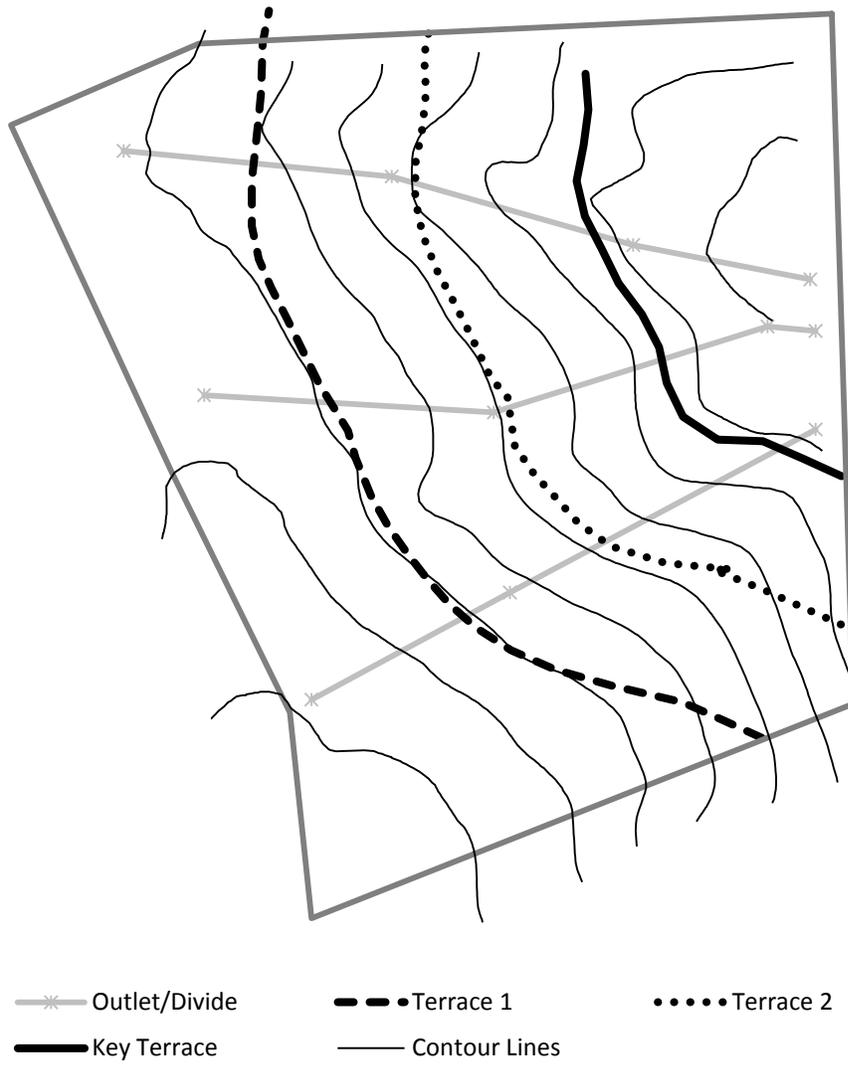


Figure E6. MO566—Key terrace 3 modified parallel layout.

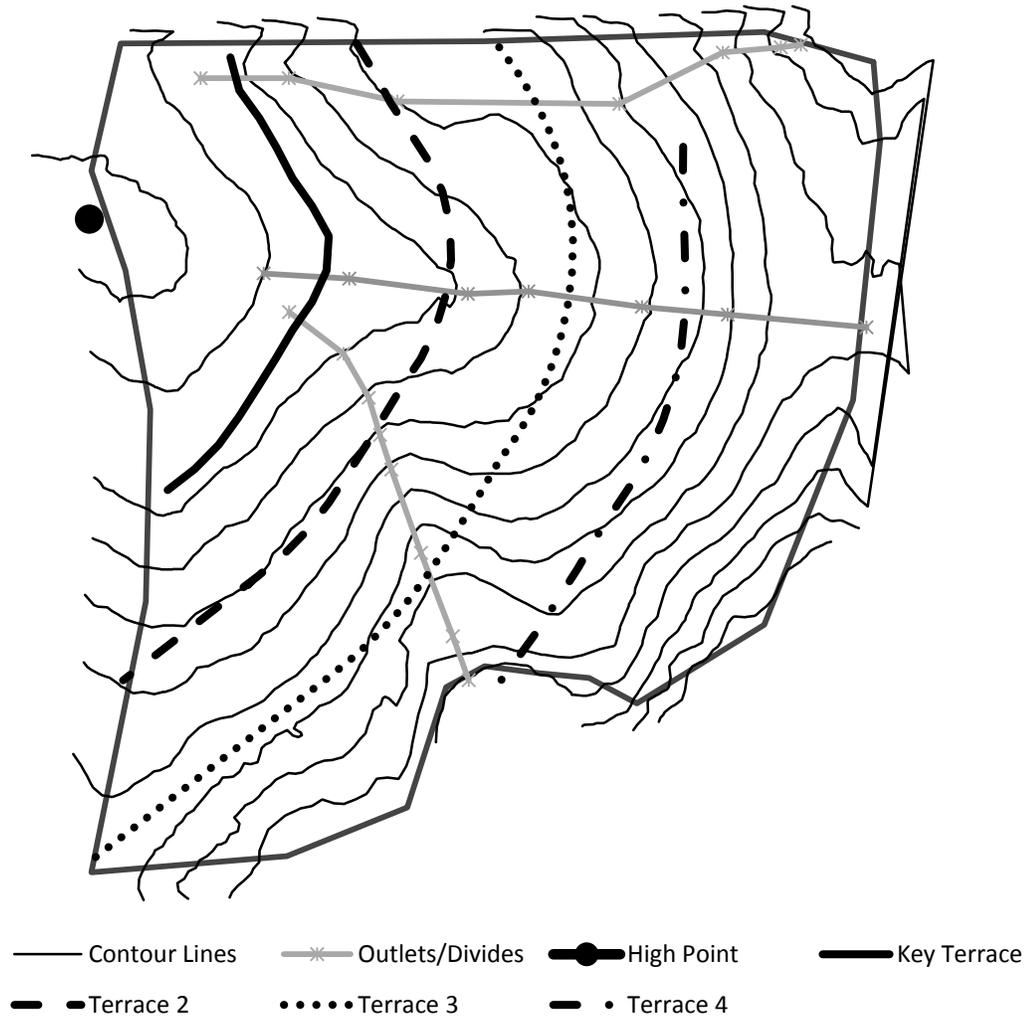


Figure E7. MO563—Key terrace 1 layout before parallel orientation modifications.

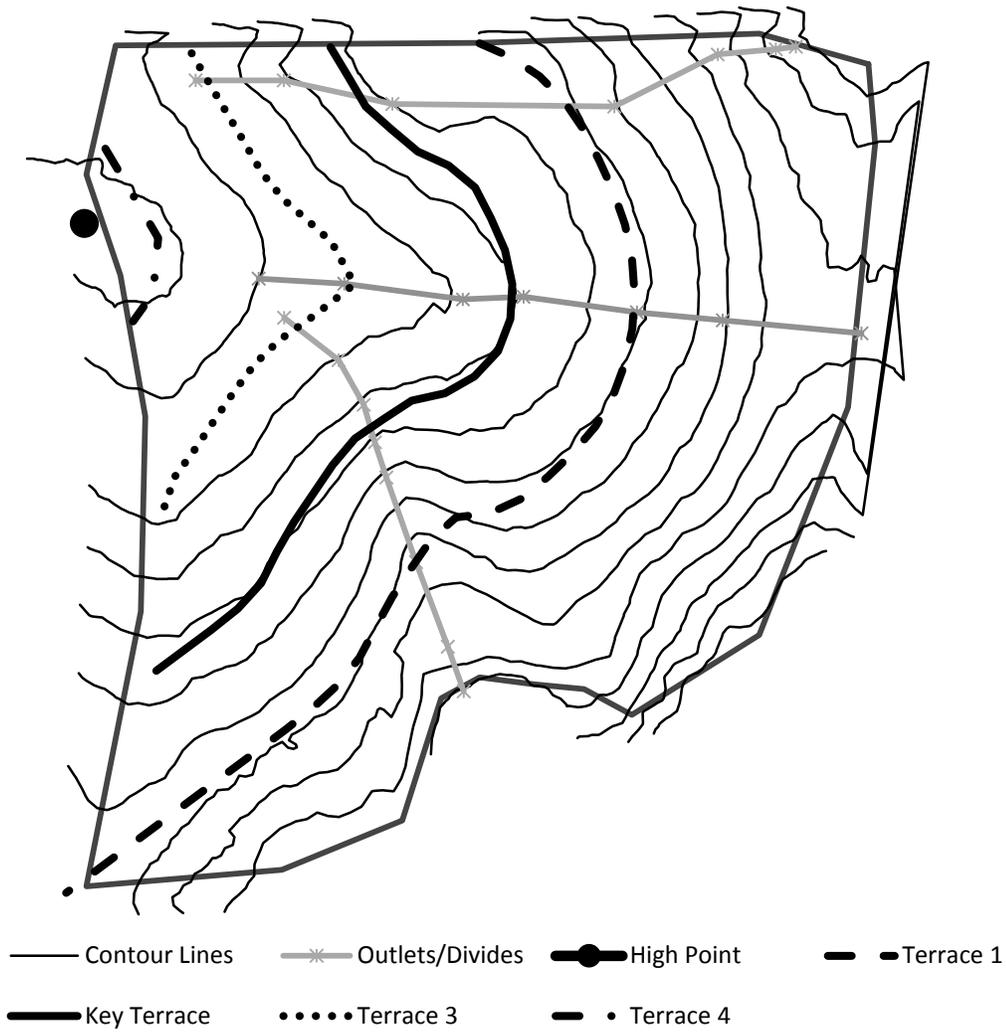


Figure E8. MO563—Key terrace 2 layout before parallel orientation modifications.

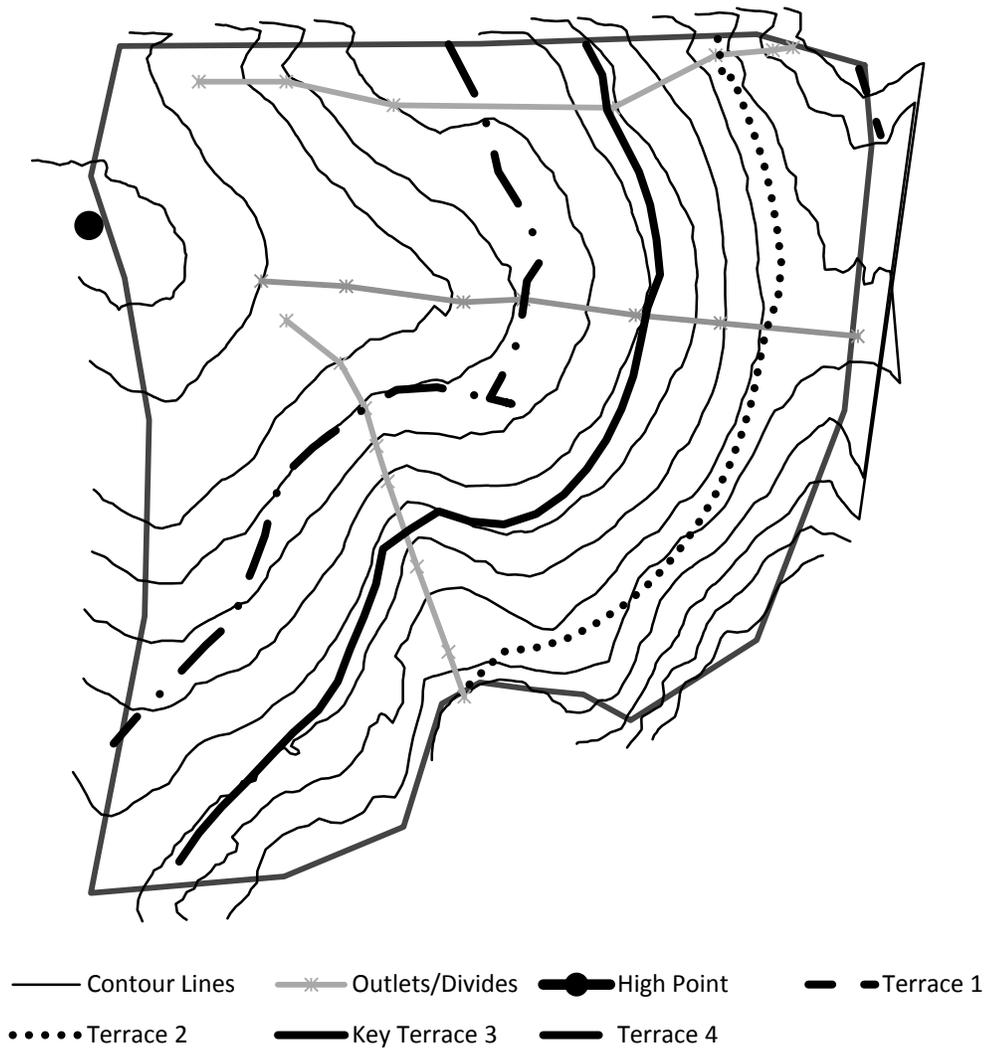


Figure E9. MO563—Key terrace 3 layout before parallel orientation modifications.

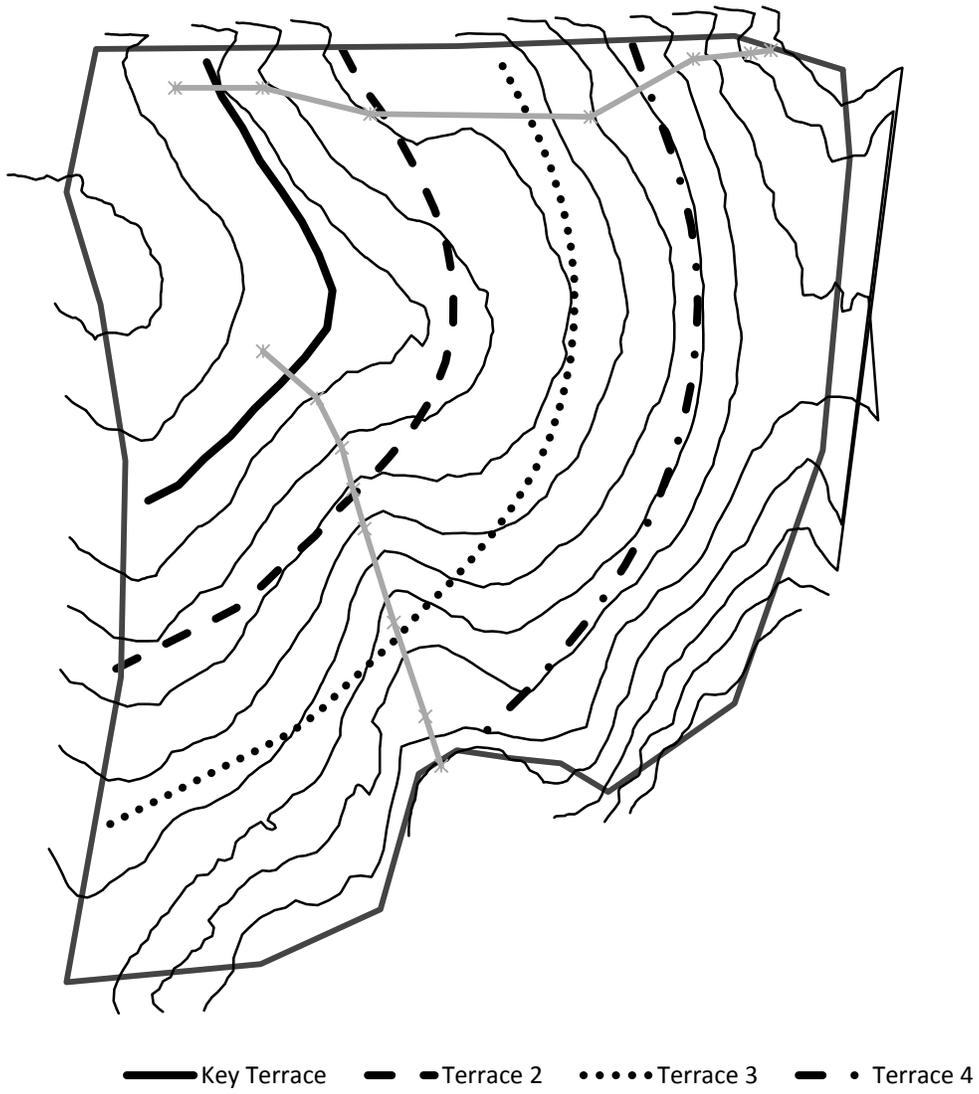


Figure E10. MO563-Key terrace 1 modified parallel layout.

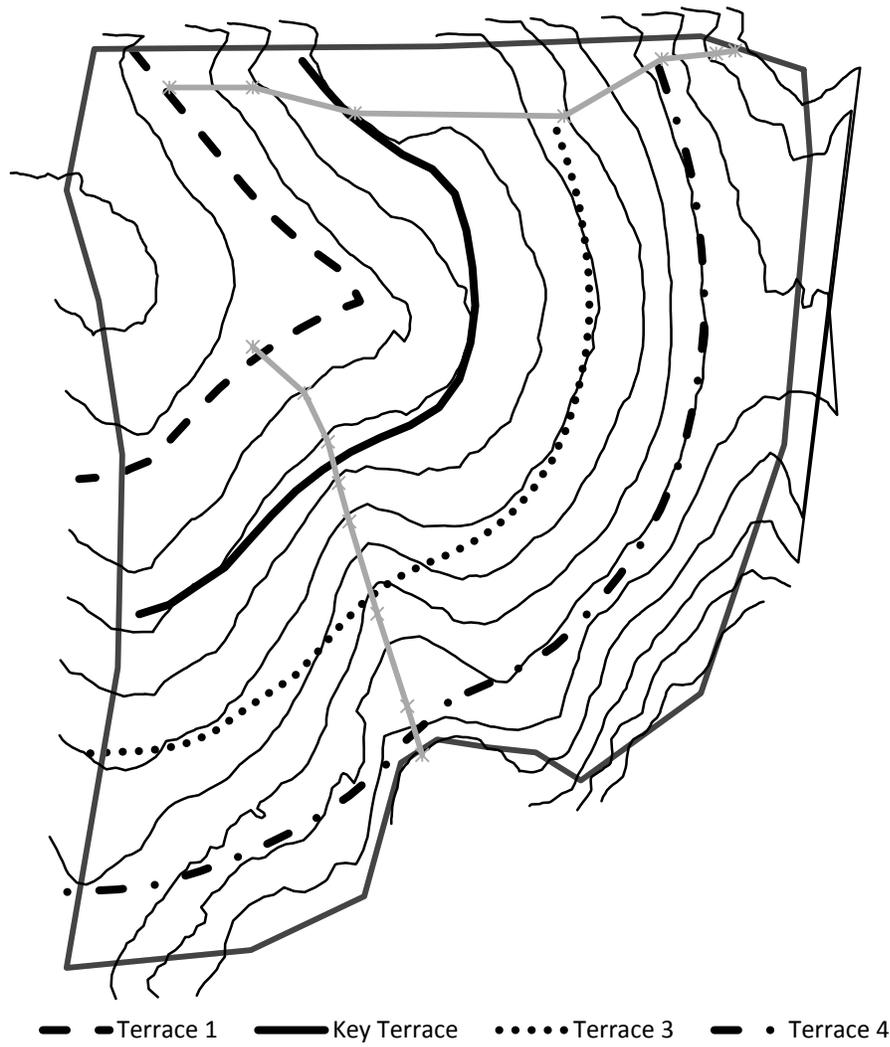


Figure E11. MO563-Key terrace 2 modified parallel layout.

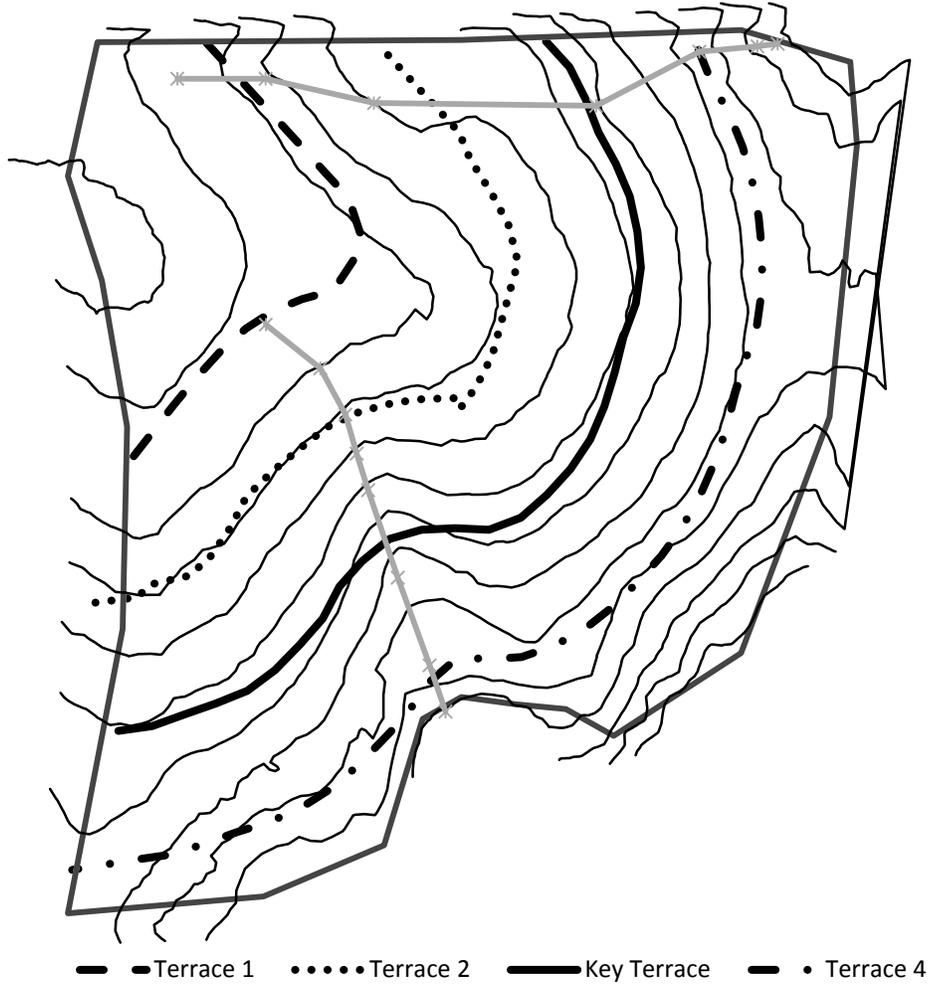


Figure E12. MO563-Key terrace 3 modified parallel layout.

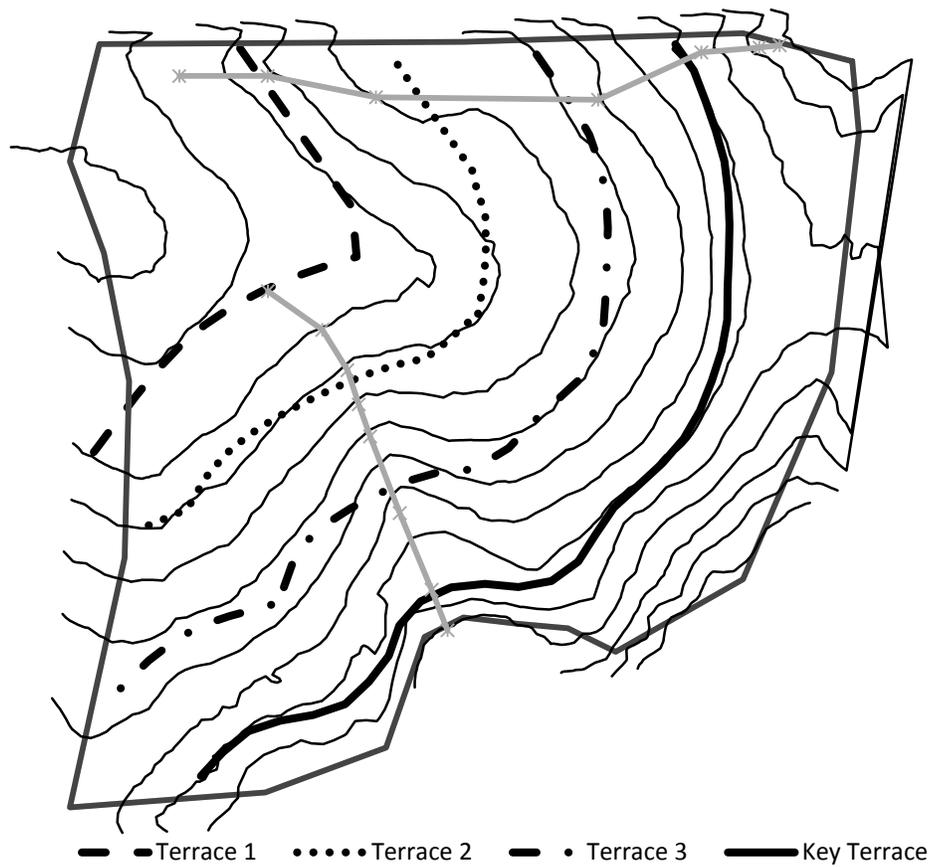


Figure E13. MO563-Key terrace 4 modified parallel layout.

## APPENDIX F: VARIABLE SPACING MODIFICATION RESULTS

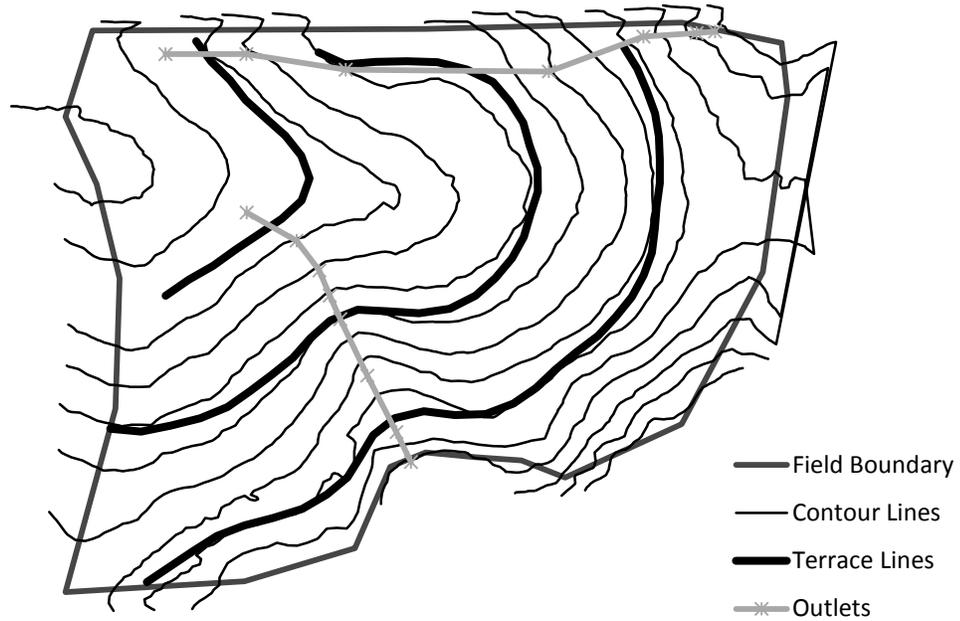


Figure F1. MO563--Saline County: Original Smoothed-Conventional Terrace Layout.

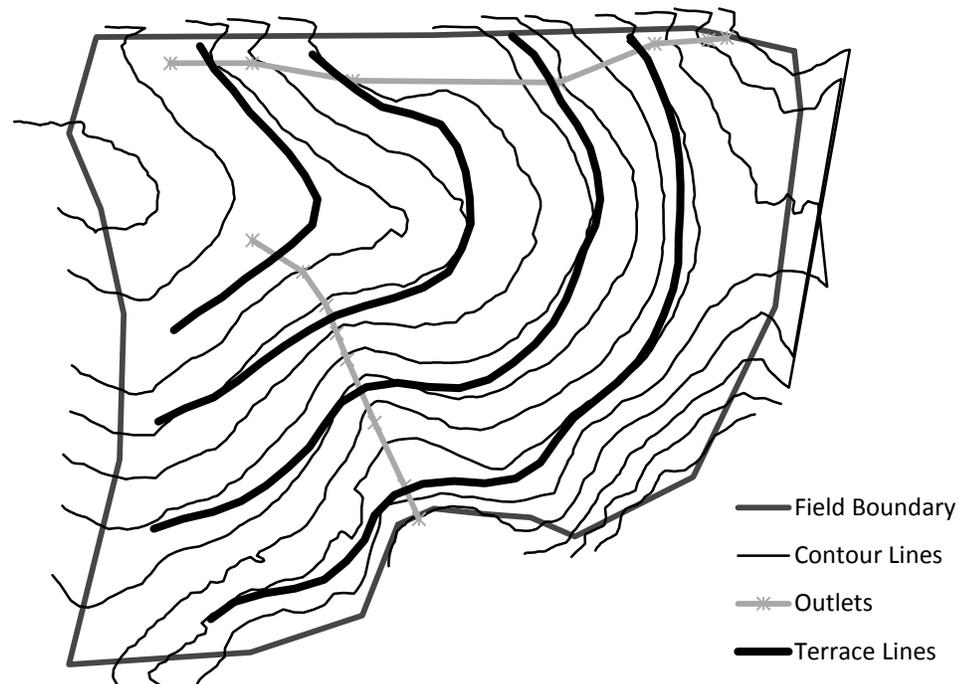


Figure F2. MO563--Saline County: Smoothed-Conventional Terrace Design –Variable Spacing Modification.

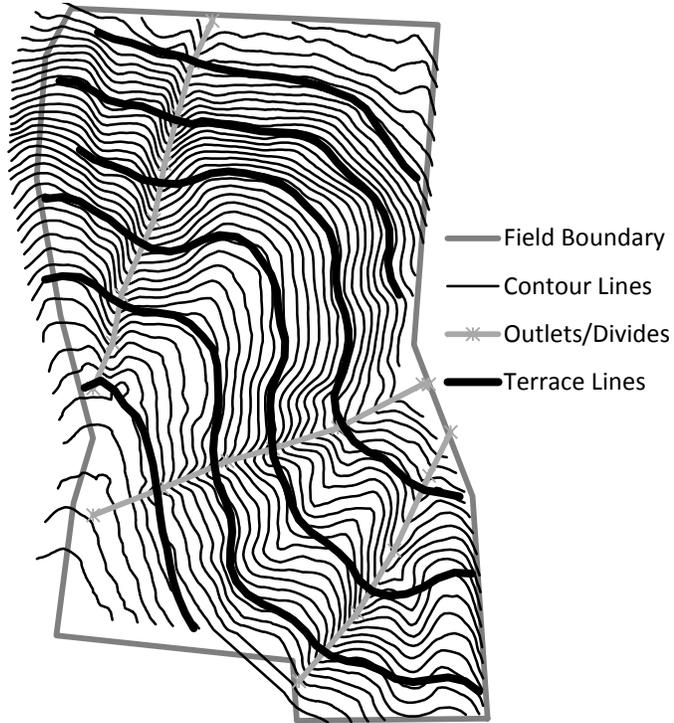


Figure F3. MO433--Monroe County: Original Smoothed-Conventional Terrace Layout.

