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INCREASED FUNCTIONALITY OF FLOODPLAIN MAPPING  
AUTOMATION: UTAH INUNDATION  
MAPPING SYSTEM (UTIMS)

by

Brian K. Stevens

A thesis submitted in partial fulfillment  
of the requirements for the degree

of

MASTER OF SCIENCE

in

Civil and Environmental Engineering

Approved:

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UTAH STATE UNIVERSITY  
Logan, Utah

2009

## ABSTRACT

Increased Functionality of Floodplain Mapping Automation:  
Utah Inundation Mapping System (UTIMS)

by

Brian K. Stevens, Master of Science

Utah State University, 2009

Major Professor: Dr. Sanjay S. Chauhan  
Department: Civil and Environmental Engineering

Floodplain mapping has become an increasingly important part of floodplain management. Floodplain mapping employs mapping software and hydraulic calculation packages to efficiently map floodplains. Modelers often utilize automation software to develop the complex geometries required to reduce the time to develop hydraulic models.

The Utah Inundation Mapping System (UTIMS) was designed to reduce the time required to develop complex geometries for use in floodplain mapping studies. UTIMS reduces the time required to develop geometries used in floodplain management studies. The automated geometries developed include: flood specific river centerlines, bank lines, flow path lines, cross sections, and areal averaged n-value polygons. Utilizing this robust and easy-to-operate software within the GIS environment modelers can significantly reduce the time required to develop accurate floodplain maps. Modelers can thus spend

less time developing complex geometries and more time modeling and analyzing  
floodplains.

(189 pages)

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Brian K. Stevens

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## CHAPTER 1

### INTRODUCTION

Floodplain mapping has become a highly specialized area of expertise within engineering relying heavily on the art of geographic data processing and hydraulic modeling for effective floodplain management. Floodplain management relies on hydrologic and hydraulic studies to investigate flood risk. Previous to the 1960's in the United States large flood control structures were built to reduce flood damage. A shift in focus in policy by the federal government nearly 40 years ago now focuses on non-structural measures to mitigate flood damage. These non-structural measures focus on determining the flood risk in specific zones, as viewed on floodplain maps, as described by the National Flood Insurance Program (NFIP). While the NFIP focuses on non-structural methods of managing the floodplain, managing the risk posed by current and proposed dams is also a vital part of floodplain management. Dam safety analyzes the risk that dams pose to society. The area of dam safety risk management seeks to bring the risk that dams pose to society under tolerable levels.

One of the important inputs into dam safety risk analyses is the extent that flooding occurs in connection with the various ways of dam operations or failures. The federal government has specified specific hydraulic models which may be used in floodplain mapping. The standard for hydraulic modeling software is provided by the Army Corps of Engineers' Hydraulic Engineering Corps (HEC). In 1985 HEC released HEC-2, which is a one-dimensional hydraulic engine to calculate water surface profiles for river analysis for both steady and unsteady flow. In subsequent releases HEC has developed a graphical user interface and released the software

package known as HEC-River Analysis Software (HEC-RAS). This software has become the standard to which all new hydraulic models are measured.

The development of HEC-RAS projects requires geometric data, flow data and plan files to delineate flooding extents. The large amount of time taken to produce complex river geometries within HEC-RAS prompted HEC to develop the software HEC-GeoRAS. HEC-GeoRAS handles geometries digitized by users within geographic information systems (GIS), located in layers, to create geometric input files which are imported into HEC-RAS to create a HEC-RAS geometry file. HEC-GeoRAS also handles output data from HEC-RAS to map flooding extents, depth and velocity. This modeling aid in the area of geometric file development was the first of its kind.

For complex riverine systems the development of these layers used by GeoRAS may take significant amounts of time to digitize by hand within a geographic information system. Although GeoRAS is effective in aiding users to develop geometric files and view output, other softwares have been developed to reduce the time required by modelers to perform these tasks by automating much of the process. Along with geometric file setup automation these new softwares have also sought to automate the setup of steady flow and plan files to create a complete hydraulic model. These softwares allow modelers the ability to significantly reduce the time required to map flood profiles.

The newly developed softwares often use GIS in developing and analyzing data. Geographic information systems provide a convenient utility to create, manage and analyze data. ESRI's ArcGIS has become a central figure in the realm of

geographic information systems due to its ability to create process and analyze large amounts of data in several formats.

This thesis describes a new floodplain mapping software which significantly increases the mapping capabilities of modelers in hydraulic analysis. This automation software significantly facilitates the correct characterization of the floodplain and reduces the time required in developing flood extents used for vital input into dam safety risk analyses and NFIP rate maps. The focus of this software is to facilitate the efficient development of reasonable RAS geometries so that a hydraulic modeler can focus their efforts on hydraulic modeling and analysis. Therefore the overarching focus of this software developed is on the reasonableness and efficiency from the practical application point of view, not necessarily on the exactness from a physics point of view. This thesis describes the reasoning and methodology of this new floodplain mapping software. Current floodplain mapping protocols and techniques with regard to hydraulic modeling are also discussed.



## CHAPTER 2

### STATE OF AUTOMATED FLOODPLAIN MAPPING

#### Floodplain Management Through Mapping

Historically water has been stored in reservoirs by utilizing dams to be used by society and provide a level of safety from flooding. While dams provide a level of benefit to society they also pose a hazard to property and life. Occasionally dams have failed releasing stored water causing economic damage and loss of life. As the knowledge of sound dam design and construction has improved the level of required safety of dam owners has been increased, and dam safety has become a vital part of the construction and maintenance of dams. Dam owners are held liable for losses or damages resulting from dam failure. In recent years the area of risk assessment and management in the area of dam safety has become increasingly important. Dam owners can assess the risk their dams pose to the surrounding population by considering the possible damages their dams may cause to impacted areas due to various events. Hazards which threaten dams include: extreme precipitation, earthquakes, landslides and internal erosion (piping) failures.

The area of risk assessment analyzes the complete spectrum of each hazard which a dam faces to identify the risk associated with dams. For all modes of possible damage to dams or complete failure the risk associated with the full spectrum of magnitudes of precipitation, earthquakes, landslides and internal erosion are identified. This allows professionals to accurately understand the risk that a dam poses, and allows owners to quickly identify and take appropriate steps to minimize the risk their

dams pose. In the case of precipitation, not only the probable maximum flood (PMF) but the full spectrum of possible inflows from threshold flood to PMF is considered, where the threshold flood is the minimum flow that can cause failure of the dam.

A critical input into dam safety risk assessment is economic damage and life loss estimates due to flooding. These estimates are acquired through floodplain mapping, which describes the extent, depth and velocity of flood waters. For estimation of economic damages and life loss modelers are often interested in key locations of flooding in the downstream areas affected by flooding water. These key locations may include population centers and/or bridges. Due to these critical points of interest in the downstream floodplain modelers will often place critical cross sections at these locations to accurately identify the extent of flooding in these sensitive areas. More details concerning the methods of dam break floodplain mapping will be discussed in the later portion of this document entitled “Extreme Flows.”

The National Flood Insurance Program (NFIP) provides property owners in communities that participate in compliance to regulations the ability to purchase insurance for protection against flood losses. The compliance with which communities must meet is to take action to prevent future flood losses by effectively managing the community’s flood zones. Flood zones are displayed on Flood Insurance Rate Maps (FIRMs) and describe the possible hazards of flooding in specific areas. The NFIP is managed by the Federal Emergency Management Agency (FEMA), from which property owners may purchase flood insurance. The standard for the insurance plan has been identified as the one-percent-annual-chance flood, also

known as the 100-year or “Base Flood.” This level of risk provides Federal agencies and most States a standard with which to govern floodplain management programs.

Flood Insurance Studies (FISs) were instituted to designate the flood risk posed in specific areas of communities. Floodplain boundaries are shown on the FIRM for the 100-year flood, and possibly the 500-year flood. Base flood elevations (BFEs) are used in developing flood insurance rate maps (FIRMs). FIRMs geographically show the results of an FIS, in determining flood hazards in various areas. An FIS along with a FIRM provide the basis for flood management, mitigation and insurance information as described by the NFIP. An FIS provides the basic information for the determination of flood insurance rates along with providing communities a floodplain management plan. The floodplain boundary is delineated using the water surface elevations at specific cross sections.

### Hydraulic Model Development

Hydraulic model development requires geographic data and flow information to define the areas inundated by a flow. Hydraulic models can take significant time to develop, specifically if complex geometries are being studied and an iterative process is required in analyzing extremely large flows. To develop complete hydraulic models modelers must consider the magnitude of flow to be studied to correctly define the spatial extent which geometries must cover. The geometry development for relatively low and extreme flows may be quite different.

The U.S. Army Corps of Engineers River Analysis System (HEC-RAS) was

developed by the Hydrologic Engineering Center (HEC) for the purpose of performing one-dimensional hydraulic river analysis. HEC-RAS is the result of the further development of the precursor HEC-2, to which a user interface was added along with some new functionalities to produce HEC-RAS. HEC-RAS supports steady and unsteady flow analyses. In conjunction with steady and unsteady flow studies, there are capabilities within HEC-RAS for performing floodway encroachment, scouring at bridge, stable channel design, sediment transport, dam break, levee overtopping and breaching, navigation dams, pump station and river profiles at confluences analyses. HEC-RAS provides an efficient manner in which to manage data, enter and edit data, perform hydraulic calculations, analyze data input and display results in tabular and graphical form.

All complete HEC-RAS projects are defined by four types of files which include: a project file (".prj"), geometric file (".g01"), flow file (either ".f01" for steady or ".u01" for unsteady flow) and a plan file (".p01"). For each project file there may be many geometry, flow and plan files to select from to perform hydraulic computations. For more than one geometric, flow or plan file HEC-RAS utilizes a digit increment file scheme which defines files by the type and number of file associated with a particular project. This is done by adding numbers to the end of the file type to indicate which file it is, for example beginning with ".g01" and increasing by one up to "nn" number of files (".gnn") for subsequent files. The content of geometry files will be focused on hereafter, however, for an interested user the content of flow and plan files are discussed in USACE (2008). The geometry file contains all the physical data defining the passageway of flow, such as cross sections, bridges,

levees, culverts, weirs, gated spillways, river ice cover and storage areas.

The required geometries to develop a floodplain inundation map are: river centerlines, cross sections, bank lines and flow path lines. River centerlines represent the centerline of flow for the level of flow that is contained within the river banks. Cross sections are the primary geometric data used in determining water surface profiles. This is because they not only represent the channel through which flow is passed, but also describe the friction factors that HEC-RAS uses in determining water surface profiles. The two bank lines (left and right) for a given river reach define the main channel and the right and left overbank areas. The three flow path lines (main, left and right) for a given river reach define the centerline of the flow path and the flow path lengths within the main channel and left and right overbank areas.

The correct development of geometric data comprising the basic cross section data is critical in developing an accurate hydraulic model, because cross sectional data is the basis with which HEC-RAS performs hydraulic computations. Cross sections should represent the perpendicular to river flow profile and are required to be oriented from left to right when looking in the downstream direction. Each cross section is defined by a unique river station on a specific river reach. River station values can range from a minimum of zero, if it were located at the bottom of a river reach, and a maximum of the length of a river reach, if the cross section was at the furthest upstream position. Therefore the river station represents how far from the downstream end of a river a cross section crosses the river reach centerline. The river station for each cross section is an identifier for the cross section. The points along a cross section, defining the shape of a cross section profile, are known as cross section

stations. For each cross section station there is an associated elevation which completes the shape of the cross section profile by defining the two-dimensional view of a cross section. Thus the cross section becomes the perpendicular profile of a river flow path. Two of the stations along the profile are designated as “main channel bank stations,” which are used by HEC-RAS in channel and overbank computations. Along with the station and elevation data are associated friction values (either  $n$  or  $K$ -values) which are used by HEC-RAS in determining conveyance through the cross sections. A cross section is divided into a maximum of 20 segments to define the distinct friction value for that segment of the cross section. Values for overbank and main channel lengths are also specified in the geometry file. The overbank and main channel lengths are determined for a specific cross section by calculating the distance from itself to the next cross section in the downstream direction. These distances represent the degree of turn or meandering in the reach between the current and subsequent cross section. For each cross section there are also contraction and expansion coefficients used in the calculation of energy loss through the cross section.

Due to HEC-RAS being a one-dimensional hydraulic model when flooding spreads out over floodplain areas hydraulic modelers will often need to create cross sections which essentially approximate the two-dimensional nature of the flow for one-dimensional modeling by HEC-RAS. These cross sections may take the form of arcs extending outward from the direction of flow (convex downstream) or the form of “dog-legs,” which are often utilized when expanding flood wave fronts fan out into the floodplain.

To facilitate the creation of geometric files for use by and the viewing of

output from HEC-RAS the software package HEC-GeoRAS was created to manage the passage of geographic information between the GIS environment and HEC-RAS. HEC-GeoRAS is a utility toolbar that is available to be loaded within the GIS environment, which can be downloaded free from the HEC website ([www.hec.usace.army.mil/software/hec-ras](http://www.hec.usace.army.mil/software/hec-ras)). HEC-GeoRAS facilitates the development of geographic features to be stored in GIS layers. Users edit the layers by digitizing or loading pre-existing data into these layers in preparation to developing a geometric file for use by HEC-RAS. The basic data HEC-GeoRAS utilizes in developing geometry files include a digital terrain model (DTM), in the form of a GRID or triangulated irregular network (TIN), and geographic features located in GIS layers. HEC-GeoRAS handles these layers and by utilizing the digital terrain model creates an input file, which HEC-RAS accepts as an input for the creation of a geometry file. Upon completion of hydraulic computations HEC-RAS allows for the export of water surface profile data into an output file. With the output file HEC-GeoRAS creates new GIS layers representing water surface extents, velocity grids, and depth grids which can be viewed and analyzed within GIS.

HEC-GeoRAS supports the creation of several types of geometric data for input into HEC-RAS including: stream networks, bank lines, flow path centerlines, cross sections, bridges, culverts, ineffective flow areas, blocked obstructions, land use areas, levees, inline structures, lateral structures and storage areas. The basic information required to develop an input file for HEC-RAS is digital terrain data, stream network, cross-sections, bank lines, flow path lines and n-value assigned land use polygons.

The stream centerline layer plays an important role in the setup of the input file for HEC-RAS. This is due to the fact that the river centerline is used as a guide, along with elevation data and possibly contour lines, in placing cross sections. Cross sections are required to be perpendicular in orientation to the river flow path. The stream centerline generally describes the centerline of the flow path, particularly for the levels of flow contained within the river banks, thus the stream centerline is used as a guide in placing cross sections. HEC-GeoRAS accepts pre-existing stream networks or allows users to digitize a river network within GIS. For each river reach of a river network a name for the river and reach are required, connectivity is tested and verified by creating junction nodes and reach lengths are calculated..

The cross section layer holds the polylines which are used along with digital terrain data to describe cross section profiles to be used by HEC-RAS. HEC-RAS computations rely upon the cross section profiles, which provide the elevation profile, main channel and overbank lengths to the next cross section, along with representative n-values for segments of each cross section in determining river surface profiles. Therefore the creation of cross sections is vitally important for correct representation of river hydraulics within HEC-RAS. Correct cross sections should be perpendicular to the direction of flow, are oriented from left to right when looking in the downstream direction, should not intersect, must cross a stream centerline only once, and must be contained within the extent of the digital terrain model. Cross sections may be either digitized using the Editor in GIS or created with the automated cross section placement tool located on the HEC-GeoRAS toolbar.

The bank layer used by GeoRAS describes the general position of bank



stations in relation to the river centerline. With this layer bank stations are calculated along a cross-sectional profile. Left and right banks are used for each reach of a river.

The flow path layer describes the center channel, left overbank and right overbank flow lines. This layer is used in calculating the center, left overbank and right overbank distances between subsequent cross sections down a river reach. These values are used within HEC-RAS to represent the degree of turning or meandering in a river reach.

The land use layer is used to determine n-values for segments of cross sections, for use as friction factors by HEC-RAS. The land use layer is comprised of polygons representing various land use areas. The land use theme must cover the extent of the cross sections. Upon completion of the polygons a user develops a land use name – n value specific table which HEC-GeoRAS utilizes to assign n values to segments of cross sections according to the type of land use type exhibited by the land use polygon layer.

For other layers that are available to be constructed to develop geometric input file, the reader is referred USACE (2005).

In hydraulic modeling, modelers must consider the scale of flow being analyzed. Flows which are relatively low will often remain in a well defined channel. Flows which surpass a well defined channel and extend into the surrounding floodplain have been termed “extreme” in nature. Examples of these “extreme” types of events include dam break and probable maximum flood. These types of events generally produce flows which leave the well defined channels and overflow into the overbank areas.

When flows are expected to go beyond their well defined river banks, significant overbank flooding occurs and thus special consideration to develop the required geometric features must be taken. As flows over bound the river banks, the river centerline will less accurately describe the centerline of the flow path. This is more particularly the case with extreme meandering river reaches on relatively flat terrain experiencing extreme flows. In this case for cross sections to be accurately described as perpendicular to the flow path, their placement must be perpendicular to the flow centerline rather than being perpendicular to the original river centerline.

In cases of extreme flooding geometry manipulation to accurately describe the flow path of large flows requires an intuitive decision making process to determine the orientation of cross sections relative to the original river centerline. Cross sections must be oriented perpendicular to the flow path of the river, thus care must be taken to carefully analyze the floodplain and its terrain including obstructions, storage areas and critical points that flow must pass. The process of cross section placement in this case becomes an art and can be difficult to develop.

In analyzing extreme flows and the associated flooding extents a modeler may iteratively make several changes to the initially assumed cross section placement after hydraulic computation to accurately describe flooding extents of particular level of flows being analyzed. Thus the mapping of extreme flows becomes iterative in nature. Modelers must analyze output results to determine if sufficient convergence has been met and that the utilized geometries have produced an accurate flood polygon. Thus in this iterative process of extreme flow modeling there exists a flow specific river centerline for each iteration which accurately describes the flow path of specific

extreme flows being modeled.

When flows are expected to remain within a narrow well defined channel the HEC-RAS model requires no special attention to geometry changes to develop the hydraulic model. The specified original river centerline sufficiently represents the main channel flow path for the flows and straight lined cross sections can be placed perpendicular to the river centerline to adequately model the flows.

#### Review of Time Requirements for Model Development

Development of the geographic features required for the development of an inundation study using HEC-GeoRas takes considerable amounts of time when digitized within the GIS environment. The time required to determine the correct placement and orientation of geographic features to be utilized by HEC-GeoRAS is often the critical factor in the total time of developing geometry files for use by HEC-RAS. The most vital of the basic geographic features required are the cross sections. These are required to lie perpendicular to the flow path and be spatially independent from each other and cross a river centerline only once. The development of appropriate cross sections for in-stream flow conditions is relatively simple and straight forward in nature. Extreme flow modeling, for reasons discussed in previous section, is of more rigorous, iterative and time intensive nature in developing appropriate cross sections. A case study was performed to determine the general time requirements to develop a basic geometry file for use within HEC-RAS.

The Utah Division of Water Rights (DWRi) led by the State Engineer is an agency of Utah State Government within the Department of Natural Resources which

regulates the dams located within the state of Utah for the purpose of protecting public safety. For the proposed research, in consultation with DWRI, the Millsite Dam and Reservoir on Ferron Creek was identified as a case study.

Ferron creek is located in eastern central Utah and provides water to the Ferron municipality, local industries and agricultural land. The creek is fairly straight in its upper portions; however, in the bottom half of the creek it meanders greatly. The headwaters of Ferron Creek are located west of Ferron, Utah, near the top of Ferron Canyon, in the Manti-La Sal Mountains. The creek travels several miles down the canyon into Millsite Reservoir. Upon passing through Millsite Reservoir Ferron Creek continues three more miles down into Ferron City. Ferron Creek then travels in a generally northeast direction for 24.8 miles before it joins Huntington creek and Cottonwood creek to form the San Rafael River. The San Rafael River then travels in a general southeast direction until it drains into the Colorado River in southeastern Utah. Figure 2-1 shows Ferron Creek and its accompanying digital terrain data.