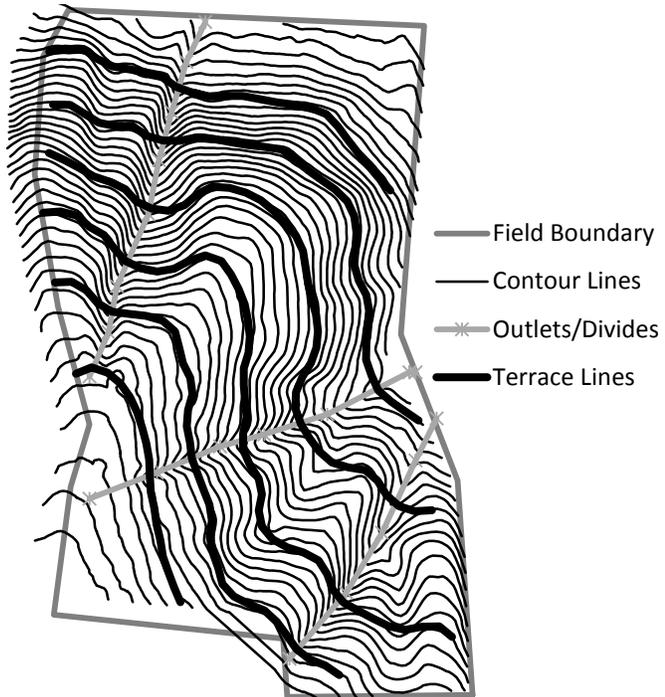


Figure F4. MO433--Monroe County: Smoothed-Conventional Terrace Layout with spacing changes.

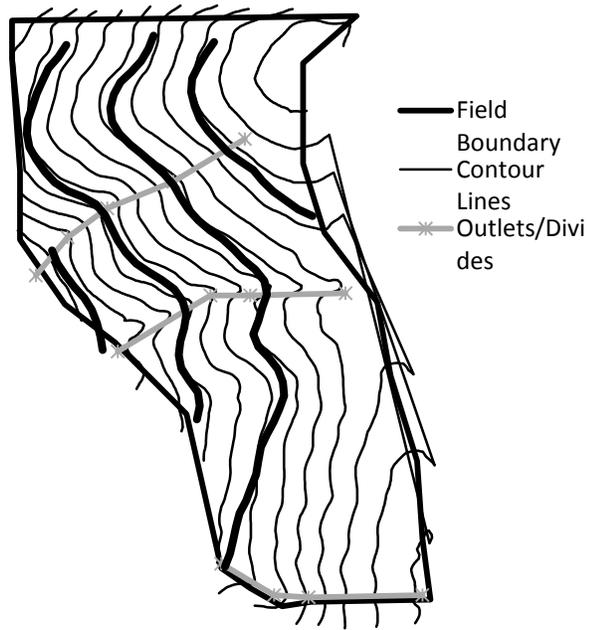


Figure F5. MO574--Monroe County: Original Smoothed-Conventional Terrace Layout.

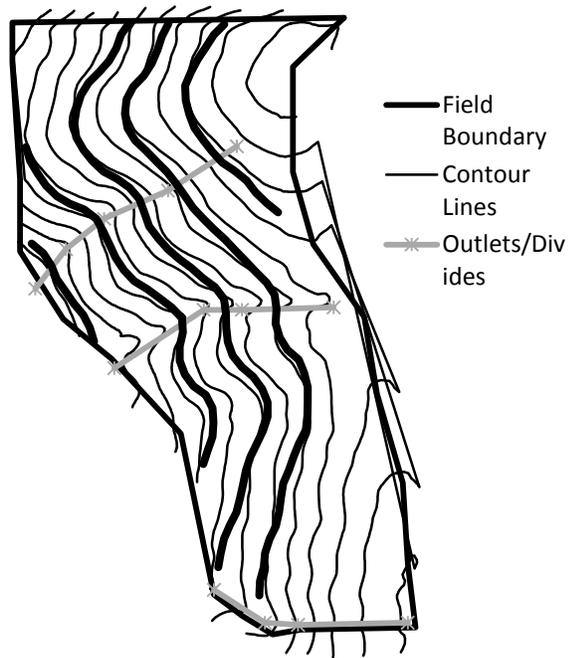


Figure F6. MO574--Monroe County: Smoothed Conventional Terrace Design –Variable Spacing Modification.

Table F1. MO563 Saline County Terrace Spacing Comparison.

<b>Terrace Interval</b>	<b>Original Spacing (ft)</b>	<b>Modified Spacing (ft)</b>
<b>1-2</b>	230	180
<b>2-3</b>	210	180
<b>3-4</b>	--	180

Table F2. MO433 Monroe County(1) Terrace Spacing Comparison.

<b>Terrace Interval</b>	<b>Original Spacing</b>	<b>Modified Spacing</b>
<b>1-2</b>	235	180
<b>2-3</b>	209	180
<b>3-4</b>	192	180
<b>4-5</b>	171	171
<b>5-6</b>	165	165

Table F3. MO574 Monroe County(2) Terrace Spacing Comparison.

<b>Terrace Interval</b>	<b>Original Spacing</b>	<b>Modified Spacing</b>
<b>1-2</b>	234	180
<b>2-3</b>	224	180
<b>3-4</b>	201	180
<b>4-5</b>	--	180

**APPENDIX G: TERRACE SMOOTHING EFFECTS**

**MO563--Terrace 1**

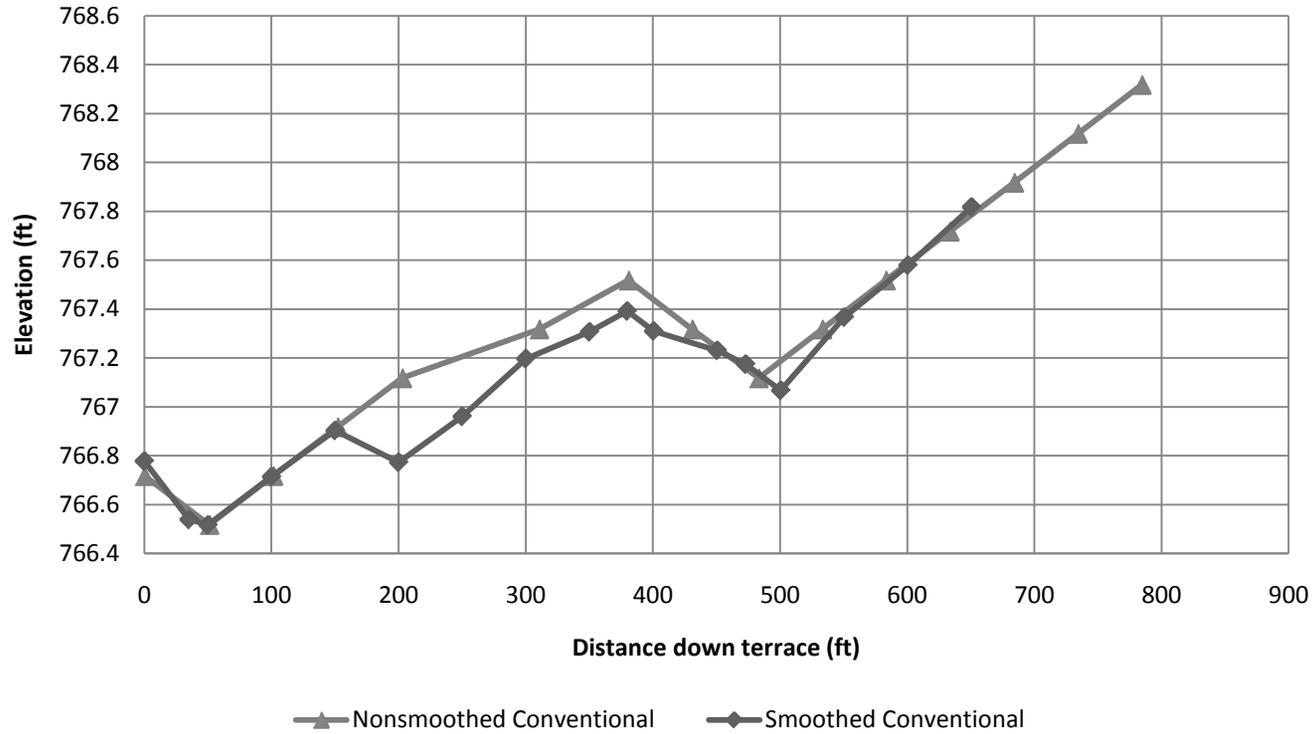


Figure G1.MO563-Saline County Terrace 1 Smoothing Results—Cross Section View.

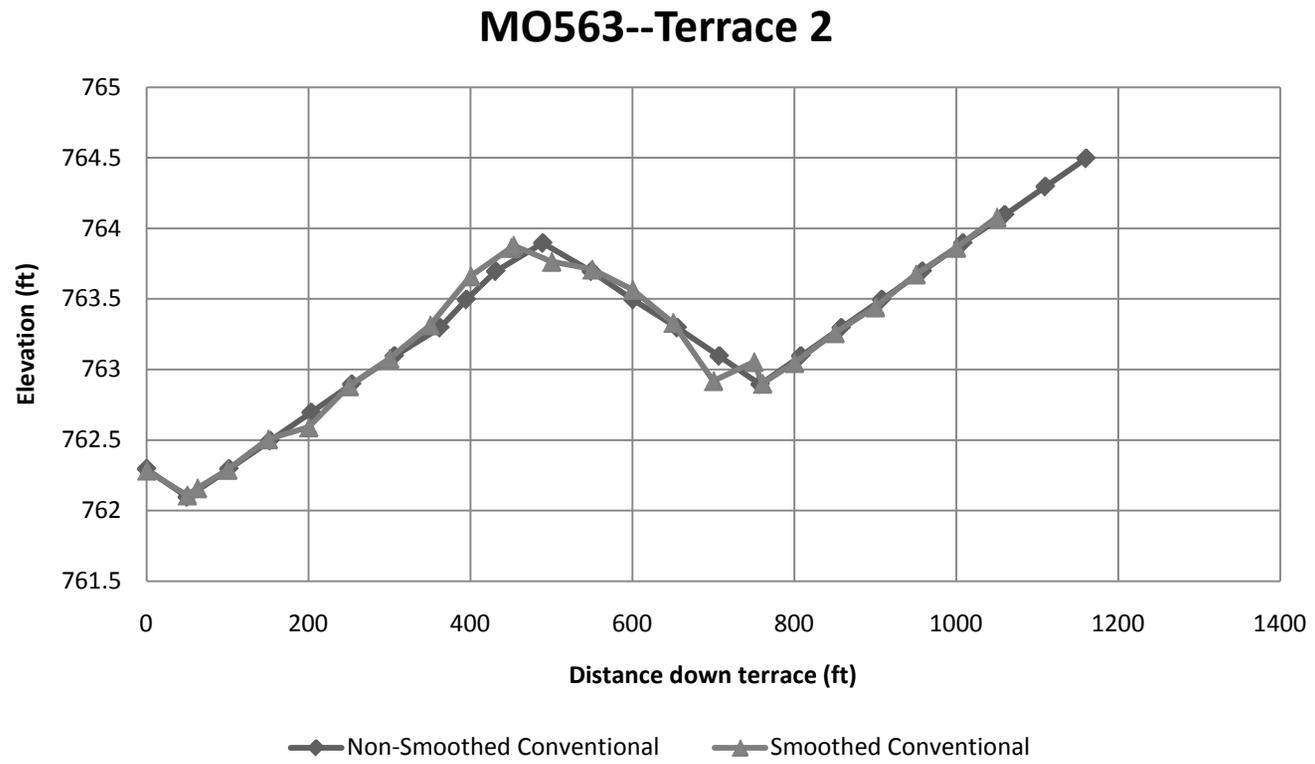


Figure G2.MO563-Saline County Terrace 2 Smoothing Results—Cross Section View.

### MO563--Terrace 3

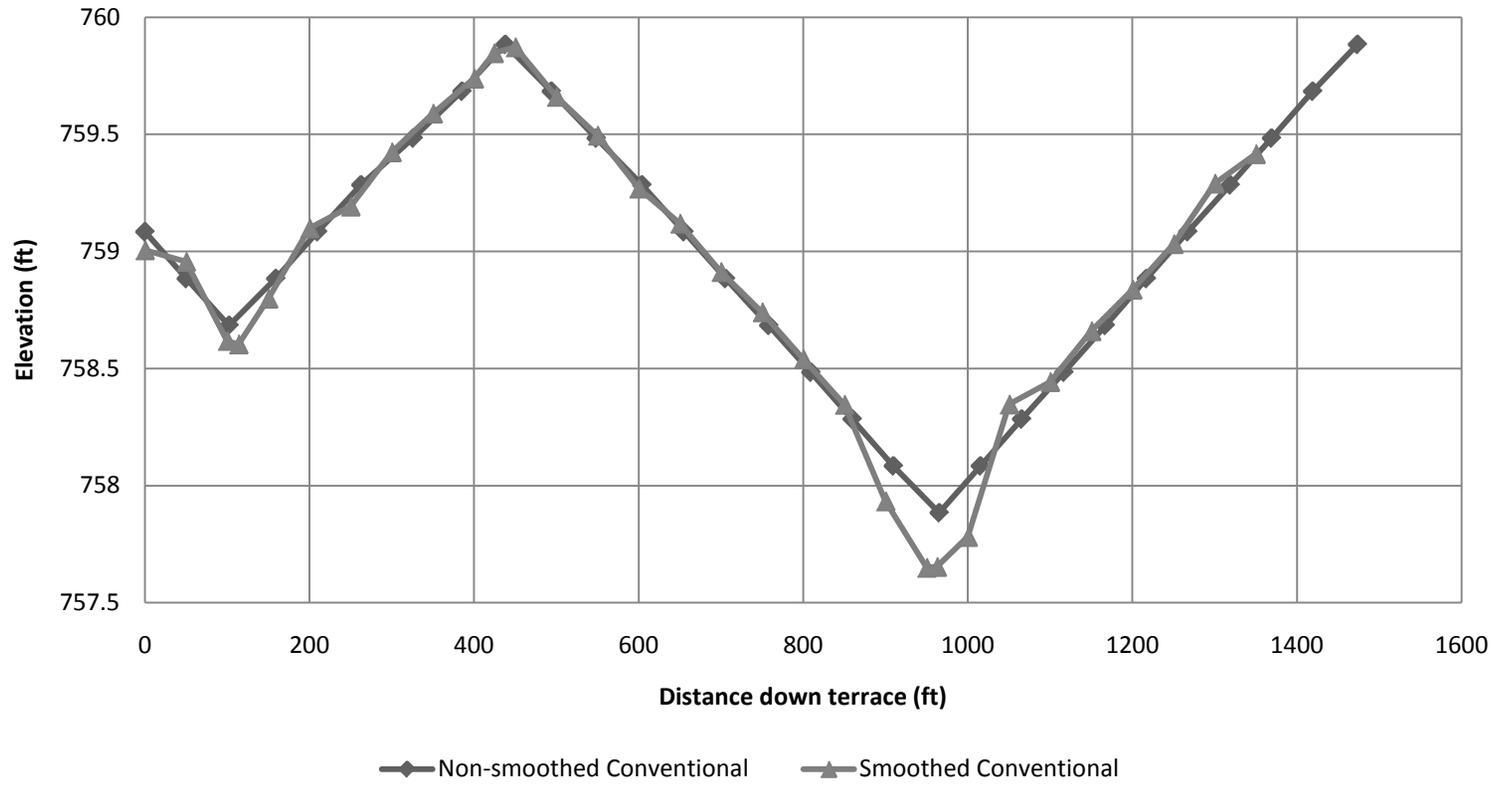
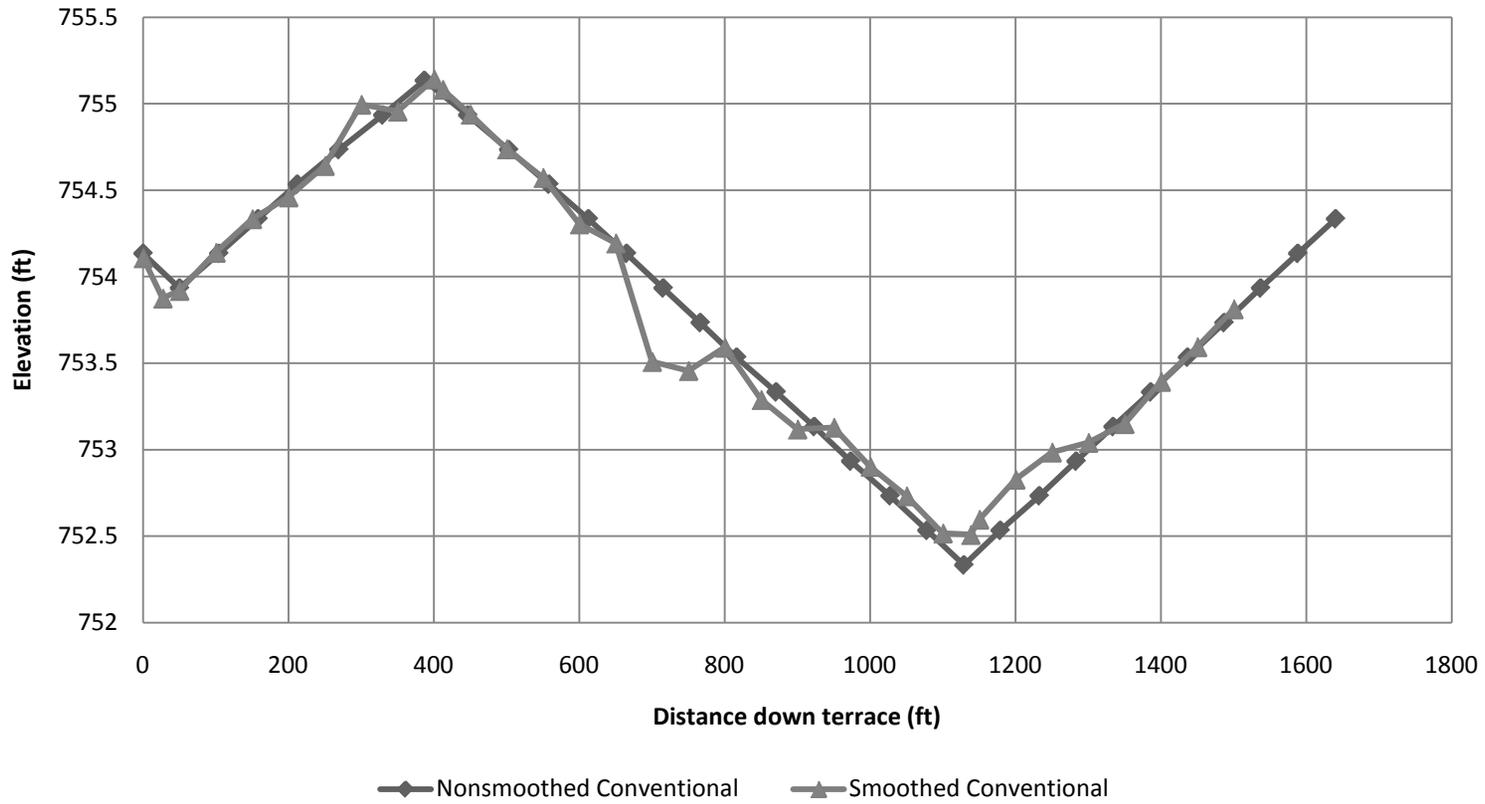


Figure G3.MO563-Saline County Terrace 3 Smoothing Results—Cross Section View.

# MO563--Terrace 4



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Figure G4.MO563-Saline County Terrace 4 Smoothing Results—Cross Section View.

### MO433--Terrace 1

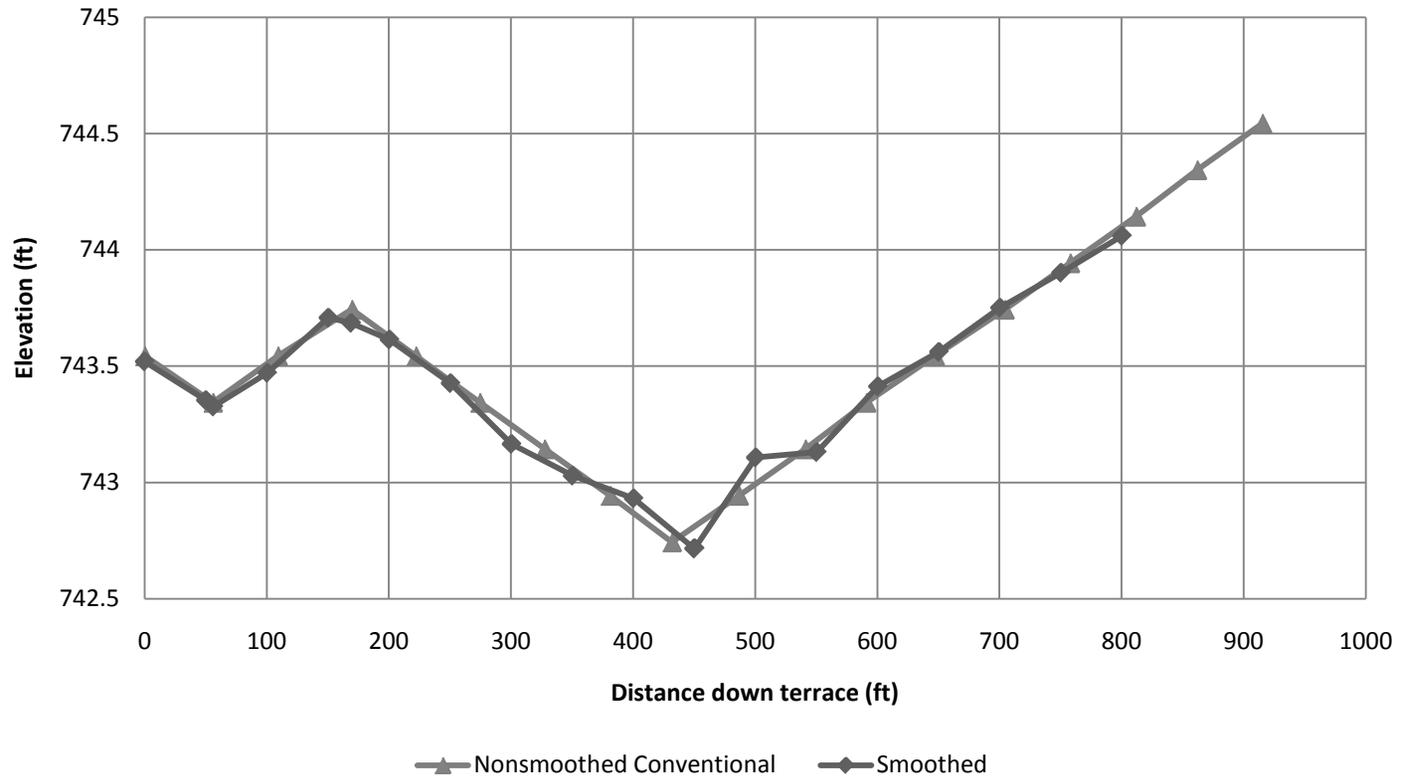
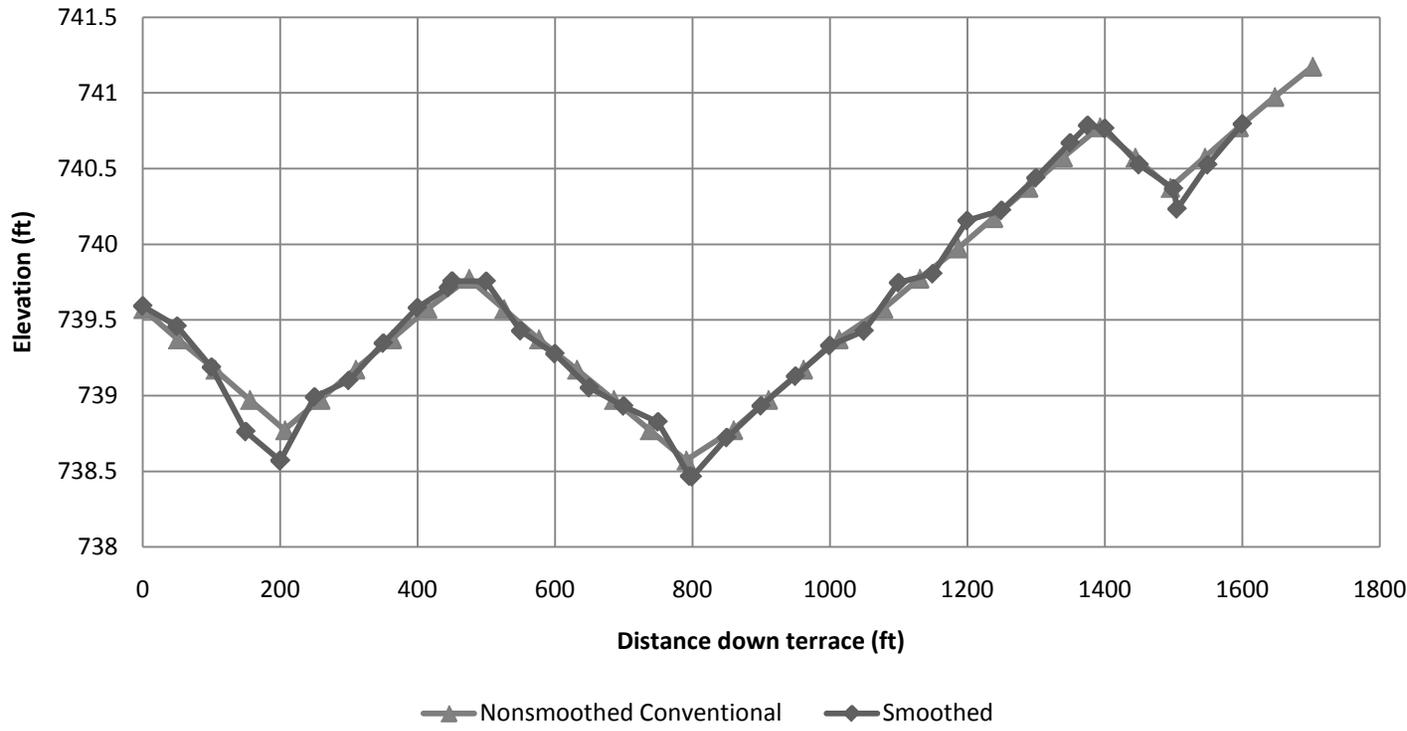


Figure G5. MO433-Monroe County Terrace 1 Smoothing Results—Cross Section View.

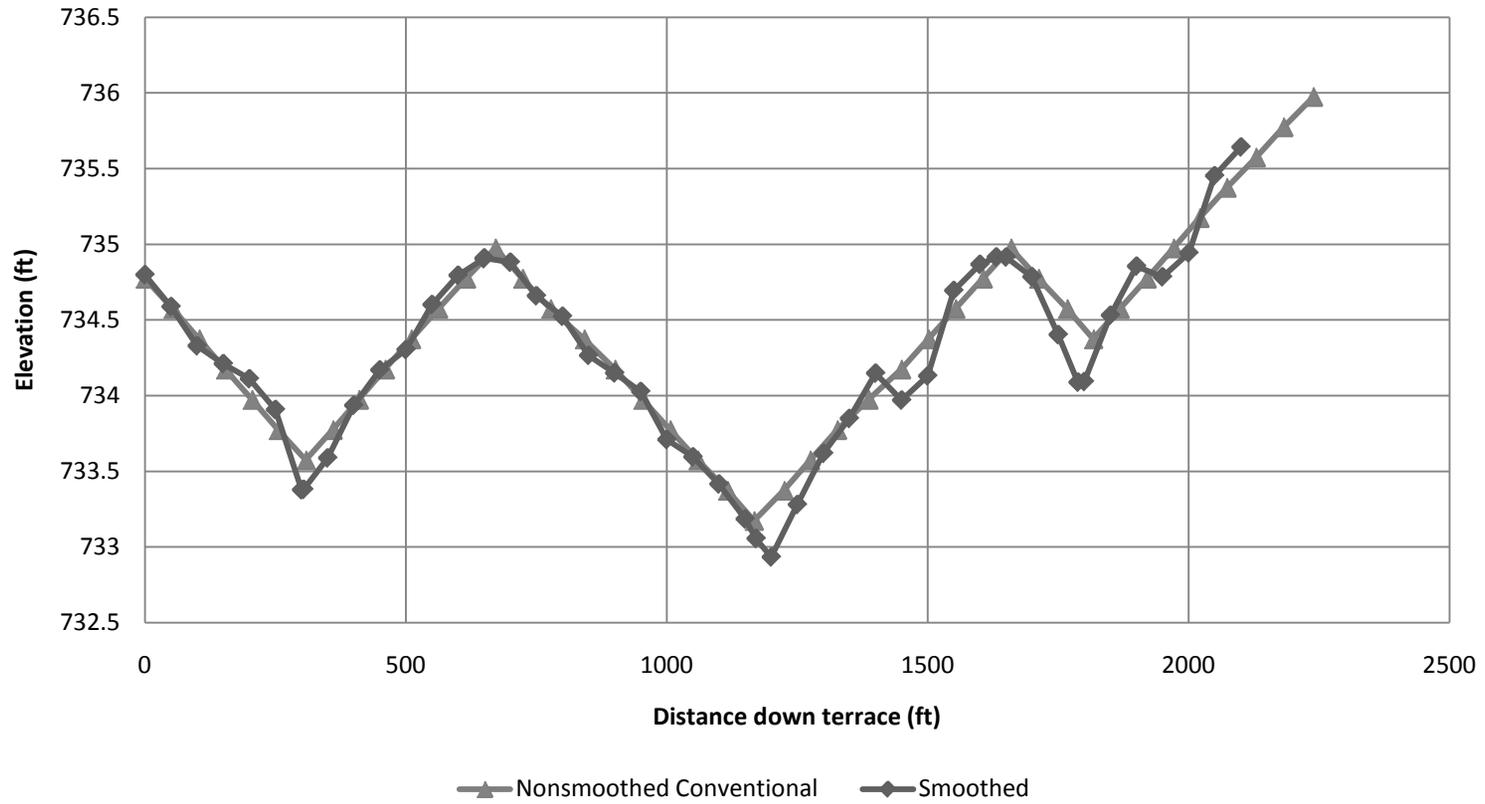
### MO433--Terrace 2



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Figure G6. MO433-Monroe County Terrace 2 Smoothing Results—Cross Section View.

### MO433--Terrace 3



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Figure G7. MO433-Monroe County Terrace 3 Smoothing Results—Cross Section View.

### MO433--Terrace 4

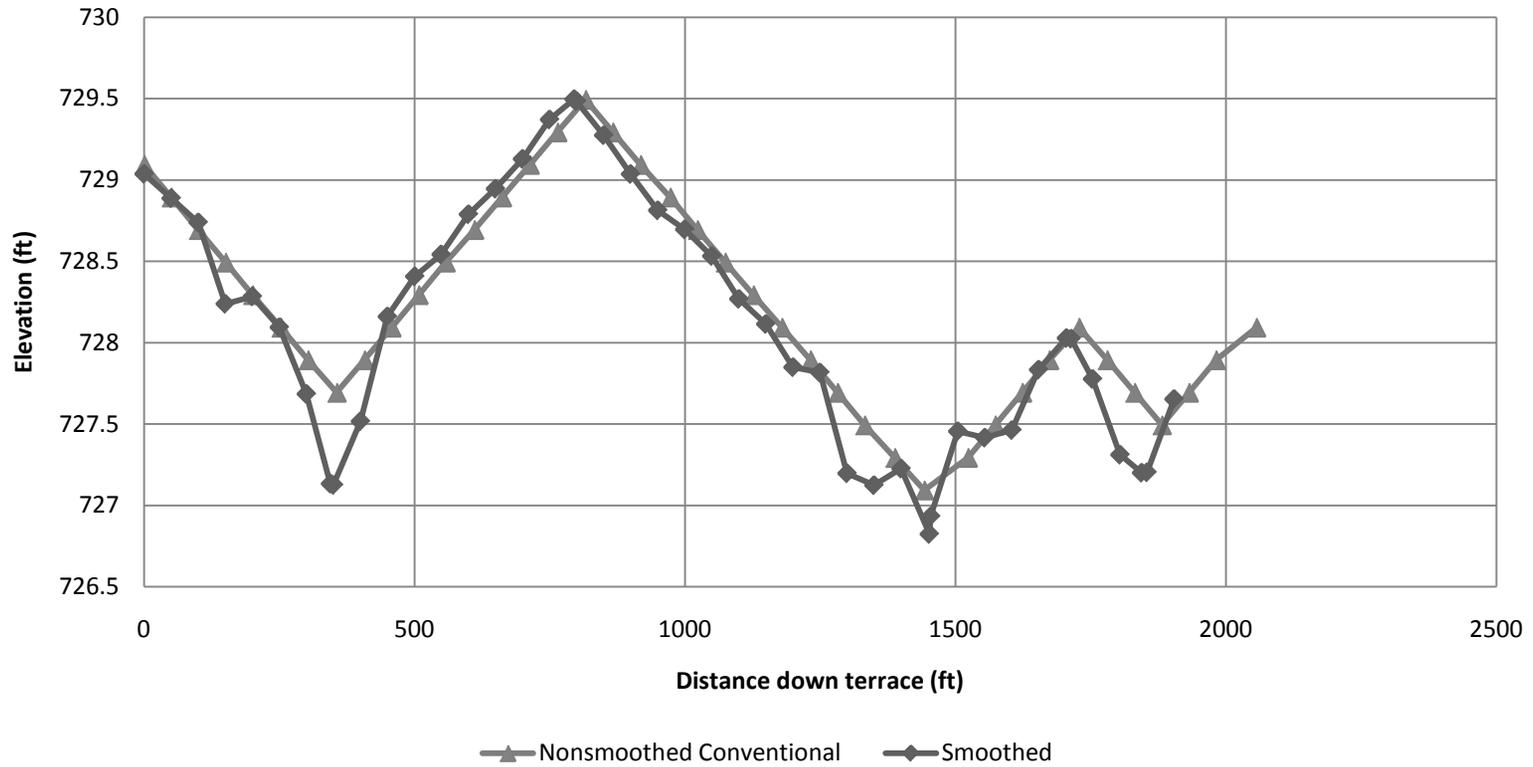
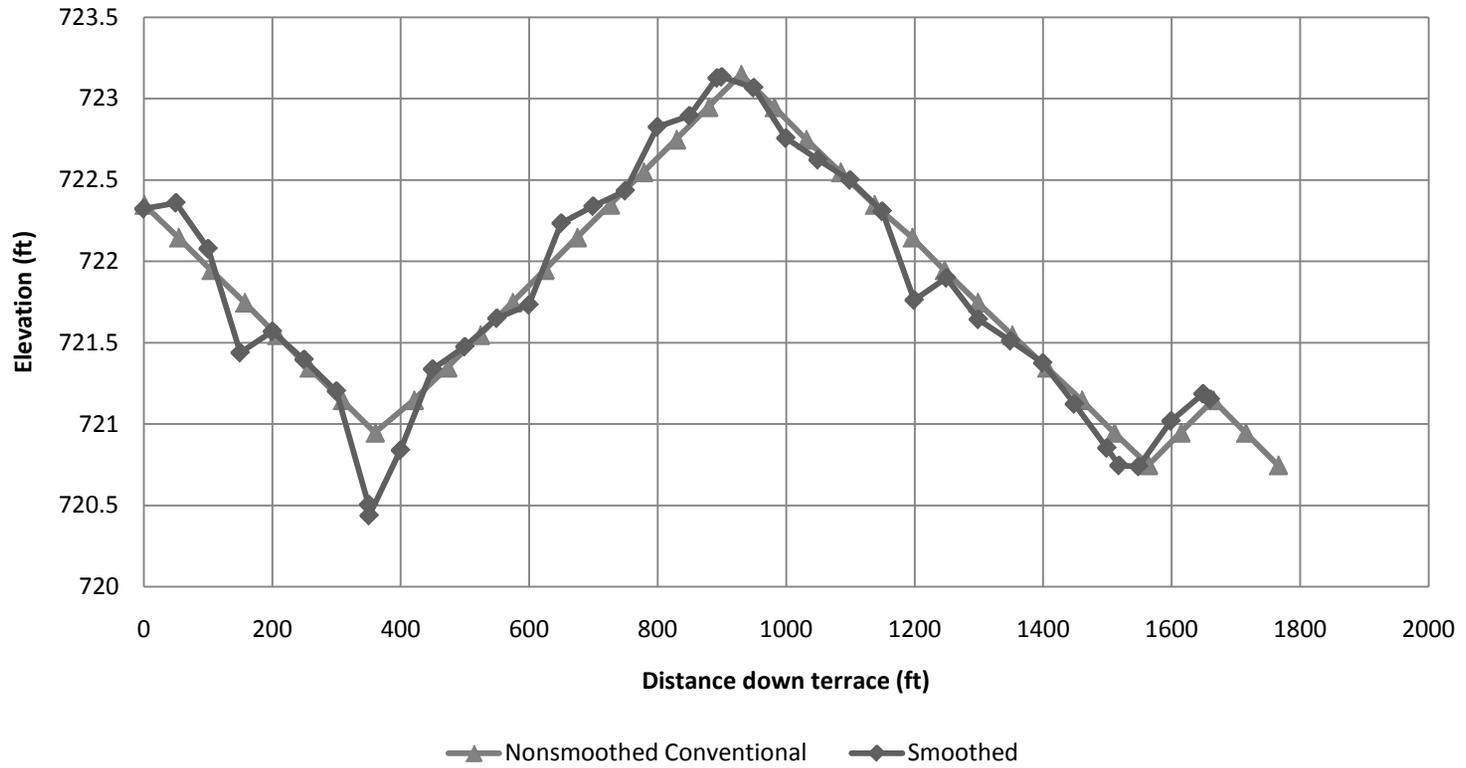


Figure G8. MO433-Monroe County Terrace 4 Smoothing Results—Cross Section View.

### MO433--Terrace 5



150

Figure G9. MO433-Monroe County Terrace 5 Smoothing Results—Cross Section View.

### MO433--Terrace 6

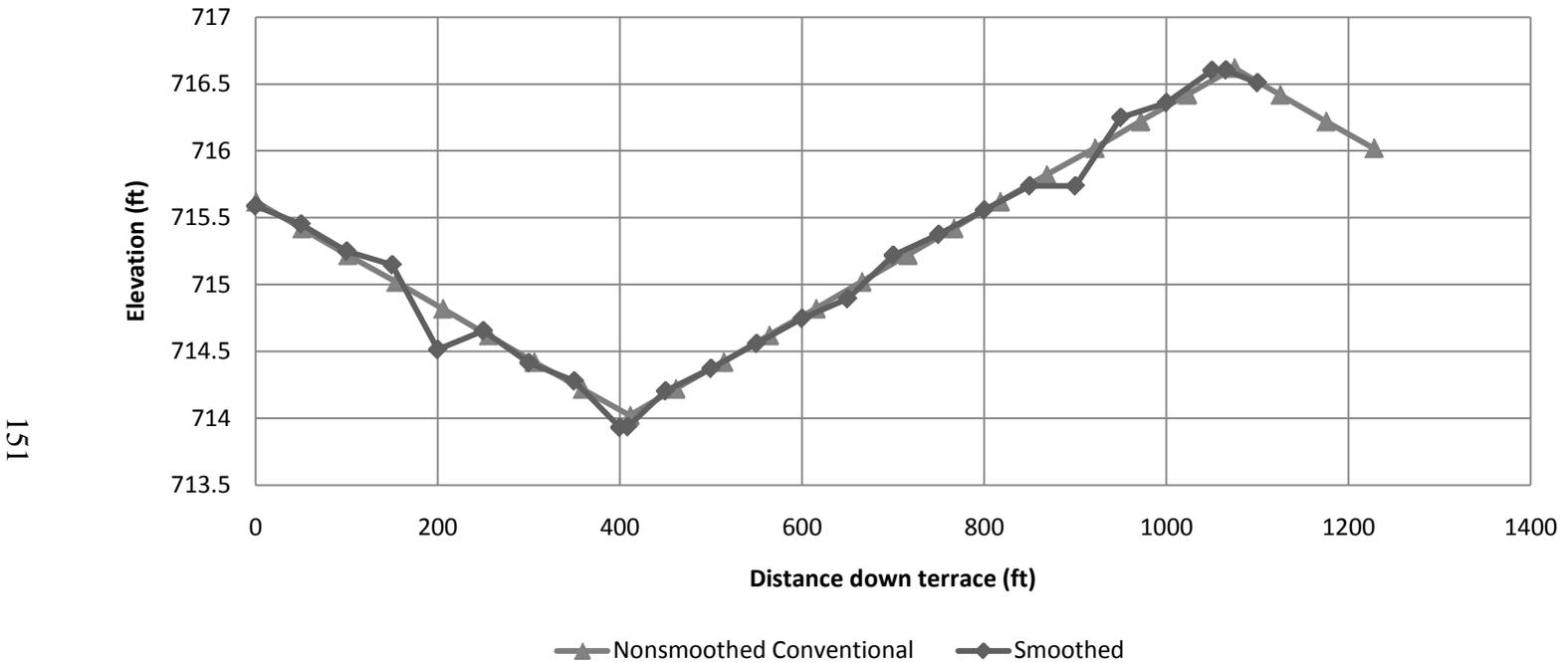


Figure G10. MO433-Monroe County Terrace 6 Smoothing Results—Cross Section View.

# MO574--Terrace 1

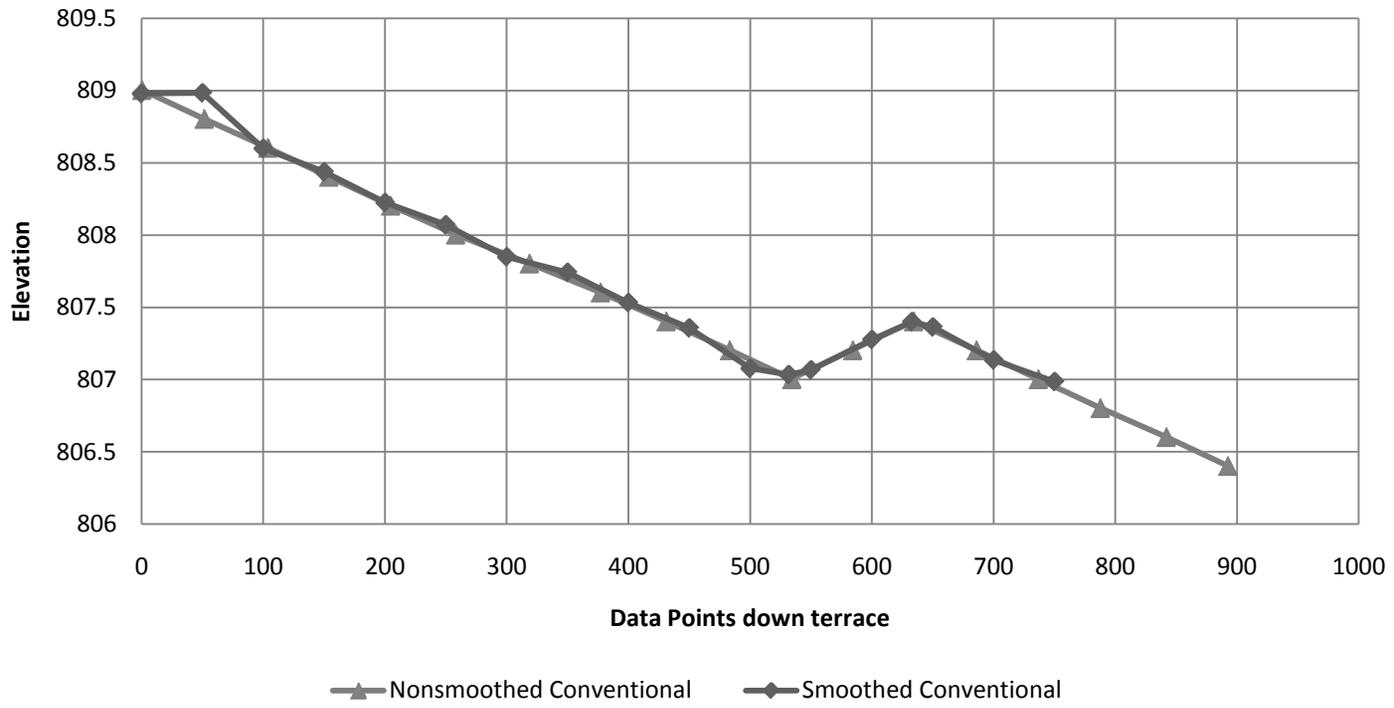


Figure G11. MO574-Monroe County Terrace 1 Smoothing Results—Cross Section View.

# MO574--Terrace 2

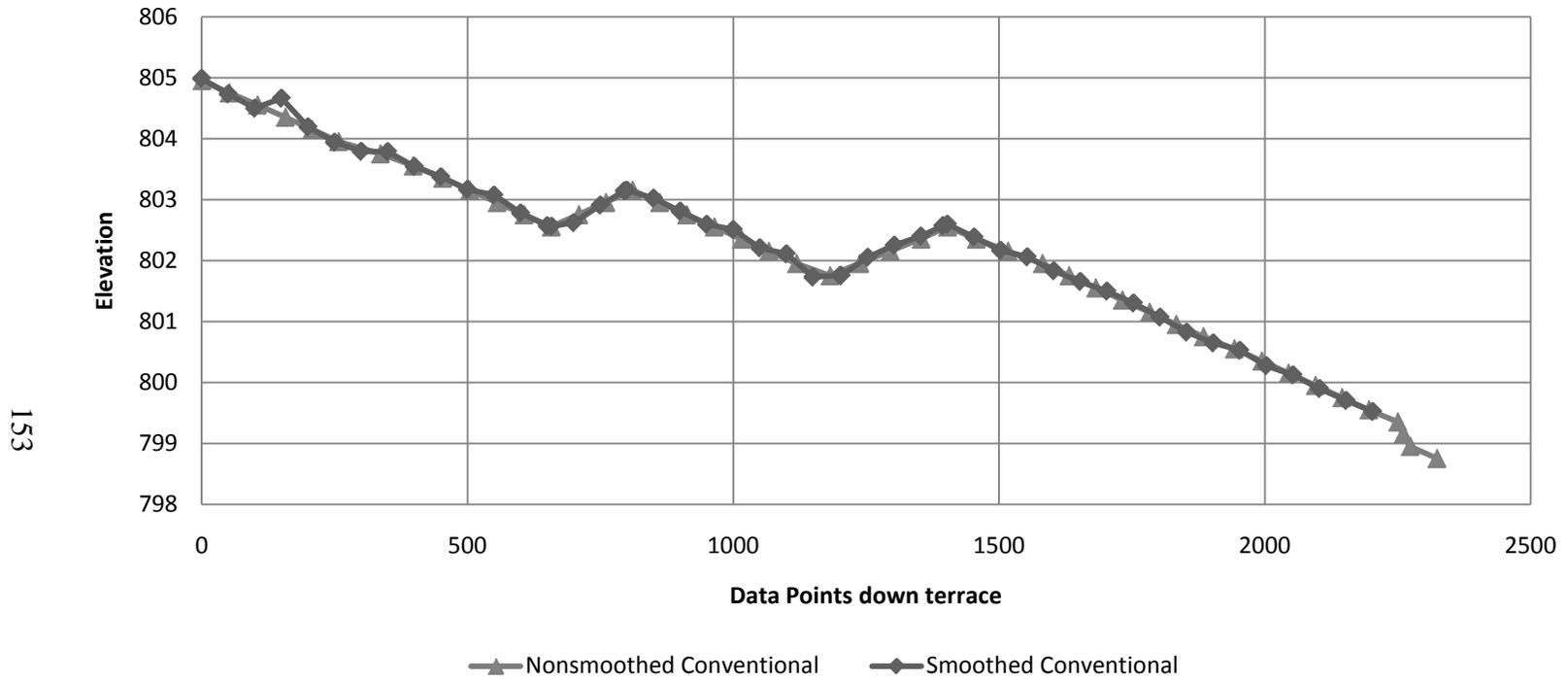


Figure G12. MO574-Monroe County Terrace 2 Smoothing Results—Cross Section View.

### MO574--Terrace 3

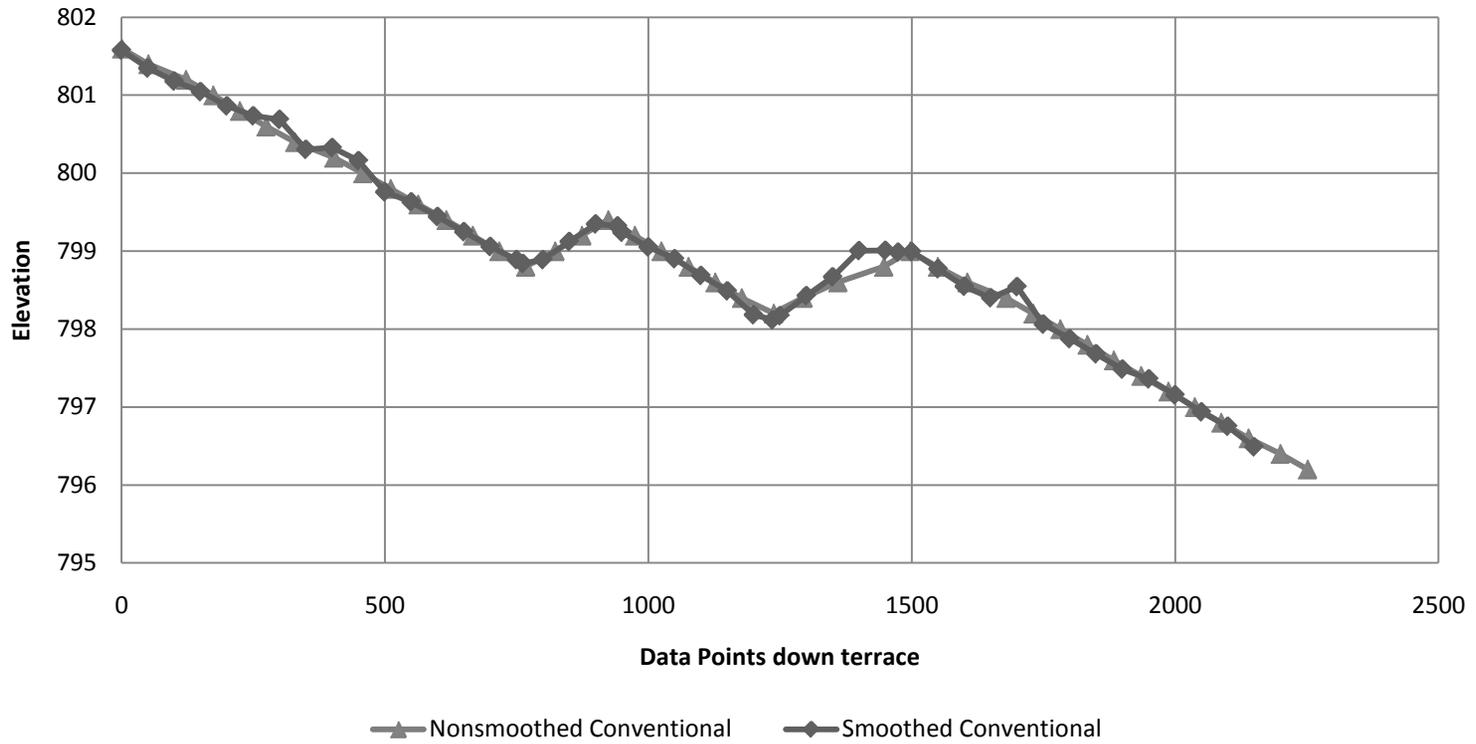


Figure G13. MO574-Monroe County Terrace 3 Smoothing Results—Cross Section View.

### MO574--Terrace 4

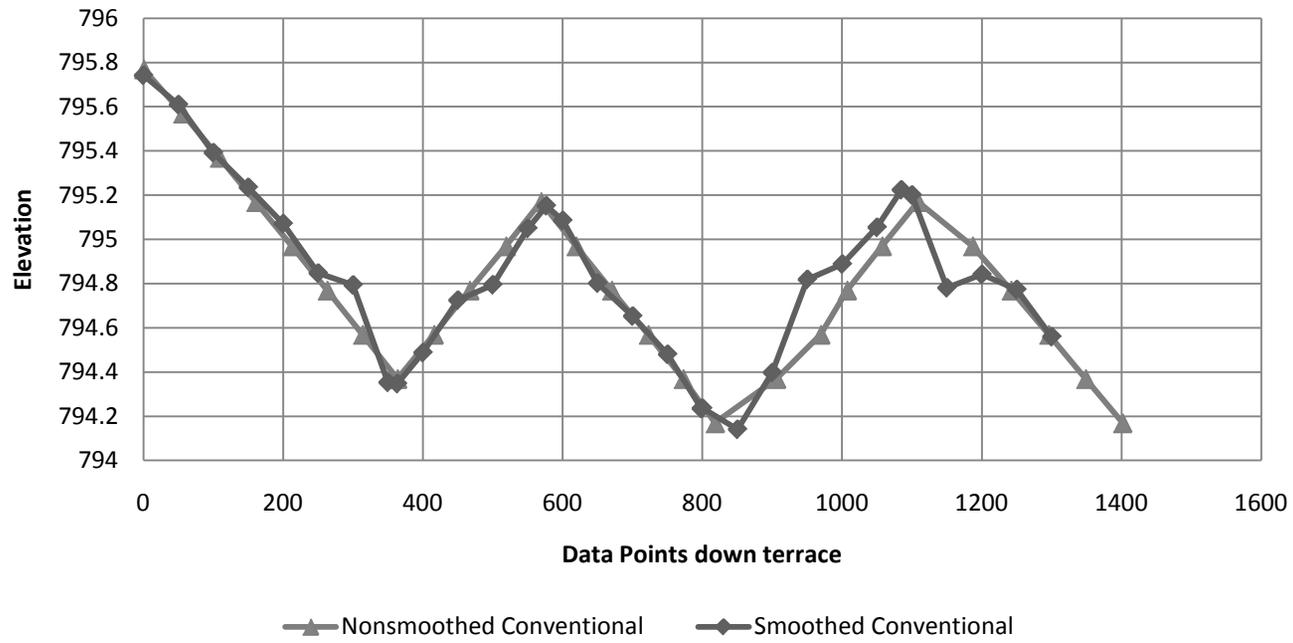
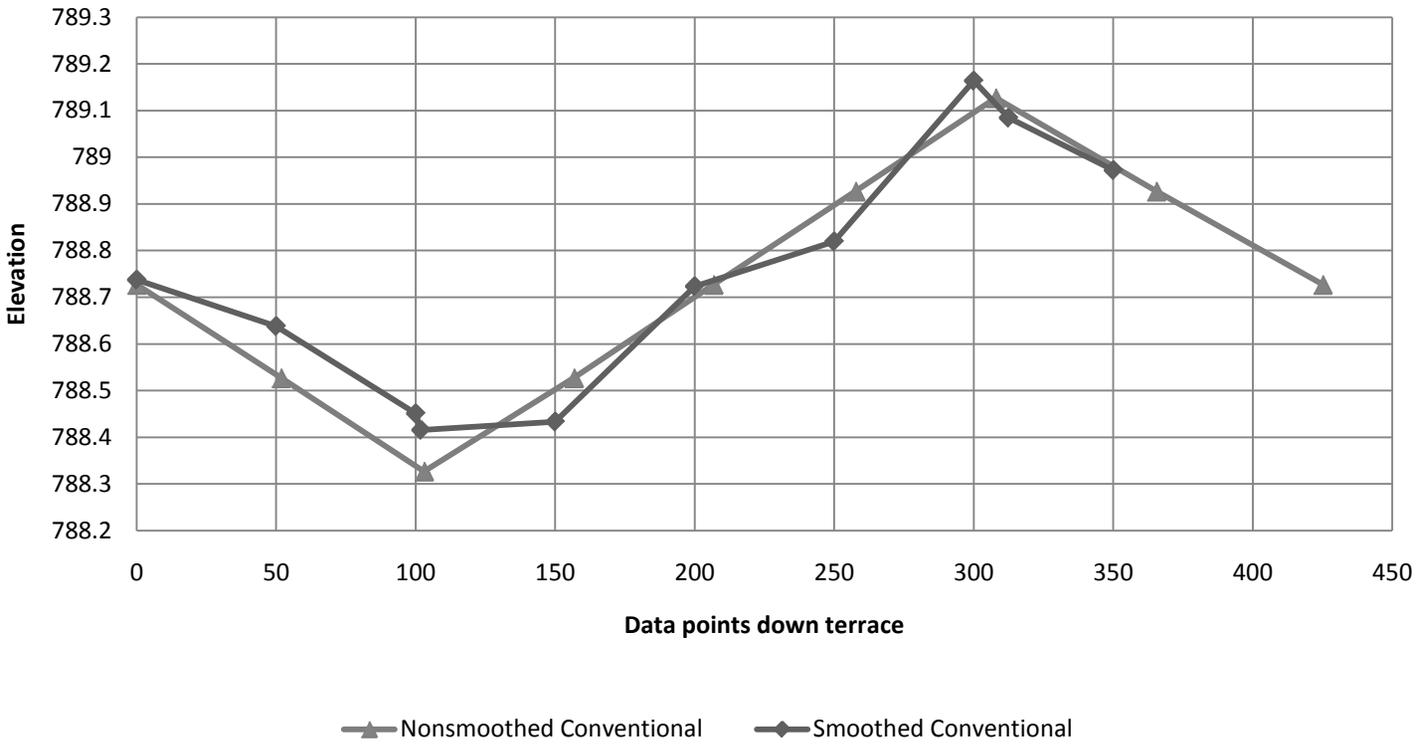


Figure G14. MO574-Monroe County Terrace 4 Smoothing Results—Cross Section View.

# MO574--Terrace 5

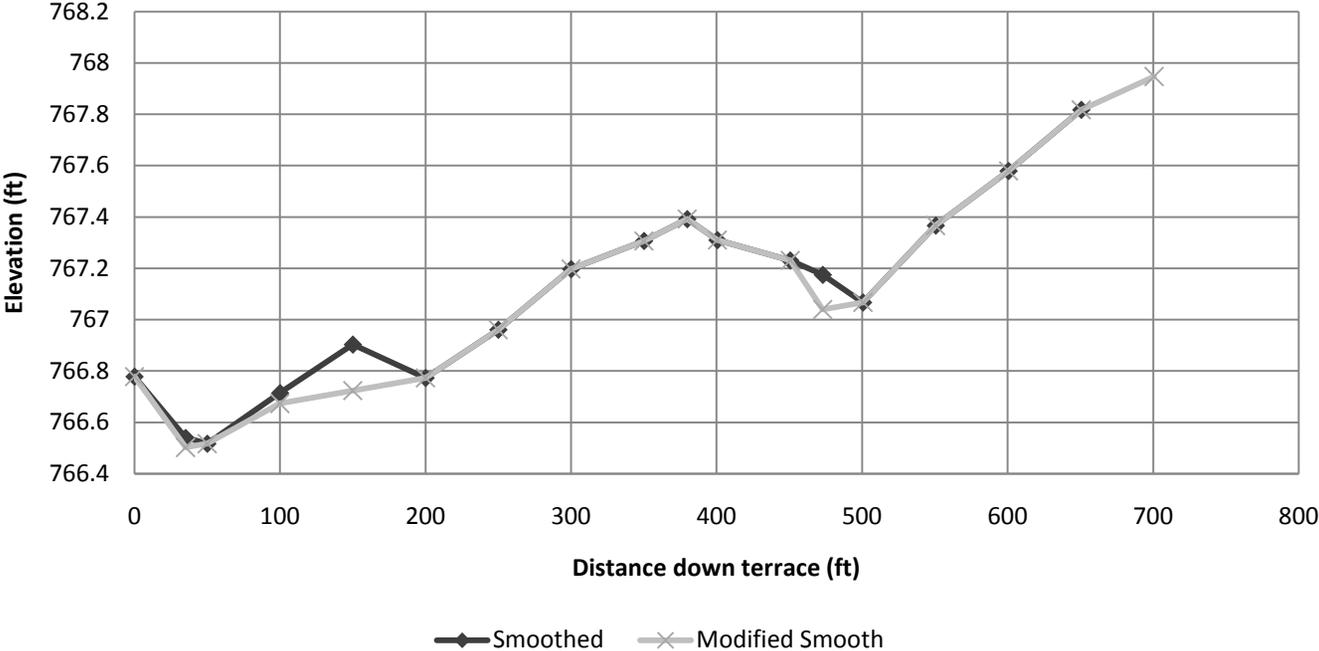


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Figure G15. MO574-Monroe County Terrace 5 Smoothing Results—Cross Section View.

**APPENDIX H: CHANNEL SLOPE MODIFICATIONS**

**MO563--Terrace 1**



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Figure H1. MO563-Saline County Terrace 1 Cross Section Modifications.

### MO563--Terrace 2

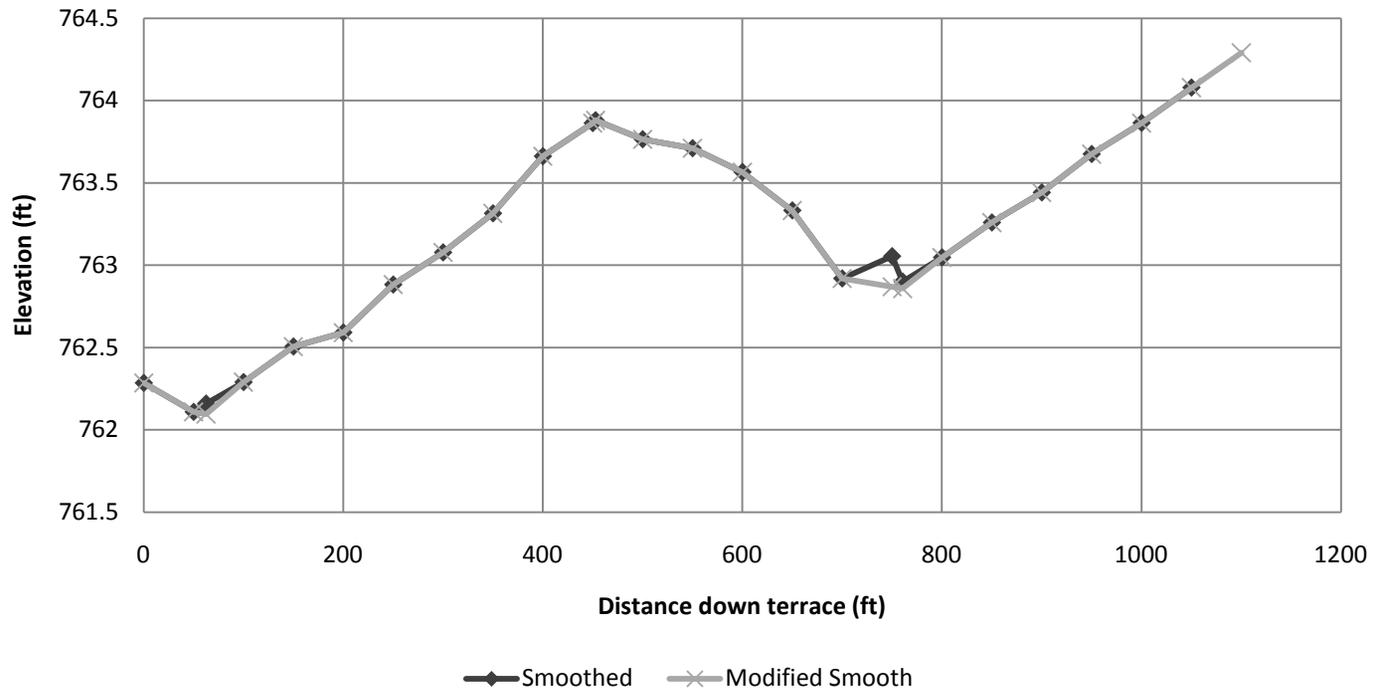


Figure H2. MO563-Saline County Terrace 2 Cross Section Modifications.