The flow type taken into consideration was in-stream conditions where the flow path would be described by the river centerline. The general process of developing geographic data, as described by the GeoRAS User's Manual, within HEC-GeoRAS was followed, digitizing all features by hand. The process prescribed by the GeoRAS User's Manual is to digitize the stream network with guidance from contour lines created using digital terrain data. Therefore contour lines (at 5-foot interval) were developed within GIS. Then the river centerline was digitized by hand using the GIS Editor. The time required to perform this process for Ferron Creek was 45 minutes. Even after spending this time to digitize the river by hand it still did not precisely

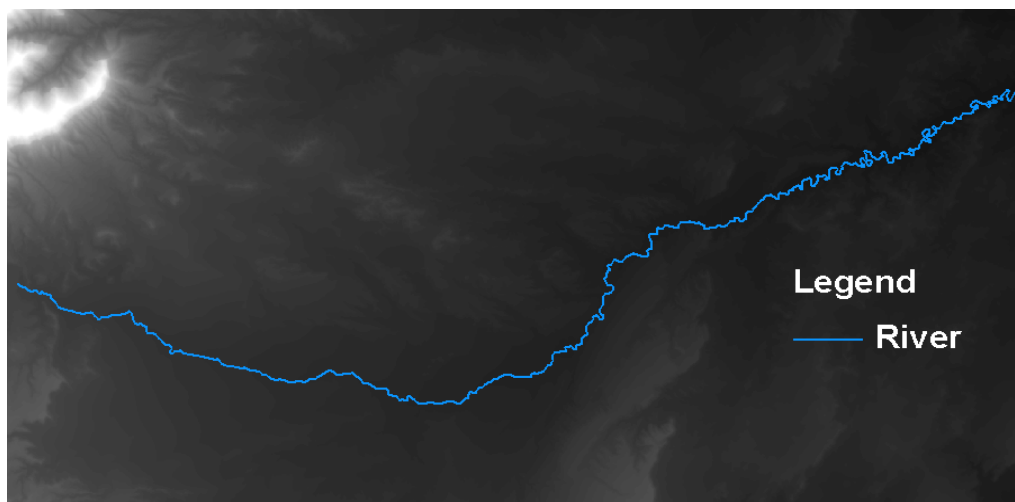


Figure 2-1. Ferron Creek.

match the original river centerline. Ferron creek has many meandering portions, making digitizing by hand difficult, therefore the centerline was loaded into the river network within ArcCatalog. Using the load feature significantly reduced the time it took to digitize the river centerline by hand. The time taken to correctly load one river centerline was five minutes.

The bank lines layer require two banks, left and right, for each reach of a river. Again the process of loading pre-existing features was used within ArcCatalog to populate the two geometries for the bank lines. The original river centerline was loaded into the bank lines layer and then was offset to create bank lines. The bank lines were offset 5 meters on either side of the original river centerline to create bank stations. An offset distance of 5 meters was chosen as the offset distance to keep the banks within narrow land form passages in the downstream reaches of Ferron Creek. This distance also worked well by not placing the bank lines in a position to overlap

any portions of the river centerline, particularly with respect to meandrous portions of the river. This process took ten minutes to complete.

The flow path centerlines layer requires a left, main channel and right flow path polylines for each reach of a river. These were again supplied by loading the original river centerline within ArcCatalog into the flow path feature class and offset 10 meters using the Editor within ArcMap. Again this distance was used to keep these lines within the narrow downstream overbanks of the Ferron Creek. This distance also did not create any overlapping between the left and right flow paths and the river centerline. This process took ten minutes to complete. Figure 2-2 shows the Ferron Creek (River), and the created bank and flow path lines. As can be seen they follow the general shape of the actual river center line.

The process of placing correct cross sections was somewhat tedious and much

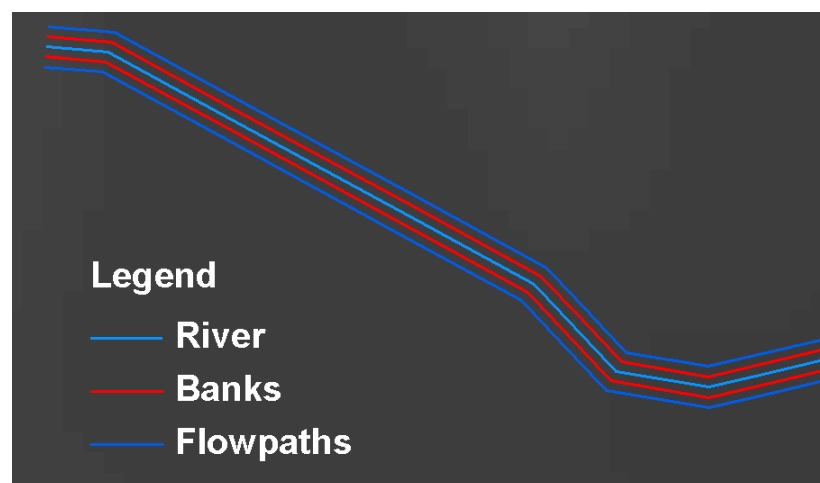


Figure 2-2. Offset banks and flowpaths used by HEC-GeoRAS.

more care in their exact placement was taken. The capability of HEC-GeoRAS to automatically place cross sections was utilized, by selecting the interval of placement and the width of the cross sections. HEC-GeoRAS, though, places cross sections with no regard to overlapping cross sections and cross sections crossing the river centerline multiple times. An interval of 100 meters and a width of 1000 meters were selected to place the cross sections along the river centerline. This distance and width were decided upon after visual inspection of the terrain over which the assumed floodplain would lie and the fact that in-stream flow was assumed to be modeled. Many of the created cross sections overlapped each other and the river centerline several times.

Figure 2-3 shows how GeoRAS placed the cross sections automatically. As can be seen they overlap and will not be accepted when the features are processed to create the input file for HEC-RAS. Figure 2-4 shows a close-up view of the lower reaches of Ferron Creek where many meanders exist.

Cross sections that either overlapped each other or crossed the river centerline more than once were deleted using the Editor within ArcGIS. Additional cross sections were added by digitizing using the following process. To satisfy the requirements of HEC-GeoRAS that no two cross sections cross each other and each may only cross the river centerline once the digital terrain data, contours and river centerline were observed in placing the cross sections in a perpendicular orientation to the river centerline going from left overbank to right overbank direction when looking the downstream direction. The process of placing cross sections took ninety minutes to complete.

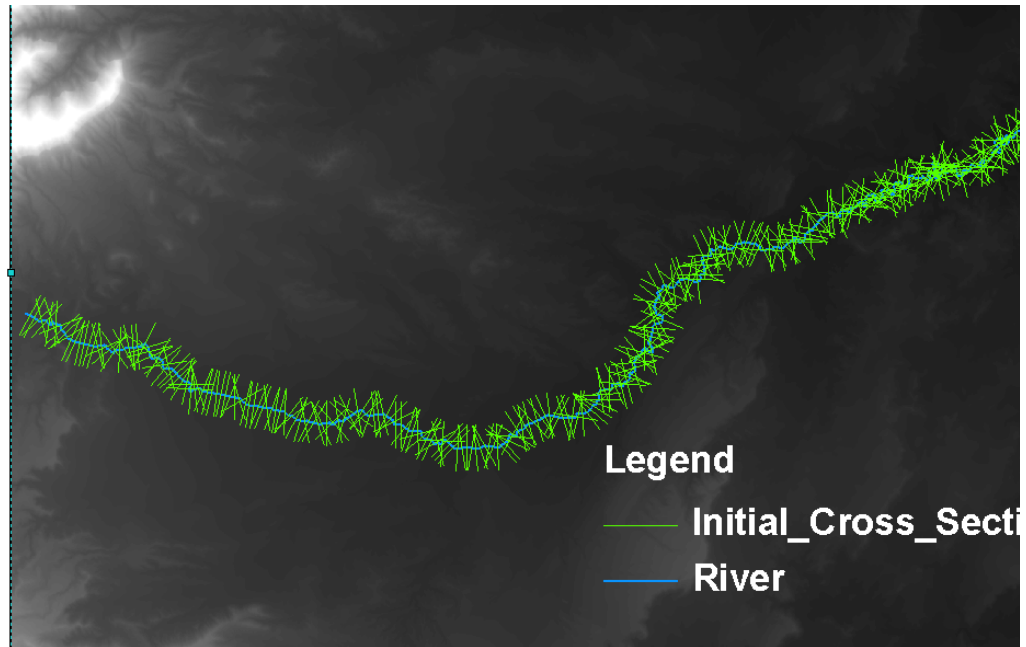


Figure 2-3. Automated placement of cross sections by HEC-GeoRAS.

The capabilities of HEC-GeoRAS in placing cross sections in comparison to UTIMS are discussed in the section entitled “Comparison of Softwares To UTIMS.” Figure 2-5 shows the corrected cross sections for the Ferron Creek. Figure 2-6 shows the meandrous portion of the Ferron Creek with the modified cross sections.

Land use polygons were obtained from the Utah state agency charged with handling GIS data for the state of Utah, the Utah Automated Geographic Reference Center (AGRC), which provided polygons depicting land use types. This data was again loaded into the land use layer created by GeoRAS. All similar land uses were merged to make a smaller land use – n value table. An extra polygon was extracted to fill in the gaps between polygons that had no land use data. This process took 20 minutes. With the completion of the land use theme a manning’s n-value table was



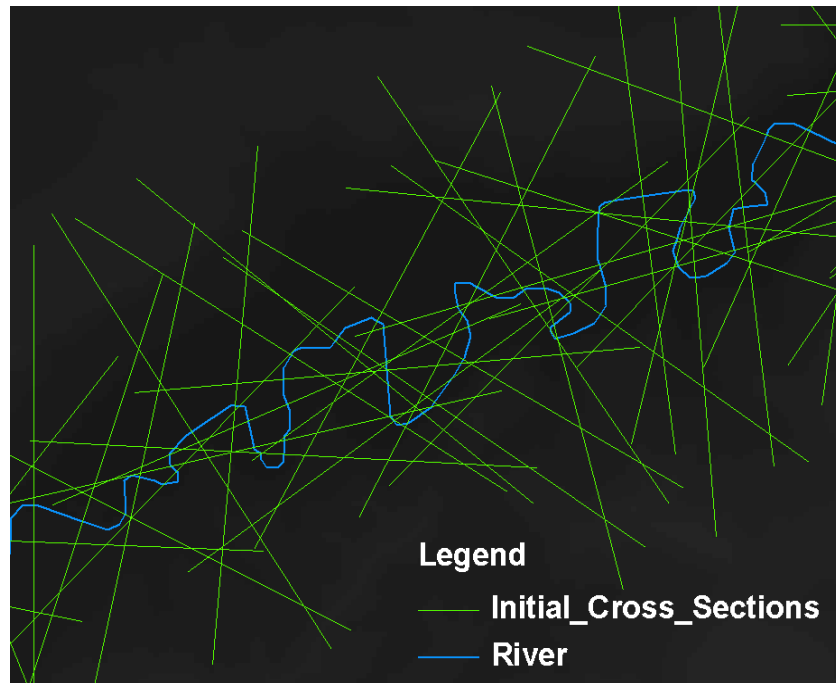


Figure 2-4. Automated placement of cross sections in meanders of Ferron Creek.

created to describe each land use an associative n-value. This process took 2 minutes to complete.

With the basic geometric data created to construct the input file for HEC-RAS, the various processes of assigning elevation values, lengths, n-values, connectivity, station values was completed. This process was internally computed by GeoRAS and took two minutes to complete.

Table 1 shows the time taken by each step and percent of total time to develop each geographic feature layer for use by HEC-GeoRAS. Figure 2- 7 shows the representative time taken to create the basic geometric data for use in GeoRAS.

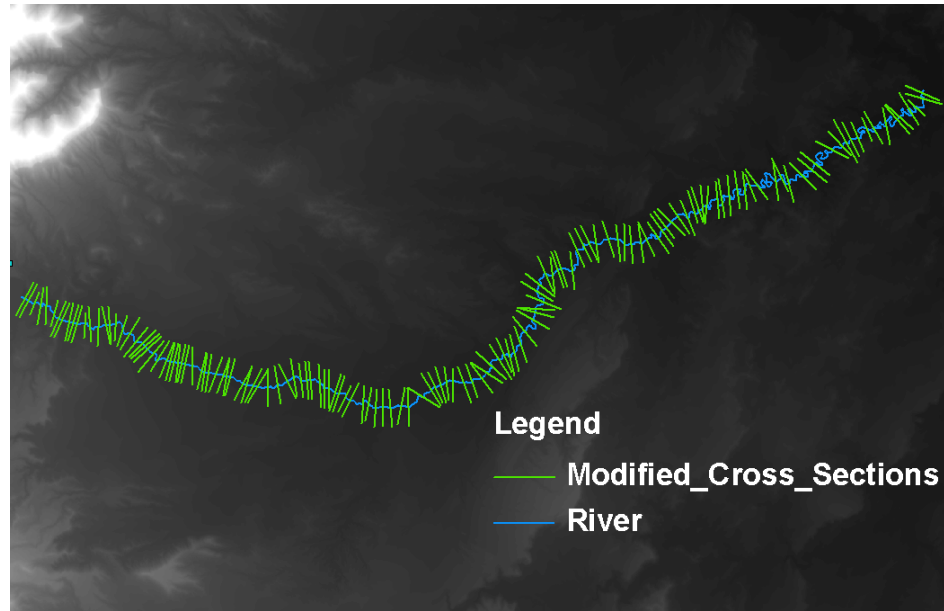


Figure 2-5. Modified cross sections digitized after using HEC-GeoRAS cross section placement.

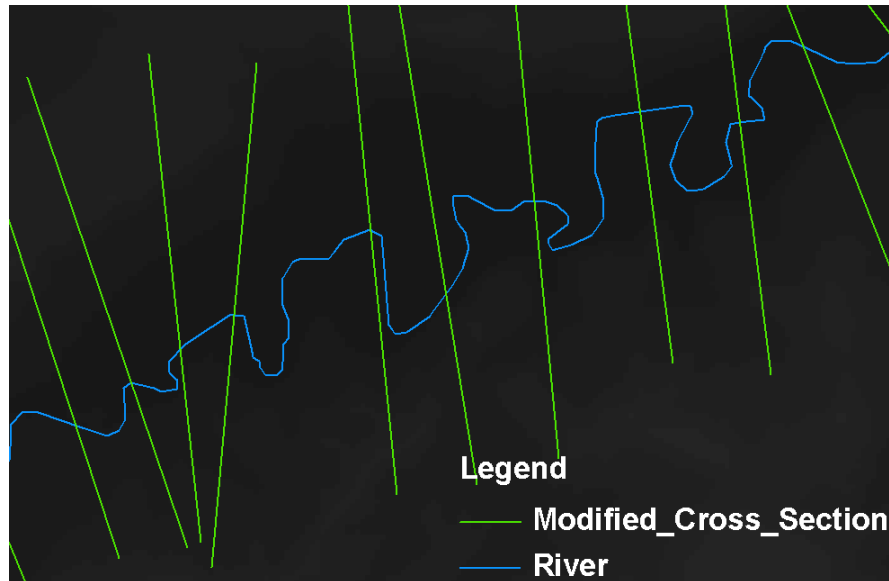


Figure 2-6. Close up view of modified cross sections.

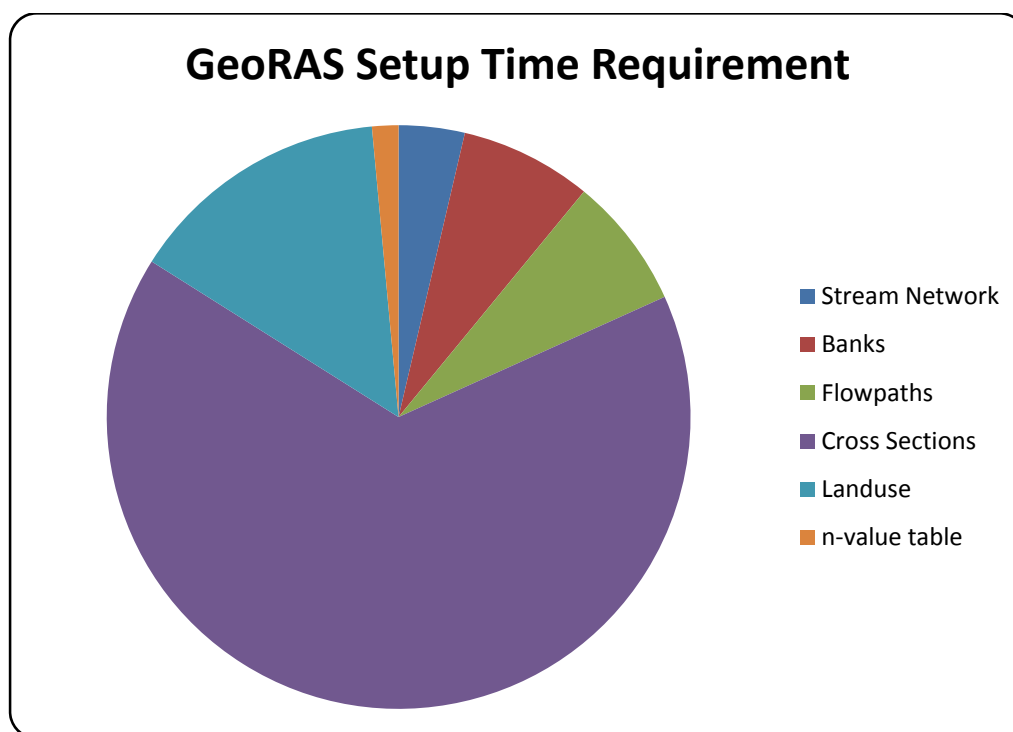


Figure 2-7. GeoRAS setup time requirement.

Table 2-1. GeoRAS setup requirement time

Feature Digitized or Loaded	Time (minutes)	% of Total
Stream Network	5	3%
Banks	10	7%
Flow Paths	10	7%
Cross Sections	90	66%
Land Use Polygons	20	15%
N-Value Assignment	2	2%
<b>Total</b>	<b>137 = 2 hrs. 17 mins.</b>	<b>100%</b>

The total time taken to develop a basic HEC-GeoRAS set of geographic features for the case study was 2 hours and 17 minutes. It is to be noted that the process was somewhat simplified due to the assumption of in-stream flow. For an extreme flow case with significant over bank flows, the process would take significantly more time and perhaps several iterations to obtain a reasonable set of geographic features. Many of the steps taken were although automated but actually added some more steps to the process, such as modifying the automated cross sections. As can be seen the placing of cross sections took the majority of the time to complete with about 66% of the total time.

For modelers it is essential to calibrate and examine hydraulic computations to develop reasonable flood inundation results. Therefore, if the time taken to develop accurate geographic features could be reduced then the modelers could spend their efforts on hydraulic modeling and analyzing the results rather than on digitizing geographic features.

#### Literature Review of Automation Process Softwares

GIS has become the standard in the United States of America with which floodplains are mapped and analyzed in the process of floodplain management. Four main relationships have been described in Babu, Thirumalaivasan and Venugopal (2006) which ties the GIS environment to the modeling environment, both of which are required in developing floodplain maps. Dependence upon industry standard GIS or creation of an “in-house” type of mapping system generally separates the softwares

which seek to automate hydraulic model development. The first two relationships tying GIS to model are called embedded coupling. These two types of relationships are incorporating the GIS environment functionalities within the model and incorporating model functionalities within a GIS environment. The last two relationships tying GIS to models are coupling the modeling and GIS environment by data exchange files (loose coupling), and using the GIS environment to develop a complete modeling system by developing user defined modeling libraries within the GIS environment (tight coupling).

The first type of relationship between GIS and the modeling environment is the incorporation of GIS functionalities within a model thus creating a single modeling package. With this approach of data handling the mapping utilities of a GIS environment are utilized, which promotes the post-processing nature of GIS. The complete functionalities of a full GIS environment are not utilized, however, as the basic mapping of output data is performed with this first type of relationship.

The second type of relationship is to incorporate the modeling environment within the GIS environment. This methodology provides an add-in environment in which increased hydrologic and/or hydraulic capabilities are added to the GIS environment. This basically provides users the ability to rely on the powerful analyst tools within company standard GIS environments in conjunction with a few added functionalities to more adequately analyze hydrologic and/or hydraulic studies. An example of this type of system is the ArcHydro data model developed to aid in water resources studies (Maidment 2008).

Loose coupling has been the traditional method in which geographic

information is passed into hydraulic model in floodplain studies. By this method a communication forum is provided to pass information back and forth between company standard GIS packages and hydraulic models. This takes into use the import and export nature of several of the hydraulic models currently available. Geographic information is stored in data exchange files, usually in ASCII files, and passed into the hydraulic model, which uses a standard data format scheme to read the ASCII files to describe the geographic information in a geometric file. In this method the GIS environment and modeling environment act independently of each other, but rely on the exchange files to pass information back and forth. Several software packages employ this method of data processing, such as HEC-GeoRAS. These software packages prepare the input files for use in a hydraulic modeling package such as HEC-RAS and read the output files from hydraulic computations to create new geographic features.

The tight coupling of GIS and models provides developers the methodology of having a central processing center which manages the passage of data back and forth between models and the GIS environment by writing process specific model libraries. This allows the model libraries to utilize the powerful tools located within GIS along with managing the overall modeling process. To utilize the tools located within GIS strict methods must be in place in designing the feature classes which are used by GIS tools. A partial tight coupling designation is given to applications which act independent of each other, but are managed by one overarching regulator of data passage. This allows user control, along with utilizing the power of the GIS environment.