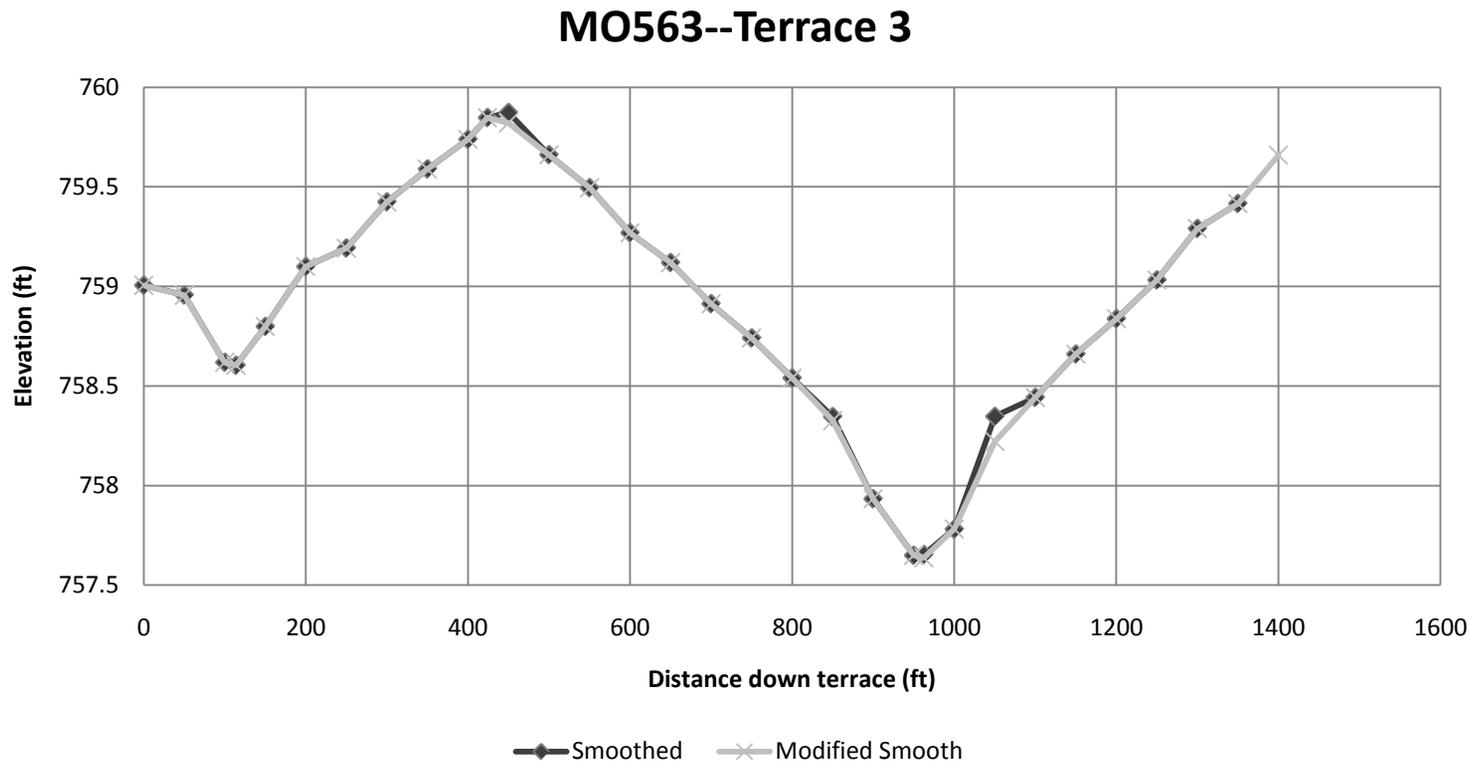


Figure H3. MO563-Saline County Terrace 3 Cross Section Modifications.

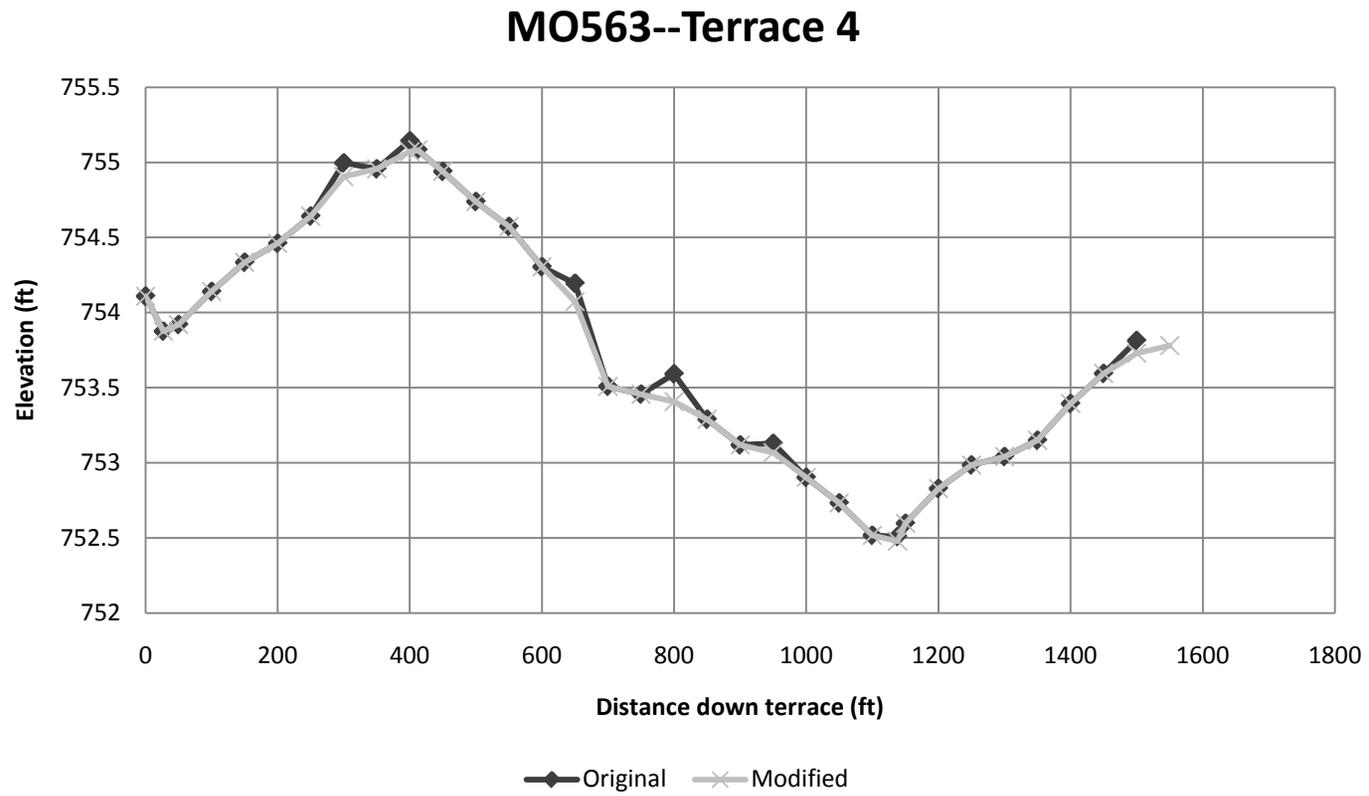


Figure H4. MO563-Saline County Terrace 4 Cross Section Modifications.

### MO433--Terrace 1

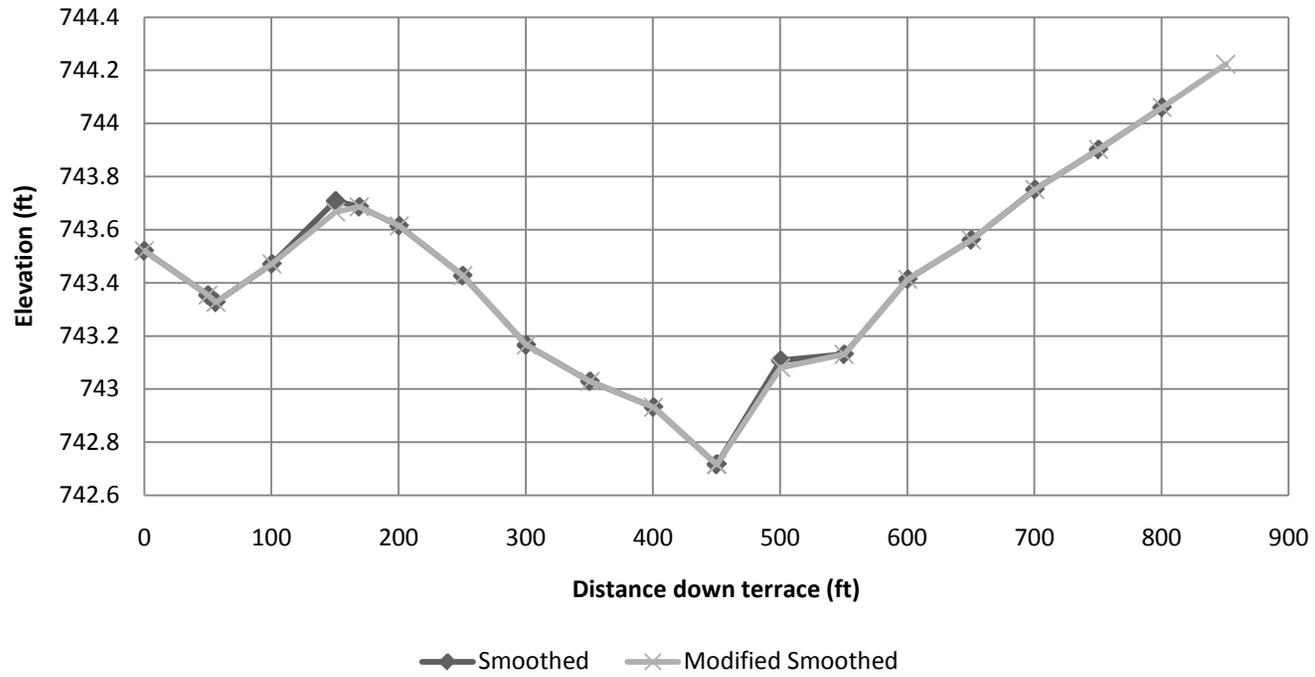


Figure H5. MO433 Monroe County—Terrace 1 Cross Section Modifications.

### MO433--Terrace 2

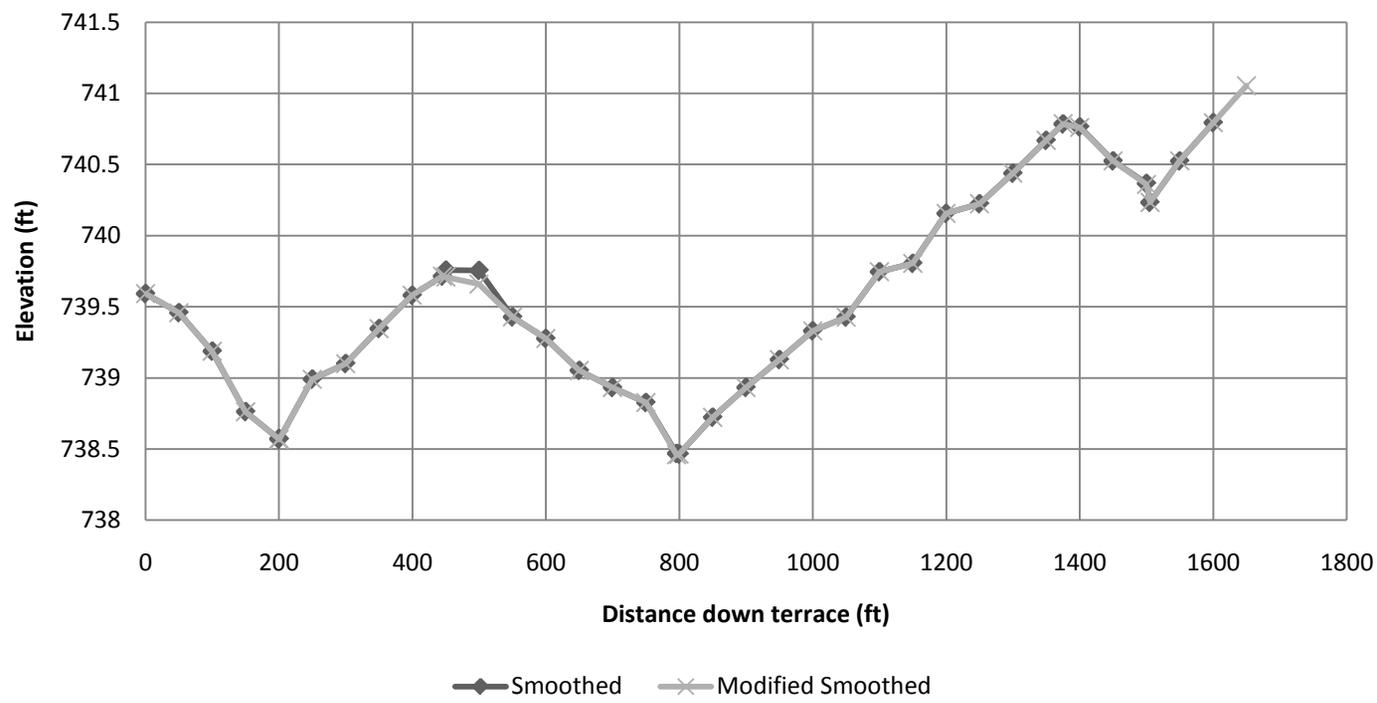


Figure H6. MO433 Monroe County—Terrace 2 Cross Section Modifications.

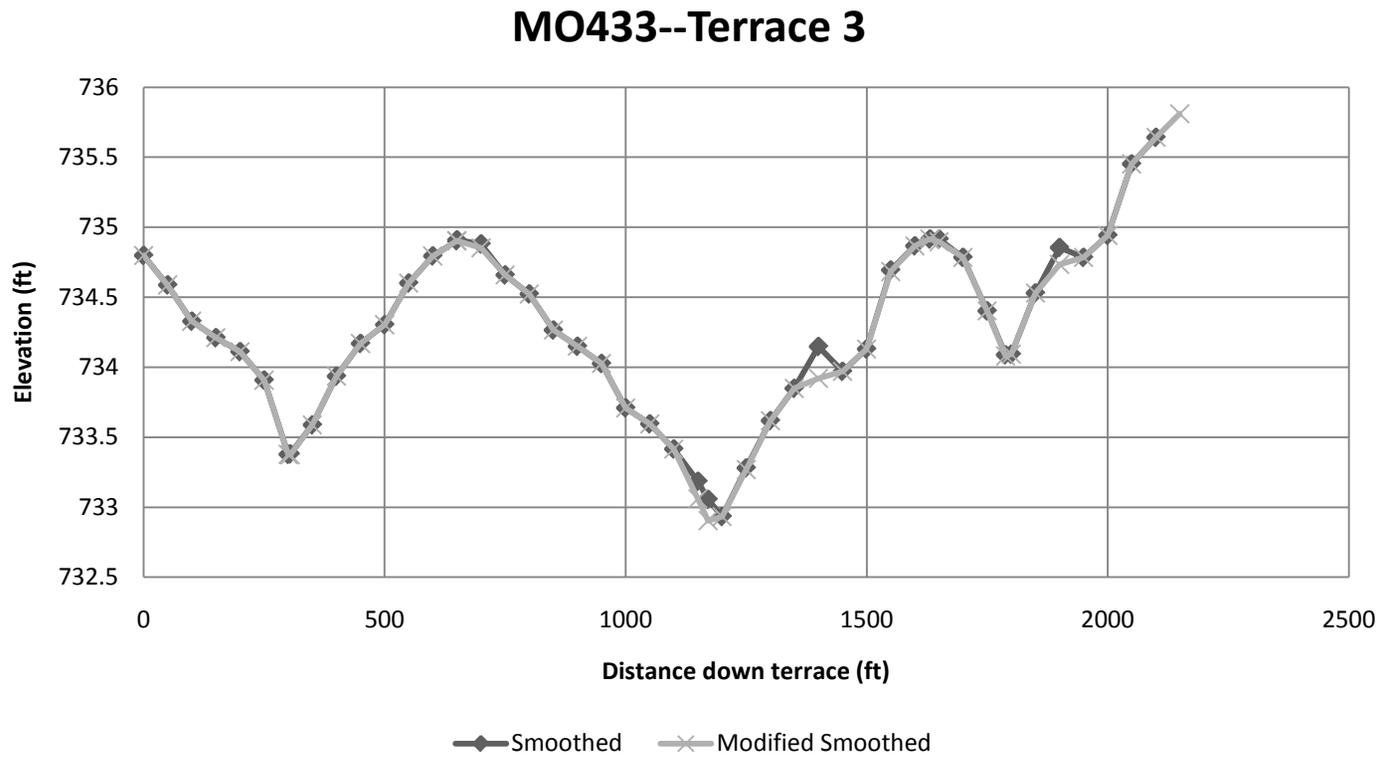


Figure H7. MO433 Monroe County—Terrace 3 Cross Section Modifications.

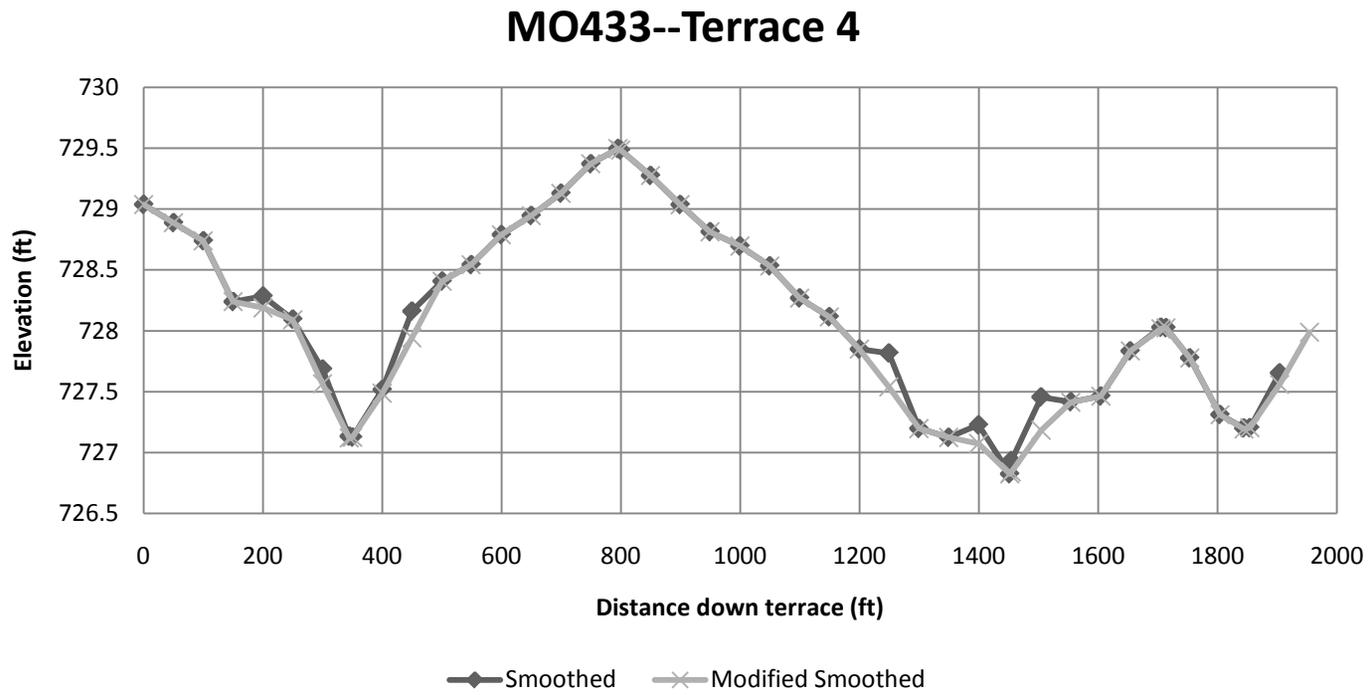


Figure H8. MO433 Monroe County—Terrace 4 Cross Section Modifications.

### MO433--Terrace 5

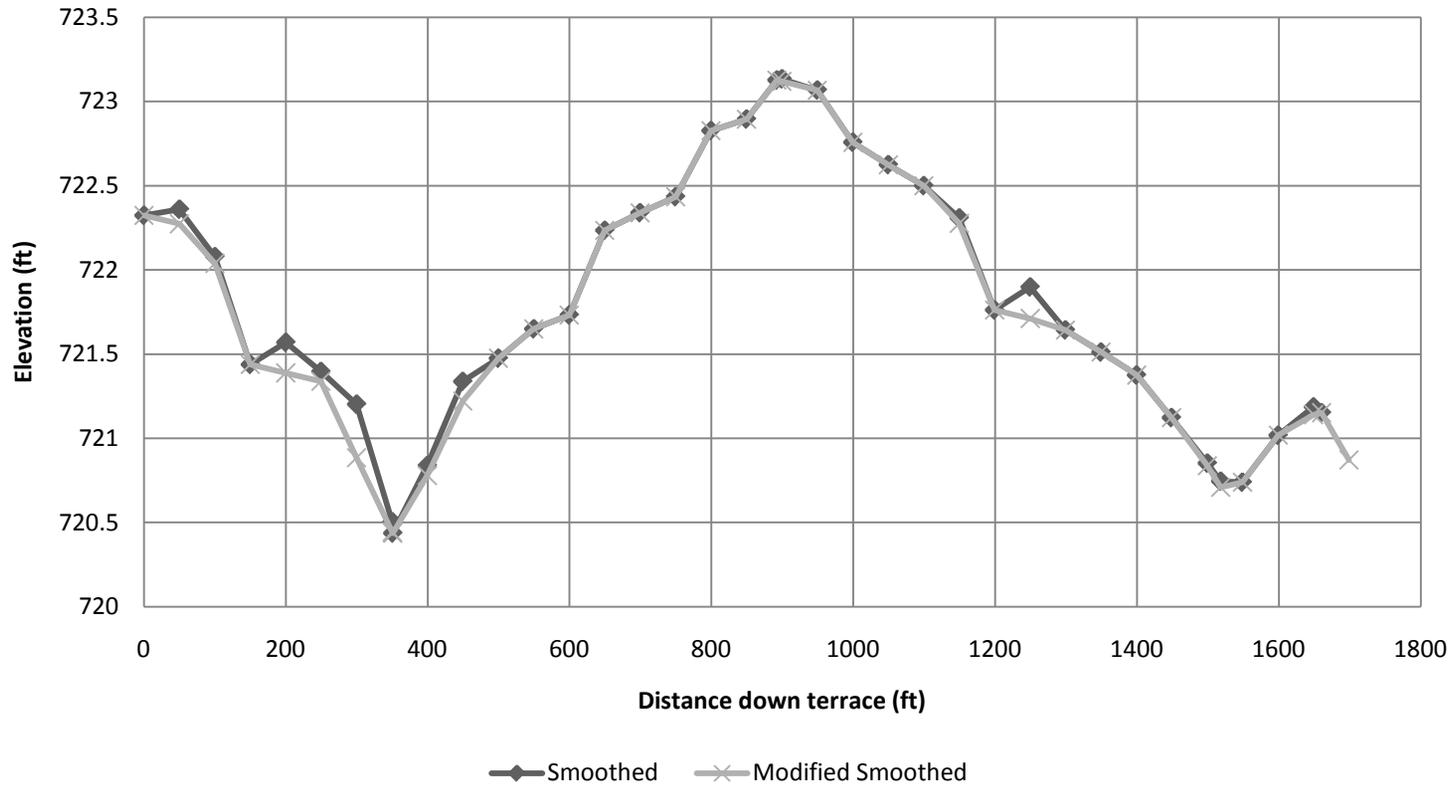


Figure H9. MO433 Monroe County—Terrace 5 Cross Section Modifications.

### MO433--Terrace 6

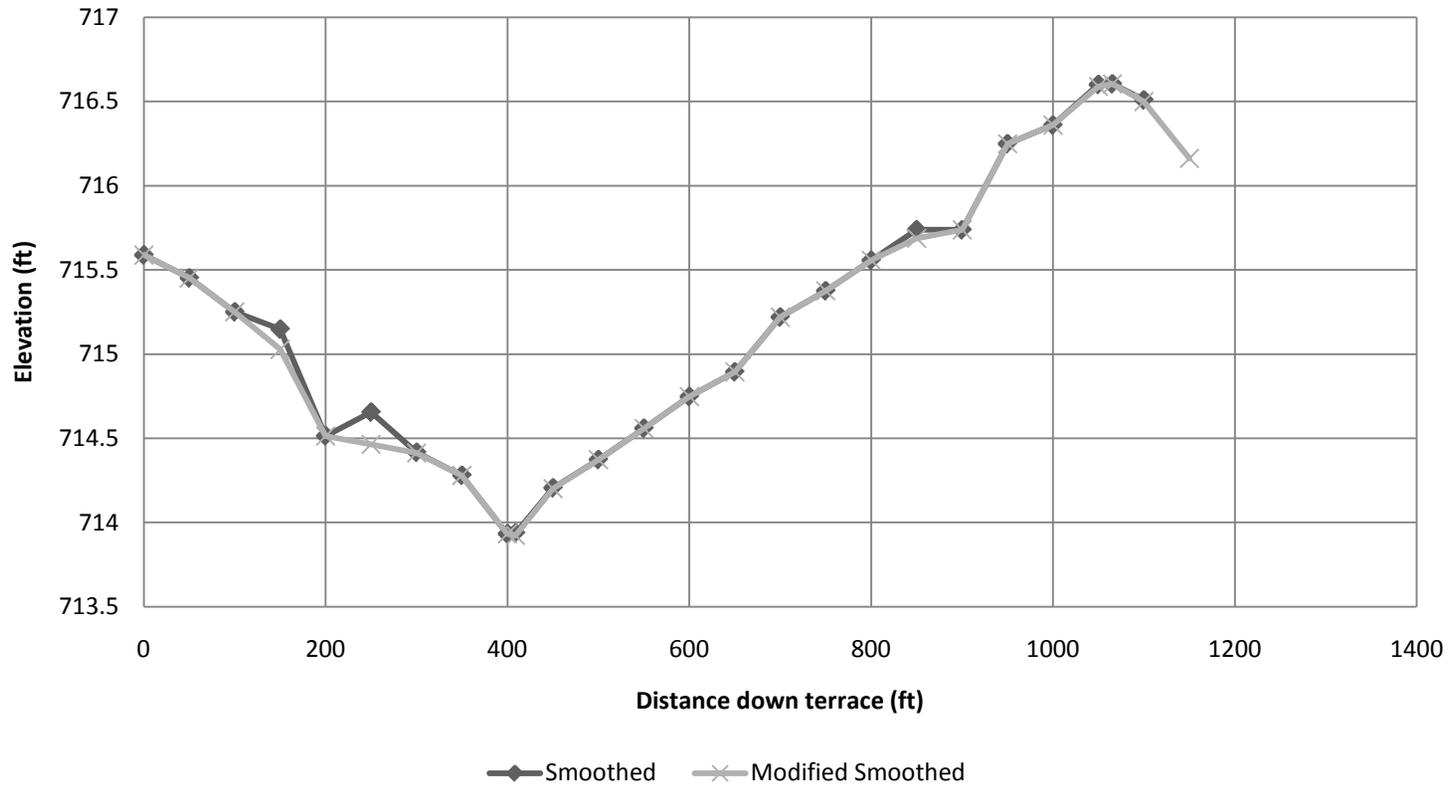


Figure H10. MO433 Monroe County—Terrace 6 Cross Section Modifications.

# MO574--Terrace 1

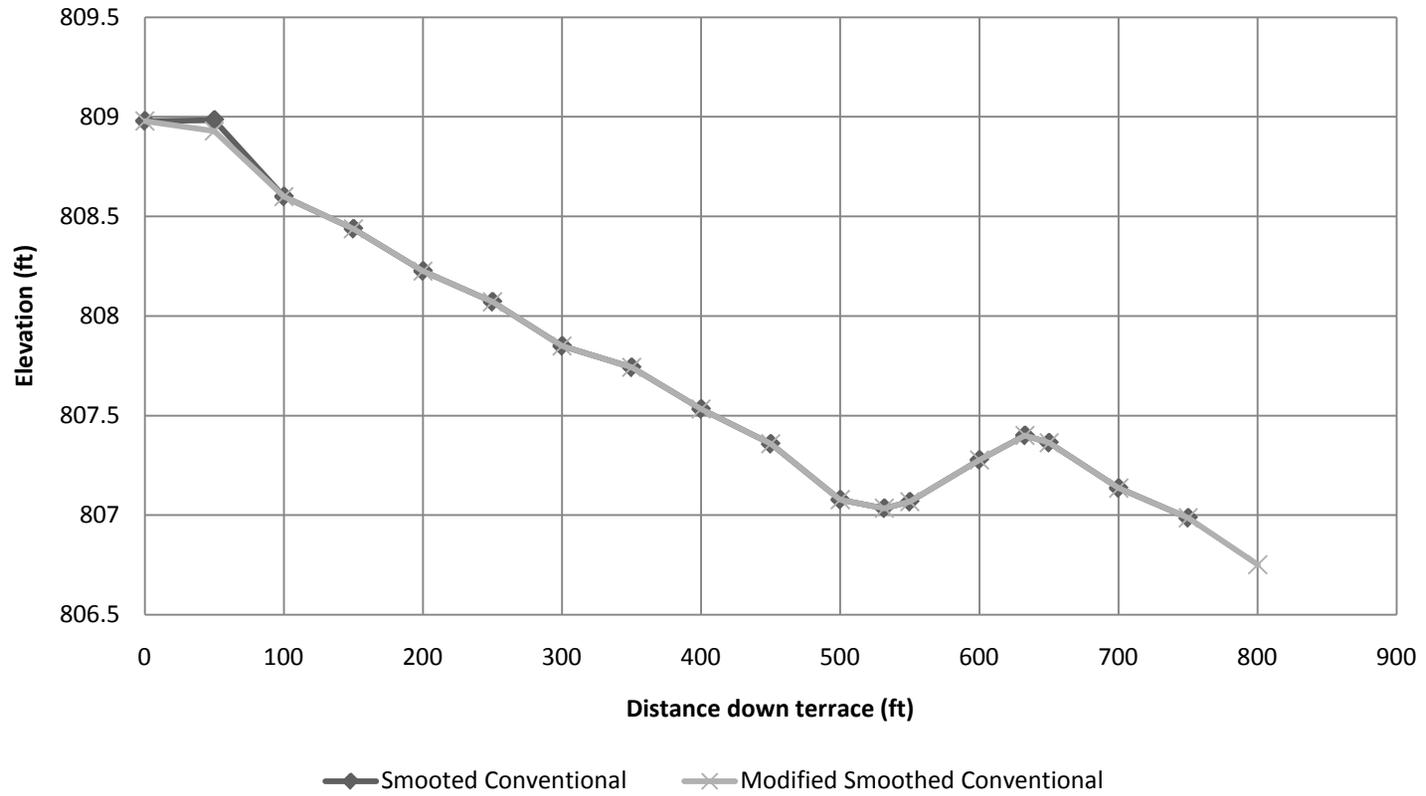


Figure H11. MO574 Monroe County—Terrace 1 Cross Section Modifications.