The Watershed Information System (WISE) is a product of Watershed Concepts Software, which provides several tools for managing water resources information. The functionality of these modules lends themselves to integrate several sources of data to develop and manage large sets of data used for floodplain modeling including hydrology and hydraulics modules. The GIS-model relationships that WISE exhibits are both the add-in capability and the loose coupling, where a data exchange file is utilized between HEC-RAS and WISE, and GIS functionalities are provided within the software. WISE though does not operate within ArcMap. It provides its own mapping and analysis tools. The system is comprised of ten modules written in Visual Basic which utilizes ESRI's MapObjects, ArcObjects and SDE technology. The hydrology module provides tools to prepare and export data to be used in conjunction with HEC-1 and TR-20. The hydraulics module allows users the ability to handle geometry data in the modeling of floodplains. WISE allows users to delineate watersheds, river centerlines, and land use files to create input files for HEC-RAS within the WISE window. The WISE window is similar to the viewing window of ArcMap. This setup is all contained within a HydraMax model within WISE. Upon hydraulic computations being performed within HEC-RAS, WISE uses the output file to create new geographic features representing flooding extents (Watershed Concepts 2008a).

Elevation data is effectively handled by WISE allowing users the ability to handle and blend digital terrain data along with original survey data. Survey data is handled in its original ASCII format. Users can select several terrain data including survey data, allowing higher priority to specific data, with which WISE creates a new

digital terrain model. This functionality allows users to create a better digital terrain model based on prioritized elevation data to create hydraulically correct cross sections. Survey data can also be handled to define several structures including bridges, culverts and dams. Users can also add structure specific data such as culvert elevations and road elevations, to define them more adequately in developing the hydraulic geometric file Watershed Concepts (2008b).

Streams can be digitized and checked for connectivity within WISE. Streams may also be defined using digital terrain data and methods in stream centerline delineation. These delineated streams are generally used for un-gauged basins. Stream networks can have connectivity checked and completed if need be. Stream meandering can also be removed by selecting a limit to a reach distance for meander removal Watershed Concepts (2008b).

Channel and overbank area n-values are determined within WISE by user defined polygon geometries in a land use shapefile. An overbank polyline shapefile, containing left, main and right polylines, is utilized to determine left, main channel and right overbank distances between subsequent cross sections Watershed Concepts (2008b).

WISE allows users several options in the placement of cross sections. Cross sections can be viewed in the WISE display as they are created. Surveyed cross sections can also be handled within WISE. Cross section placement intervals can also be specified along with distances above stream confluences at which to place cross sections. Cross sections may also be added (by digitizing), deleted and edited within WISE Watershed Concepts (2008b).



Cross section placement is automated by utilizing the steepest point within the overbank area within a specified searching distance. The process is begun by placing a virtual line perpendicular to the streamline. A sweep angle parameter then indicates to WISE how far to expand a search in the upstream, downstream and away from the end point directions, thus creating a triangle. This triangle is then searched to find the point with the steepest slope. This is done with both end points and the two points are connected to create the cross sections Watershed Concepts (2008b).

The hydraulic model setup capabilities also allow a user to create flow and plan files. Flow files (only steady files in the current WISE version) can be developed by specifying river stations and associated flows for various flow profiles defined by the user. Plan files can be created which specify various hydraulic modeling parameters along with steady flow file and geometry file. Floodway encroachment studies can also be setup with WISE Watershed Concepts (2008b).

WISE allows users the ability to make any corrections to cross sections, n values and other feature data in preparation to export geographic to HEC-RAS. WISE reads HEC-RAS output data to develop floodplain boundaries, flood profiles and base flood elevations. Upon viewing the output a user can modify any geographic data to re-import into HEC-RAS. This allows users to graphically come to a solution after several computations within HEC-RAS Watershed Concepts (2008b).

The Watershed Modeling System (WMS) is a software package developed to be a complete graphical modeling environment for hydrologic and hydraulic modeling. WMS can also be classified along with WISE into a cross over between the GIS add-in and loose coupling GIS-model relationship. WMS does not operate within ArcMap,

rather it supplies its own viewing and functionality tools. WMS utilizes a data exchange file to pass information to and from HEC-RAS. In the hydraulic modeling portion of the program a user may digitize a river centerline, bank lines and cross sections, with the ability to view a TIN or image file as a background. Land use polygons are defined by selecting polygons as delineated by the polylines digitized such as between the river centerline and the bank. Each polygon is assigned a specific n-value (WMS, 2002).

Upon completion of digitizing of features and specifying n-values, WMS launches HEC-RAS and loads the geometry file. The user can then enter flow data and create a plan file and run a HEC-RAS computation. In the post-processing stage WMS creates flood extent, flood depth and flood impact maps (WMS, 2002).

AMEC Earth and Environmental has developed a full hydrologic and hydraulic analysis tool pack to develop floodplain maps. This complete package (AFG) automates the setup and geographic information output process in generating floodplain maps. AFG exhibits the characteristics which fit in the partial loose coupling category of the GIS-model relationship. The software is a plug-in to GIS, which utilizes defined model libraries in conjunction with utilizing a data exchange file to communicate between itself and HEC-RAS. Therefore the AFG takes the role of overseeing the modeling process in conjunction with the company standard softwares of ArcGIS and HEC-RAS. Same as WISE and WMS, the AFG also develops hydrologic information, including delineated streams and hydrologic information useful for modeling. The hydraulics portion of the AFG is split into three processes: PreRAS, RunRAS, and PostRAS. The hydraulic component of the AFG

software initially runs PreRAS generating cross sections, flow and bank lines from stream lines and digital terrain data (AMEC, 2007).

In PreRAS a user defines critical data for channel widths and specifications for cross section extractions. A user may specify cross section spacing and width. If the channel is a uniform shape, such as trapezoidal, a user may specify appropriate parameters for the width and side slopes of the channel, where channel top width defines the bank lines. A flow path buffer is also available to be set. In RunRAS a user may generate several floodplains (generated from individual geodatabases) in batch mode, or run a single stream floodplain delineation which can then be merged with an existing floodplain model. PostRAS generates a water surface TIN from the output of HEC-RAS. Multiple floodplains may be generated for several HEC-RAS profiles in a single batch run. In the Interactive Floodway Editor encroachment stations may be moved to more correctly model the floodplain in subsequent applications of RunRAS (AMEC, 2007).

## CHAPTER 3

### UTIMS METHODOLOGY

#### UTIMS Capabilities

The process of floodplain delineation requires precise geometric data development to accurately map floodplain inundation. The software described in this thesis is called the UTah Inundation Mapping System (UTIMS). This software package is designed to be an add-in to the ArcGIS environment which relies upon the multitude of functionalities GIS provides for developing geographic features. UTIMS provides users an easy to use automation process (as shown in Figure 3-1) to create the appropriate geographic features for use by HEC-RAS and easily interpret the output from hydraulic calculations within the GIS environment to create new geographic features such as flooding extent polygons. UTIMS streamlines the process of floodplain mapping simplifying it for modelers to develop complex geometries for use within HEC-RAS without spending large amounts of time. UTIMS strengths lend themselves specifically useful in the area of extreme flow modeling, where an iterative process is utilized to efficiently define the floodplain and n-value assignment for use by HEC-RAS. This time saving is extremely useful in developing the flood magnitude specific geometries which can then be utilized in modeling the specific level of floods. This aids a modeler in moving away from the bias introduced in extreme flow modeling by the assumption that one set of geometries can be used to model various levels of flow magnitudes. In practice, various scenarios for dam breach modeling such as PMF-no failure, PMF-failure, sunny day failure, and breach of smaller

sections, including cases where uncertainty in breach sizes are considered, need to be developed. The UTIMS can be used to tailor the development of the required geometries to these specific modeling cases. The UTIMS automation facilitates development of these flow specific geometries for various flow magnitudes in significantly reduced time. UTIMS provides powerful tools to a modeler in developing flood magnitude specific flow path centerlines, cross sectional placement and creation, and n-value assignment from land use data for use in floodplain mapping. Other features of UTIMS include: an easy to understand user interface (as shown in Figure 3-42), effective data management by creating folders in an iterative process, storing UTIMS project information in a UTIMS file (".uif"), progress display, checking and completing river network connectivity, point specific cross section placement to monitor convergence status at user selected critical locations, specify change in flow at river stations, automated creation of bank and flow path lines, and the ability to directly write HEC-RAS geometry and project files. While other softwares provide many automation process tools, UTIMS adds several powerful capabilities in providing modelers tools they need to easily and correctly determine flooding extents without sacrificing large amounts of time.

UTIMS allows users the ability to conduct in-stream as well as extreme flow studies. UTIMS provides a powerful set of tools to modelers to easily and accurately describe an extreme flow path centerline through an iterative and generalization process. As was discussed previously, the original river centerline may not accurately describe the flow path centerline of an overbank flow in case of extreme flood modeling. For this fact UTIMS has been designed to aid a modeler in developing the

flow path centerline of a flood. This capability of UTIMS is available to modelers to choose as an option between an in-stream or extreme flow model development.

In the case of extreme flows the flow path centerline is initially unknown. UTIMS approximates an initial flood polygon by utilizing the user specified trial upstream and trial downstream depths for a specific flood magnitude. UTIMS approximates the extents of the flood polygon by linearly interpolating trial flood depths along the river centerline at user specified cross-section intervals and identifies a trial flood extent at each point along a river centerline to derive an initial flood polygon. UTIMS then approximates the centerline of this initial flood polygon and uses this as an approximation for the flow specific flow path centerline. For the subsequent iterations the flood specific river centerline is derived from HEC-RAS output. UTIMS identifies the flood specific river centerline by approximating the centerline of the flood polygon acquired from HEC-RAS output. In this manner the flow path centerline of a flood can easily and effectively be identified by iterating the process of passing geographic information to HEC-RAS, analyzing the flood polygon output to develop a new flow path centerline and passing new geographic information to HEC-RAS until user specified convergence at the user specified critical locations has been reached. The convergence in floodplain mapping is treated to have reached when the change in water surface profile elevations from successive HEC-RAS computations at the user specified critical locations is less than the user specified value for the convergence criteria.

UTIMS provides users a reasonable method to assign n-values for use by HEC-RAS in hydraulic computations. The cross sections hold profile data as well as n-

values for the segments of the cross section. The cross section profile represents the changing terrain through which flow must pass. The n-values associated with the segments of the cross section represent the change in land use. Through several steps UTIMS defines the extent within which each cross section represents the change in land use by creating a proximity map identifying the closest areas to each segment of a cross section. Therefore for each segment of a cross section the land use area defines the land use that the specific segment must represent in its n-value. UTIMS integrates this seamless process into the overall UTIMS automation process by employing a computation method developed by Maged Aboelata, as described by Nanadoum (2005). This capability is extremely useful in floodplain delineation by allowing modelers to assign reasonable n-values for cross sections.

User control of UTIMS is simple and allows easy data input to setup a basic hydraulic model. UTIMS provides buttons to allow users the ability to browse for the appropriate data required by UTIMS. The data required by UTIMS include: a river network shapefile, raster dataset layer, TIN dataset layer, National Land Cover Dataset (NLCD) layer and a text file containing a table of NLCD grid code values and the n-values associated with them. Additional information required includes a process output folder, a project name, project units and the river network shapefile fields which provide a river's name and reach name, and a few user defined parameters used in developing geographic features. An additional label entitled "Output Location:" displays to users the specific folder into which UTIMS is saving shapefiles and other output files. The current iteration (for use in the iterative nature of UTIMS) is also displayed in a label entitled "Iteration." Buttons on the main interface allow users the

ability to load a river network into UTIMS, load a UTIMS file (".uif") containing project specific information, save a UTIMS configuration into a UTIMS file (".uif"), begin the UTIMS processing, assign required cross section information, read HEC-RAS output and begin the iterative process of UTIMS. A check box is also available to indicate to UTIMS to keep the cross sections from the current iteration to the next – thus preserving cross sections that a user feels are appropriate for the magnitude of flow being analyzed.

UTIMS' effective data management is handled in two manners. Firstly UTIMS allows users the ability to store project information used in a UTIMS project in a special UTIMS file (\*.uif). This file stores the file paths to access required geographic data (shapefiles, terrain and land use data), project information (project name, units, etc.), river network specific parameters (information describing stream generalization, cross section placement, etc.), and general parameters for use by UTIMS. The UTIMS project file is created in a main output folder, as selected by users, having the name "[project name].uif". The "UtIms File" allows users the ability to load a past project configuration and save new UTIMS project configurations. The second manner of data management lies in UTIMS design of a folder system for data storage. UTIMS employs a numbered system for the output of geographic data and storage of HEC-RAS projects. For each of UTIMS iterations it creates "Data" and "Run" folders. "Data" folders hold shapefiles created to hold geographic data and "Run" folders are created to hold HEC-RAS files. This process begins with UTIMS creating a "Data1" folder and a "Run1" folder in the main output folder selected by the user. Then to iterate the process UTIMS creates a "Data2" & "Run2" folder in the



output folder selected by the user to hold a new set of geographic data and HEC-RAS files for the second iteration and so on.

Progress is displayed within the ArcMap progress bar. This allows modelers the ability to monitor the progress of UTIMS while it is running. The overall process as well as smaller task process progress is displayed to modelers. The lower left progress bar displays what process is being performed and the progress bar on the lower right displays the percentage of the overall process completed.

UTIMS checks, and completes if necessary, the connectivity of the river network provided. Upon completion of checking and verifying the connectivity of the river network UTIMS determines upstream and downstream connectivity of the river network and assigns nodes within the connectivity framework of the network. This process of network checking and validation ensures that a complete hydraulic model is developed for use within HEC-RAS.

UTIMS provides modelers the ability to specify points (locations along the stream network) at which to monitor changes in water surface elevations. This allows modelers the ability to monitor the convergence of the iterative process at the locations of interest in determining a correct flood polygon in extreme flood cases. A user may provide paths to a shapefile on the main user interface for the critical points of interest at which to create cross sections. UTIMS will monitor the changes in water surface elevations at these cross sections to aid modelers in determining whether or not a convergence tolerance has been met in the mapping process. This capability, in conjunction with the capability of creating a new river centerline from HEC-RAS output flood polygons, provides modelers an enhanced process of floodplain mapping

specifically in the area of extreme flood modeling.

UTIMS also allows users the ability to specify a shapefile containing change in flow point locations. In case a modeler may need to specify a change in flow at a particular location, UTIMS will create cross sections at these points.

UTIMS automates the creation of bank and flow path lines. Bank lines are placed an offset distance from the actual river centerline supplied by the user at the beginning of iteration. Flow path lines are automatically developed by calculating the centroid of the left and right overbank areas and then connecting successive overbank area centroid points to derive the left and right overbank flow path lines.

UTIMS, though automates much of the input development process, it does require user judgment and intervention to complete the modeling process. The software seeks to put a user in position to reduce the time required to develop complex geometries for use in particularly for extreme flow hydraulic modeling. Therefore there is a learning curve required to become accustomed to and expert in using the software. The learning curve is although very manageable and a UTIMS User manual (Stevens and Chauhan, 2009) is prepared to facilitate this process.

### Process Walkthrough

To demonstrate the iterative nature of UTIMS Figure 3-1 displays the path of data processing and handling by UTIMS. UTIMS initiates the process by requiring five layers (elevation grid dataset, TIN dataset, river network, critical points and National Land Cover Dataset layer) and a tab delimited table representing the National

Land Cover Dataset – n value relationship table in a text file.

As is depicted in Figure 3-1 the path of geographic data processing begins with

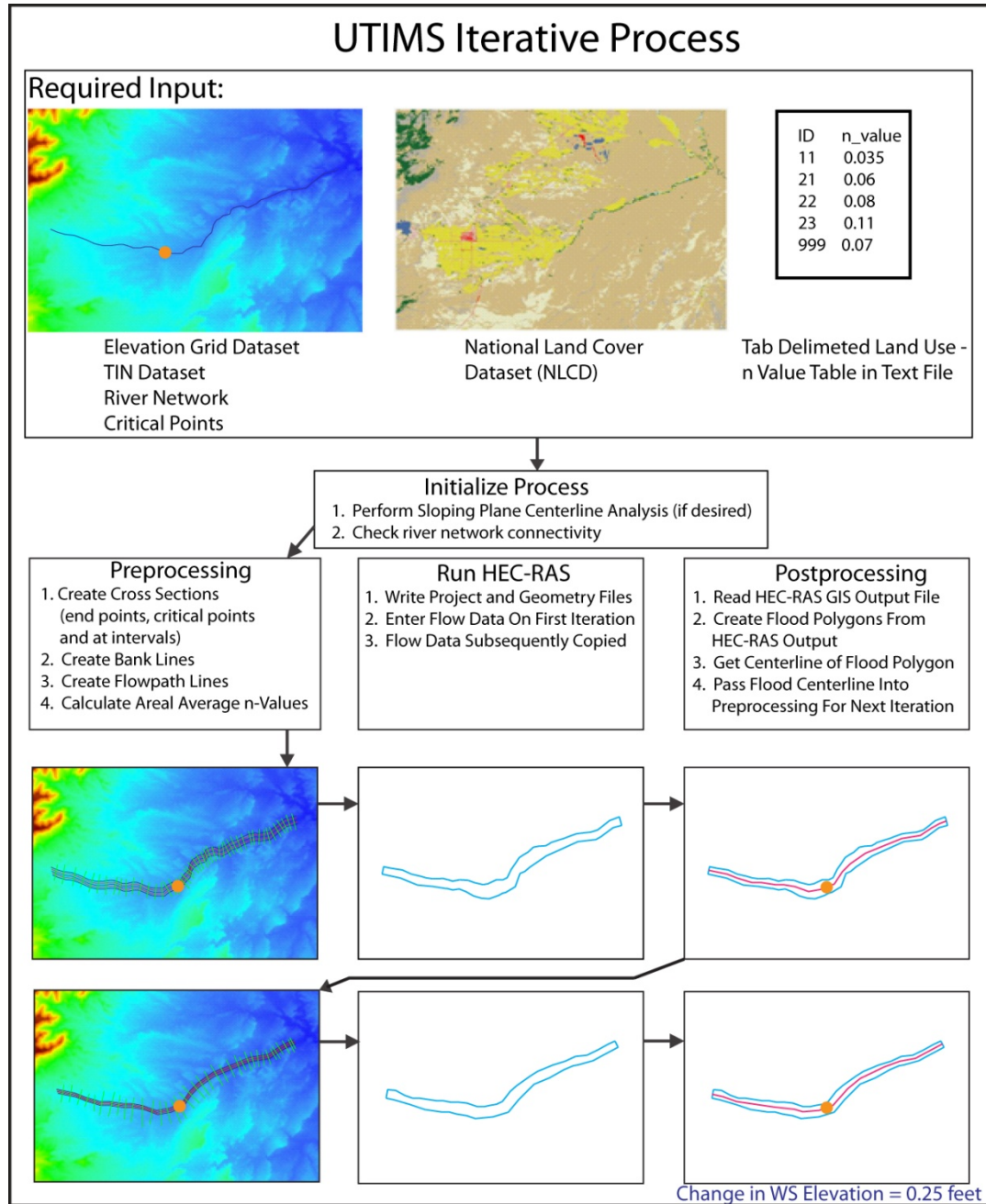


Figure 3-1. UTIMS iterative process.

the actual river network. As shown in the “Initialize Process” portion of Figure 3-1 UTIMS is capable of performing a generalization of the pre-existing river network to more accurately describe an extreme flow case. UTIMS also verifies river network connectivity, completing it if necessary.

As shown in the “Preprocessing” column the initial river centerline is used as a template to create bank lines by simply offsetting the river centerline by a user specified distance. Flow path lines are constructed by calculating the centroid of each overbank area for each cross section. Cross sections are also created and areal averaged n-values are assigned to segments of the cross sections. The geometric data is passed into HEC-RAS to perform a flow calculation to obtain the first flood polygon as shown in the “Run HEC-RAS” column. UTIMS then takes the flood polygon and approximates the flood polygon flow path centerline. The flood polygon flow path centerline is used as an approximation for the flow path centerline in the next iteration of the process. Therefore it is passed into the “Preprocessing” stage and the same process is performed again using this first flow path centerline. HEC-RAS is run again and a second flood polygon is analyzed to determine the change in water surface elevation at the user specified critical points. If the change in water surface elevation is too large (i.e. greater than the user specified tolerance), then a second flood polygon flow path centerline is derived from the second flood polygon.

The process begins again by UTIMS sending the second flow path centerline into the “Preprocessing” stage and the process is repeated again. The process ends when the change in water surface at the user supplied point(s) is within the convergence tolerance.

### Sloping Plane Analysis to Identify Flow Specific Centerlines

UTIMS aids modelers in defining a flow specific river centerline for extreme flows in floodplain management studies. This process utilizes some initial calculations made by a modeler on the upstream and downstream depths expected for a certain flow magnitude. Some initial calculations may be employed to calculate these upstream and downstream expected flow depths by using the upstream and downstream cross sectional areas and the peak flow to calculate “trial upstream” and “trial downstream” depths. UTIMS uses these trial depths to derive an initial sloping flood polygon. This sloping plane is derived using the terrain and the trial depths to approximate an initial polygon resulting from the peak flow. The process of deriving the sloping flood polygon plane and associated initial river centerline will subsequently be discussed. This analysis, though, is subject to user input, and is only performed as specified by the user.

The required geographic inputs for this sloping plane analysis include two layers. Firstly an actual river centerline is used to query points along the flow path, and secondly a digital terrain model in GRID format which represents the terrain elevations held in pixel cells. The actual river centerline is used as a guide for defining the flow specific centerline in the sloping plane analysis. The GRID format digital terrain model, also commonly referred to as a terrain raster, is used in raster calculations to extract appropriate elevation data in the sloping plane analysis.

In summary the sloping plane analysis begins by taking the actual river centerline and using the “trial upstream” and “trial downstream” depths UTIMS

assigns linearly interpolated trial depths to thalweg points at a user specified interval along the actual river centerline. With the specified trial depths UTIMS identifies trial depth points (using the elevation at the queried thalweg points and their associated trial depths) which are elevated up off the initial river centerline. UTIMS uses these trial flood depth points and queries the closest points on the terrain on the left and right hand sides of the actual river centerline. These closest points located on the terrain to the trial flood depth points are termed terrain query points. UTIMS utilizes the terrain query points as an initial approximation of the flooding extents on the left and right hand sides of the actual river centerline derived at specific intervals down the initial river centerline. UTIMS then uses these terrain query points to construct an initial flood polygon. UTIMS utilizes the initial flood polygon to approximate the flow path centerline as the centerline of the initial flood polygon. The approximated flow path centerline is then used in placing cross sections and is used as the main channel flow path centerline.

To illustrate how the sloping plane analysis is used in developing a flow specific centerline Figure 3-2 shows a three-dimensional view of a river centerline located in the thalweg of a terrain model. There are three reaches shown in Figure 3-2 each with a different slope to help illustrate how the trial flood depths are influenced by the underlying terrain. Figure 3-2 shows the thalweg elevations decreasing as the river proceeds to the bottom of the terrain data with the direction of flow going from left to right.

Trial flood depths are used by UTIMS to approximate the extents of an initial flood polygon. These trial depths are shown in Figure 3-3. As shown in Figure 3-3

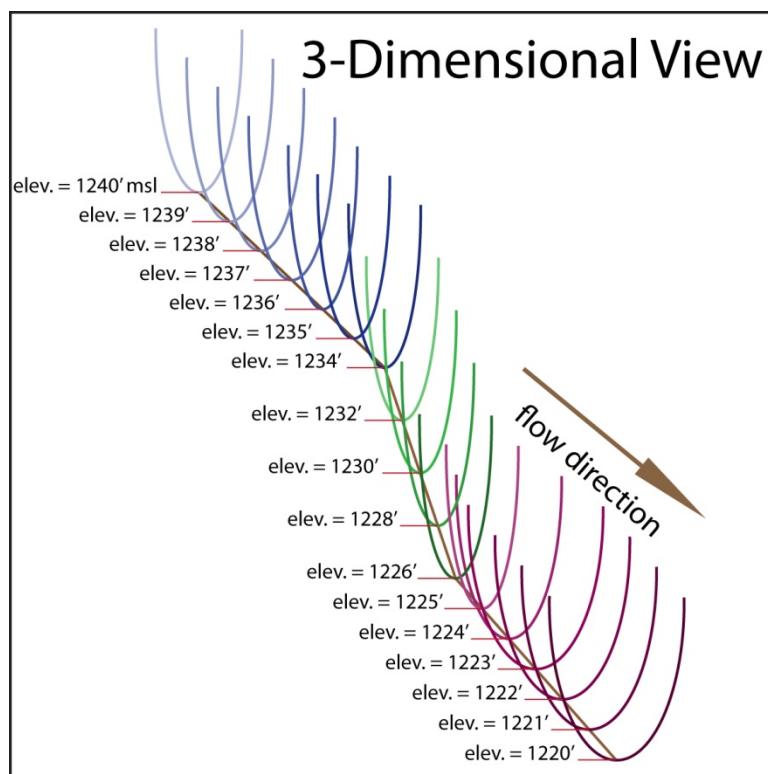


Figure 3-2. Three-dimensional view of river centerline.

trial flood depths are linearly interpolated along the actual river centerline to elevate the actual river centerline.

Combining the elevated river centerline shown in Figure 3-3 and the three dimensional terrain shown in Figure 3-2 yields a three-dimensional sloping river centerline as depicted in Figure 3-4. The river centerline is shown lifted up out of the thalweg of the terrain at depths linearly interpolated along the river centerline. This methodology leads to developing a flow specific river centerline in cases of extreme flow modeling where flow bypasses meanders in the actual river centerline. Thus by elevating the centerline out of the thalweg a flow specific centerline can be constructed.

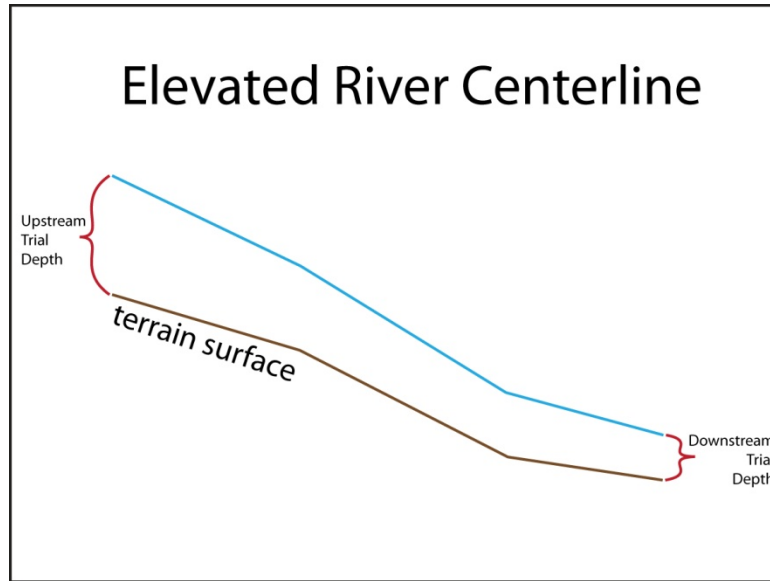


Figure 3-3. Trial upstream and downstream depths.

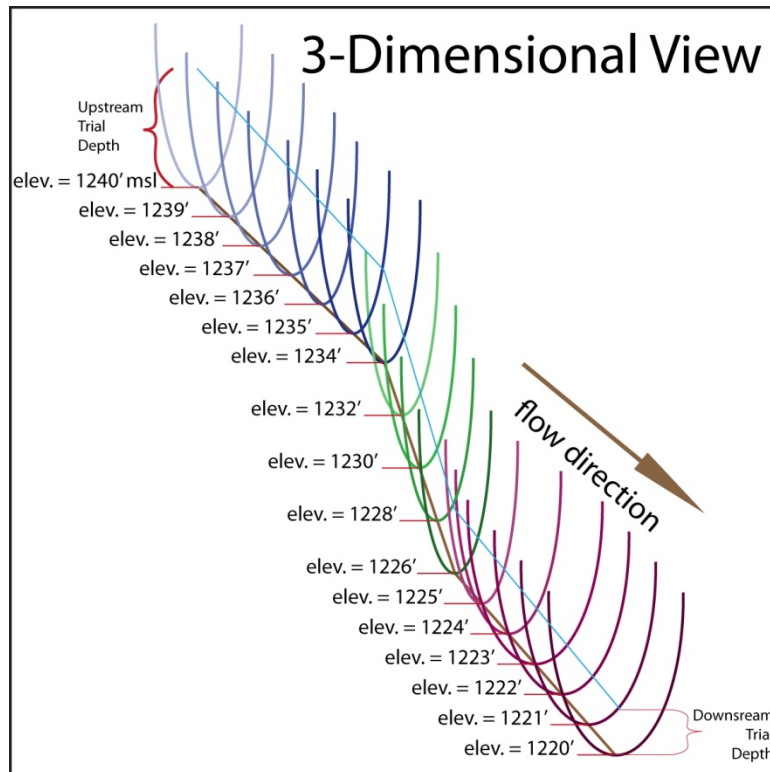


Figure 3-4. Elevated river centerline.



Figure 3-5 shows a cross section profile of the uppermost portion of the terrain shown in Figure 3-2. The depicted thalweg point is at an elevation of 1240 feet. Assuming that a user supplied a “trial depth” at the upstream portion of the river of ten feet UTIMS identifies a point at a depth of ten feet above the thalweg point. This trial depth point shown in Figure 3-5 represents the first sloping plane elevation.

In order to accurately determine the closest point on the terrain to the trial depth point UTIMS constructs a contour line at the trial depth point elevation. As shown in Figure 3-5 the elevation of the trial depth point is 1250 feet. UTIMS uses this elevation to construct a contour line to identify the closest point on the terrain at the trial depth elevation, shown in Figure 3-5 as the terrain query point. UTIMS thus

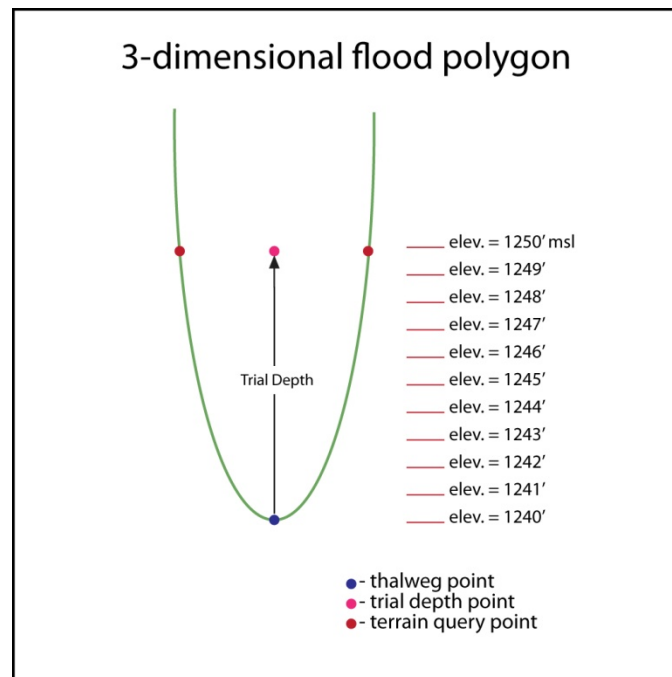


Figure 3-5. Cross section view of terrain with trial depth point assuming 10 foot increase.

constructs a contour line for each cross section by using terrain data and the trial flood depth.

UTIMS constructs these contour lines internally for each point queried along the river centerline. In order for UTIMS to take into account an appropriate extent of terrain data UTIMS creates an extent polygon with which to extract elevation data to create contour lines. UTIMS utilizes the river centerline and creates a buffer polygon around the river centerline. The polygon edge is located at a user specified distance away from the river centerline. The buffer polygon is used to clip the terrain GRID for use in creating contour lines. This is done in order to utilize only an appropriate extent of elevation data in constructing contour lines and reducing the size of data UTIMS uses to define the contour lines. This derived clipping mask polygon is stored on disk space to be utilized in developing a clipping mask raster for use in raster calculations. For multiple river centerlines UTIMS will create individual clipping mask feature classes with numbers at the end of the clipping feature class file representing the order of river centerlines processed starting with "0" (zero). The first polygon feature class is stored in the user specified output folder with the name of "Mask\_Polygon0.shp."

For each point queried along the river centerline to identify the closest points on the terrain UTIMS creates a clipping GRID raster from the masking polygon with a value of "0" (zero). For each point a clipping grid is used and is named appropriately for the river it was created from and the point it represents along the river centerline. This grid is stored using the following naming methodology. For the first point on the first river encountered requiring the sloping plane analysis UTIMS creates "mygrid\_0\_0" and stores it in the specified output folder. The second point analyzed

along the river would yield a grid entitled “mygrid\_0\_1” where “0” represents the first river being analyzed and “1” (one) for the second point analyzed. Thus the naming terminology is “mygrid\_rivernumber\_pointnumber” for the clipping grid UTIMS utilizes to clip the digital terrain model for use with the sloping plane analysis. This clipping grid raster is utilized primarily to reduce the size of grids resulting from this analysis.

UTIMS performs a raster calculation by adding the digital terrain model to the clipping mask raster to obtain a clipped digital terrain model. UTIMS utilizes this clipped digital terrain model to obtain a specific contour. Figure 3-6 shows an example of a clipped elevation grid.

Figure 3-6 displays a 5x5 grid representing a portion of a clipped digital terrain

9	9	9	9	9
9	6	5	7	9
9	5	5	5	9
9	4	3	3	4
9	4	4	2	2

Figure 3-6. Clipped digital terrain data.

model. Each pixel in the grid holds a representative elevation for that grid cell portion of the actual terrain.

To create a contour line at the trial depth point elevation UTIMS uses the raster extraction operator to “extract” the elevations located within the clipped grid which are less than or equal to the elevation of the trial depth point. The “extraction” returns to UTIMS an internal raster

Figure 3-7 shows an example of the clipped elevation data with a river centerline identifying the path the river may take on the clipped elevation grid. The “query point” shown in Figure 3-7 represents the “From” point, or uppermost point, of the river centerline.

UTIMS extracts elevation data beginning with the uppermost point on a river

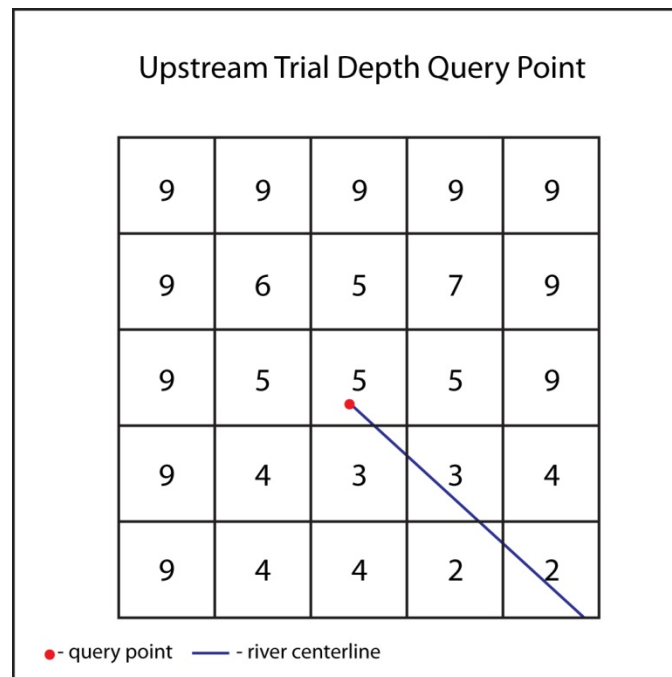


Figure 3-7. Terrain data with river centerline.

centerline. UTIMS uses the trial upstream flood depth as an increase in elevation to identify a contour line at the increased elevation. Taking for example the clipped elevation grid shown in Figure 3-7 if a user had specified a trial upstream depth of “2” (two) units UTIMS would take the clipped elevation data and extract all the elevation grid cells less than or equal to “7” (seven) units. A value of “5” comes from the elevation grid cell value for the “query point” and the “2” due to the trial upstream flood depth as specified by the user thus an elevation of seven units will be used for the elevation extraction, as indicated in Figure 3-8. Figure 3-9 displays the grid cells from the grid shown in Figure 3-7 which would be identified by a grid extraction which have cell values less than or equal to the trial depth point elevation at the specified “query point.”

All the grid cells with a value less than the increased elevation value of “7” (seven) were selected as the extraction set. UTIMS takes the extracted cells and converts them into a polygon to be able to identify the “7” unit contour line. The created polygon represents the areas within the clipped elevation model which have an elevation less than or equal to the elevation of the trial depth point. UTIMS utilizes the edge of the created polygon to create the appropriate contour line. Figure 3-10 shows the polygon resulting from the extraction.

As can be seen in Figure 3-9 UTIMS creates a polygon from the extracted data cells. Due to the nature of the trial depth used in the extraction process the resulting polygon extends further upstream than the initial query point on the river centerline. The increased elevation polygon would continue past the downstream end of the river centerline. If there are more than one polygon created by the conversion from grid to

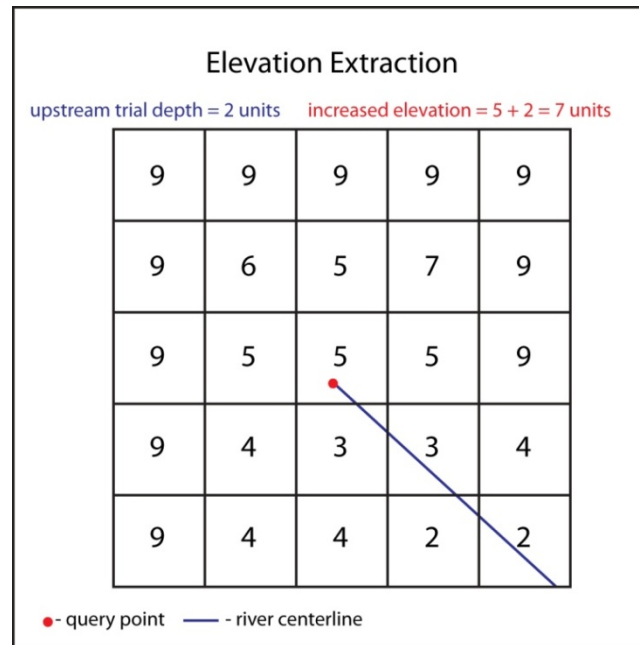


Figure 3-8. Calculation of trial depth point elevation.

polygon type UTIMS unites all the polygons to identify the outermost edges of the increased elevation polygon. UTIMS names the polygon shape file based on the same naming convention as explained above for naming the grid i.e.

“polygon\_rivernumber\_pointnumber.shp.” UTIMS identifies the first river and first point queried with the number “0” (zero), therefore the resultant polygon from the first point queried on the first river centerline would be stored in the appropriate output folder with the name “polygon\_0\_0.shp.”

zHaving created the increased elevation polygon UTIMS uses the river centerline to cut the increased elevation polygon into a left and right increased elevation polygon. Using the left and right polygons UTIMS performs a difference operation between the boundary of both the left and right polygons (removing the river

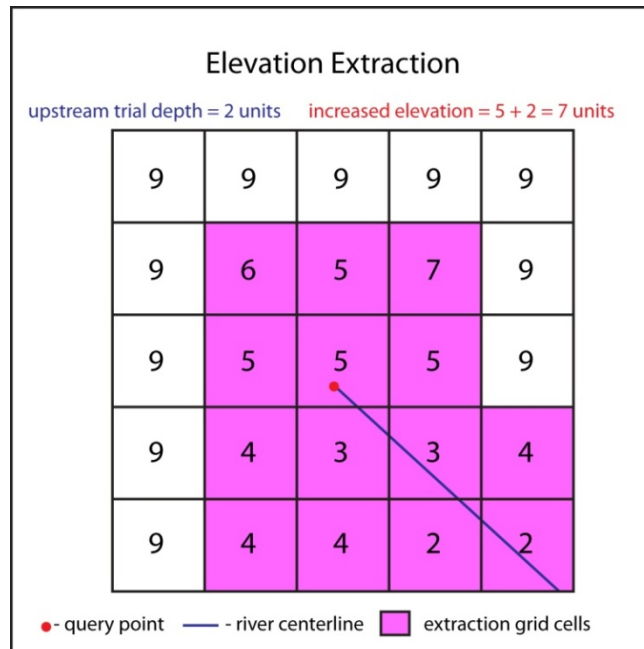


Figure 3-9. Elevation extraction cells.

centerline edge from the left and right polygon boundaries) to obtain the left and right portions of the contour line at the trial depth point elevation. Using these left and right contour lines for a given elevation UTIMS queries these contour lines to find the closest point on both the left and right portions of the contour line to identify the terrain query point as shown in Figure 3-5. As indicated in Figure 3-8 the query point is the base query point for this operation for identifying the closest points on the terrain.

Figure 3-11 displays the contour line for “7” units which was shown in Figure 3-10 as the increased elevation polygon. The polygon is converted to a polyline from the polygon without smoothing the polygon boundary, thus preserving the shape of the queried polygon.