# MO574--Terrace 2

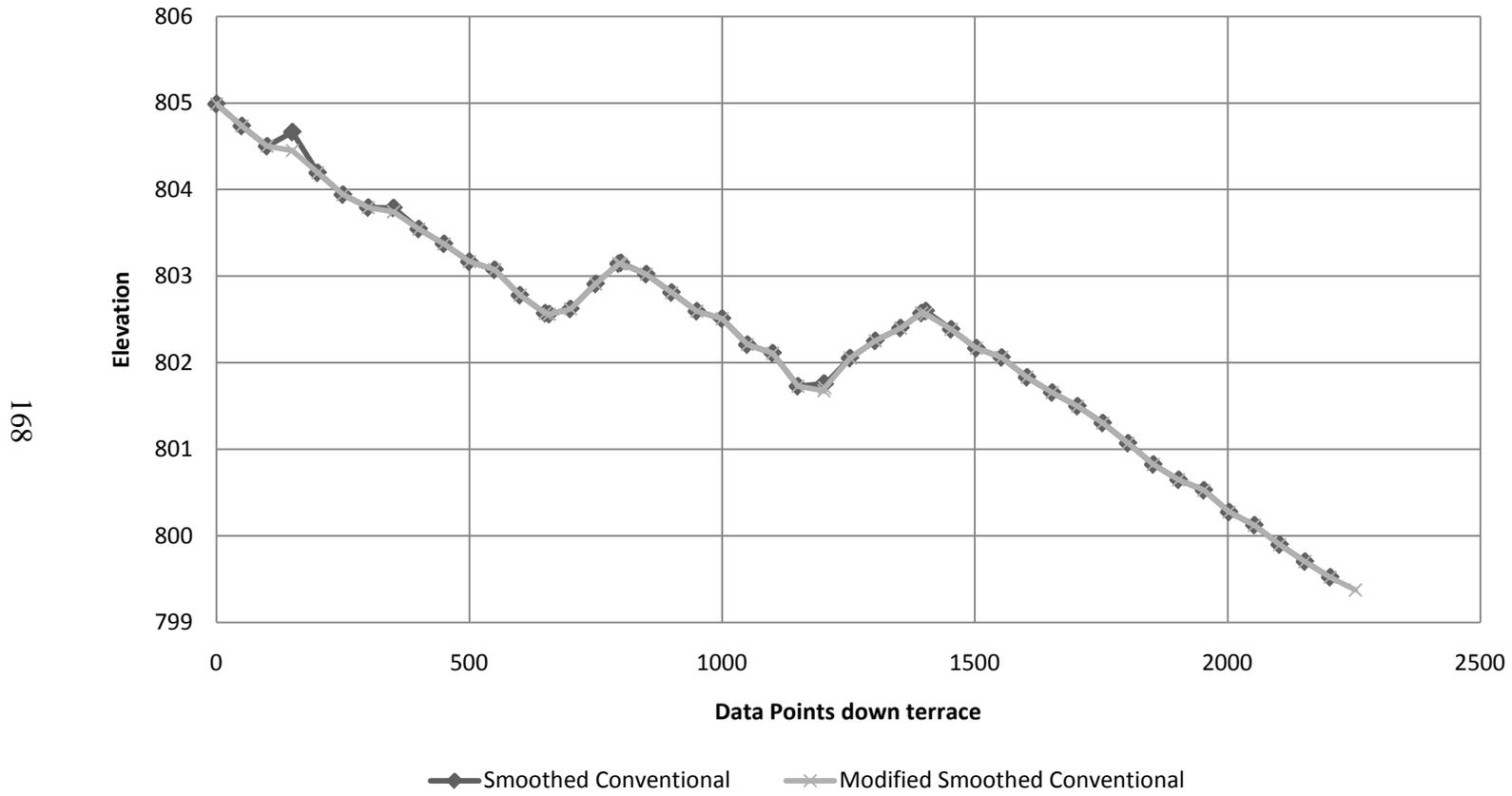
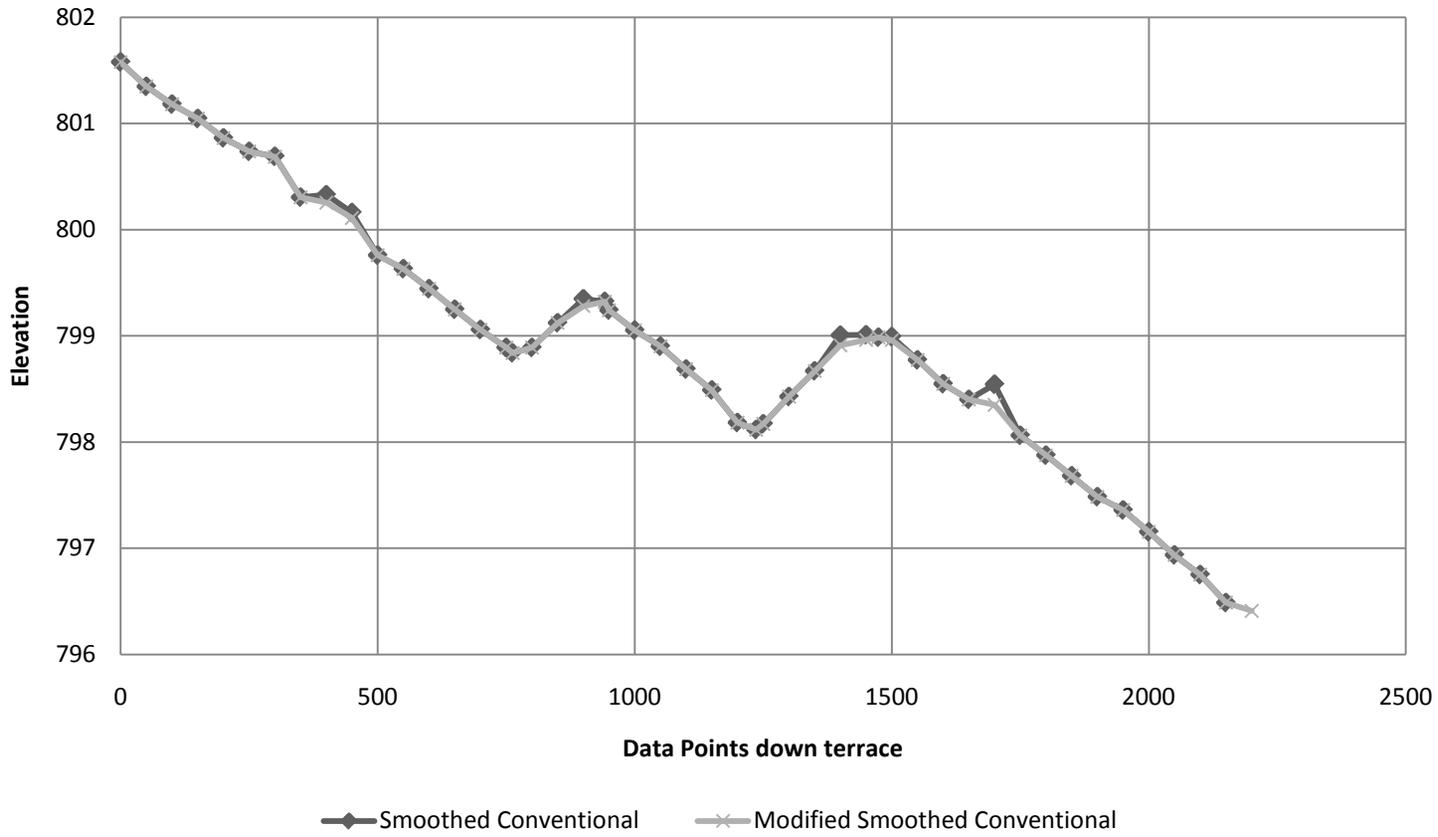


Figure H12. MO574 Monroe County—Terrace 2 Cross Section Modifications.

### MO574--Terrace 3



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Figure H13: MO574 Monroe County—Terrace 3 Cross Section Modifications.

# MO574--Terrace 4

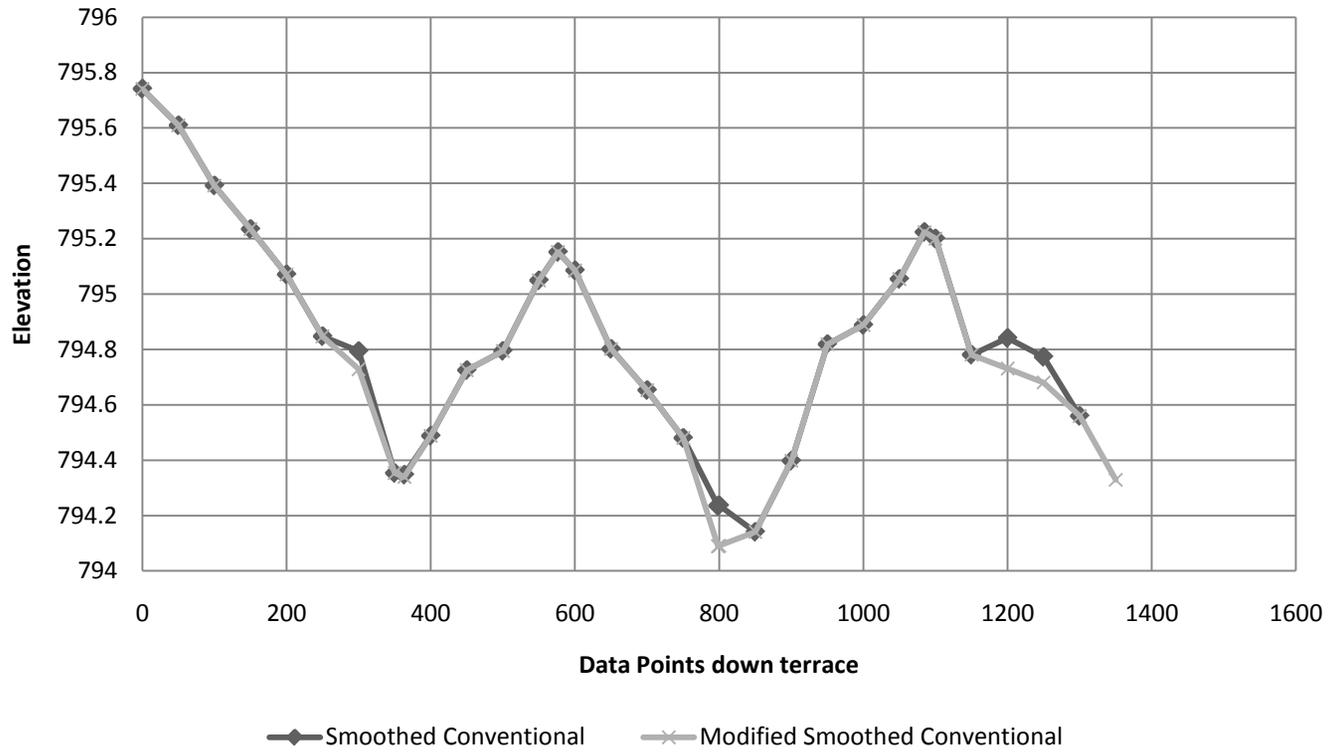


Figure H14. MO574 Monroe County—Terrace 4 Cross Section Modifications.

### MO574--Terrace 5

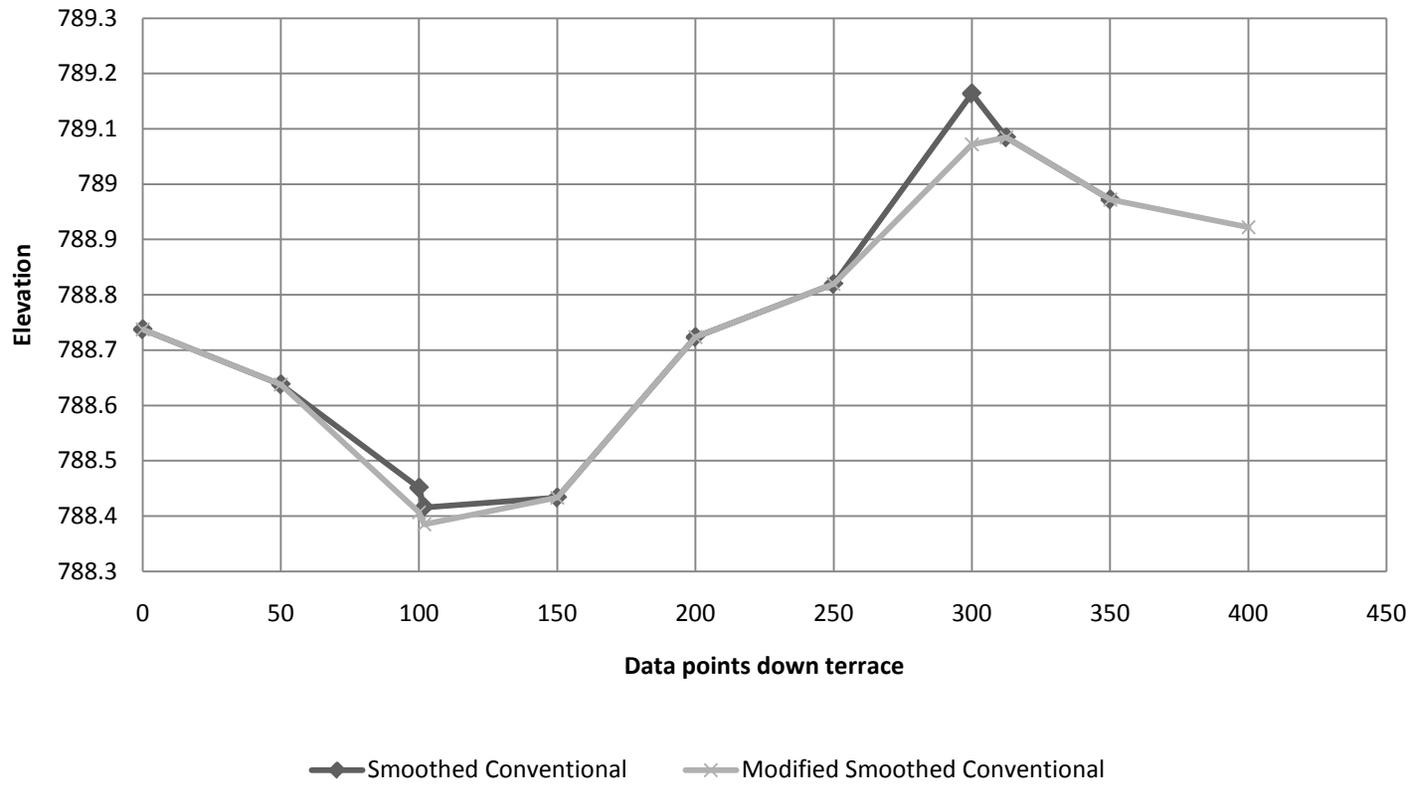


Figure H15. MO574 Monroe County—Terrace5 Cross Section Modifications.

## APPENDIX I: CENTERLINE CUT DEPTHS

Table I1: Required Cut Depth (feet) of terrace channel centerline

<b>Terrace</b>	<b>Field</b>		
	<b>MO563 Saline County</b>	<b>MO433-Monroe County</b>	<b>MO574-Monroe County</b>
1	0.39	0.08	0.05
2	0.29	0.16	0.42
3	0.21	0.71	0.56
4	0.64	1.48	0.57
5	--	1.25	0.29
6	--	0.4	--
<b>TOTAL</b>	<b>1.54</b>	<b>4.08</b>	<b>1.89</b>

## APPENDIX J: UNDERGROUND OUTLET DESIGN

Table J1. MO563—Saline County UGO Results

<b>UNDERGROUND OUTLET 1</b>					
<b>Terrace</b>	<b>Berm Height (ft)</b>	<b>Inlet Holes</b>	<b>Orifice Diameter (in)</b>	<b>Conduit Pipe Diameter (in)</b>	<b>Secondary Pipe Diameter (in)</b>
1	1.133158	21	2	4	--
2	1.104138	28	2.25	6	--
3	1.140932	32	2.5	8	--
4	1.174472	21	2	10	--
<b>UNDERGROUND OUTLET 2</b>					
1	1.133158	20	2	4	--
2	1.104138	22	2	6	--
3	1.140932	42	3	8	--
4	1.174472	48	3	10	--

Table J2.MO433—Monroe County UGO Results

<b>UNDERGROUND OUTLET 1</b>					
<b>Terrace</b>	<b>Berm Height (ft)</b>	<b>Inlet Holes</b>	<b>Orifice Diameter (in)</b>	<b>Conduit Pipe Diameter (in)</b>	<b>Secondary Pipe Diameter(in)</b>
1	1.214149	20	2	4	--
2	1.107874	22	2	6	--
3	1.149958	33	2.5	8	--
4	1.19173	42	3	10	--
5	1.200444	47	3	12	4
6	1.211493	51	3.25	12	8
<b>UNDERGROUND OUTLET 2</b>					
1	1.214149	43	3	6	--
2	1.107874	29	2.5	8	--
3	1.149958	56	3.25	10	--
4	1.19173	63	3.5	12	4
5	1.200444	45	3	12	8
<b>UNDERGROUND OUTLET 3</b>					
2	1.107874	6	1.5	4	--
3	1.149958	20	2	6	--
4	1.19173	14	1.75	8	--

Table J3. MO574—Monroe County UGO Design

<b>UNDERGROUND OUTLET 1</b>					
<b>Terrace</b>	<b>Berm Height (ft)</b>	<b>Inlet Holes</b>	<b>Orifice Diameter (in)</b>	<b>Conduit Pipe Diameter (in)</b>	<b>Secondary Pipe Diameter (in)</b>
1	1.14683	36	2.75	6	--
2	1.193857	39	2.75	8	--
3	1.222246	40	3	10	--
4	1.212001	35	2.75	12	4
5	1.207708	28	2.25	12	4
<b>UNDERGROUND OUTLET 2</b>					
2	1.193857	22	2	4	--
3	1.222246	26	2.25	6	--
4	1.212001	27	2.25	8	--
<b>UNDERGROUND OUTLET 3</b>					
--	--	--	--	--	--

**APPENDIX K: MULTIPLE KEY TERRACE OPTIONS**

175

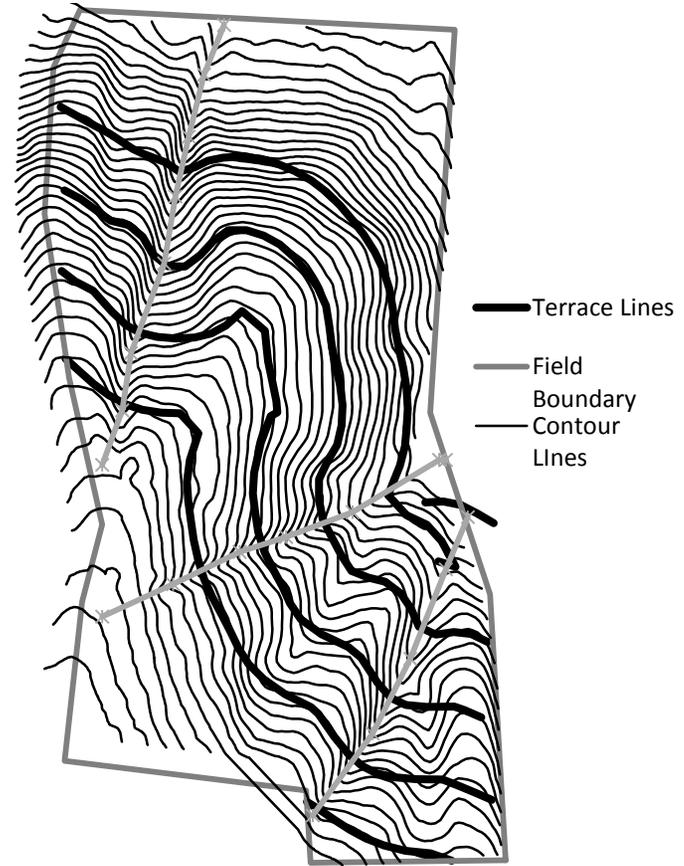
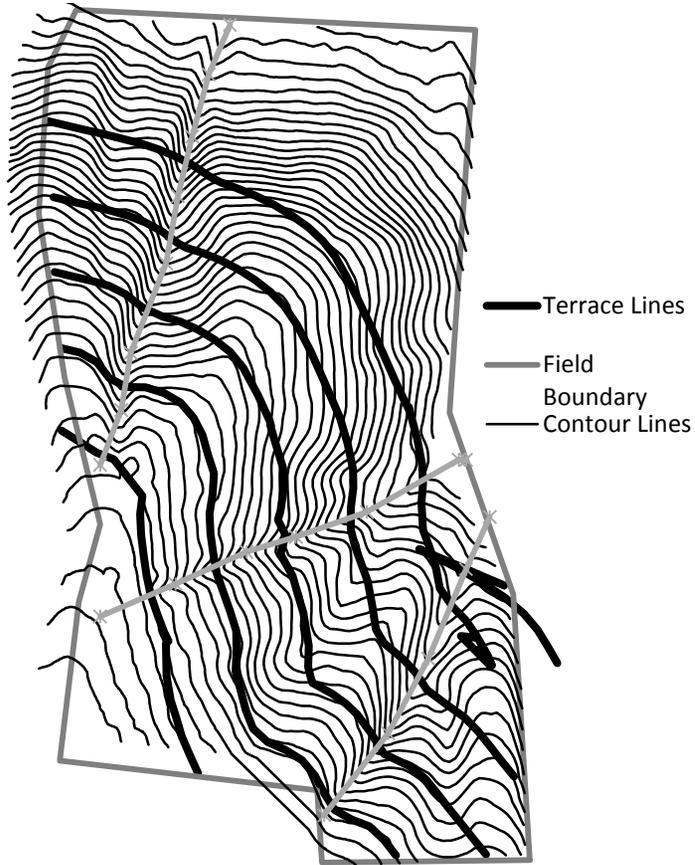


Figure K1. Parallel Terraces using Key Terrace 2

Figure K2. Parallel Terraces using Key Terrace 4

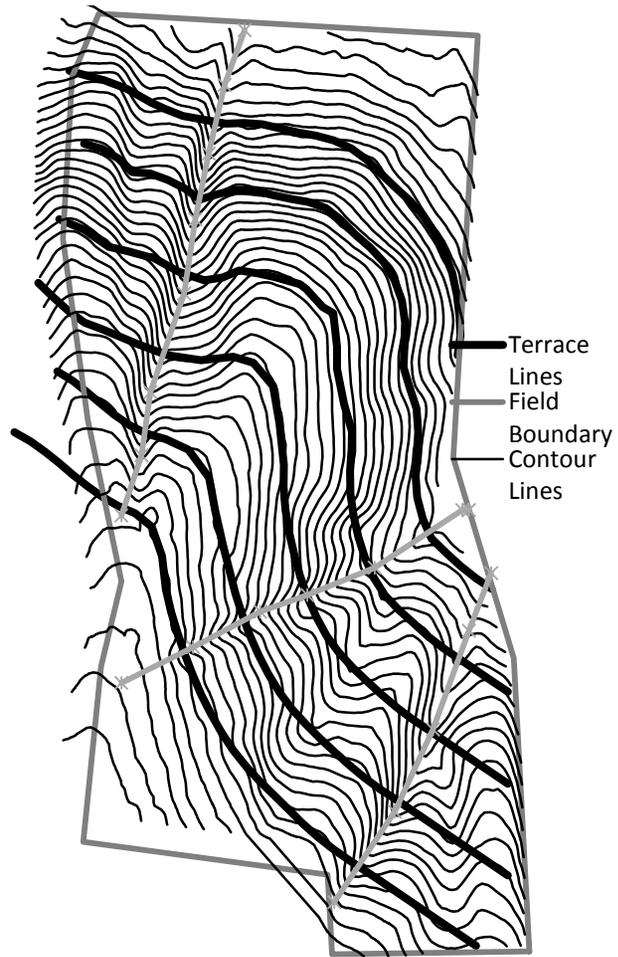


Figure K3.Parallel Terraces using Key Terrace 5

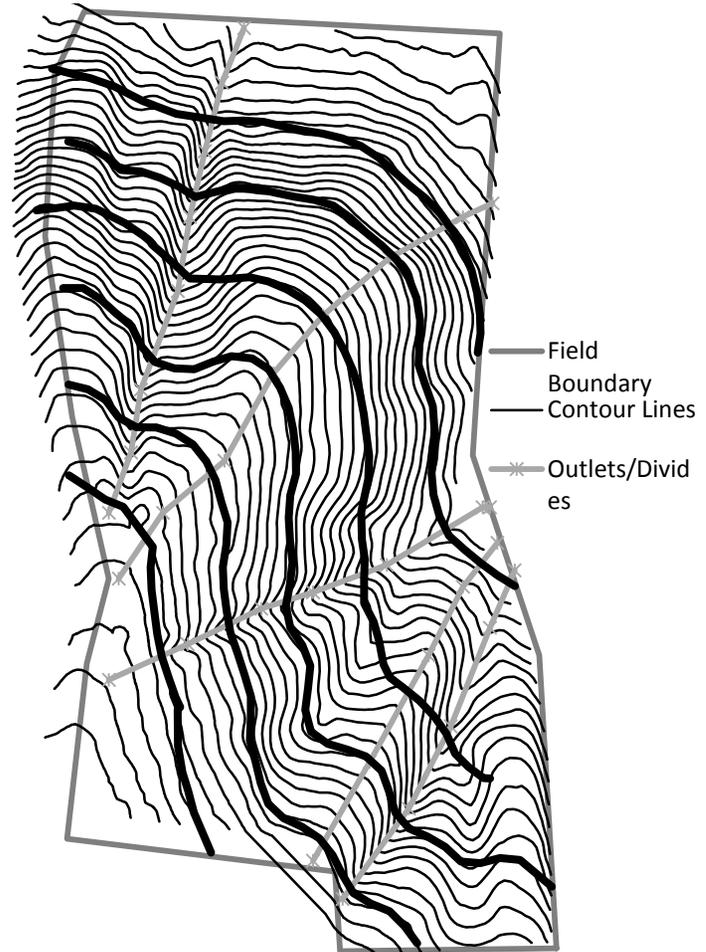


Figure K4. Parallel Terraces using Key Terrace 2,4,5

### MO414-Platte County Key Terrace 3

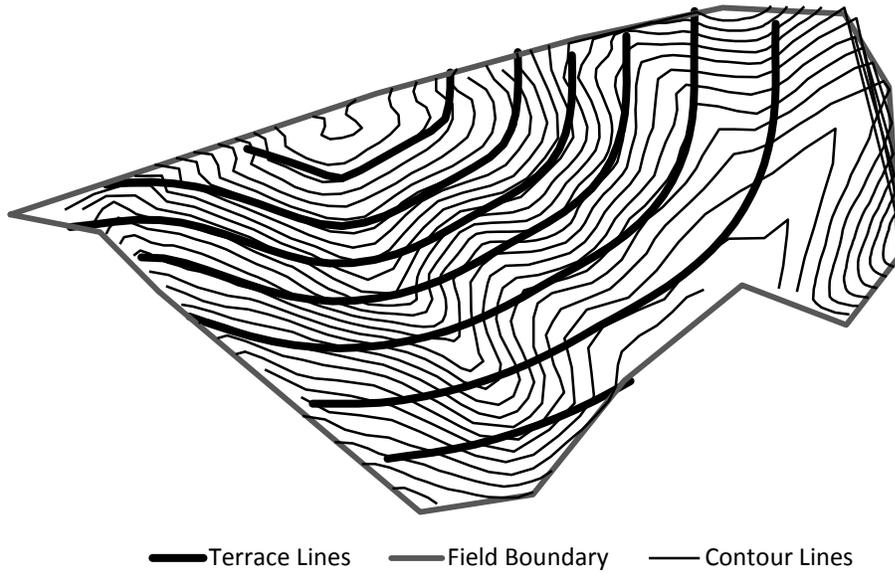


Figure K5. MO414-Platte County Parallel Terraces using Key Terrace 3

### MO414-Platte County Key Terrace 5

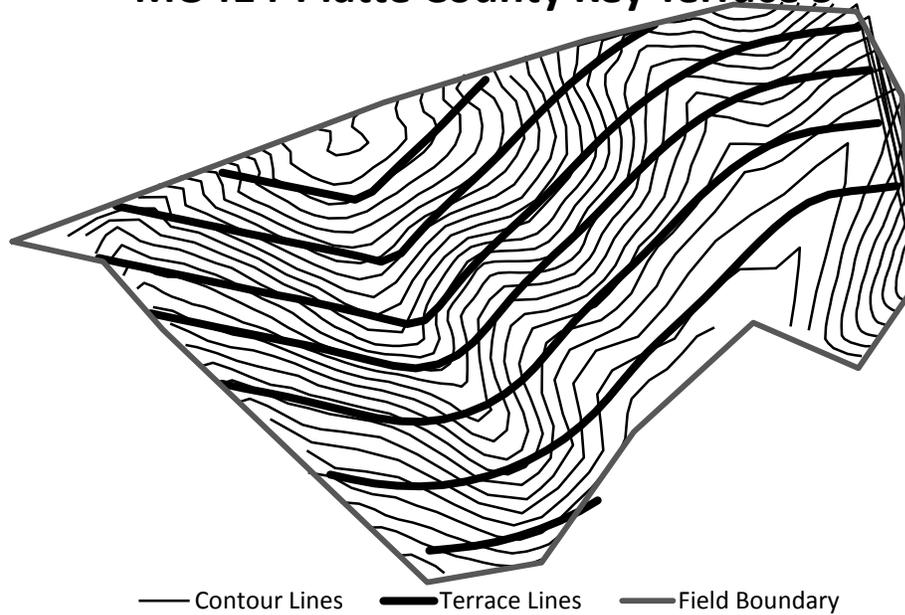


Figure K6. MO414-Platte County Parallel Terraces using Key Terrace 5

# MO414--Platte County Key Terrace 3 & 5

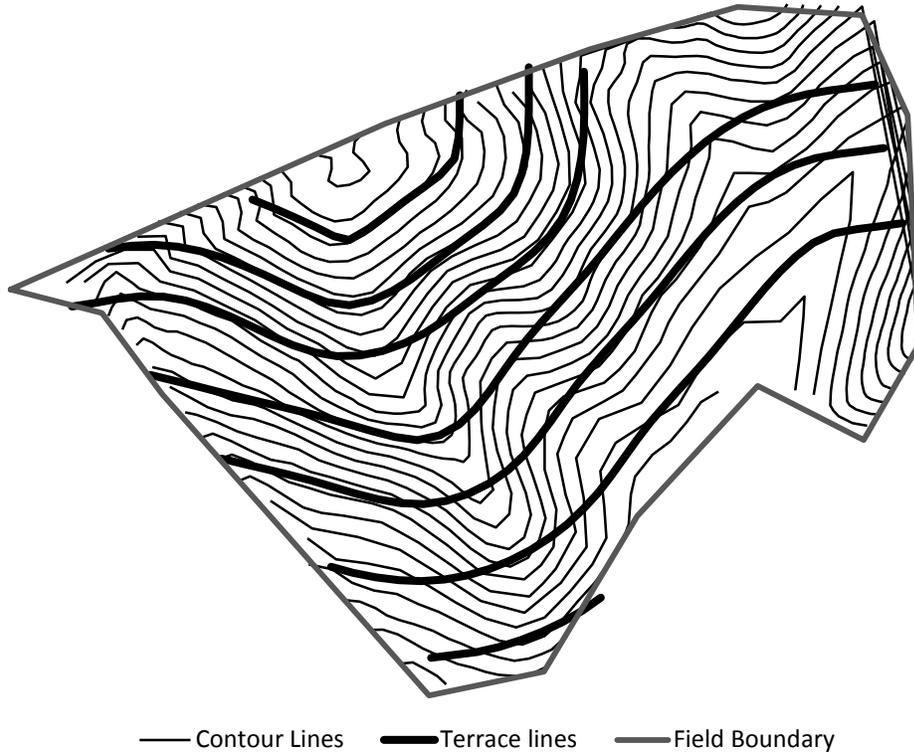


Figure K7. MO414-Platte County Parallel Terraces using Key Terrace 3 & 5

**APPENDIX L: AERIAL PHOTOS OF SAMPLE FIELDS USED FOR ANALYSIS**

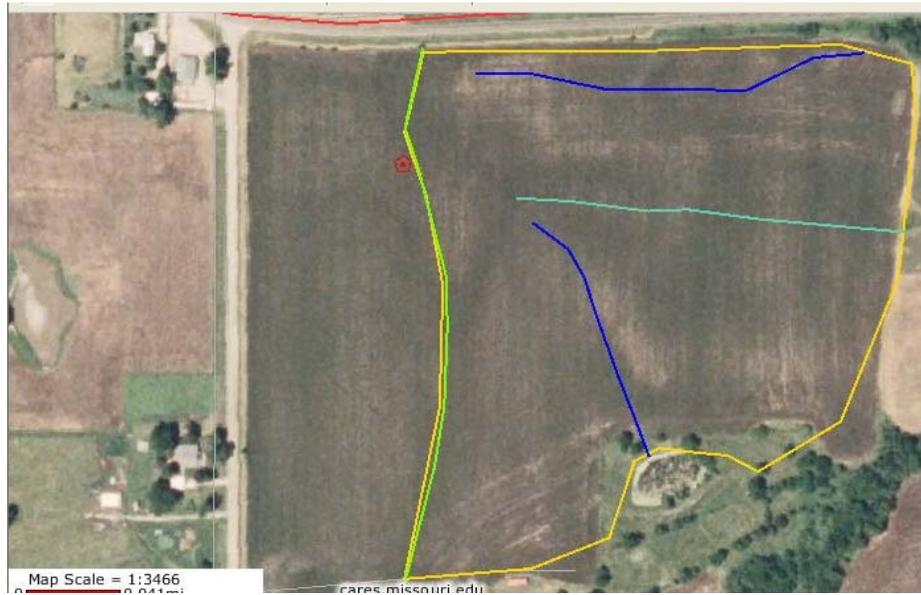


Figure L1.MO563—Saline County Field. Field boundary (yellow), ridgeline(green), outlets(blue), divides(cyan), high point (red point).