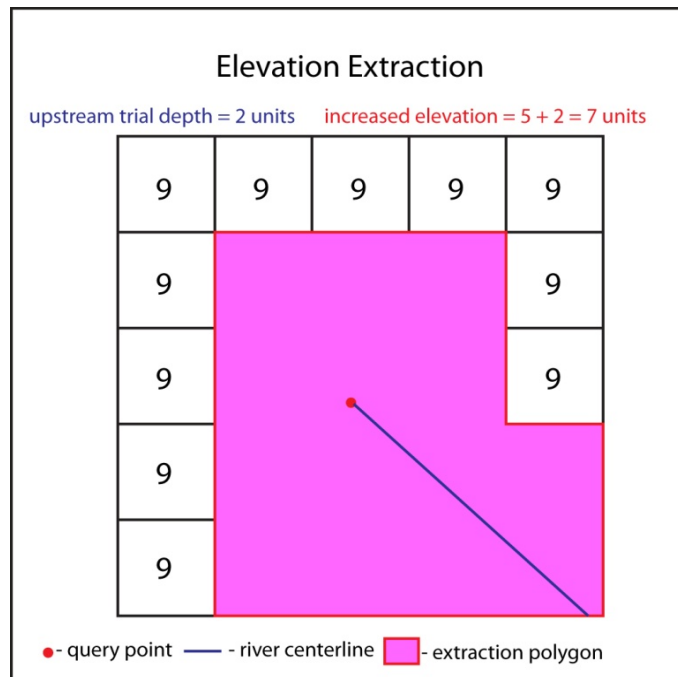


Figure 3-10. Elevation extraction polygon.

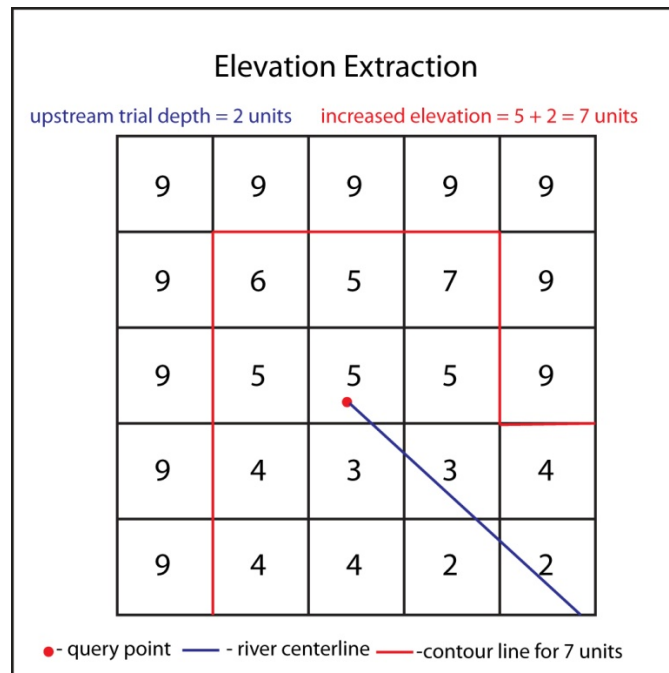


Figure 3-11. Created contour line.



Using the contour line for 7 units, as shown in Figure 3-11 UTIMS queries the contour line to identify the closest point on both the left and right sides of the contour line to find the closest point on the terrain to the trial depth point. Figure 3-12 shows the two points queried on the left and right sides of the contour line. These two points represent the closest points on the terrain to the trial depth point which are utilized in creating an initial flood polygon.

Using the user specified distance to query points along the river centerline for the sloping plane analysis UTIMS continues down the river centerline by querying more points on the river centerline to again find the trial depth point and develops the appropriate elevation contour line to develop an initial flood polygon.

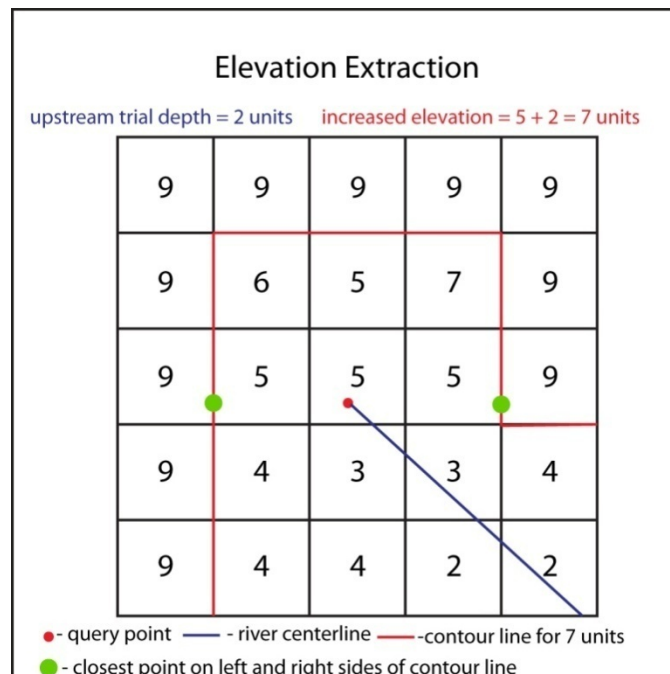


Figure 3-12. Queried points on contour line.

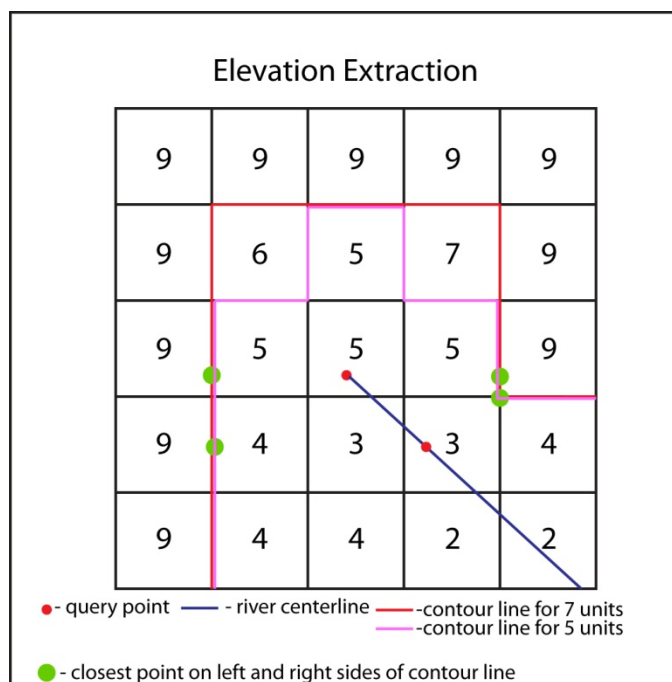


Figure 3-13. Second set of queried contour points.

Figure 3-13 displays a second point queried on the river centerline and the associated contour line at an elevation of “5” (five) units. UTIMS utilized the second query point and constructed the “five” (five) unit contour line to identify the closest points to the second query point's trial depth point on the five unit contour line. This second pair of points represents the closest points on the terrain to the second trial depth point. The contour line for 5 units was constructed by using the point value in the base elevation grid of “3” (three) for the second query point and adding a value of “2” (two) to get the trial depth point elevation of “5” (five) units. Trial flood depths are linearly interpolated from the trial upstream and downstream depths.

Figure 3-14 displays a third query point on the river centerline, and the associated contour line for “4” (four) units and the terrain query points identified. The

four unit contour was developed by using the base grid value of “2” (two) for the third query point and a trial depth of “2” (two) was applied to get an elevation of “4” (four) units.

Figure 3-15 shows how the initial flood polygon is developed using the three sets of the terrain query points. The flood polygon is constructed by adding the segments between the points to a polygon feature. In this manner UTIMS not only creates a flood polygon but has control of which points are in order from top to bottom in the polygon. Figure 3-15 indicates that there are more points downstream to be added as terrain query points, but only the first three sets of terrain query points are shown. UTIMS continues down the river centerline identifying terrain query points

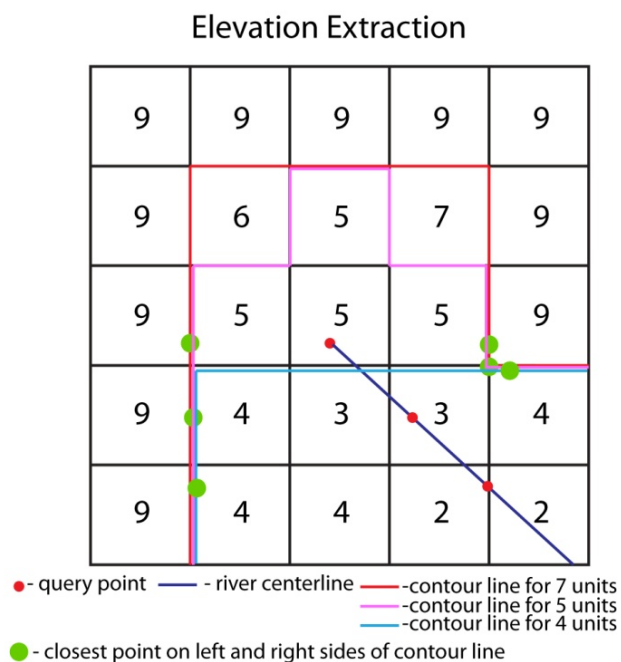


Figure 3-14. Third set of queried contour points.

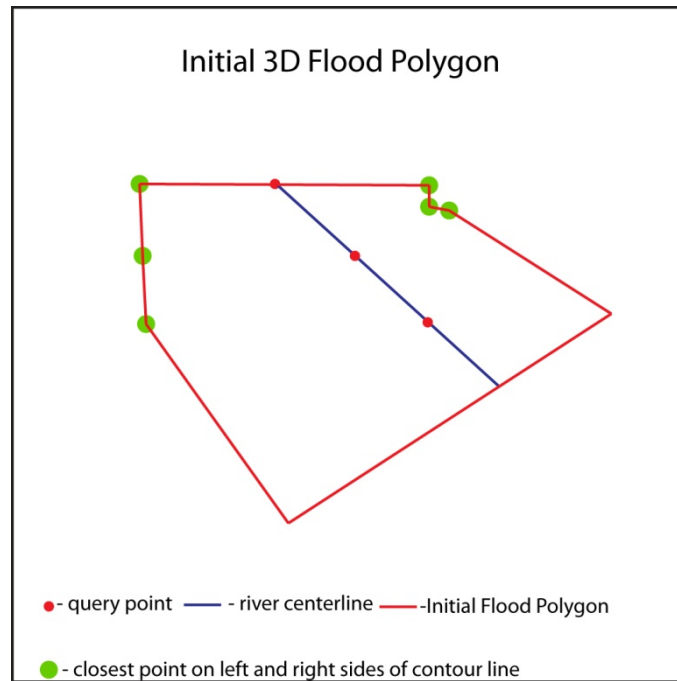


Figure 3-15. Initial three-dimensional flood polygon.

and constructs the initial flood polygon utilizing the left and right side terrain query points.

To aid in extreme flow modeling of meandrous portions of river reaches UTIMS ensures that the terrain points derived from query points below a certain station on the river centerline do not lie in the initial flood polygon already constructed. This ensures that in meandrous portions of a river reach a complete initial flood polygon is constructed which does not have overlapping paths forming the edge of the polygon.

Figure 3-16 shows the three dimensional view of the terrain with the trial depth points which are “elevated” off the thalweg of the terrain at depths equal to the trial depth linearly interpolated along the river centerline given the upstream and

downstream trial depths. Figure 3-16 also shows the terrain query points which have been determined to be the closest points on the terrain to the trial depth points.

UTIMS utilizes these terrain query points to construct a three dimensional polygon by connecting the terrain query points as the boundary of the initial flood polygon.

Figure 3-17 shows the constructed initial flood polygon.

The initial flood polygon shown in Figure 3-17 represents an initial flood inundation polygon which is utilized to approximate the flow path centerline of a certain magnitude of flow. As can be seen any meandering in the thalweg of the terrain is in essence removed by elevating points out the thalweg and connecting

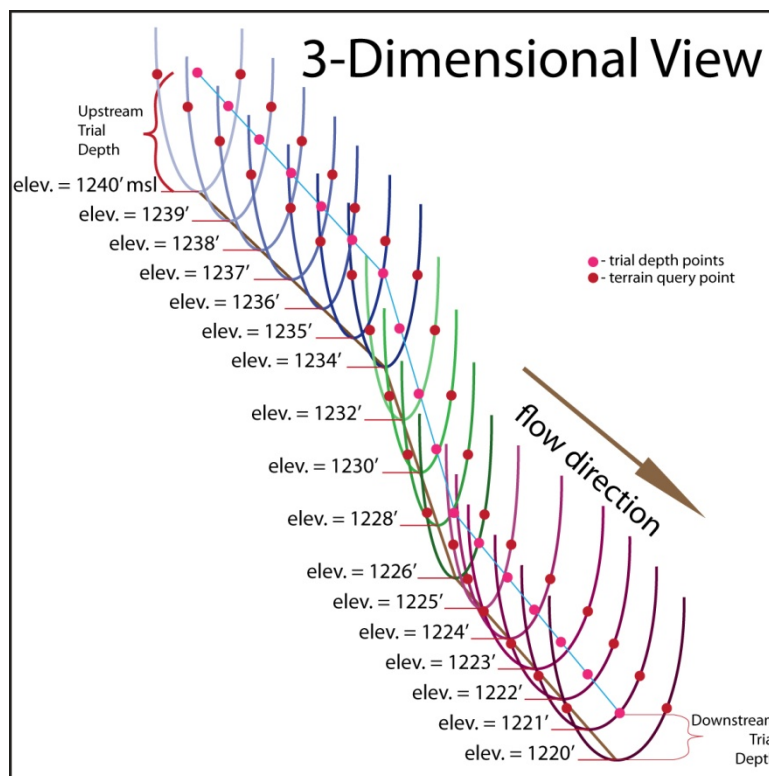


Figure 3-16. Nearest terrain query points.

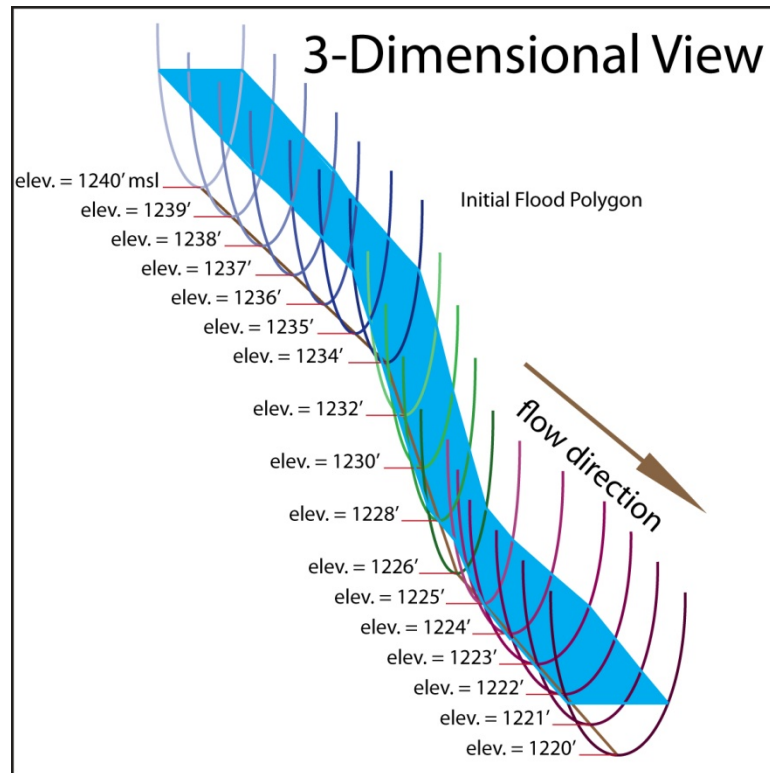


Figure 3-17. Constructed initial flood polygon.

terrain points to form an elevated flood polygon and approximating the centerline of the polygon. This process proves extremely useful when modelers may not know the flow path centerline of an extreme flow in extreme flow modeling case studies.

UTIMS aids users in approximating the centerline of the flow path so that cross sections can be placed perpendicular to the flow path centerline and essentially reduce the time in developing geometries for extreme flow modeling case studies.

#### Flood Polygon Centerline Approximation

UTIMS creates a flood specific river centerline for use by modelers in cases of extreme flow modeling. UTIMS approximates the flood specific river centerline as

the centerline of an initial flood polygon derived by utilizing terrain data and the user input trial upstream and trial downstream depths. For subsequent iterations, UTIMS also performs this approximation of a flood polygon centerline by finding the centerline of the flood polygons read into UTIMS from HEC-RAS.

Several techniques to approximate flood polygon centerlines were tested to identify a reasonable approximation of the flood polygon centerlines. The first technique investigated was to cut the flood polygon into many parts by cutting the polygon into successive halves until the area of each small polygon reached a minimum area. Then by taking the center points of each of the smaller flood polygon parts and connecting them to construct the flood polygon centerline. This method did not create uniform smaller polygons, therefore when the smaller polygon center points were connected the centerline did not represent the centerline of the flood polygon.

The second technique investigated was to isolate the left and right paths of the flood polygon and cut them up into equal number of segments. Taking the first two segments (the first on the left and the first on the right) the “from” points of each segment were connected and a “midpoint” was created in memory at half the distance of the connected line. Then the second pair of segments were identified and the “from” points of these two segments were connected and a “midpoint” was identified along the connected line at half the connected line length. This process was continued down the left and right paths of the flood polygon. These “midpoints” were then connected to construct an approximation of the flood polygon centerline. This technique proved useful when the left and right paths of the flood polygon were of approximately the same length. However, when the left and right path lengths varied

greatly the created “midpoints” were created outside of the flood polygon itself.

Therefore this technique did not prove useful to be included in UTIMS.

The third technique was to take query points along the left path of the polygon and then query the closest points on the right side of the polygon to each of the points along the left path of the polygon. For each left path point and its closest right path point a line was constructed and the midpoint of the connected line was identified. By taking these “midpoints” and stringing them together an approximate flood polygon centerline was constructed. This method proved useful when the left and right paths of the flood polygon were uniform in length and very nearly mirrored each other. When the left and right paths of the flood polygons varied greatly in length and expanded away from each other the constructed centerline crossed out of the flood polygon due to great variances in lengths of the left and right paths.

The fourth technique was a modification of the third technique mentioned above. This technique followed the third technique where base query points are taken on the left and the right paths of the polygon with a limit on where the closest points along the opposite paths of the polygon could be found. This method proved sufficient in approximating the centerline of the flood polygons in cases where the left and right paths were nearly the same length as well in cases where the paths differed greatly in length. This method was accepted as the method with which UTIMS identifies a flood polygon centerline considering the scope of this thesis and the degree to which the flood polygon centerline must be truly in the center of the flood polygon at all times. Further elucidation of this method and its output is continued on page 61.



A method to identify the centerline of a flood polygon through partial differential equations was discussed by Chai, Miyoshi and Nakamae (1998). The method described in Chai, Miyoshi and Nakamae (1998) shows how a true flood polygon centerline could be developed. The research by Chai, Miyoshi and Nakamae (1998) describes the process through which a centerline which is both globally smooth and exactly simultaneous central to two bounding contour lines or polylines can be constructed by using gradient controlled partial differential equations. The methodology is constructed by considering two contour lines which can be governed by partial differential equations. By solving the partial differential equations and considering their gradient conditions a piecewise linear polygonal terrain surface is constructed. Then by sampling on the constructed surface at an intermediate contour elevation a new contour line can be constructed.

Although the method as described by Chai, Miyoshi and Nakamae (1998) would be useful in developing a true flood polygon centerline, but it was not pursued in UTIMS development. UTIMS works in conjunction with HEC-RAS, a one-dimensional modeling engine, to produce floodplain maps. Therefore, it was not considered appropriate in UTIMS to implement a mathematically rigorous technique to identify “true” or “exact” flow path centerline, but a computationally efficient “reasonable” approximation of it and allow the user to do any necessary adjustments by visual inspection. The following section describes the method that UTIMS uses for flood polygon centerline approximation.

### UTIMS Flood Polygon Centerline Approximation

UTIMS creates a flood specific river centerline for use by modelers in cases of extreme flow modeling. UTIMS approximates the flood specific river centerline as the centerline of an initial flood polygon derived by utilizing terrain data and trial upstream and trial downstream depths. For subsequent iterations, UTIMS also performs this approximation of a flood polygon centerline by finding the centerline of the flood polygons which are read into UTIMS from HEC-RAS.