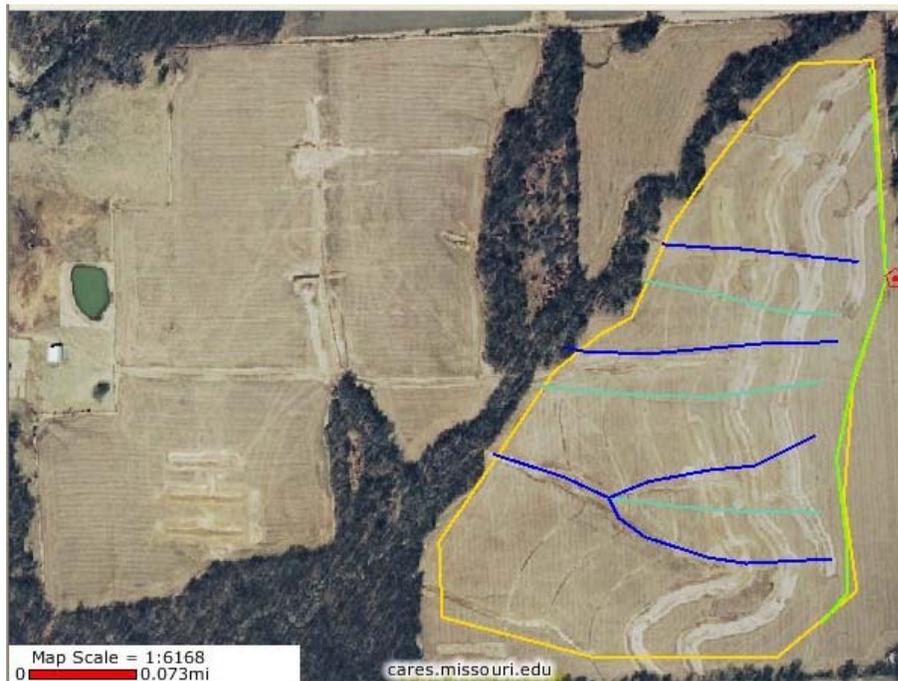


Figure L2.MO599—Pike County Field. Field boundary (yellow), ridgeline(green), outlets(blue), divides(cyan), high point (red point).



Figure L3.MO574—Monroe County Field. Field boundary (yellow), ridgeline(green), outlets(blue), divides(cyan), high point (red point).



Figure L4.MO509—Boone County Field. Field boundary (yellow), ridgeline(green), outlets(blue), divides(cyan), high point (red point).

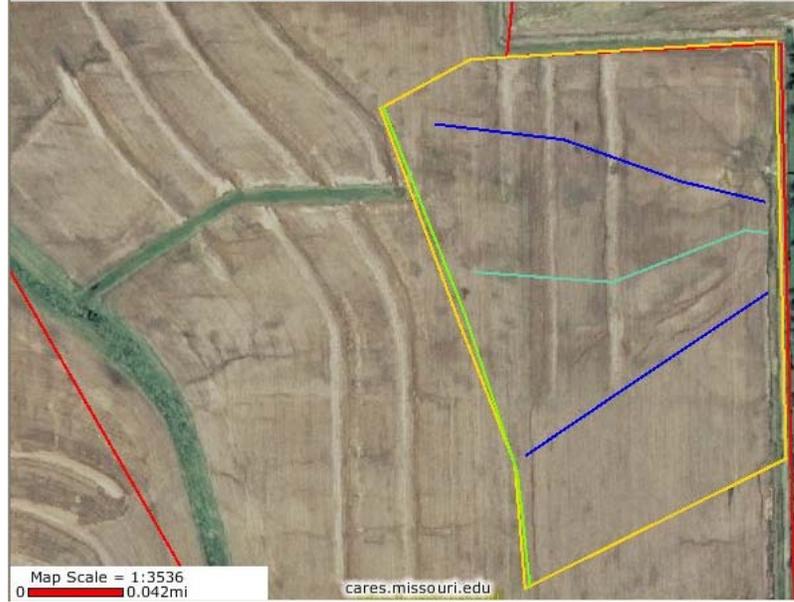


Figure L5 MO566—Monroe County Field. Field boundary (yellow), ridgeline(green), outlets(blue), divides(cyan), high point (red point).

## APPENDIX M: MANUAL TERRACE LAYOUT RESULTS

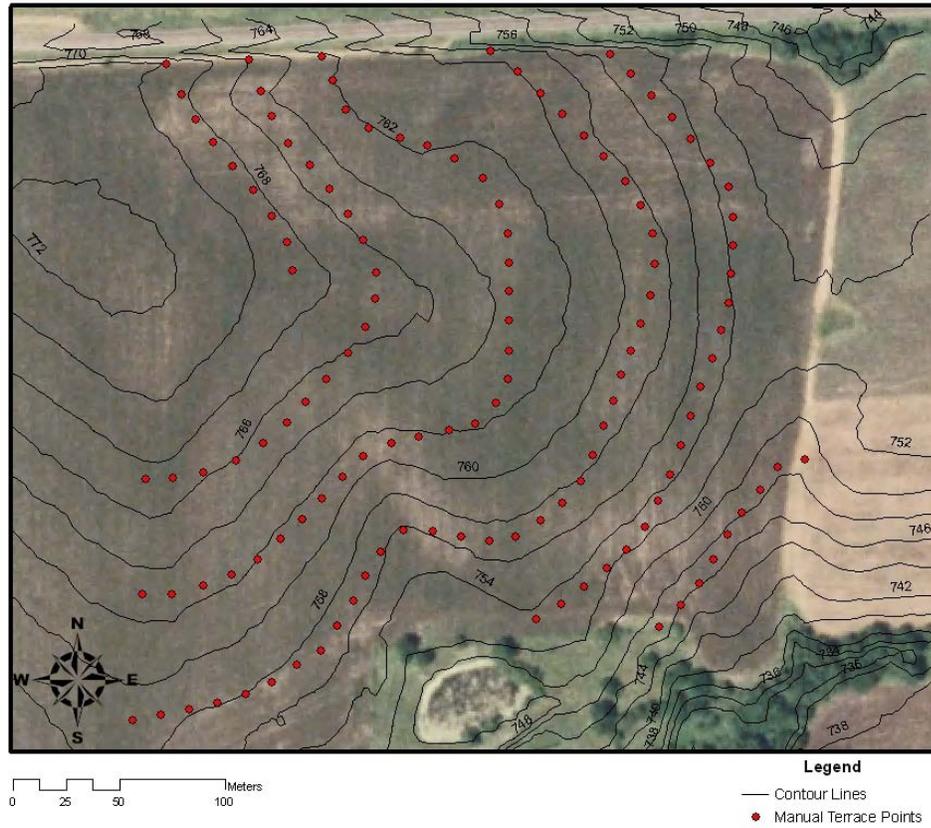


Figure M1. Manual Terrace Layout and Outlet Points for Saline County—MO563

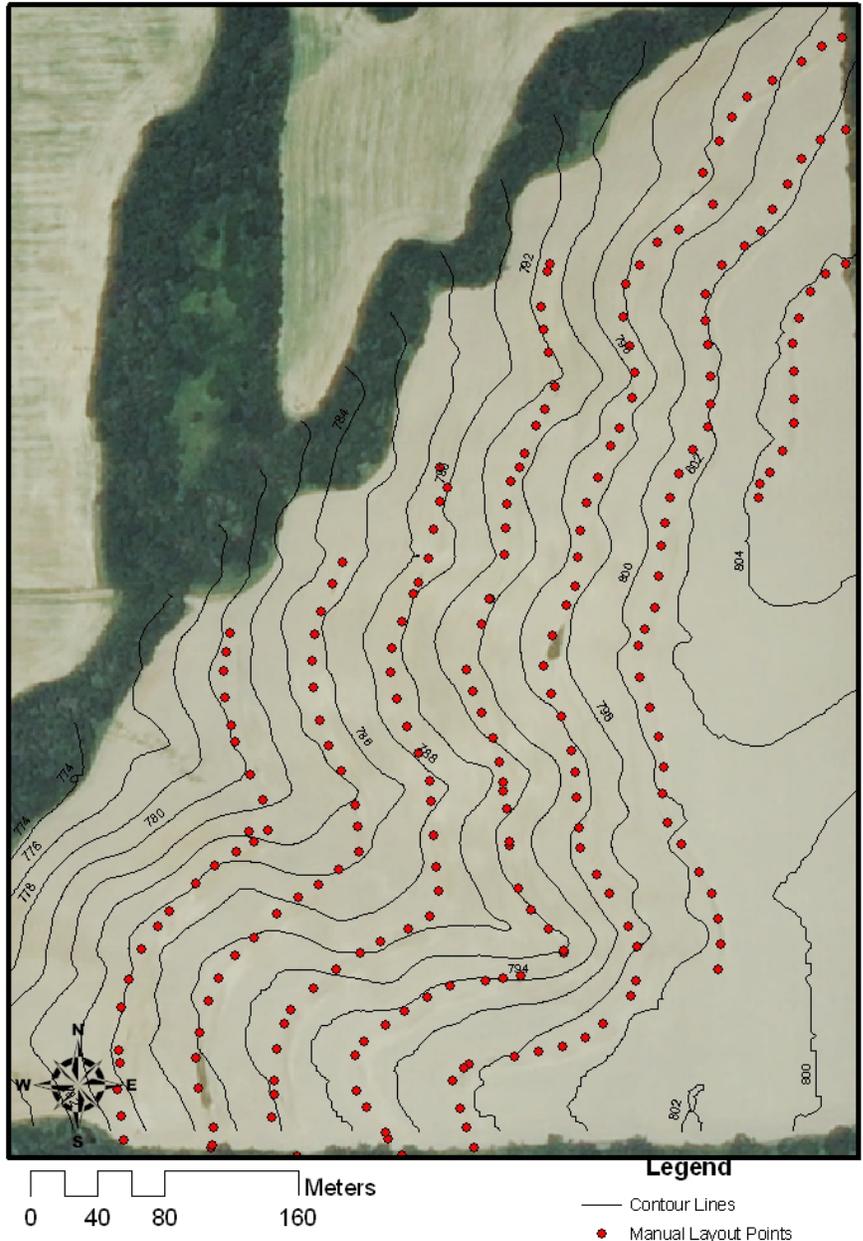
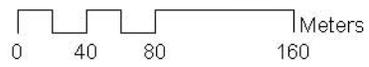


Figure M2. Manual Terrace Layout and Outlet Points for Pike County—MO599



**Legend**

- Manual Terrace Line:
- Contour Lines

Figure M3. Manual Terrace Layout and Outlet Points for Monroe County—MO574

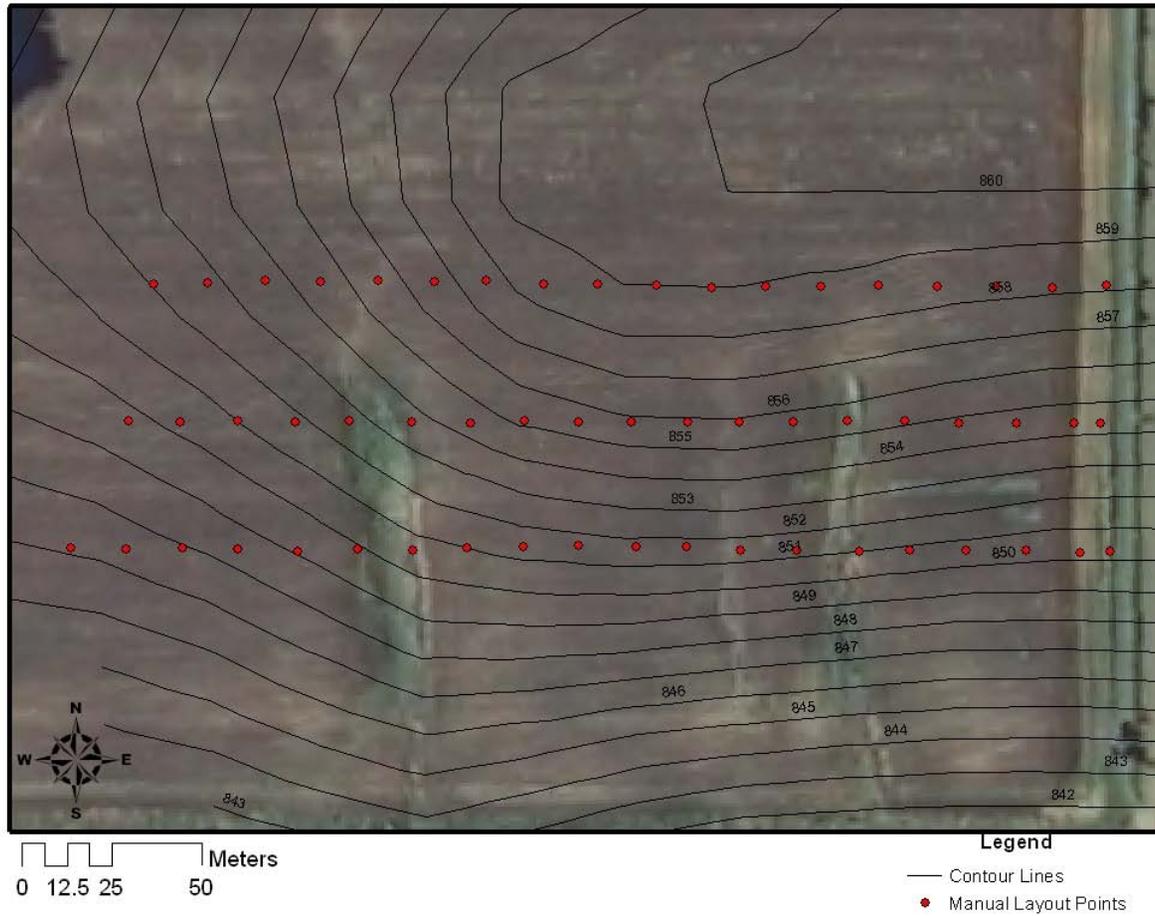


Figure M4. Manual Terrace Layout and Outlet Points for Boone County—MO509

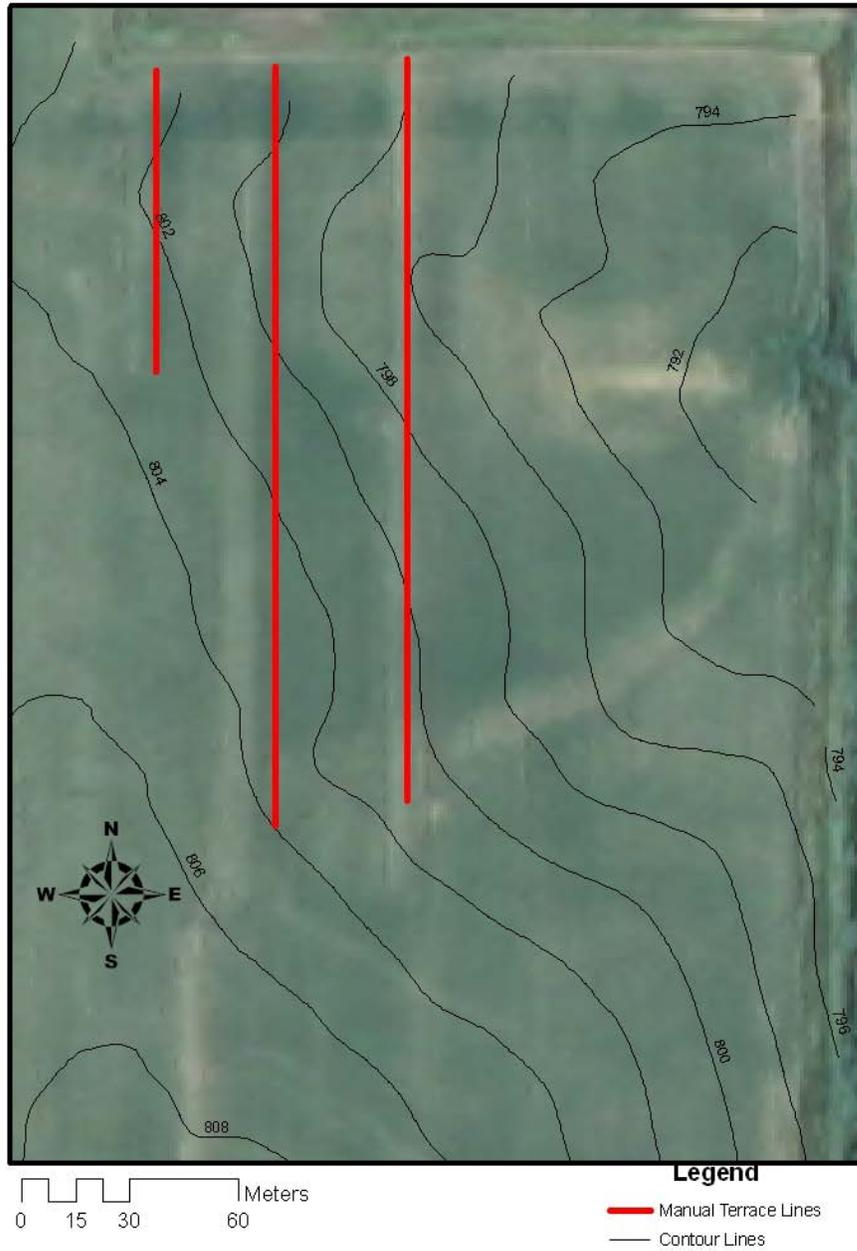


Figure M5. Manual Terrace Layout and Outlet Points for Monroe County—MO566

## APPENDIX N: PROGRAM TERRACE LAYOUT RESULTS

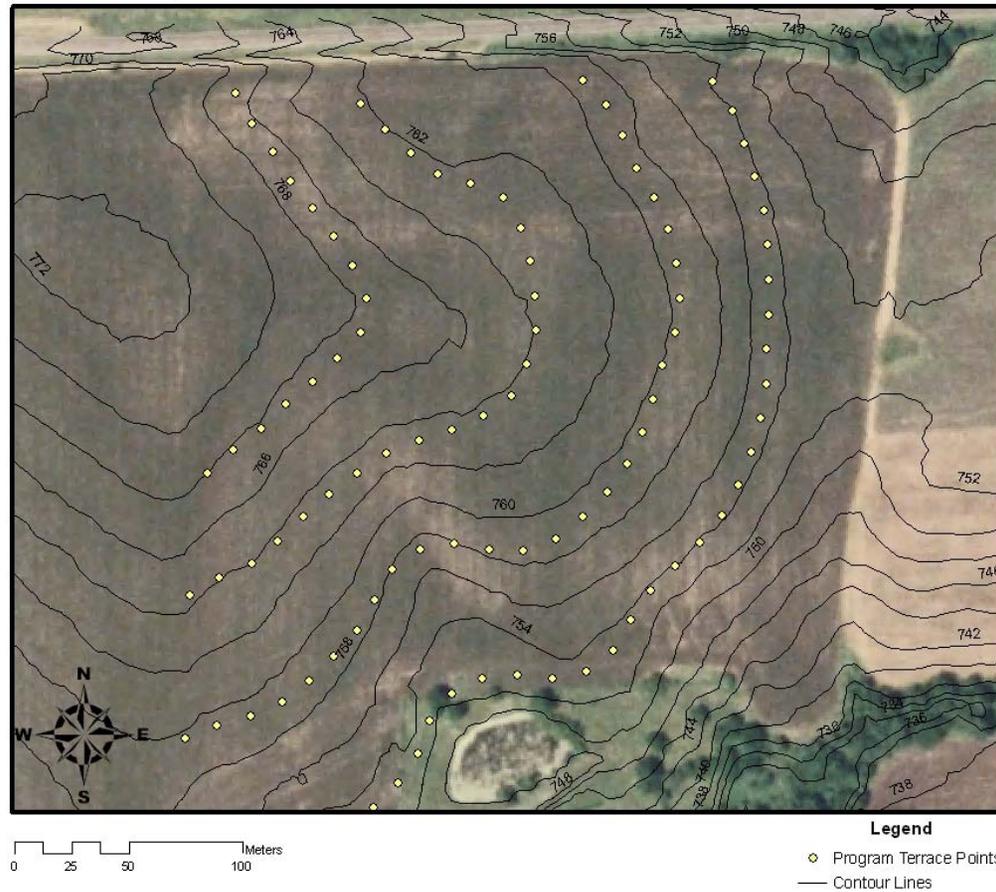
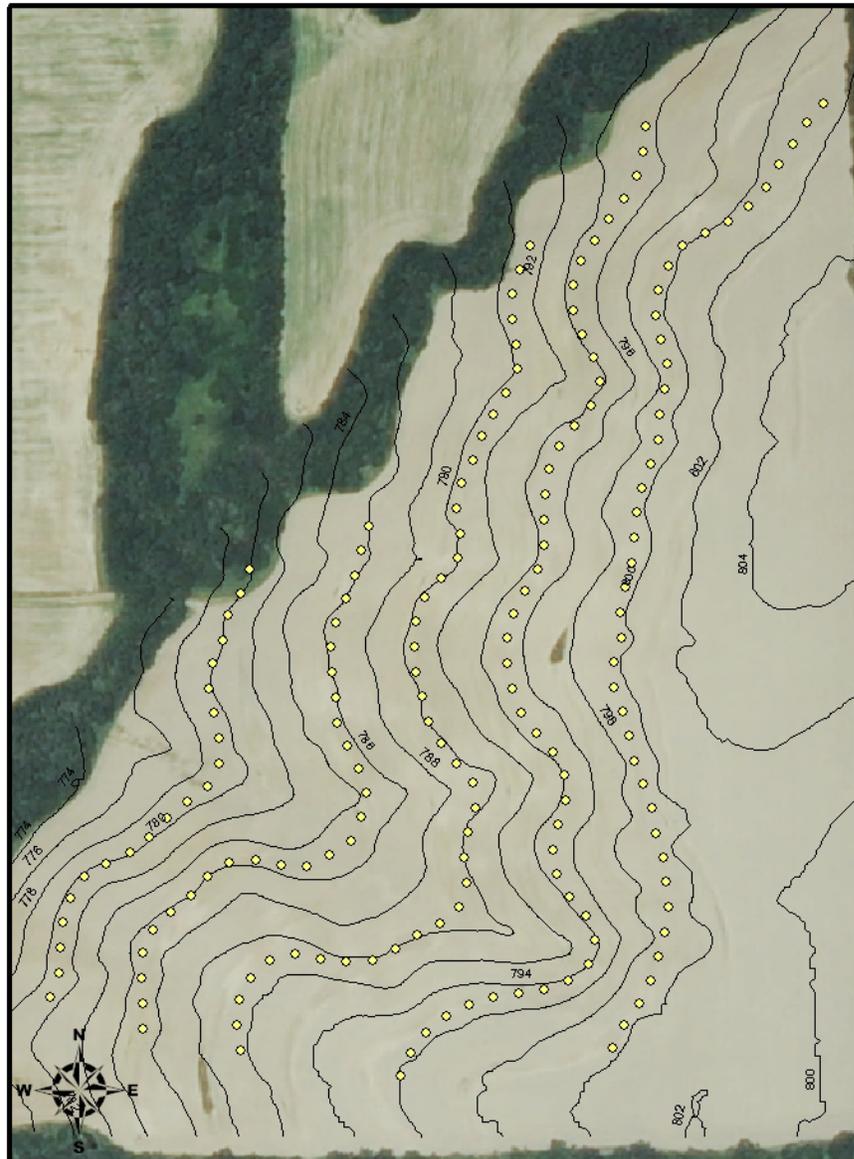


Figure N1. Program Terrace Layout for Saline County—MO563



0 40 80 160 Meters

**Legend**

- ◆ Program Layout Points
- Contour Lines

Figure N2. Program Terrace Layout for Pike County—MO599



Figure N3. Program Terrace Layout for Monroe County—MO574



Figure N4. Program Terrace Layout for Boone County—MO509



**Legend**  
 ◆ Program Layout Points  
 — Contour Lines

Figure N5. Program Terrace Layout for Monroe County—MO566

## APPENDIX O: MANUAL AND PROGRAM LAYOUT COMPARISON

Table O1. Terrace Length Comparison

<b>Saline County—MO563</b>		
<b>Terrace #</b>	<b>Program Length in meters ( feet)</b>	<b>Manual Length in meters (feet)</b>
1	228 (749)	116 (380)
2	351(1150)	281(922)
3	439(1440)	414(1357)
4	487(1598)	503(1651)
5	--	323(1060)
6	--	110(362)
<b>TOTAL</b>	<b>1505(4937)</b>	<b>1747(5732)</b>
<b>Boone County—MO509</b>		
<b>Terrace #</b>	<b>Program Length in meters ( feet)</b>	<b>Manual Length in meters (feet)</b>
1	408(1338)	266(874)
2	436(1431)	272(892)
3	448(1471)	291(955)
<b>TOTAL</b>	<b>1292(4240)</b>	<b>829(2721)</b>
<b>Pike County—MO599</b>		
<b>Terrace #</b>	<b>Program Length in meters ( feet)</b>	<b>Manual Length in meters (feet)</b>
1	639(2097)	159(520)
2	686(2250)	532(1745)
3	625(2050)	773(2535)
4	411(1350)	651(2135)
5	319(1045)	442(1450)
6	--	381(1250)
7	--	328(1075)
Total	<b>2680 (8792)</b>	<b>3266(10,710)</b>
<b>Monroe County—MO574</b>		
<b>Terrace #</b>	<b>Program Length in meters ( feet)</b>	<b>Manual Length in meters (feet)</b>
1	258(848)	336(1102)
2	700(2296)	683(2241)
3	685(2246)	631(2070)
4	425(1395)	207(679)
5	122(400)	--
<b>TOTAL</b>	<b>2190(7185)</b>	<b>1857(6092)</b>
<b>Monroe County—MO566</b>		
<b>Terrace #</b>	<b>Program Length in meters ( feet)</b>	<b>Manual Length in meters (feet)</b>
1	333(1094)	84(276)
2	320(1050)	210(688)
3	209(685)	209(686)
<b>TOTAL</b>	<b>862(2829)</b>	<b>503(1650)</b>

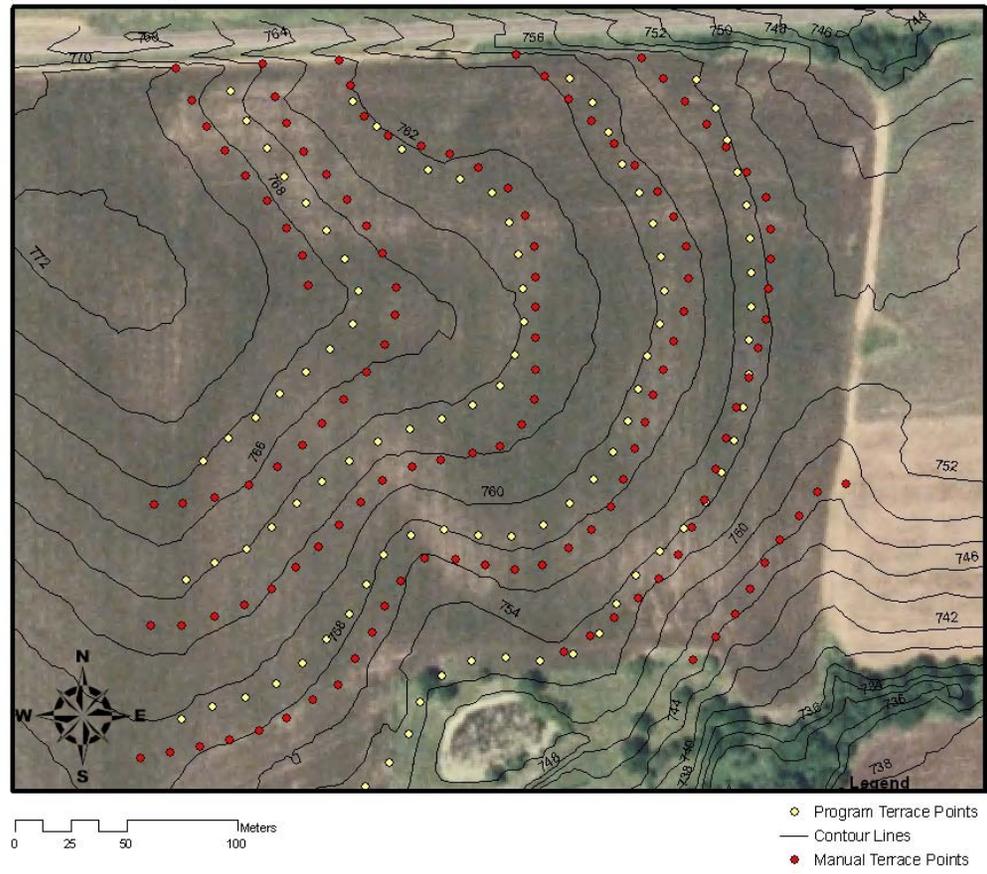


Figure O1. Comparison of Manual and Program Terrace Layout for Saline County—MO563

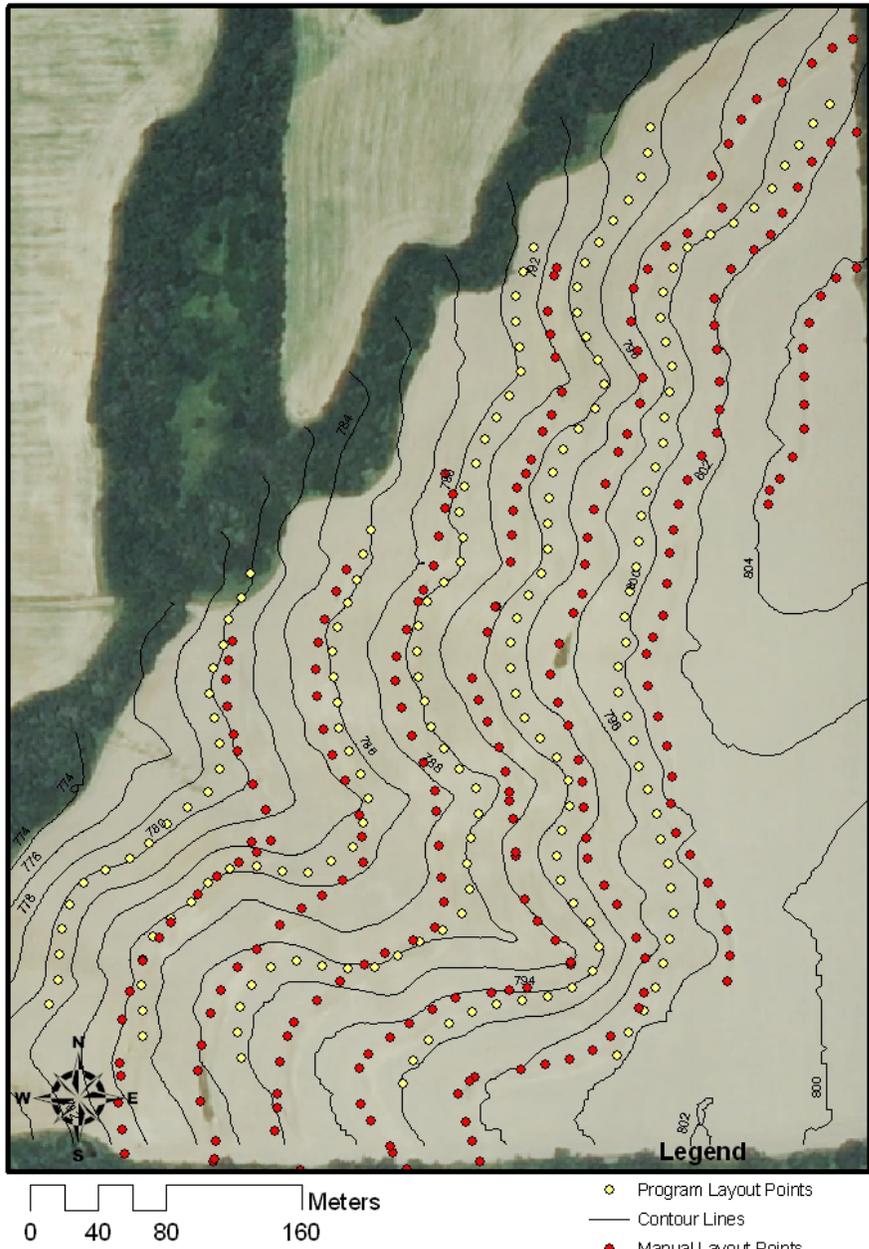


Figure O2. Comparison of Manual and Program Terrace Layout for Pike County—MO599



0 40 80 160 Meters

- Manual Terrace Lines
- ◆ Program Layout Points
- Contour Lines

Figure O3. Comparison of Manual and Program Terrace Layout for Monroe County—MO574

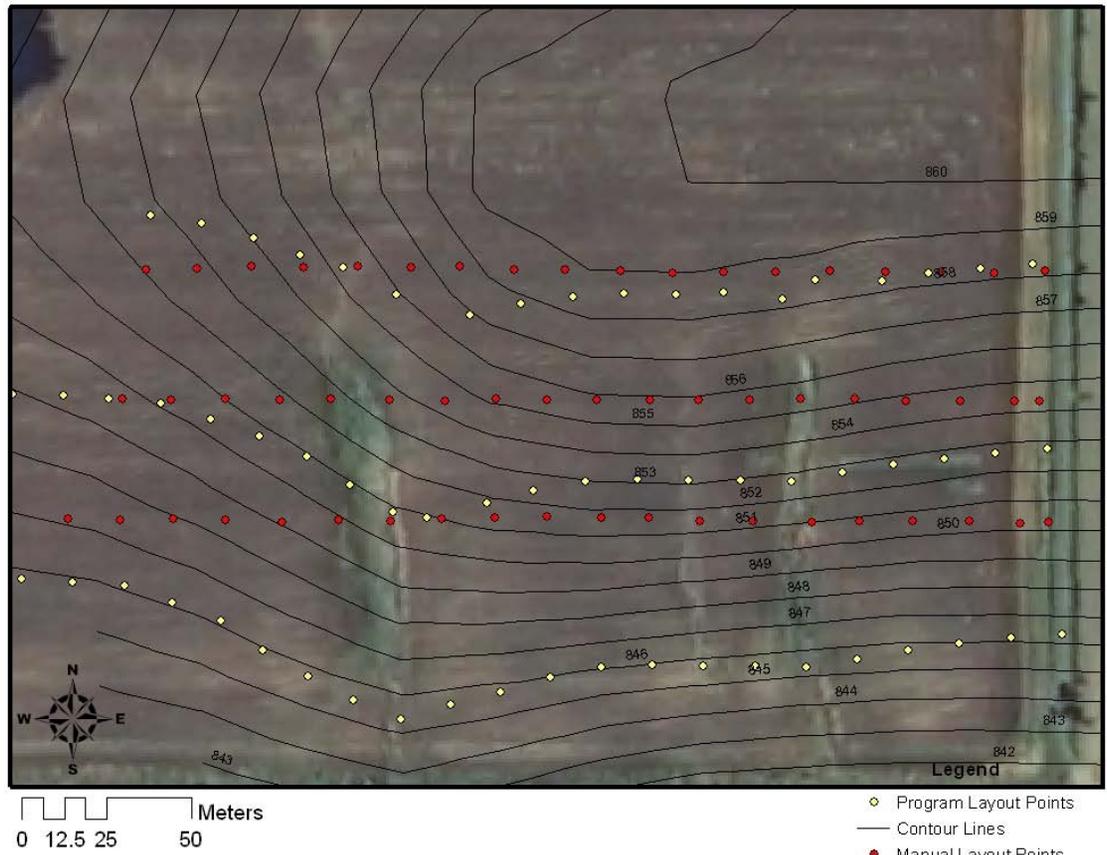


Figure O4. Comparison of Manual and Program Terrace Layout for Boone County—MO509

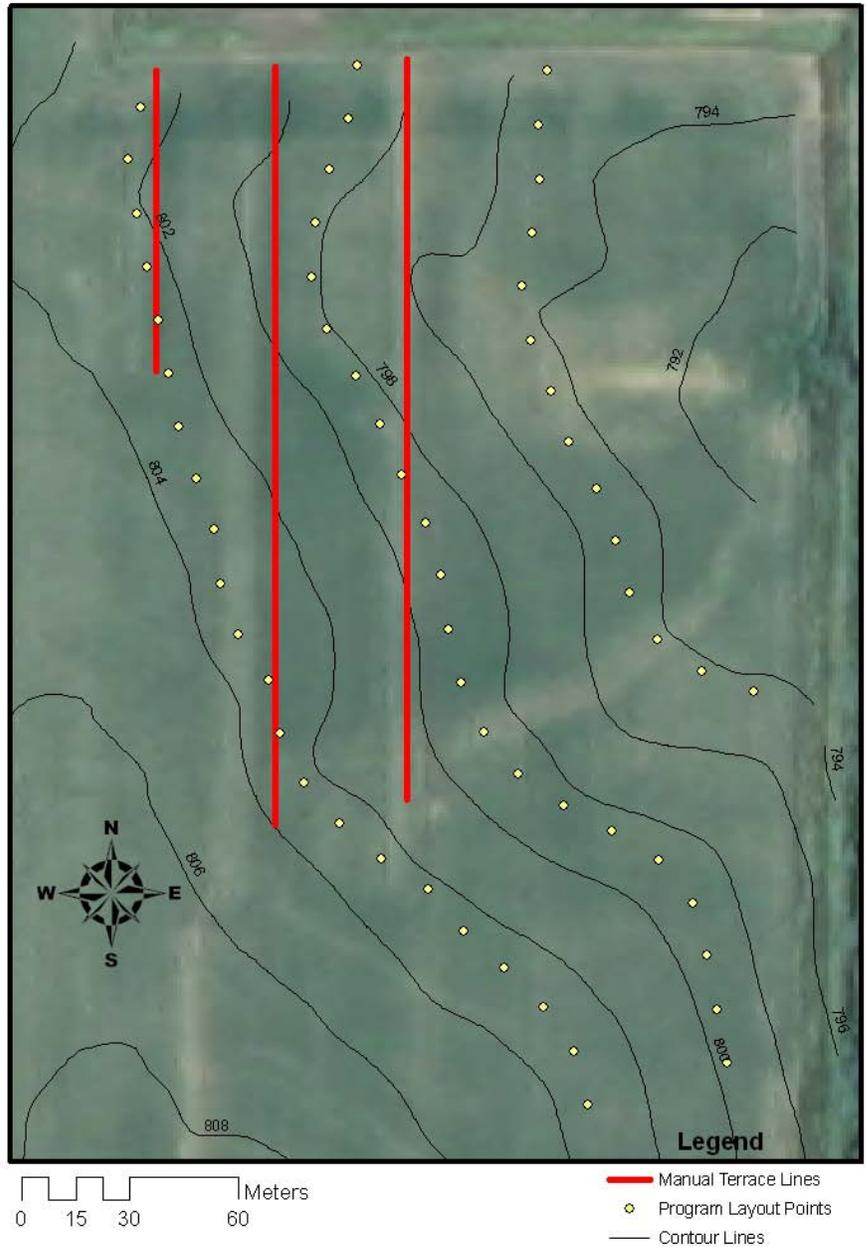


Figure O5. Comparison of Manual and Program Terrace Layout for Monroe County—MO566

## APPENDIX P: CUSTOM FORTRAN CODE

```

SUBROUTINE MELISSAV17( MaxTerr, MaxTerrPts, MaxWW,NPM,NWP, NT, TotWW, NTPTS, X, Y, Z, WWTerrXInt,
WWTerrYInt, WWElev,
    NElev, Cut, WARN, NX, NY, NZ, L,
NP1, TWAY, XWAY, YWAY, EPSI, HIX, HIY, HIZ, D_2, D_SEALED, ORF_DIAMETER, NUM_HOLES, BERM_HEIGHT)

```

```

C *** **
C * MELISSA -- Checks channel elevations of points down a terrace to *
C *           ensure that the channel slope allows water to drain *
C *           toward an outlet at a non-erosive channel velocity. *
C * I/O Variables: *
C * MaxTerr      Maximum number of Terraces (Array sizing)          IN *
C * MaxTerrPts   Maximum number of points in a Terraces             *
C *              (Array sizing)                                     IN *
C * MaxWW        Maximum number of Waterways (Array sizing)         IN *
C * NPM          Maximum number of point in Waterway (Array sizing) IN *
C * NT           Number of Terraces                                  IN *
C * TotWW        Number of Waterways                                 IN *
C * TotDiv       Number of Divides                                   IN *
C * NTPTS        Number of Points on Terrace                        IN *
C * NWP          Number of Point on Waterways                       IN *
C * X            X location of Terrace                              IN *
C * Y            Y location of Terrace                              IN *
C * Z            Elevation at X,Y of Terrace                        IN *
C * WWTerrXInt   X location of Waterway Terrace Intersection         IN *
C * WWTerrYInt   Y location of Waterway Terrace Intersection         IN *
C * WWElev       Elevation at Waterway Terrace Intersection         IN *
C * DivTerrXInt  X location of Divide Terrace Intersection          IN *
C * DivTerrYInt  Y location of Divide Terrace Intersection          IN *
C * DivElev      Elevation at Divide Terrace Intersection            IN *

```

```

C * TotalDiv      Number of Divides on a Terrace      IN   *
C * NElev        FINAL Elevation at X,Y of Terrace  OUT  *
C * Cut          Depth of cut at X,Y of Terrace     OUT  *
C * WARN         Warning message for point on Terrace OUT  *
C * NX           New Terrace X locations            OUT  *
C * NY           New Terrace Y Locations            OUT  *
C * NZ           New Terrace Elevations             OUT  *
C * L            Distance between two points        OUT  *
C * NP1          New number of points per terrace    OUT  *
C *
C *** **
C Variables for Array Size Constants
      INTEGER MaxTerr
      INTEGER MaxTerrPts
      INTEGER MaxWW

C X & Y coordinates for the Terraces
      REAL X(MaxTerr, MaxTerrPts)
      REAL Y(MaxTerr, MaxTerrPts)
      REAL Z(MaxTerr, MaxTerrPts)
      REAL NX2(MaxTerr, 4, MaxTerrPts), NY2(MaxTerr,4,MaxTerrPts)
      REAL AREA2(MAXTERR,MAXWW+1)
      REAL CUT(15, 200)
      REAL NELEV(15, 200)
      CHARACTER * 60 WARN(15, 200)

C Total # of index points for each terrace
      INTEGER NTPTS(15), NP1(15), I1A(15),IFINAL(15)

C Total # of Divides on each terrace
C      INTEGER TotalDiv(15)
      INTEGER SPACE1
      INTEGER SPACE(15,200)

C X & Y coordinates for intersection of WW and Terrace
      REAL WWTerrXInt(MaxTerr, MaxWW+1)
      REAL WWTerrYInt(maxterr, maxww+1)

C X & Y coordinates for intersection of Div and Terrace

```

```

C      REAL DivTerrXInt(15, 9)
C      REAL DivTerrYInt(15, 9)
C Elevation of the WW (and Div) and Terrace intersection point
      REAL WVElev(15, 10)
C      REAL DivElev(15, 9)
C Revised Terraces
      REAL NX(15, 200),NY(15,200),NZ(15,200)
      REAL L(15, 200)

      INTEGER TotWW
C      INTEGER TotDiv
C      INTEGER DivCount
C Looping Variables Declaration
      INTEGER NT, NP, I, NW
C **** End of Standard Dim Statements

C **** Start of Melissa Function Dim Statements
C X & Y coordinates for the boundary points used to calculate areas
      REAL XB(15, 200, 200)
      REAL YB(15, 200, 200)
C Vertical distance that needs to be cut to acheive maximum allowable slope
      REAL G(15, 200)

      INTEGER I2
      INTEGER NBDRY
      REAL J2
C ****6/10/09 Change
      REAL ASLOPE
      REAL TARE(15,200)
      REAL NTARE(15,200)
      REAL V
      REAL HI(15,200)
      REAL N
      REAL Z1
      REAL C

```

```

REAL P
REAL D
REAL B
REAL MXSLP1(15,200)
REAL DIST
C for beginning of cut/fill calculations-- Dimension range (MAXTERR,Max Terr Pts)
REAL QPeak(15, 200)
INTEGER K1
INTEGER WWPt(MAXTERR, MAXWW+1)
C Array to establish which waterway is being approached at each point
INTEGER APLIN(15,200)
REAL AVG_DEPTH(15), LENGTH(15,200)
REAL ys(15, 200)
REAL ys1(15, 200)
REAL ys2(15, 200)
C-- REAL cutfill(15, 200)
C-- REAL totalcutfill(15)
C-- REAL areacutfill(15, 200)
C-- REAL volumecutfill(15, 200)
C-- REAL cost(15)
C-- REAL constD
REAL tempys(15, 200)
INTEGER intdiv
REAL J3
REAL W
REAL landslope,MANNINGSN
REAL N3
REAL tempslope
INTEGER NWP(MaxWW)
REAL TWAY(MaxWW,NPM), XWAY(MaxWW,4,NPM), YWAY(MaxWW,4,NPM)
REAL EPSI
INTEGER NPTS(100)
REAL VOL_RUNOFF(MAXTERR,10),
Q_RELEASE_OUT(MAXTERR,10),Q_IN(MAXTERR,10),Q_RATIO(MAXTERR,10),D_2(MAXTERR,10)

```

```

      REAL
VOL_STORAGE(MAXTERR,10),BERM_HEIGHT(MAXTERR,10),NUM_HOLES(MAXTERR,10),ORF_DIAMETER(MAXTERR,10)
      REAL AVERAGE_VI(MAXTERR), AVERAGE_HI(MAXTERR),Q_DISCHARGE(MAXTERR,10),D_SEALED(MAXTERR,10),
TOBEROUNDED
      INTEGER EPSI2
C ***+ End of Matched Variables
      INTEGER Decimal_Points
C Extra debugging lines
      LOGICAL DEBUG_FLAG, VERBOSE_FLAG
      COMMON /DEBUG/ DEBUG_FLAG, VERBOSE_FLAG

C *****END OF DIM*****

C *****-- PRINT INPUT FILE DATA*****UPON MR.CUTTS
REQUEST*****
      Decimal_Points = 4
C Dump Melissa's Input Values some how
      IF (Verbose_Flag) THEN
          WRITE(6,8139)
8139  FORMAT('-----')
-----
          /'Data Dump from Melissa Function')
          WRITE(6,8140) "Number of Terraces: ", NT, " Waterways: ", TotWW
8140  FORMAT(A22,4X,I5,4X,A15,4X,I5,4X,A13,4X,I5,4X)
C      Print #1, "Number of Terraces: " & NT & " Waterways: " & TotWW & " Divides: " & TotDiv
          DO 60 I=1,NT
              WRITE(6,8150) "Terrace # ", I, " has ", NTPTS(I), " points."
8150  FORMAT(A12,4X,I5,4X,A7,4X,I5,4X,A10,4X)
C      Print #1, "Terrace # " & I & " has " & NTPTS(I) & " points."
              WRITE(6,8160) " X", " Y", " Z"
8160  FORMAT(A7,4X,A7,4X,A9,4X)
C      Print #1, " X", " Y", " Z"
              DO 70 NP=1,NTPTS(I)
                  WRITE(6,8170) X(I,NP), Y(I, NP), Z(I,NP)

```

```

8170  FORMAT(F11.4,4X,F11.4,4X,F11.4,4X)
C      Print #1, Round(X(I, NP), Decimal_Points), Round(Y(I, NP), Decimal_Points), Round(Z(I, NP),
Decimal_Points)
70      CONTINUE
        WRITE(6,8180) "Terrace # ", I, " Waterway Intersections"
8180  FORMAT(A12,4X,I5,4X,A25,4X)
C      Print #1, "Terrace # " & I & " Waterway Intersections"
        WRITE(6,8190) " X", " Y", " Z"
8190  FORMAT(A7,4X,A7,4X,A9,4X)
C      Print #1, " X", " Y", " Z"
        DO 80 NW=1,TotWW
            WRITE(6,8200) WWTerrXInt(I, NW), WWTerrYInt(I, NW), WVElev(I, NW)
8200  FORMAT(F11.4,4X,F11.4,4X,F11.4,4X)
C      Print #1, Round(WWTerrXInt(I, NW), Decimal_Points), Round(WWTerrYInt(I, NW),
Decimal_Points), Round(WVElev(I, NW), Decimal_Points)
80      CONTINUE
        WRITE(6,8210) "Terrace # ", I, " Divide Intersections"
8210  FORMAT(A12,4X,I5,4X,A23,4X)
C      Print #1, "Terrace # " & I & " Divide Intersections"
        WRITE(6,8220) " X", " Y", " Z"
8220  FORMAT(A7,4X,A7,4X,A9,4X)
C      Print #1, " X", " Y", " Z"
C      DO 90 ND=1,TotDiv
C          WRITE(6,8230) DivTerrXInt(I, ND), DivTerrYInt(I, ND), DivElev(I, ND)
C8230  FORMAT(F11.4,4X,F11.4,4X,F11.4,4X)
C      Print #1, Round(DivTerrXInt(I, ND), Decimal_Points), Round(DivTerrYInt(I, ND),
Decimal_Points), Round(DivElev(I, ND), Decimal_Points)
90      CONTINUE
60      CONTINUE
        WRITE(6,8139)
        write(6,6010) MaxTerr, MaxTerrPts, MaxWW, NT, TotWW
        write(6,6011) (I,NTPTS(I),I=1,NT)
        IF (DEBUG_FLAG) THEN
            WRITE(*,7360) NT, TOTWW, TOTDiv
        DO 1200 I=1,NT

```

```

        WRITE(*,7365) I,NTPTS(I)
        WRITE(*,7370)
        DO 1210 NP=1,NTPTS(I)
1210    WRITE(*,7375) X(I, NP), Y(I, NP), Z(I, NP)
        WRITE(*,7380) I
        WRITE(*,7370)
        DO 1220 NW=1,TOTWW
1220    WRITE(*,7375) WWTerrXInt(I,NW),WWTerrYInt(I,NW),WWElev(I,NW)
        WRITE(*,7385) I
        WRITE(*,7370)
C        DO 1230 ND=1,TOTDiv
C1230    WRITE(*,7375) DivTerrXInt(I,ND),DivTerrYInt(I,ND),DivElev(I,ND)
1200    CONTINUE
        ENDIF
6010    FORMAT('NX Melissa Data Dump',/, 'NX MaxTerr=',I3,' MaxTerrPts=',I4,' MaxWW=',I3,' NT=',I3,'
TotWW=',I3)
6011    FORMAT('NX NTPTS',15(/'NX',I2,'=>'I3))
6012    FORMAT('NX TotalDiv(',I2,',')=',I3)
6013    FORMAT('NX NEW Terrace #', I3, ' has ', I3, ' points. - Should be all blank initially.'
/'NX      X          Y          Z          Adj Z          Cuts          Distance          Warning')
6014    FORMAT('NX', 6(F11.4,2X),A)
7360    FORMAT(/'NX Number of Terraces:',I3,' Waterways:',I3,' Divides:',I3)
7365    FORMAT('NX Terrace #', I3, ' has ', I3, ' points.')
7370    FORMAT('NX      X          Y          Z')
7375    FORMAT('NX ',3(F9.3,2X))
7380    FORMAT('NX Terrace #',I3,' Waterway Intersections')
7385    FORMAT('NX Terrace #',I3,' Divide Intersections')
C TotalDiv, NElev, Cut, WARN, NX, NY, , L
C      write(6,6012) (I,TotalDiv(I),I=1,NT)
        DO 1240 I=1,NT
            write(6,6013) I,NTPTS(I)
            DO 1250 NP=1,NTPTS(I)
                write(6,6014) NX(I,NP), NY(I,NP),NZ(I,NP), NElev(I,NP), Cut(I,NP), L(I,NP), Warn(I,NP)
1250    CONTINUE
1240    CONTINUE

```

**ENDIF**

```
C*****
C****STARTING AT ZERO END OF EACH TERRACE-- DETERMINE WHICH WATERWAY/DIVIDE OCCURS FIRST (I1) & LAST
(IFINAL).
C*****
      DO 1910 II=1,NT
        DIST=99999.
        DISTF=99999.

        DO 1920 I=1, TOTWW
          TBX=X(II,1)
          TBY=Y(II,1)
C      INITIALIZING AREA2 ARRAY
          AREA2(II,I)=0
          WWPT(II,I)=0
          CALL PLDIST_BF(TBX,TBY,NWP,I,TWAY,XWAY,YWAY,MaxWW,NPM,DIST1,EPSI,S,T)
          IF (DIST1.LE.DIST.AND.WWTERRXInt(II,I).NE.0.AND.WWTERRYInt(II,I).NE.0) THEN
            DIST=DIST1
            I1A(II)=I
          END IF
          TNX=X(II,NTPTS(II))
          TNY=Y(II,NTPTS(II))
          CALL PLDIST_BF(TNX,TNY,NWP,I,TWAY,XWAY,YWAY,MaxWW,NPM,DIST2,EPSI,S,T)
          IF (DIST2.LE.DISTF.AND.WWTERRXInt(II,I).NE.0.AND.WWTERRYInt(II,I).NE.0) THEN
            DISTF=DIST2
            IFINAL(II)=I
1920      END IF
          IF (II.EQ.NT.AND.I1A(II).EQ.0.AND.IFINAL(II).EQ.0) NT=NT-1
1910      CONTINUE
C*****
      I=I1A(II)
```

C\*\*\*\*\*LOOP TO RENUMBER DATA POINTS DOWN TERRACE TO ADD IN INTERSECTION DATA POINTS  
 \*\*\*\*\*

```

DO 2009 II=1,NT
  DLO1=99999.
  DLO2=99999.
  DHI1=99999.
  DHI2=99999.
  D1=99999.
  NP1(II)=NTPTS(II)
  K1=0
  I=I1A(II)
  I2=0
  J=1
  KLIN=I1A(II)
  EPSI2=20

```

C LOOP TO ADD EXTRA POINTS TO THE TOTAL TERRACE PTS

```

DO 2002 I1=1, TOTWW
2002 IF (WWTERRXINT(II,I1).NE.0.AND.WWTERRYINT(II,I1).NE.0) NP1(II)=NP1(II)+1
2000 IF (J.GT.NP1(II))GOTO 2001
  IF (J.EQ.NP1(II)) GOTO 2008
  X1=X(II,J)
  Y1=Y(II,J)
  X2=X(II,J+1)
  Y2=Y(II,J+1)
  IF (I1A(II).EQ.IFINAL(II).AND.K1.GT.0) THEN
    KLIN=IFINAL(II)+1
    GOTO 2008
  END IF

```

C\*\*RENUMBERING FIRST PORTION OF TERRACE\*\*\*\*\*

```

IF (I.EQ.I1A(II)) THEN
  D2=((X1-WWTERRXINT(II,KLIN))**2+(Y1-WWTERRYINT(II,KLIN))**2)** 0.5
  D3=((X2-WWTERRXINT(II,KLIN))**2+(Y2-WWTERRYINT(II,KLIN))**2)** 0.5
  IF ((D1-D2.LE.D3-D2).AND.(D2.LT.D1)) GOTO 2007
  IF ((D1-D2.GE.D3-D2).AND.(D2.GT.D1)) GOTO 2007
  IF (D1.LT.D2.AND.D3.GT.D2) GOTO 2007

```

2007

**IF** (D2.EQ.0)**GOTO** 2007

**GO TO** 2008

D1=D2

**IF** (K1.NE.0) **THEN**

NX(II,J)=X(II,J-K1)

NY(II,J)=Y(II,J-K1)

NZ(II,J)=Z(II,J-K1)

APLIN(II,J)=KLIN

**END IF**

NX(II,J+K1)=WWTERRXINT(II,KLIN)

NY(II,J+K1)=WWTERRYINT(II,KLIN)

NZ(II,J+K1)=WWELEV(II,KLIN)

APLIN(II,J+K1)=KLIN

WWPT(II,KLIN)=J+K1

K1=K1+1

**IF** (D2.EQ.0) **THEN**

NP1(II)=NP1(II)-1

K1=K1-1

**GOTO** 2107

**END IF**

NX(II,J+K1)=X(II,J)

NY(II,J+K1)=Y(II,J)

NZ(II,J+K1)=Z(II,J)

APLIN(II,J+K1)=KLIN+1

2107

**IF** (WWTERRXINT(II,KLIN+1).NE.0.AND.WWTERRYINT(II,KLIN+1).NE.0)**THEN**

**IF** (WWTERRXINT(II,KLIN+2).NE.0.AND.WWTERRYINT(II,KLIN+2).NE.0)**THEN**

D1=DIFF(WWTERRXINT(II,KLIN+1),WWTERRYINT(II,KLIN+1),WWTERRXINT(II,KLIN),WWTERRYINT(II,KLIN))

D2=DIFF(WWTERRXINT(II,KLIN+2),WWTERRYINT(II,KLIN+2),WWTERRXINT(II,KLIN),WWTERRYINT(II,KLIN))

**IF** (D1.LT.EPSI2.AND.D2.LT.EPSI2) **THEN**

APLIN(II,J+K1-1)=KLIN+2

WWPT(II,KLIN)=J+K1-1

WWPT(II,KLIN+1)=J+K1-1

WWPT(II,KLIN+2)=J+K1-1

```

                APLIN(II,J+K1)=KLIN+3
                NP1(II)=NP1(II)-2
                KLIN=KLIN+3
                I=KLIN-1
                D1=9999.
                GO TO 2001
            END IF
        END IF
    END IF
    IF (I1A(II).NE.IFINAL(II)) THEN
        KLIN=KLIN+1
        I=KLIN-1
    END IF
    D1=9999.
    GO TO 2001
2008    IF (D2.LT.D1) D1=D2
        NX(II,J)=X(II,J-K1)
        NY(II,J)=Y(II,J-K1)
        NZ(II,J)=Z(II,J-K1)
        APLIN(II,J)=KLIN
        GO TO 2001
    END IF
*****
    IF (J.EQ.NP1(II)) GO TO 1963
    IF (I.EQ.IFINAL(II).AND.TOTWW.NE.1.AND.I1A(II).NE.IFINAL(II)) GO TO 1961
    DLO1=((X1-WWTERRXINT(II,I-1)**2+(Y1-WWTERRYINT(II,I-1))**2)**0.5
    DLO2=((X2-WWTERRXINT(II,I-1)**2+(Y2-WWTERRYINT(II,I-1))**2)**0.5
    DHI1=((X1-WWTERRXINT(II,KLIN))**2+(Y1-WWTERRYINT(II,KLIN))**2)**0.5
    DHI2=((X2-WWTERRXINT(II,KLIN))**2+(Y2-WWTERRYINT(II,KLIN))**2)**0.5
    DT=DIFF(X1,Y1,X2,Y2)
1962    IF (DLO2.GT.DLO1.AND.DHI2.LT.DHI1.AND.(DHI1+DHI2).GT.(1.1*DT)) GOTO 1961
    IF(DLO2.LT.DLO1.AND.(DLO1-DLO2).GT.(DHI1-DHI2)) GO TO 1961
C      DISTANCE TO WATERWAYS MUST BE GREATER THAN DISTANCE TO NEXT POINT IF STILL APPROACHING A
LINE
    IF(DLO2.GT.DLO1.AND.(DLO2-DLO1).LT.(DHI2-DHI1).AND.DHI1.GT.DT) GO TO 1961

```

```

                IF (DHI1.GT.2*DT.OR.DHI2.GT.2*DT) GOTO 1961
                KLIN=KLIN+1
C              WHEN CROSSING FINAL TERRACE-->KLIN+1 WILL BE CALCULATED, BUT I2 WILL RETURN TO IFINAL
1961            I2=KLIN-1
C              IF A WW/DIV HAVE BEEN CROSSED I2 WILL NOT EQUAL I--ADD INTERSECTION POINT. IF THEY ARE EQUAL,
CONTINUE FILLING ARRAY WILL TERRACE POINTS
1963            IF (J.EQ.NP1(II).AND.I.NE.IFINAL(II)) I2=IFINAL(II)
                IF (I.EQ.I1A(II).AND.I2.EQ.0) GOTO 1964
                IF (I.EQ.I1A(II).AND.I2.EQ.1) THEN
                    IF (K1.EQ.0) GOTO 1965
                    IF (K1.GT.0) GOTO 1964
                END IF
1965            IF (I2.NE.I) THEN
                NX(II,J+K1)=X(II,J)
                NY(II,J+K1)=Y(II,J)
                NZ(II,J+K1)=Z(II,J)
                APLIN(II,J+K1)=I2
                NX(II,J+K1+1)=WWTERRXINT(II,I2)
                NY(II,J+K1+1)=WWTERRYINT(II,I2)
                NZ(II,J+K1+1)=WWELEV(II,I2)
                IF (WWTERRXINT(II,I2+1).NE.0.AND.WWTERRYINT(II,I2+1).NE.0) THEN
                    IF (WWTERRXINT(II,I2+2).NE.0.AND.WWTERRYINT(II,I2+2).NE.0) THEN

                        D1=DIFF(WWTERRXINT(II,I2+1),WWTERRYINT(II,I2+1),WWTERRXINT(II,I2),WWTERRYINT(II,I2)
                        )
                        D2=DIFF(WWTERRXINT(II,I2+2),WWTERRYINT(II,I2+2),WWTERRXINT(II,I2),WWTERRYINT(II,I2)
                        )

                            IF (D1.LT.EPSI.AND.D2.LT.EPSI) THEN
                                APLIN(II,J+K1+1)=I2+2
                                WWPT(II,I2)=J+K1+1
                                WWPT(II,I2+1)=J+K1+1
                                WWPT(II,I2+2)=J+K1+1
                                NP1(II)=NP1(II)-2
                                KLIN=KLIN+2
                                I2=KLIN-1