The approximation UTIMS uses to derive the flood specific centerline relies upon the boundaries of the initial flood polygon. UTIMS uses a proximity analysis of points along the left and right boundaries of a flood polygon. Figure 3-18 displays

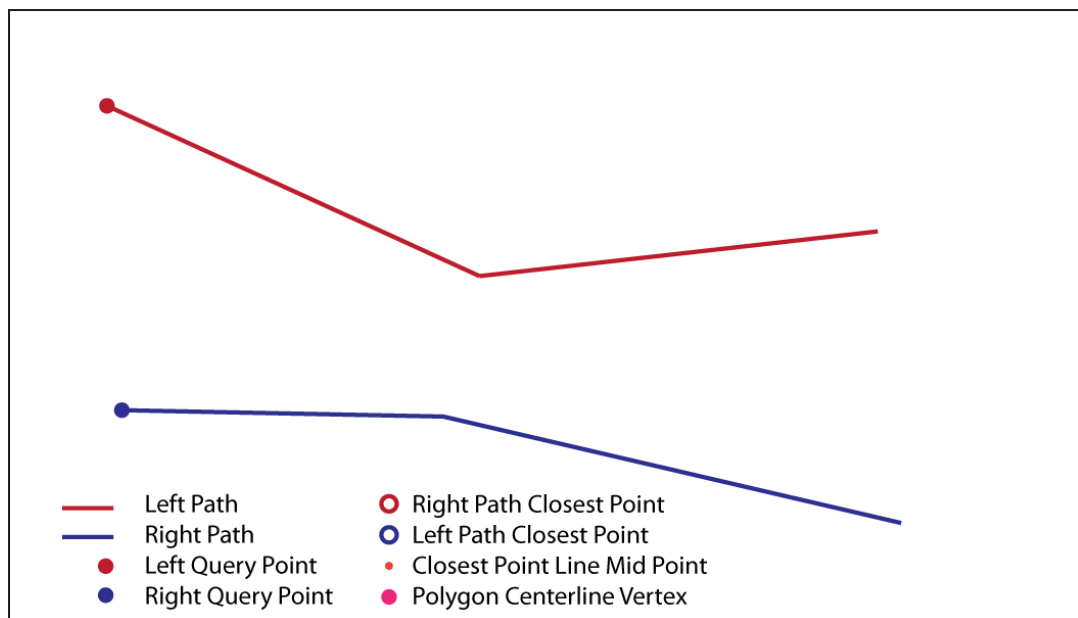


Figure 3-18. Query points on left and right sides of initial flood polygon.

how UTIMS identifies the left and right sides of the initial flood polygon and uses these to approximate the centerline of the flood polygon. As can be seen in Figure 3-18 a left and right query point on the appropriate boundary lines are used to initiate the analysis. This type of analysis was chosen as an appropriate approximation due to its ability to efficiently characterize the centerline of the initial flood polygon.

UTIMS uses the left and right query points to query the closest point on the opposite side of the polygon (i.e. the closest point on right path closest to the left query point). Figure 3-19 shows the closest points identified on the opposite sides of the polygon closest to the initial query points. UTIMS then connects the appropriate query point with its accompanying closest point on the opposite side of the polygon and queries the mid points of the two line constructed. Figure 3-19 shows how

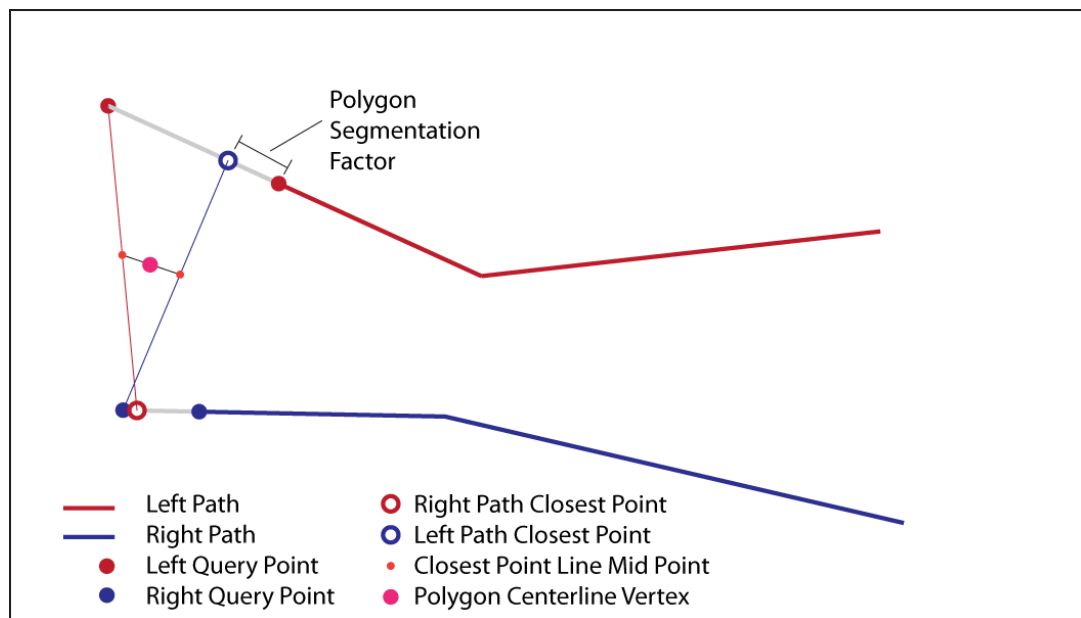


Figure 3-19. Closest points on opposite polygon path querying and polygon segmentation factor.

UTIMS connects the appropriate points on the left to right and right to left paths to create two connected lines. UTIMS queries the midpoint of these connected lines and connects the two points found and takes the midpoint of the newly created line as a new vertex in the approximated flood polygon centerline. The new polygon centerline vertex is shown in Figure 3-19 as an approximation of the center of a portion of the main flood polygon by utilizing closest point neighbors on opposite sides of the flood polygon.

To continue the process in the downstream direction, UTIMS increments the stations of the closest points by a user specified distance to identify new base query points. This distance is termed the “Polygon Segmentation Factor.” This user specified distance has a role in how accurately a user wants UTIMS to identify the flood polygon centerline. The value entered by the user is applied to the left path of the polygon and a value for the right path of the polygon is calculated as proportional to the “Polygon Segmentation Factor” based on the left and right path lengths. Another way in which UTIMS ensures that this process continues in downstream direction is that UTIMS only allows the closest points on the opposite side of the flood polygon to be at a station downstream of or at the base query point station. As can be seen in Figure 3-19 where upstream portions of the left and right paths of the flood polygon have been “grayed” out and are no more available.

Figure 3-20 also shows the second pair of newly queried closest points to the new base query points. Again the base query points are connected with their appropriate closest point neighbor. The mid points of these newly create lines are

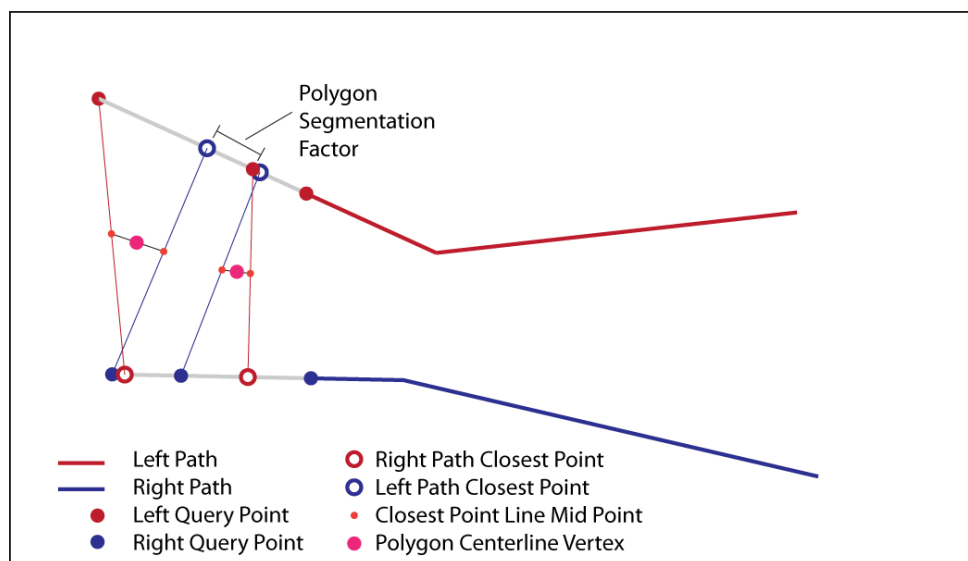


Figure 3-20. Closest point analysis in uniform flood polygon.

queried. UTIMS again joins these two midpoints and queries this new line to obtain a new vertex in the centerline approximation process.

Figure 3-20 shows the new base query points and the available portions of the left and right paths of the flood polygon with which to query opposite side points.

Figure 3-21 shows the third set of base query points and their closest point queried on the opposite side of the flood polygon and a new vertex of the flood polygon centerline. Figure 3-22 shows how the process continues downstream until the last points on the left and right paths of the flood polygon are used to complete the flood polygon centerline.

This process proves useful in cases where a flood polygon does not have uniform left and right paths to query. As seen in Figure 3-23a an example of left and right paths which are not uniform shows how UTIMS would approximate the centerline of the shown flood polygon.

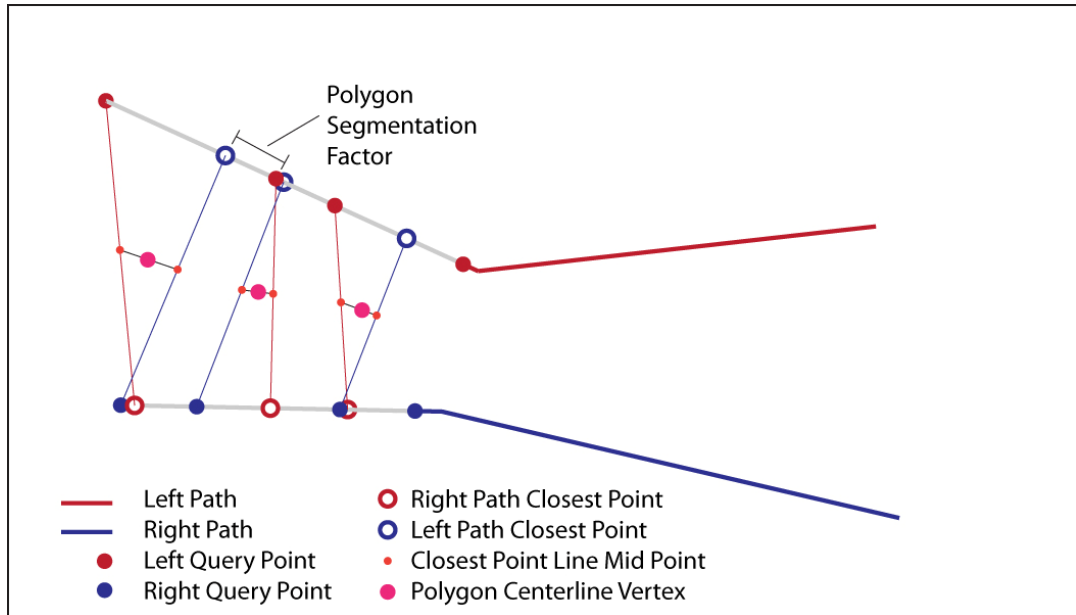


Figure 3-21. Continued closest point analysis.

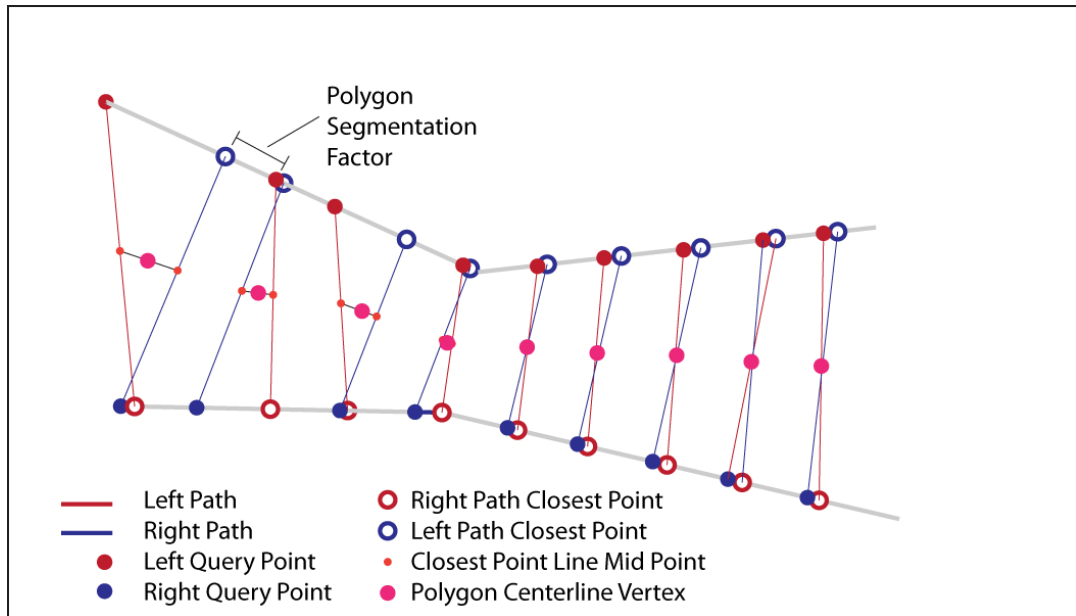


Figure 3-22. Completed closest point analysis.

Figure 3-23b shows the approximated flood polygon centerline from the irregular flood polygon shown in Figure 3-23a. As can be seen UTIMS handles the somewhat jagged left and right polygon paths well and stays mainly in the center path of the polygon. In this process UTIMS ensures that the centerline continues in a downstream direction by limiting the available path length which can be queried when identifying the closest points on the opposite path from the base query points.

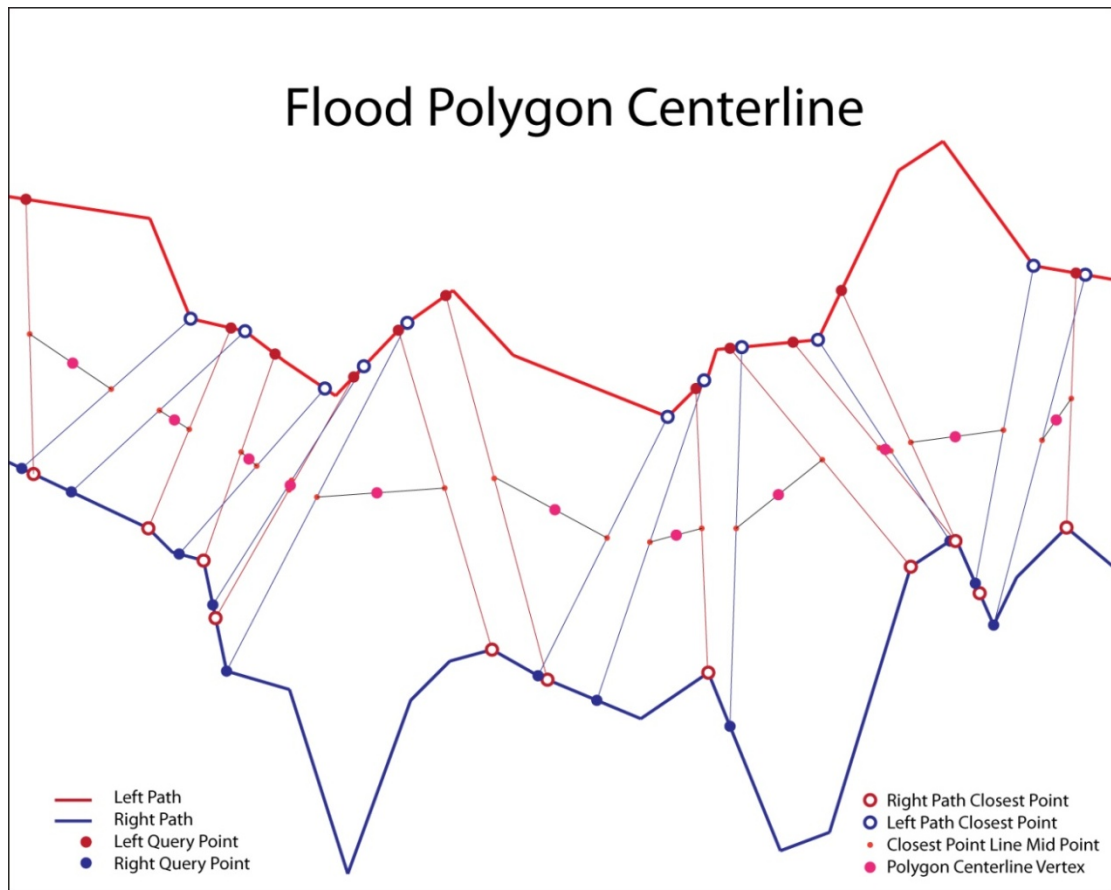


Figure 3-23a. Irregular polygon shape flow path centerline determination.

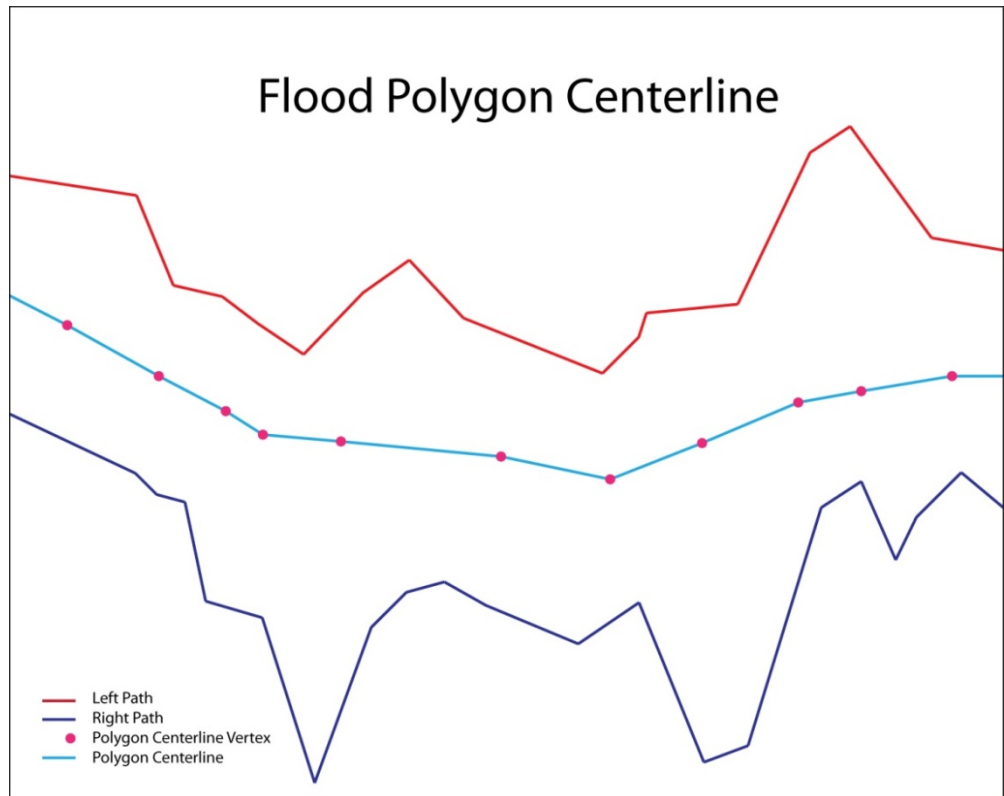


Figure 3-23b. Completed irregular flood polygon flow path centerline.

To further illustrate the pathway in which a flood polygon centerline is developed when the left and right path lengths vary Figure 3-24 shows a case in which the right path is longer than the left path. As shown in Figure 3-24 the right path is jagged and the left path stays straight. Due to the much longer length of the right path the segmentation factor for the right is longer than the one used for the left. The paired left and right query points are similarly numbered (1, 2, 3, ...) until the end of the polygon is reached. As can be seen the presence of the jagged edge of the right path influences the centerline of the flood polygon in a small degree. To handle the jagged edge on the right path UTIMS does place a query point on the right path in the



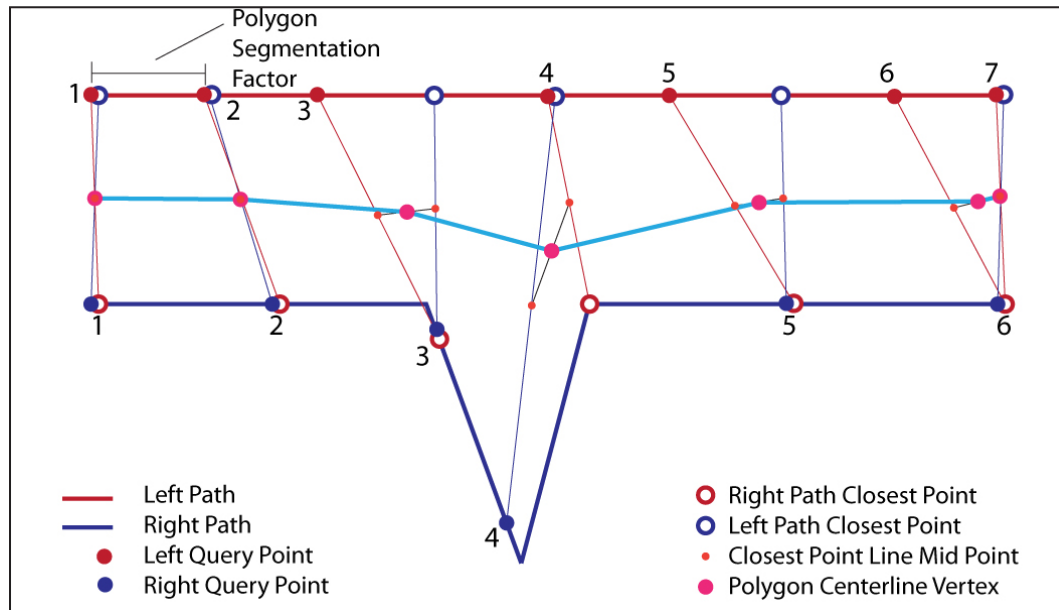


Figure 3-24. Irregular right path flood polygon flow path centerline.