```

```

                                GOTO 1970
                                END IF
                                END IF
                                END IF
1970   APLIN(II,J+K1+1)=I2
        WWPT(II,I2)=J+K1+1
        K1=K1+1
        IF (DLO2.EQ.0) THEN
            NP1(II)=NP1(II)-1
            K1=K1-1
        END IF
        ELSE
1964   NX(II,J+K1)=X(II,J)
        NY(II,J+K1)=Y(II,J)
        NZ(II,J+K1)=Z(II,J)
        APLIN(II,J+K1)=K1
        END IF
        I=I2
2001  CONTINUE
        IF ((J+K1-1).LT. NP1(II))THEN
            J=J+1
            GOTO 2000
        END IF
2009  CONTINUE

C*****PRINT STATEMENTS FOR DEBUGGING*****
        DO 2040 II=1,NT
7000  FORMAT('D',5X,'Terrace #', I2)
            WRITE(6,7000) II
            DO 2040 J=1, NP1(II)
7010  FORMAT('D',5X,I4,2F8.2)
            WRITE (6,7010)J,NX(II,J),NY(II,J)
2040  CONTINUE
C*****

```

```

*****
C   CONVERTING NX TO A 3 DIMENSIONAL ARRAY FOR THE INTRVL SUBROUTINE USE
*****
      DO 2005 II=1, NT
        DO 2005 J=1, NP1(II)
          NX2(II,1,J)=NX(II,J)
2005      NY2(II,1,J)=NY(II,J)
*****

C*****INITIALIZE ALL AREA2VARIABLES*****
      DO 2020 II=1,MAXTERR
        DO 2020 I=1, MAXWW
2020      AREA2(II,I)=0
*****

*****
**LOOP TO CALCULATE AREA, CHANNEL DEPTH, AND MAXIMUM SLOPE*****
*****
      SPACE1=1
      COUNTER=0
      SUM_DEPTH=0
      DO 2004 II=1,NT
        I=I1A(II)
        KBTEMP=0
        DO 2004 J=1, NP1(II)

C   IF WE CROSS A WATERWAY/DIVIDE--> MODIFY DRAINAGE DIRECTION
      IF (APLIN(II,J)/2.NE.APLIN(II,J)/2.) THEN
        SPACE1=-1
      ELSE
        SPACE1=1
      END IF
      IF (APLIN(II,J)-3.EQ.I) THEN
        I=APLIN(II,J)-3
        GOTO 2050

```

```

END IF
IF (APLIN(II,J)-1.NE.I.AND.APLIN(II,J).NE.I1A(II)) KBTEMP=0
IF (APLIN(II,J).GT.I1A(II)) I=APLIN(II,J)-1

2050    TBX=NX(II,J)
        TBY=NY(II,J)
        TNX=NX(II,J+1)
        TNY=NY(II,J+1)

*****
C**ESTABLISH DRAINAGE AREA BOUNDARY POINTS TO CALCULATE DRAINAGE AREA*****
C***AT EACH POINT DOWN THE CURRENT TERRACE.*****
*****
C    BOUNDARY PTS WHEN APPROACHING A WATERWAY (START AT DIVIDE AND GO DOWNHILL)
1943    IF (SPACE1.LT.0) THEN
        KB3=1
        IF (I.NE.I1A(II)) KB3=WWPT(II,I)
        IF (I1A(II).EQ.IFINAL(II).AND.APLIN(II,J).GT.IFINAL(II)) KB3=WWPT(II,IFINAL(II))
        KB4=J
        END IF
C    BOUNDARY PTS WHEN APPROACHING A DIVIDE
        IF (SPACE1.GE.0) THEN
            KB3=J
            KB4=NP1(II)
            IF (SPACE1.GT.0.AND.J.EQ.WWPT(II,APLIN(II,J)).AND.APLIN(II,J)/2.NE.APLIN(II,J)/2.) THEN
                IF (APLIN(II,J).NE.IFINAL(II)) KB4=WWPT(II,APLIN(II,J)+1)
                IF (APLIN(II,J).EQ.I1A(II)) KB4=WWPT(II,APLIN(II,J)+1)
            ELSE
                IF (I.NE.IFINAL(II)) KB4=WWPT(II,APLIN(II,J))
                IF (APLIN(II,J).EQ.I1A(II)) KB4=WWPT(II,APLIN(II,J))
            END IF
        END IF

C    NEXT STATEMENT ACCOUNTS FOR TOP TERRACE AREA CALCULATION

```

```

      IF (II.EQ.1) THEN
        KB1= 1
        KB2= 1
        GO TO 2006
      END IF
C*****
C**ESTABLISH DRAINAGE AREA BOUNDARY POINTS TO CALCULATE DRAINAGE AREA*****
C**AT AT PREVIOUS TERRACE (UPPER PORTION OF WATERSHED FOR CURRENT TERRACE)**
C*****
C   BOUNDARY PTS WHEN APPROACHING A WATERWAY
      IF (SPACE1.LT.0)THEN
        KB1=1
        IF (WWPT(II-1,I).EQ.0) THEN
          MD2=99999.
C DETERMINE WHICH WATERWAY/DIVIDE IS CLOSEST
          DO 2017 E=I1A(II-1), IFINAL(II-1)
            MD3=DIFF(NX(II,J),NY(II,J),NX(II,WWPT(II-1,E)),NY(II,WWPT(II-1,E)))
            IF (MD3.LT.MD2)THEN
              MD2=MD3
              LMD2=E
            END IF
          2017 IF (I.LT.I1A(II-1))THEN
            MD=DIFF(NX(II,J),NY(II,J),NX(II-1,1),NY(II-1,1))
            IF (MD.LT.MD2) THEN
              KB1=1
            ELSE
              KB1=LMD2
            END IF
          ELSE
            MD=DIFF(NX(II,J),NY(II,J),NX(II-1,NP1(II-1)),NY(II-1,NP1(II-1)))
            IF (MD.LT.MD2) THEN
              KB1=NP1(II-1)
            ELSE
              KB1=LMD2
            END IF
          END IF
        END IF
      END IF

```

```

                END IF
                KB2=KB1
            ELSE
                IF (KBTEMP.EQ.0) KBTEMP=WWPT(II-1,I)
                KB1=WWPT(II-1,I)
                B1=KBTEMP
                B2=WWPT(II-1,APLIN(II,J))
C      ACCOUNTS FOR WHEN WWPT(II-1, APLIN(II,J))=0
                IF (APLIN(II,J).GT.IFINAL(II-1).OR.APLIN(II-1,J).EQ.0) B2=NP1(II-1)
                KB2=MDIST(NX,NY,II,J,B1,B2)
                KBTEMP=KB2
                IF (I.EQ.I1A(II).AND.I1A(II).NE.IFINAL(II)) KB1=1
                IF (J.EQ.NP1(II)) KB2=NP1(II-1)
            END IF
        END IF

C      BOUNDARY PTS WHEN APPROACHING A DIVIDE
        IF (SPACE1.GE.0) THEN
            IF (WWPT(II-1,I).EQ.0) THEN
                MD2=99999.
C      DETERMINE WHICH WATERWAY/DIVIDE IS CLOSEST
                DO 2016 E=I1A(II-1), IFINAL(II-1)
                    MD3=DIFF(NX(II,J),NY(II,J),NX(II,WWPT(II-1,E)),NY(II,WWPT(II-1,E)))
                    IF (MD3.LT.MD2) THEN
                        MD2=MD3
                        LMD2=E
                2016                END IF
                IF (I.LT.I1A(II-1)) THEN
                    MD=DIFF(NX(II,J),NY(II,J),NX(II-1,1),NY(II-1,1))
                    IF (MD.LT.MD2) THEN
                        KB1=1
                    ELSE
                        KB1=LMD2
                    END IF
                ELSE
                    KB1=LMD2
                END IF
            ELSE
                KB1=LMD2
            END IF
        ELSE
            KB1=LMD2
        END IF
    ELSE
        KB1=LMD2
    END IF

```

```

MD=DIFF(NX(II,J),NY(II,J),NX(II-1,NP1(II-1)),NY(II-1,NP1(II-1)))
IF (MD.LT.MD2) THEN
  KB1=NP1(II-1)
ELSE
  KB1=LMD2
END IF
END IF
KB2=KB1
ELSE
  IF (KBTEMP.EQ.0) KBTEMP=WWPT(II-1,I)
  B1=KBTEMP
  B2=WWPT(II-1,APLIN(II,J))
  IF (APLIN(II,J).GT.IFINAL(II-1).OR.APLIN(II-1,J).EQ.0) B2=NP1(II-1)
  KB1=MDIST(NX,NY,II,J,B1,B2)
  KB2=WWPT(II-1, APLIN(II,J))
  IF (APLIN(II,J).GT.IFINAL(II-1).OR.WWPT(II-1,APLIN(II,J)).EQ.0) KB2=NP1(II-1)
  KBTEMP=KB1
  IF (J.EQ.WWPT(II,APLIN(II,J)).AND.APLIN(II,J)/2.NE.APLIN(II,J)/2.) THEN
    KB1=WWPT(II-1,APLIN(II,J))
    IF (APLIN(II-1,J).GT.IFINAL(II-1).OR.APLIN(II-1,J).EQ.0) KB1=NP1(II-1)
    IF (APLIN(II,J).GT.IFINAL(II-1)) KB1=NP1(II-1)
    KB2=NP1(II-1)
    IF (APLIN(II,J).NE.IFINAL(II-1).AND.APLIN(II,J).LT.IFINAL(II-1)) KB2=WWPT(II-
1,APLIN(II,J)+1)
    IF (APLIN(II,J).EQ.I1A(II-1)) KB2=WWPT(II-1,APLIN(II,J)+1)
  END IF
  IF (J.EQ.1) KB1=1
  IF (J.EQ.NP1(II)) KB2=NP1(II-1)
END IF
END IF
7020 FORMAT('D',5X,I2,I4,I4,I4,I4,I4)
WRITE(6,7020) II,J,KB1,KB2,KB3,KB4
2006 CONTINUE

```

\*\*\*\*\*CALCULATE AREA FOR TOP TERRACE & FOR ANY KB1=KB2\*\*\*\*\*

\*6/9/2010--AREA FOR TOP TERRACE CAN NOW BE COMPLETED WITH HIGH POINT USING INTRVL  
 \*INTRVL CAN ALSO CALCULATE AREA WITH 3 POINTS (TRIANGULAR AREA)  
 \*\*\*\*\*

C\*\*\*\*\*  
 C\*\*\*CALCULATE DRAINAGE AREA (TARE), DISTANCE BETWEEN POINTS(L), & SPACING (HI) USING BOUNDARY  
 POINTS\*\*\*\*\*

C\*\*\*\*\*  
 C SPECIAL CONSIDERATIONS FOR AREA CALCULATIONS AT WATERWAYS AND DIVIDES  
 C AT A DIVIDE-- NO AREA; AT A WATERWAY, CONSIDER AREA FROM MULTIPLE DIVIDES (IF PRESENT)  
 IF (KB3.EQ.KB4) THEN  
 TARE(II,J)=0  
 QPeak(II,J) = 0  
 SPACE(II,J)=SPACE1  
 GOTO 2004  
 END IF  
 CALL

INTRVLMELISSA(NPTS,NX2,NY2,II,PERDIS,AREA,MaxTerr,MaxTerrPts,XB,YB,NBDRY,KB1,KB2,KB3,KB4,HIX,HIY)

IF (SPACE1.GT.0.AND.J.EQ.WWPT(II,APLIN(II,J))) THEN  
 IF (AREA2(II,APLIN(II,J)).EQ.0.AND.TARE(II,J).NE.0) THEN  
 AREA2(II,APLIN(II,J))=AREA  
 HI2=PERDIS  
 GO TO 2014  
 END IF  
 END IF  
 HI(II,J)=PERDIS  
 TARE(II,J)=AREA

\*\*\*\*\*  
 \*\*\*\*\*PEAK FLOW AND CHANNEL DEPTH  
 CALCULATIONS(CFS)\*\*\*\*\*  
 \*\*\*\*\*

C All these values for the cross section of the terrace channel are assumed to be correct

```

C velocity(m/s)-->reflects soils with moderate erodibility
  V = 2
C Roughness coefficient
  N = 0.03
C Sideslope ratio
  Z1 = 10
C Runoff coefficient
  C = 0.7
C Rainfall Intensity(IN/HR)
  P = 7
C D = 1 'Depth of Water
C Bottom width (0=>triangular shaped channel)
  B = 0
C 30 ft equipment (assuming cutslope, backslope, and frontslope widths are equal)
  W = 30
C assumption=original land slope=7%
  landslope = 0.07
C QPEAK HAS UNITS OF CFS
*****
2014  QPeak(II, J) = C * (P / 43200) * TARE(II,J)
      IF (SPACE1.GT.0.AND.J.EQ.WWPT(II,APLIN(II,J))) THEN
          IF (AREA2(II,APLIN(II,J)).NE.0.AND.TARE(II,J).NE.0)THEN
              QPEAK(II,J)=C*(P/43200)*AREA2(II,APLIN(II,J))
          END IF
      END IF
      IF (SPACE1.GT.0.AND.J.EQ.WWPT(II,APLIN(II,J))) THEN
          IF (ys(II, J).NE. 0) tempys(II, J) = ys(II, J)
      End If
C Depth for trapezoid channel depth of flow at stability limit
  ys1(II, J) = ((-B * (V) ** 0.5) + ((B ** 2 * V) + (4 * QPeak(II, J) * Z1)) ** 0.5) / (2 *
(V) ** 0.5 * Z1)
C Depth for trapezoid channel depth of flow at stability limit
  ys2(II, J) = ((-B * (V) ** 0.5) - ((B ** 2 * V) + (4 * QPeak(II, J) * Z1)) ** 0.5) / (2 *
(V) ** 0.5 * Z1)
  ys(II,J)= ys1(II,J)

```

```

      IF (ys2(II,J).LT.ys1(II, J)) THEN
        IF (ys2(II,J).GT.0) ys(II,J) = ys2(II,J)
      End If
      IF (ys(II,J).LT.0) THEN
        WRITE(6,*) "WARNING! SLOPE MAY BE TOO FLAT FOR PROPER DRAINAGE IN TERRACE CHANNEL."
        ys(II,J)=1
      END IF
      IF (KB3.EQ.KB4) THEN
        IF (tempys(II, J).GT. ys(II,J)) ys(II,J) = tempys(II,J)
      End If
      D = ys(II, J)
      IF (SPACE1.LT.0.AND.J.EQ.WWPT(II,APLIN(II,J))) THEN
        IF (AREA2(II,APLIN(II,J)).NE.0) GOTO 2004
        SPACE(II,J)=SPACE1
        SPACE1=-SPACE1
        GOTO 1943
      END IF
      SPACE(II,J)=SPACE1
C   CALCULATE AVERAGE CHANNEL DEPTH
      COUNTER=COUNTER+1
      SUM_DEPTH=ys(II,J)+SUM_DEPTH
      AVG_DEPTH(II)=SUM_DEPTH/COUNTER
2004  CONTINUE

*****
* CALCULATE MAXIMUM SLOPE USING MANNING'S EQUATION AND RATIONAL METHOD*****
C   ADDITION--MELISSA BAY 6.10.2010*****

DO 2011 II=1,NT
  continue
  DO 2011 J=1, NP1(II)-1
    LENGTH(II,1)=0
    IF (SPACE(II,J).EQ.-1) NTARE(II,J+1)=TARE(II,J+1)

```

```

      IF (SPACE(II,J).EQ.1) NTARE(II,J+1)=TARE(II,J)
      IF (J.EQ.WWPT(II,APLIN(II,J))) THEN
        IF (APLIN(II,J)/2.NE.APLIN(II,J)/2.) THEN
          NTARE(II,J+1)=AREA2(II,APLIN(II,J))
        ELSE
          NTARE(II,J+1)=TARE(II,J+1)
          SPACE(II,J)=-SPACE(II,J)
        END IF
      END IF
C*****

      MXSLP1(II,J+1) = ((V ** (8.0 / 3.0)) * (N ** 2) * 1238.01 * (B + (2 * D * (Z1 ** 2 + 1) ** 0.5))
** (4.0 / 3.0)) / (2.21 * ((B
  * D) + (Z1 * D ** 2)) ** (2.0 / 3.0) * ((NTARE(II,J+1)) * P * C) ** (2.0 / 3.0))
      L(II,J+1)= DIFF(NX(II,J), NY(II,J), NX(II,J+1),NY(II,J+1))
      LENGTH(II,J+1)=LENGTH(II,J)+L(II,J+1)
*****
*****
      IF (NELEV(II,J).EQ.0) NELEV(II,J)=NZ(II,J)
      IF (NELEV(II,J+1).EQ.0) NELEV(II,J+1)=NZ(II,J+1)
      J3=(NELEV(II,J+1)-NELEV(II,J))*SPACE(II,J)
      ASLOPE=J3/L(II,J+1)
*****
*****
**CHECK FOR MAXIMUM SLOPE REQUIREMENT--ADJUSTS ELEVATIONS IF NEEDED*****
*****
C ** ELEVATION ADJUSTMENTS ARE LIMITED TO CUTS ONLY (PER NRCS)
      G(II, J) = (L(II, J+1) * MXSLP1(II,J+1))
C ** ADJUSTS ELEVATION OF NEXT DATA POINT IF SLOPE TOO STEEP
      IF (ASLOPE .GT. MXSLP1(II,J+1)) THEN
        IF (SPACE(II,J).GT.0) THEN
          NELEV(II, J+1) = NELEV(II, J) +(SPACE(II,J)* G(II, J))

```

```
CUT(II, J+1) = (NZ(II, J+1) - NELEV(II, J+1))
```

```
ELSE
```

```
NELEV(II, J)=NELEV(II, J+1)+G(II, J)
```

```
CUT(II, J)=(NZ(II, J)-NELEV(II, J))
```

```
END IF
```

```
End If
```

```
C ** SETS DEFAULT OF 4FT AS MAX CUT DEPTH
```

```
IF (CUT(II, J+1) .GT. 4) WARN(II, J+1) = "TOO MUCH CUT NEEDED--RECOMMENDED TO PICK NEW  
KEY TERRACE"
```

```
C ** KEEPS OLD ELEVATIONS IF SLOPE IS LESS THAN OR EQUAL TO MAX SLOPE
```

```
IF (ASLOPE.LE.MXSPL1(II, J+1).AND.ASLOPE.GE.0.001) THEN
```

```
IF (NELEV(II, J+1) .EQ. 0) THEN
```

```
NELEV(II, J+1) = NZ(II, J+1)
```

```
End If
```

```
GOTO 175
```

```
End If
```

```
C ** CALCULATES NEW ELEVATIONS IF FLOW IS IN THE WRONG DIRECTION
```

```
IF (ASLOPE .LT. 0.001) THEN
```

```
IF (SPACE(II, J).GT.0) THEN
```

```
NELEV(II, J)=NELEV(II, J+1)-(0.001*L(II, J+1))
```

```
CUT(II, J)=NZ(II, J)-NELEV(II, J)
```

```
END IF
```

```
IF (SPACE(II, J).LE.0) THEN
```

```
NELEV(II, J+1)=NELEV(II, J)-(0.001*L(II, J+1))
```

```
CUT(II, J+1)=NZ(II, J+1)-NELEV(II, J+1)
```

```
END IF
```

```
END IF
```

```
IF (NELEV(II, J+1) .EQ.0) NELEV(II, J+1) = NZ(II, J+1)
```

```
IF (J.LT.2) GOTO 175
```

```
*****  
*****
```

```
C ADDITION--6/30/2010-- MELISSA BAY-- LOOP TO GO BACK THROUGH POINTS AND CHECK THAT CHANGES IN  
CURRENT POINTS DO NOT AFFECT PREVIOUS POINTS
```

```
C LOOP WORKS BACKWARDS DOWN TERRACE
```

```

DO 340 J2=J, 2 , -1
  N3=NELEV(II, J2-1)
  TEMPSLOPE=((NELEV(II, J2)-N3)*SPACE(II, J2-1))/L(II, J2)

```

```

C   CAN ONLY BE TOO STEEP WHEN SPACE=-1
  IF (TEMPSLOPE .GT. MXSLP1(II, J2)) THEN
    NELEV(II, J2-1) = NELEV(II, J2) - (SPACE(II, J2-1)* G(II, J2-1))
    CUT(II, J2-1) = (NZ(II, J2-1) - NELEV(II, J2-1))
  End If

```

```

C   WHEN MXSLP1 IS NOT EXCEEDED, THEN WE CAN STOP CHECK PREVIOUS POINTS AND FINISH CHECKING REST OF
TERRACE
  IF (TEMPSLOPE .LE. MXSLP1(II, J2).AND.TEMPSLOPE.GE.0.001) GOTO 175

```

```

C   CAN ONLY BE TOO FLAT WHEN SPACE=1
  IF (TEMPSLOPE .LT. 0.001) THEN
    IF (SPACE(II, J2-1).GT.0) THEN
      IF (NELEV(II, J2)-(0.001*L(II, J2)).GT.NELEV(II, J2-1)) THEN
        NELEV(II, J2-1) = NELEV(II, J2) - (G(II, J2-1))
      ELSE
        NELEV(II, J2-1) = NELEV(II, J2) - (0.001 * L(II, J2))
      END IF
      CUT(II, J2-1)=NZ(II, J2-1)-NELEV(II, J2-1)
    END IF
    IF (SPACE(II, J2-1).LE.0) THEN
      NELEV(II, J2)=NELEV(II, J2-1)-(0.001 * L(II, J2))
      CUT(II, J2)=NZ(II, J)-NELEV(II, J2)
    END IF
  END IF

```

```

  IF (NELEV(II, J2) .EQ. 0) NELEV(II, J2) = NZ(II, J2)
  IF (CUT(II, J2-1) .GT. 4) WARN(II, J2-1) = "TOO MUCH CUT NEEDED--RECOMMENDED TO PICK NEW
+ KEY TERRACE"
  IF (CUT(II, J2) .GT. 4) WARN(II, J2-1) = "TOO MUCH CUT NEEDED--RECOMMENDED TO PICK NEW
+ KEY TERRACE"

```

340 CONTINUE

C\*\*\*\*\*  
\*\*\*\*\*

175 CONTINUE

8240 FORMAT(I5,4X,I5,4X,I5,4X,I5,4X,F11.4,4X,F11.4,4X,F11.4,4X,F11.4,4X,A60,4X,F11.4,4X,F11.4,4X)  
\*\*\*\*\*  
\*\*\*\*\*

7030 FORMAT('D',5X,I2,I4,F8.2,F10.4,F10.4)  
WRITE(6,7030)II,J,NZ(II,J),ASLOPE,MXSLP1(II,J+1)

2011 CONTINUE

DO 2031 II=1, NT

7040 FORMAT('D',5X,'TERRACE #',I2,5X,'TERRACE POINT', 'X',5X,'Y',5X,'ELEVATION',5X,'CUT  
DEPTH(FEET)')

WRITE(6,7040) II

DO 2031 J=1, NP1(II)

7050 FORMAT('D',25X,I4,F10.4,F10.4,F10.4,F10.4)

2031 WRITE(6,7050) J,NX(II,J),NY(II,J),NELEV(II,J),CUT(II,J)

CALL UGO\_DESIGN

(NT,TOTWW,WWPT,AREA2,TARE,C,AVG\_DEPTH,NP1,AVERAGE\_VI,AVERAGE\_HI,HI,NZ,BERM\_HEIGHT,NUM\_HOLES,ORF\_DIAME  
TER,

+D\_SEALED,D\_2)

END

SUBROUTINE UGO\_DESIGN

(NT,TOTWW,WWPT,AREA2,TARE,C,AVG\_DEPTH,NP1,AVERAGE\_VI,AVERAGE\_HI,HI,NZ,BERM\_HEIGHT,NUM\_HOLES,ORF\_DIAME  
TER,

+ D\_SEALED,D\_2)

C \*\*\* \*\*

C \*

C \* UGO\_DESIGN -- FINDS DISCHARGE FROM EACH TERRACE AND DETERMINES \*

```

C *           WHAT CONDUIT PIPE SIZE IS REQUIRED FOR PROPER DRAINAGE *
C * I/O VARIABLES: *
C * NT         TOTAL NUMBER OF TERRACES                IN *
C * TOTWW      TOTAL NUMBER OF WATERWAYS (INCLUDING DIVIDES) IN *
C * WWPT()     WATERWAY INTERSECTION INDEX PT ON TERRACE IN *
C * TARE()     DRAINAGE AREA AT OUTLET FOR FIRST SIDE   IN *
C * AREA2()    DRAINAGE AREA AT OUTLET FOR SECOND SIDE IN *
C * C          RUNOFF COEFFICIENT (DIMENSIONLESS)      IN *
C * AVG_DEPTH  AVERAGE WATER DEPTH IN TERRACE CHANNEL IN *
C * NZ         ELEVATION AT TERRACE POINT              IN *
C * *
C *** ** *
REAL AREA2(15,10),NZ(15,200), TARE(15,200),MANNINGSN
INTEGER NT, TOTWW, WWPT(15,10),NP1(15)
REAL Q_RELEASE_OUT(15,10),Q_IN(15,10),Q_RATIO(15,10),VOL_STORAGE(15,10)
REAL BERM_HEIGHT(15,10), NUM_HOLES(15,10), ORF_DIAMETER(15,10)
REAL Q_DISCHARGE(15,10), D_2(15,10), D_SEALED(15,10),VOL_RUNOFF(15,10)
REAL AVERAGE_VI(15),AVERAGE_HI(15),AVG_DEPTH(15),HI(15,200)
CHARACTER * 60 WARN2(15, 10)
REAL P_GRADIENT

DO 2990 II=1,NT
    AVERAGE_HI(II)=0
    AVERAGE_VI(II)=0
    DO 2990 I=1,TOTWW
        Q_RELEASE_OUT(II,I)=0
        Q_IN(II,I)=0
        Q_RATIO(II,I)=0
        VOL_STORAGE(II,I)=0
        BERM_HEIGHT(II,I)=0
        NUM_HOLES(II,I)=0
        ORF_DIAMETER(II,I)=0
        Q_DISCHARGE(II,I)=0
        D_2(II,I)=0
2990 D_SEALED(II,I)=0

```

```

        SUM_VI=0
        SUM_HI=0
T_RELEASE=24
S_DURATION=24
I_24=5.4
PI=3.14593
DO 3000 II=1, NT
    DO 3000 I=1, TOTWW
        IF (WWPT(II,I).EQ.0) GOTO 3000
        IF (I.LE.2) GOTO 3030
        IF (WWPT(II,I).EQ.WWPT(II,I-2))GOTO 3000
3030    IF (I/2.EQ.I/2.0) GOTO 3000
        SUM_VI=0
        SUM_HI=0
        P_GRADIENT=0
C---STEP 1-- CALCULATE DESIGN FLOW RATE (ACRE-IN/HR=CFS) NEEDED FOR RELEASE
        VOL_RUNOFF(II,I)=C*(I_24)*((AREA2(II,I)+TARE(II,WWPT(II,I)))/43560)
        Q_RELEASE_OUT(II,I)=VOL_RUNOFF(II,I)/T_RELEASE

C--STEP 2--CALCULATE FLOW RATE (ACRE-IN/HR) OF PEAK STORM RUNNOFF--TRIANGULAR HYDROGRAPH ASSUMED
CALCULATE RATIO OF Q_RELEASE_OUT/Q_IN & PLUG INTO UNDERGROUND OUTLET ROUTINE CURVE EQUATION
        Q_IN(II,I)=2*VOL_RUNOFF(II,I)/S_DURATION
        Q_RATIO(II,I)=Q_RELEASE_OUT(II,I)/Q_IN(II,I)
        VOL_STORAGE(II,I)=VOL_RUNOFF(II,I)*((0.4817*(Q_RATIO(II,I))**2)-
(1.4491*Q_RATIO(II,I))+0.9814)

STEP 4--CALCULATE BERM HEIGHT--BHEIGHT=(AVG_DEPTH(II)/0.7)+FREEBOARD(0.5 FT)
        BERM_HEIGHT(II,I)= (AVG_DEPTH(II)/0.7)+0.5
        IF (BERM_HEIGHT(II,I).LT.1) BERM_HEIGHT(II,I)=1
        BERM_HEIGHT(II,I)=(1.1*BERM_HEIGHT(II,I))

C--STEP 5--DESIGN INLET HOLES & PIPE SIZE
        HOLE_AREA=0.00545

```

```
NUM_HOLES(II,I)= CEILING((0.3*2*Q_RELEASE_OUT(II,I))/(HOLE_AREA*BERM_HEIGHT(II,I)**0.5))
```

```
C--STEP 6--DESIGN ORIFICE PLATE AND ACTUAL DISCHARGE TO PROPERLY DRAIN TERRACE CHANNEL
```

```
H2=2.5
```

```
HEAD=(0.7*BERM_HEIGHT(II,I)+ H2)
```

```
A_ORF=Q_RELEASE_OUT(II,I)/(0.6*(2*32.2*HEAD)**0.5)
```

```
D_ORF=((4*(A_ORF)/PI)**0.5)*12
```

```
ORF_DIAMETER(II,I)= QuarterRound(D_ORF)
```

```
IF (ORF_DIAMETER(II,I).LT.1.5) ORF_DIAMETER(II,I)=1.5
```

```
Q_OUT=0.6*PI*((ORF_DIAMETER(II,I)/12)**2.0)/4*(2*32.2*HEAD)**0.5
```

```
C--STEP 7--DESIGN OUTLET CONDUIT
```

```
MANNINGSN=0.016
```

```
C PARALLEL PIPE ALONG GROUND SURFACE--USE SAME GRADIENT
```

```
NP2=NP1(II)
```

```
IF (II.EQ.NT) THEN
```

```
    P_GRADIENT=AVERAGE_VI(II-1)/AVERAGE_HI(II-1)
```

```
    GOTO 3001
```

```
ENDIF
```

```
IF (NP1(II+1).LT.NP1(II)) NP2=NP1(II+1)
```

```
DO 3010 J4=1,NP2
```

```
    SUM_VI=SUM_VI+(NZ(II,J4)-NZ(II+1,J4))
```

```
3010    SUM_HI=SUM_HI+HI(II+1,J4)
```

```
AVERAGE_VI(II)=SUM_VI/NP2
```

```
AVERAGE_HI(II)=SUM_HI/NP2
```

```
P_GRADIENT=AVERAGE_VI(II)/AVERAGE_HI(II)
```

```
Q_DISCHARGE(II,I)=Q_OUT
```

```
3001 IF (II.NE.1) Q_DISCHARGE(II,I)=Q_DISCHARGE(II-1,I)+Q_OUT
```

```
D_SEALED(II,I)=CEILING(((3.22*Q_DISCHARGE(II,I)*MANNINGSN)/(1.485*P_GRADIENT**(0.50)))**(3.0/8.0)*12)
```

```
    D_TEST1=CEILING(D_SEALED(II,I)/2)
```

```
    D_TEST2=D_SEALED(II,I)/2.0
```

```
    IF (D_TEST1.NE.D_TEST2) D_SEALED(II,I)=D_SEALED(II,I)+1
```

```
IF (D_SEALED(II,I).LT.4) D_SEALED(II,I)=4
```

```
IF (D_SEALED(II,I).GT.12) THEN
```

```

                WARN2(II,I)="WARNING! CONDUIT PIPE DIAMETER OVER 12 INCHES IS REQUIRED!"
                D_2(II,I)=D_SEALED(II,I)-12
                D_SEALED(II,I)=12
                IF (D_2(II,I).LT.4) D_2(II,I)=4
        END IF
3020
Q_DISCHARGE(II,I)=(1.485/MANNINGSN*PI/4*((D_SEALED(II,I)+D_2(II,I))/12)**2.0)*((D_SEALED(II,I)+D_2(II
,I))/(4*12))**(2.0/3.0)*
        (P_GRADIENT**0.5)
        IF (II.NE.1)
Q_DISCHARGE(II,I)=(1.485/MANNINGSN*PI/4*((D_SEALED(II,I)+D_2(II,I))/12)**2.0)*((D_SEALED(II,I)+D_2(II
,I))/(4*12))
        ** (2.0/3.0)*(P_GRADIENT**0.5)+Q_DISCHARGE(II-1,I)
3000        CONTINUE

```