V-shape of the right path. This point (in Figure 3-24 right point 4) queries the left path and finds the closest point available on the left path which is just next to the left query point on the left path (also numbered 4). The left query point does not find a point in the V-shape of the right path as it finds the closest point on the right path which is at the top of the V-shape. This aids in keeping the flow path centerline in the flood polygon. In this manner UTIMS seeks to develop a flow path centerline which reasonably represents the path that water would flow through the flood polygon as shown in Figure 3-24. Figure 3-24 also shows the final flood polygon centerline developed by UTIMS. It is to be noted, that a mathematically “true” centerline would be inappropriate here, because most likely user will define some ineffective flow area on the right hand side.

### Line of Sight Analysis

To aid construct a smooth flow path centerline UTIMS also utilizes a “line of sight” analysis to smooth the approximated flood polygon centerline for use in placing cross sections. Due to the possibility of short kinks in the flood polygon centerline UTIMS smoothes the centerline by looking in the downstream direction for possible portions of the flood polygon centerline which can be short-circuited or removed. This is done to allow for cross sections to be placed normal to the flow path centerline and not be severely altered in orientation to the main direction of flow path by short kinks in the approximated flood polygon centerline.

The degree to which the flood polygon centerline is generalized is user defined. This process is extremely useful when the floodplain opens up and is expansive in breadth where the flow path centerline should follow a general direction rather than have short kinks in its path. UTIMS guards against over generalization in meandering portions of terrain by not allowing the line of sight centerline intersect the terrain itself, thus keeping the general shape of meanders if they are defined by the terrain and the magnitude of flow under consideration.

Figure 3-25 shows a short segment of a meandering flood polygon centerline which will be used to illustrate how the line of sight analysis operates on the approximated flood polygon centerline. As can be seen in Figure 3-25 query points are placed along the centerline at a user specified distance. The user specified distance is termed the “Line Of Sight Point Interval” and its value can impact the degree to which a centerline is generalized or short-circuited.

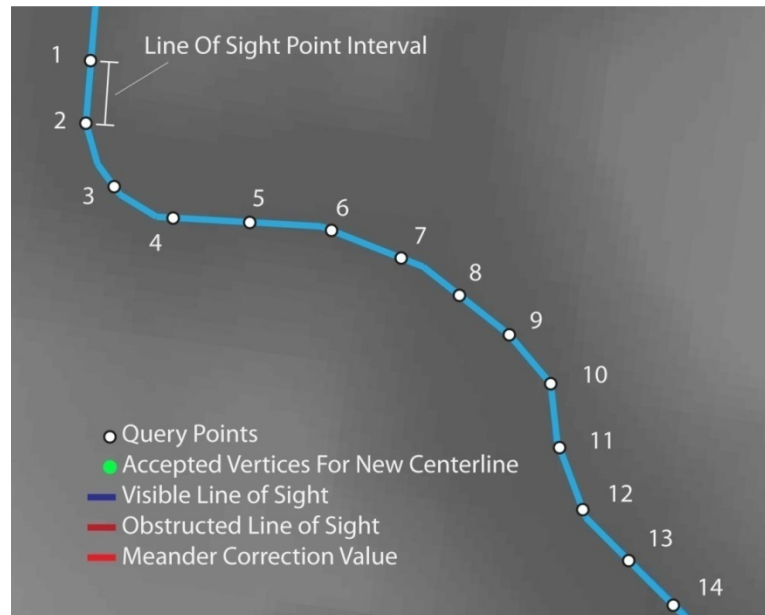


Figure 3-25. Line of sight points.

The query points as shown in Figure 3-25 are the possible vertices of the line of sight centerline. The query points along the centerline are given an elevation increase to be used in the line of sight analysis. These elevation increase values are assigned based upon a linear interpolation of the user specified upstream and downstream trial depths. To begin the process UTIMS identifies the first point on the centerline as the base query point. From the base query point UTIMS connects to the subsequent points along the centerline until one of the points cannot be “seen” or there is an obstruction impeding the viewing of subsequent points along the centerline.

Figure 3-26 shows the connected lines from the first point to subsequent points along the centerline until an obstruction is encountered and UTIMS could not “see” a point downstream.

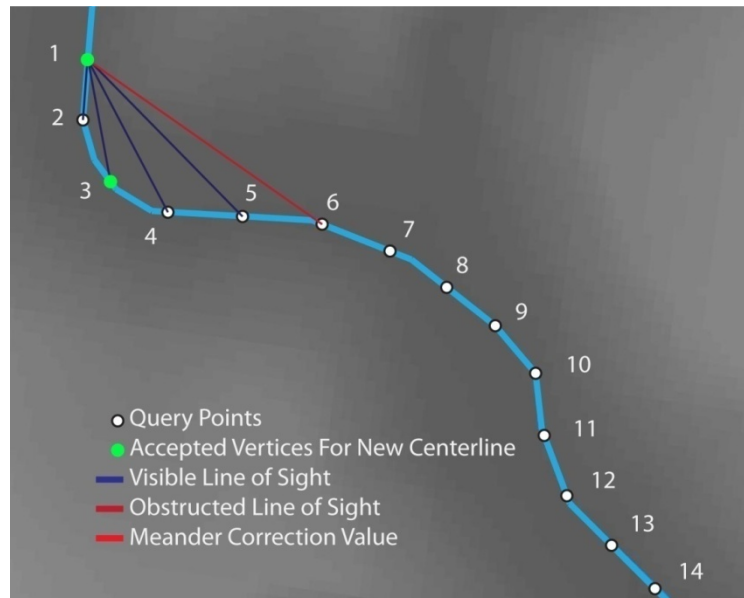


Figure 3-26. First set of line of sight analysis points.

As seen in Figure 3-26 UTIMS encountered no obstruction by the terrain in connecting the first point to the second, third, fourth, and fifth points. Between the first and sixth points, though, there was an elevation encountered which impeded the line of sight. To avoid causing the line of sight analysis to give new centerline that may intersect the terrain surface UTIMS does not take the last point seen as the second point to add to the line of sight centerline. Instead, UTIMS selects the point at half the distance between the base query point and the last seen point. Therefore, as seen in Figure 3-26, UTIMS accepts the third point as the next point in the line of sight centerline. UTIMS then utilizes the third point as the new base query point.

Figure 3-27 shows the connected lines from the third point to the subsequent points which can be “seen” down the flood polygon centerline. As shown in Figure 3-

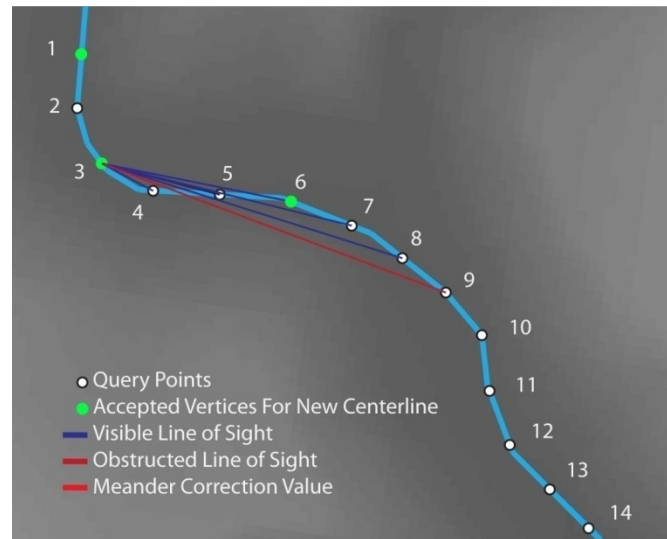


Figure 3-27. Second set of line of sight analysis points.

27 UTIMS encountered an obstruction between the third and ninth point, therefore UTIMS selected the sixth point as the third point in the line of sight centerline.

As seen in Figure 3-28 UTIMS encountered no obstructions from the sixth to the thirteenth point. To avoid too much generalization UTIMS requires a “Meander Correction Value” to be utilized in restricting how much length the line of sight analysis can remove from the flood polygon centerline. Figure 3-29 shows that UTIMS could see past the meander correction value distance therefore, UTIMS takes the point which is at two-thirds of the distance which UTIMS could “see.” Therefore the eleventh point was taken as the next vertex in the line of sight analysis centerline.

The meander correction value also tells UTIMS that a user wants the sloping plane analysis and line of sight analysis to be performed on the input river centerlines. Therefore the meander correction value plays a twofold part in the sloping plane analysis and the line of sight analysis. If the meander correction value is zero then no

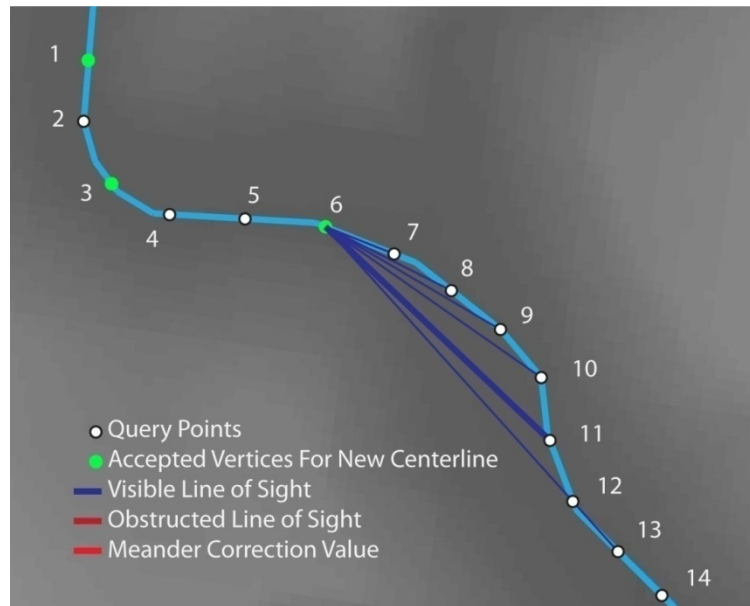


Figure 3-28. Long segment of line of sight analysis considered.

sloping plane analysis or line of sight analysis is performed, which may be useful in modeling in-stream flows. However, if the meander correction value is greater than zero then UTIMS performs both the sloping plane analysis and line of sight analysis on the river centerline for the first iteration. For subsequent iterations, instead of the sloping plane analysis, the maximum water surface polygon obtained from HEC-RAS output is utilized to generate a flow path centerline for the flood polygon.

The line of sight analysis is also performed on the flood polygon centerline for the subsequent iterations.

Figure 3-30 shows the line of sight centerline constructed from the polygon centerline depicted in Figure 3-25. The line of sight analysis smoothes flood polygon centerlines providing a more representative flow centerline with which to place cross sections perpendicular to flow and to build HEC-RAS models.

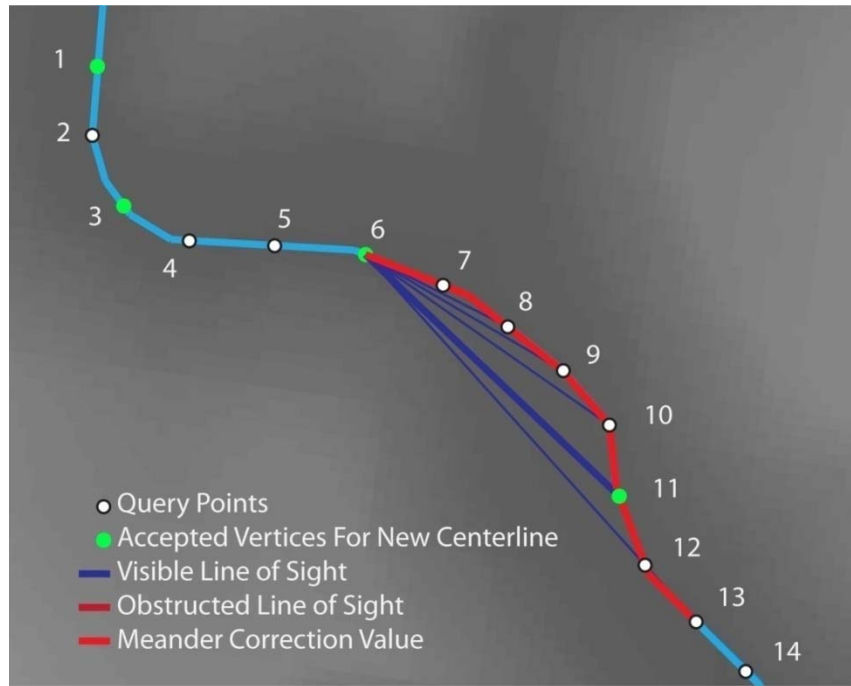


Figure 3-29. Meander correction distance.

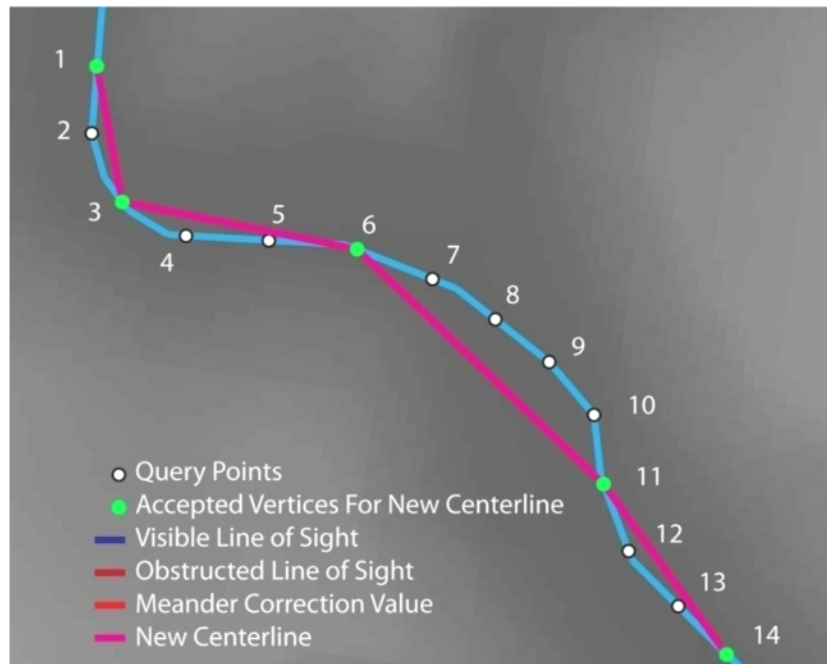


Figure 3-30. Line Of sight analysis completion.

### Areal Averaged n-Value Assignment

In the process of determining n-values for input to HEC-RAS, UTIMS completely automates the assignment of n values to segments of cross sections with the aid of standard land use data. UTIMS automates the creation of n-value polygons which represent the n-value described by the spatial land use extent of each segment of a cross section. The development of the appropriate areal extent to assign to a specific portion of a cross section ensures that an appropriate n-value is assigned to the correct portion of a cross section. As cross sections represent the change in cross section profiles between the upstream and downstream cross sections the n-value must also be representative of the change in land use type and thus the n-value from the upstream to downstream cross sections for each cross section. UTIMS creates representative polygons derived from segments of each cross section by creating a proximity map. The proximity map utilized ensures that the n-value for each segment of a cross section more reasonably represents the actual spatially derived n-value based upon the land use types located within the extent of a cross section segment. UTIMS uses the National Landcover Dataset (NLCD) as the standard input with which it calculates representative n-values for segment derived polygons.

The process of assigning n-values to various segments of cross sections begins with the cross sections themselves. Cross sections associated with a single reach are processed together at a time so that the spatial extent of segments based upon surrounding segments can be more accurately described. The extent of the segments of cross sections is derived by using the Euclidean allocation method made available



by ArcMap. The Euclidean allocation method is the same process as utilized in producing the Thiessen polygons. The function can be performed on data sources of feature class and raster type.

Input data sources into the Euclidean allocation contain what are known as “source” cells which hold source values. The Euclidean allocation function uses source cells to find the boundaries of the closest areas to each source cell relative to the other source cells in the input data source. The function is ultimately performed on only raster datasets, however if a feature class is input into the function then the function will internally convert the features within the feature class first to a raster dataset before performing the Euclidean allocation. The basic premise of Euclidean allocation is shown in Figure 3-31.

As is seen in Figure 3-31 the input data source contains what are known as “source” cells. For each source cell there is an associated value. The Euclidean allocation in essence scans the cells located within the input data source and for each cell the distance from itself to each source cell is calculated. The closest source cells value is recorded as the scanned cell’s value. As can be seen in Figure 3-31 the distances calculated is the hypotenuse or true Euclidean distance. This distance is the distance from the center of each scanned cell to the center of the source cells.

The Euclidean allocation produces an output raster which holds the cells which have been assigned the value of their closest source cell’s values. Figure 3-32 depicts the output from a Euclidean allocation. As can be seen in Figure 3-32 each cell has been assigned the value of the nearest source cells, as indicated by the various zones (the source cells are still indicated by the cells with bold white border).

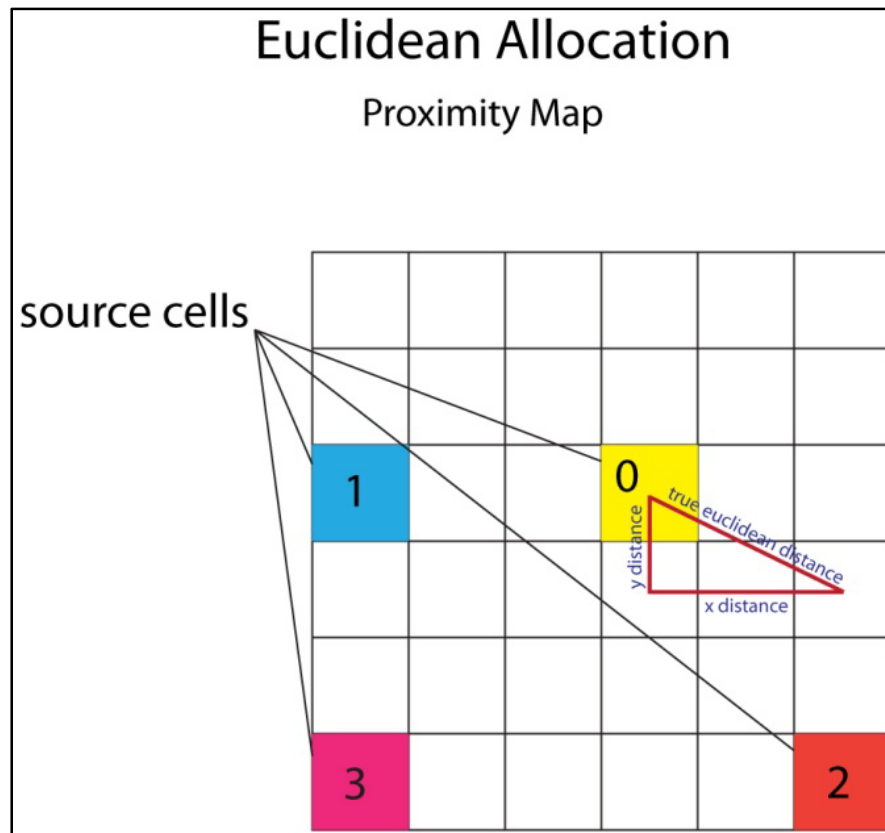


Figure 3-31. Euclidean allocation input.

In overview of the n-value assignment capabilities of UTIMS Figure 3-33 shows the general pathways through which UTIMS travels to derive areal averaged n-values. There are two adjacent paths of data flow that occur during the assignment of n values to segments of the polylines created. These paths are graphically shown in Figure 3-33. The two paths are first the spatial extent path and second the land use determination path. The first path, the spatial extent path, ultimately determines the Euclidean allocation feature boundaries for each cross section segment. This first path of determining the spatial extent to be assigned to each segment of a cross sections generates the source cells used in the Euclidean allocation to determine the proximity

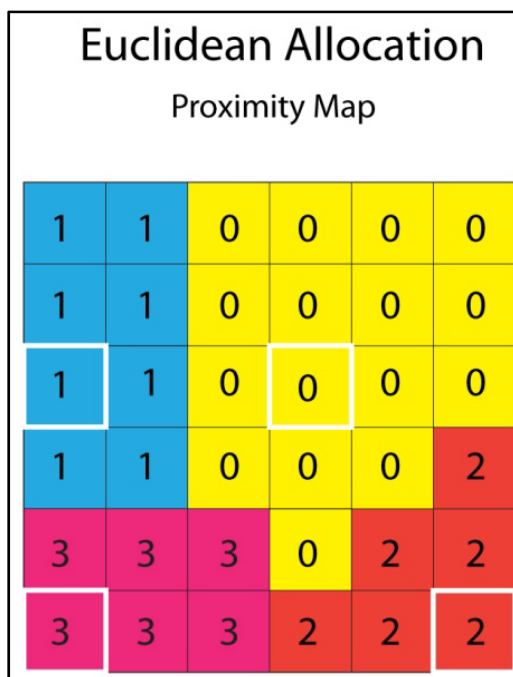


Figure 3-32. Proximity map derived from euclidean allocation.

map used in assigning areal average n-values. The land use determination path defines the n-values possible within each Euclidean allocated polygon.

Due to only a single collection of cross sections associated with one river reach being analyzed at a time UTIMS employs a numbering system which allows effective file handling. For each dataset created UTIMS adds a special identifier number to the end of the file name. The identifier number represents which river reach in the original river centerline shapefile the cross section collection belongs to. For example, the first cross section collection, being associated with the first river in the original shapefile, would be given the ending “0” (zero) for each of the datasets created for that collection of cross sections. The second collection would receive a “1” (one) and so forth until all the cross sections have been processed and assigned

average n-values. The datasets described in the remainder of this section will be assuming the value of “0” (zero) at the end indicating a simulated first dataset being handled.

The process of assigning n values to segments of cross sections handles a single collection of cross sections that are associated with a single reach. These cross sections are located in the “Cross Sections.shp” shapefile located in the current output folder (“Data” & iteration number), indicating which iteration UTIMS is conducting. Figure 3-34 displays a sample set of four cross sections.

UTIMS allows users the ability to specify how many segments each cross section should be divided into in determining n values. From the specified number of segments for a specific reach UTIMS divides each cross section into a user specified number of segments. Figure 3-35 shows how these four cross sections would be divided if they were divided into five segments each. As per HEC-RAS requirement, the cross sections are to be oriented left to right when looking in the downstream direction. Figure 3-35 indicates that indeed this is the case with the UTIMS process as the first segment (located on cross section one) is in the upper right hand corner of the figure. The shapefile which holds the polyline segments in preparation for the Euclidean allocation is entitled “polylinesegments0.shp.”

In preparation for Euclidean allocation, UTIMS converts the features located within the polyline segment feature class into a GRID format and stores them in the current iteration data output folder as “seg\_raster0.” The values for the cells in the GRID format hold the value of which segment it was derived from. For example the first segment in the raster created would have the value of “1” (one), and so forth.

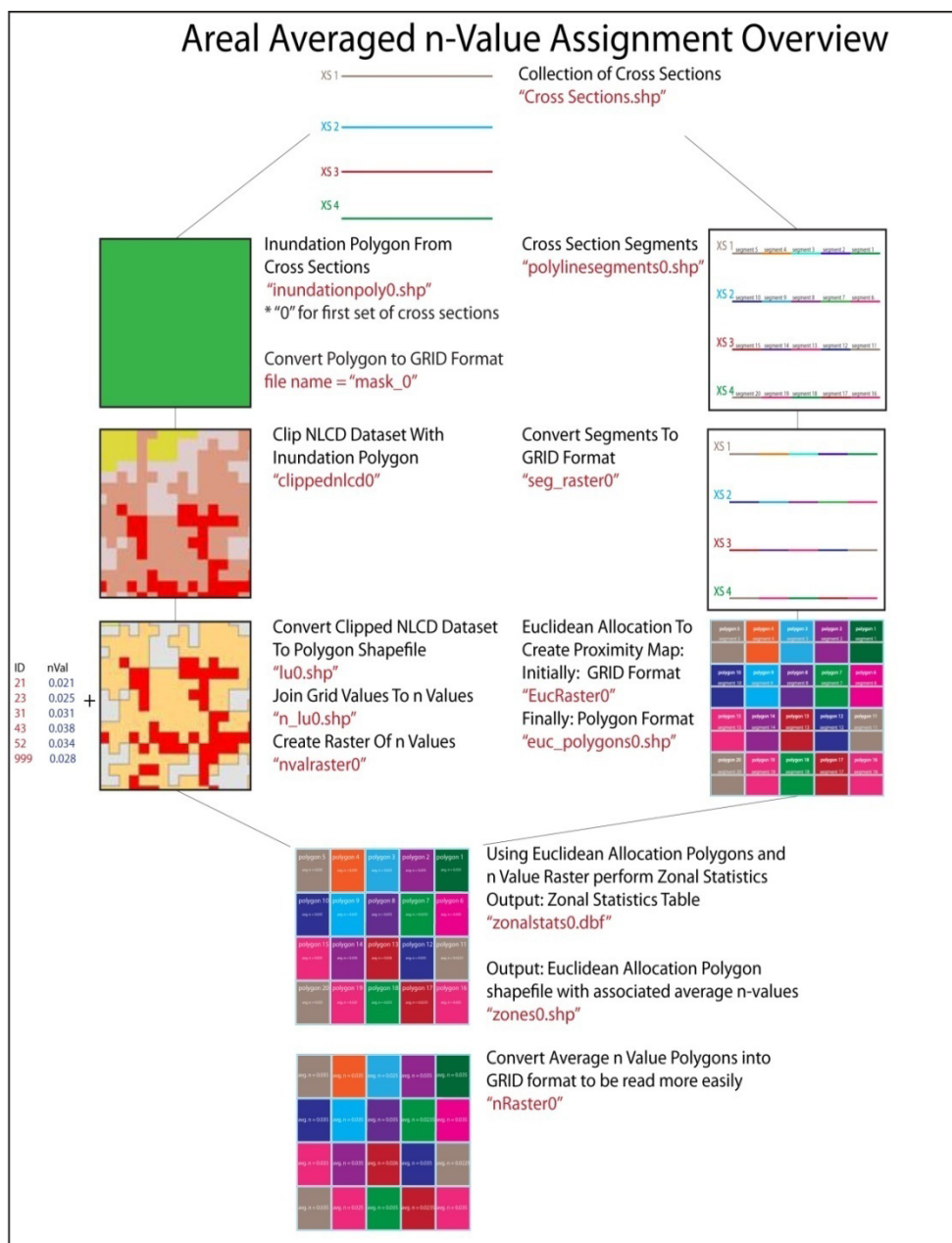


Figure 3-33. Overview of areal average n-value assignment.

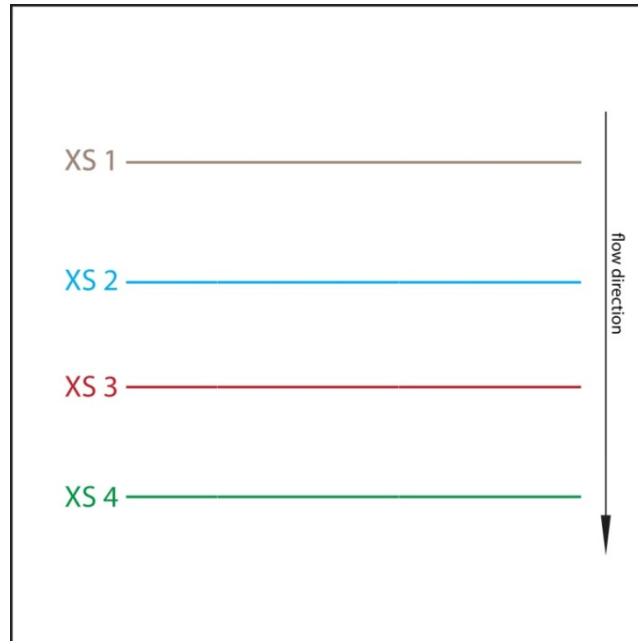


Figure 3-34. Original cross sections.

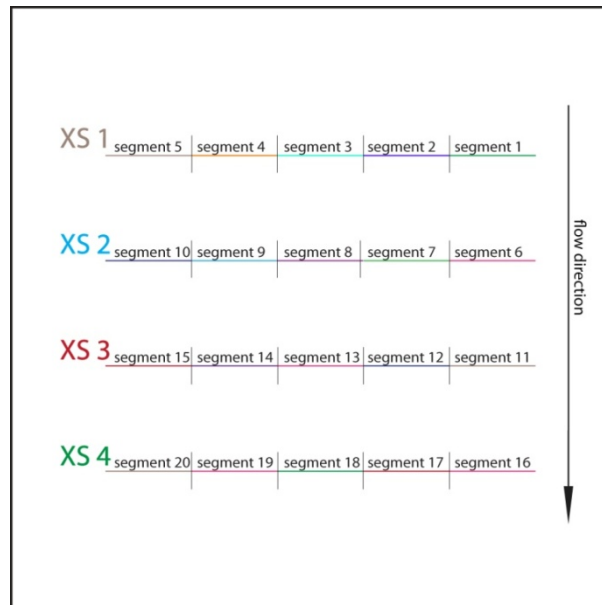


Figure 3-35. Cross section segments.

The Euclidean allocation is performed on the grid format of the polyline segments, thus creating the required proximity map for use in assigning areal average n-values. The Euclidean allocation creates an internal raster format of the output, which is stored in the data output folder as “EucRaster0.” UTIMS converts the raster into a polygon shapefile for the purpose of associating each raster zone with an area averaged n-value. The resulting shapefile containing the polygons created by the Euclidean allocation is stored as “euc\_polygons0.shp.” Figure 3-36 depicts how the Euclidean allocation would calculate the Euclidean polygons from the previously shown polyline segments in Figure 3-35. As can be seen in Figure 3-36 the created polygons extend to neighboring segments on the same cross section and then half-way between the previous and subsequent cross sections (upstream and downstream). The extent for the Euclidean allocation raster environments settings for this step are extended 100 units both upstream and downstream to get more representative polygons for the furthest upstream and furthest downstream cross sections.

Thus constructing the Euclidean allocation polygons for each segment derived from each initial cross section UTIMS determines the extent under each cross section segment to assign an average n-value. Figure 3-37 displays the proximity map or “window frame” with which to view and account for land use associated with a particular segment analysis extent. Polygon 13 from the Figure 3-36 is shown as an example in Figure 3-37.



Figure 3-36. Euclidean allocation polygons.

The proximity map derived from using the Euclidean allocation provides the extent with which to examine the land uses that define the area surrounding a segment of a cross section. Up to this point UTIMS completes the first path of data handling which creates an appropriate proximity map.

The second path of data handling utilizes the specific land use data source to determine areal average n-values. UTIMS utilizes the standard and widely accessible National Land Cover Dataset as the input for n-value assignment.



The National Land Cover Dataset is the product of many surveys compiled by the United States Geological Survey (USGS). The values assigned to each grid cell in the dataset are an integer representation of the dominant land use type within the particular grid cell. These integers representing land types range from 11 to 99. Figure 3-38 displays the representative integer and land use type for the 2001 National

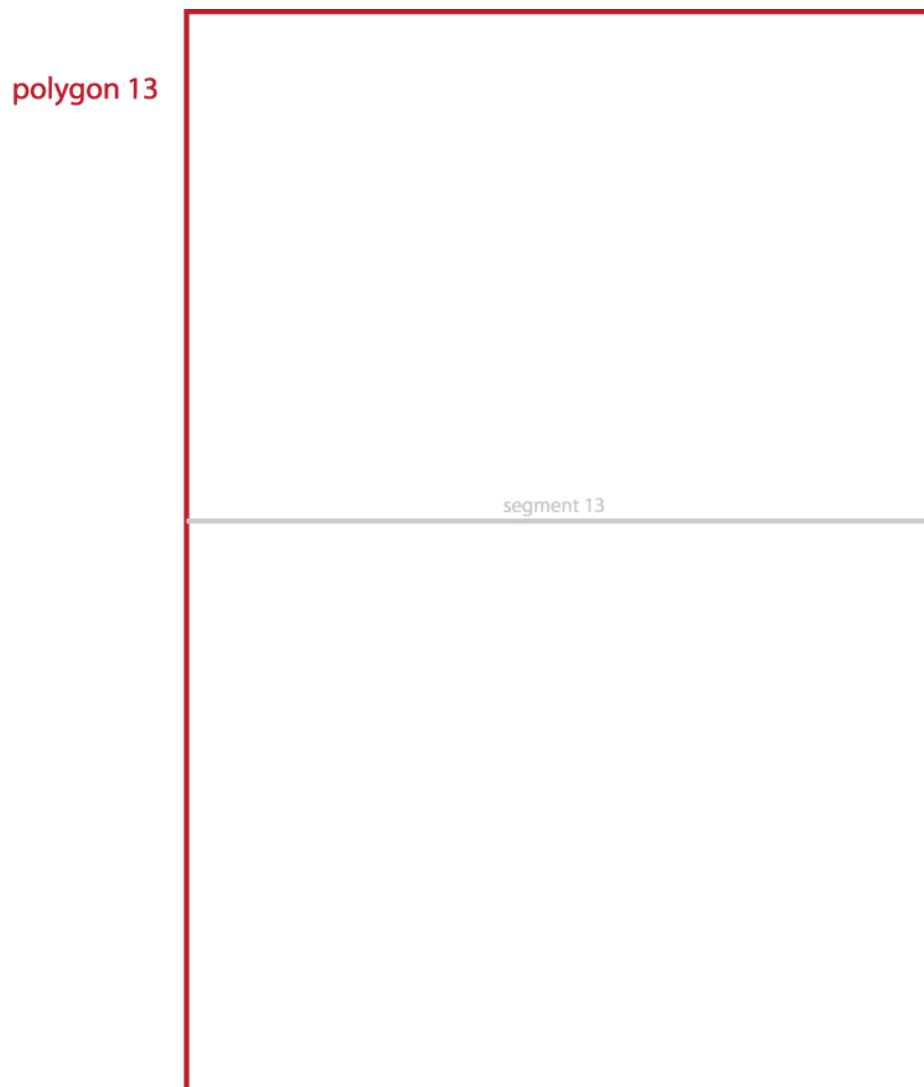


Figure 3-37. Proximity map for example polygon 13.

Land Cover Dataset.

Utilizing the National Land Cover Dataset a user can specify a land use – n value table relating each land use type to a specific n value. This allows for representative assignment of n-values for large areas being studied. Figure 3-39 shows a table as an example for several land use types and associated n-values as input into UTIMS. UTIMS requires a text (“\*.txt”) file containing land use ID on each line followed by a tab and a representative n-value for that specific land use type, as shown

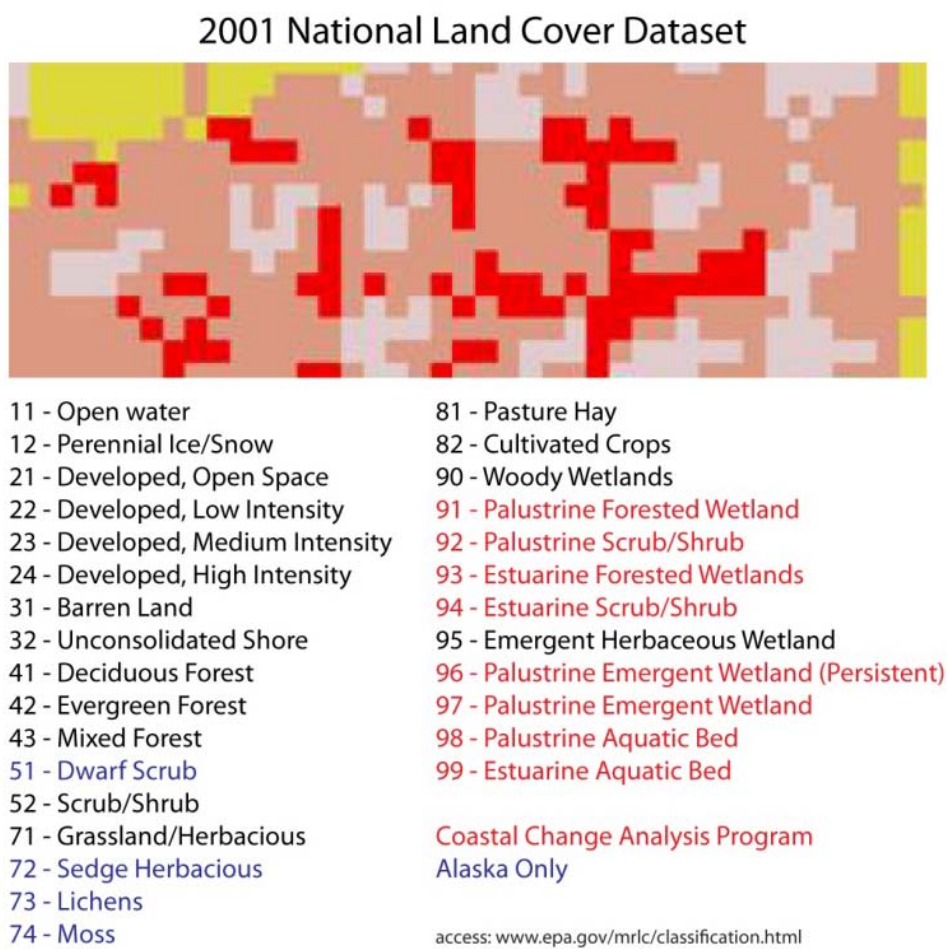


Figure 3-38. National land cover dataset grid cell values.

in Figure 3-39. In cases where there may be no data assigned or a user may wish to specify a specific n-value for all other land use types, the last value in the file has an ID of “999” and then a representative n-value for all other land use types or for no ID values in the grid. Column titles of “ID” and “nVal” are required on the first line of the text file defining first the grid code values and then the n-values.

UTIMS utilizes the National Land Cover Dataset (NLCD) by clipping the land use dataset to the extent of the collection of cross sections being considered. UTIMS takes the cross sections specified by the user and constructs a polygon which encloses all the cross sections in a collection. The polygon is constructed by using the end points of each of the cross sections to create a complete possible inundation polygon.

NLCD Code - n Value Table

ID	nVal	
21	0.021	
23	0.025	
31	0.031	
43	0.038	
52	0.034	
999	0.028	located in tab delimited text (*.txt*) file

11 - Open water	81 - Pasture Hay
12 - Perennial Ice/Snow	82 - Cultivated Crops
21 - Developed, Open Space	90 - Woody Wetlands
22 - Developed, Low Intensity	91 - Palustrine Forested Wetland
23 - Developed, Medium Intensity	92 - Palustrine Scrub/Shrub
24 - Developed, High Intensity	93 - Estuarine Forested Wetlands
31 - Barren Land	94 - Estuarine Scrub/Shrub
32 - Unconsolidated Shore	95 - Emergent Herbaceous Wetland
41 - Deciduous Forest	96 - Palustrine Emergent Wetland (Persistent)
42 - Evergreen Forest	97 - Palustrine Emergent Wetland
43 - Mixed Forest	98 - Palustrine Aquatic Bed
51 - Dwarf Scrub	99 - Estuarine Aquatic Bed
52 - Scrub/Shrub	
71 - Grassland/Herbacious	
72 - Sedge Herbacious	
73 - Lichens	
74 - Moss	

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Figure 3-39. NLCD dataset n-value assignment relationship.

This polygon is stored in a shapefile entitled “inundationpoly0.shp” located in the data output for the current iteration, “0” for the first collection in a set of cross section collections.

UTIMS uses the inundation polygon to create a single raster band which has the value of “1.” This raster is saved in the data output folder as “mask\_0.” Using this raster a raster calculation is performed by multiplying the mask raster having a value of “1” and the NLCD dataset. The resulting output is a clipped NLCD layer which represents the extent of the cross section collection being considered. The clipped NLCD dataset is store as “clippednlcd0.” Figure 3-40 displays a clipped portion of a much larger NLCD dataset, derived from clipping the larger dataset by the extent of an inundation polygon. The clipped NLCD dataset is then converted into a polygon shape file containing polygons holding the values of the appropriate land use grid values from the clipped NLCD dataset. This shape file is entitled “lu0.shp” and is located in the data output folder for the current iteration.

UTIMS then utilizes the n-value/NLCD grid value table by joining the appropriate n-value from the relationship to each polygon, based on the NLCD grid code value in the polygon shapefile fields, in the “lu0.shp” shape file as shown in Figure 3-41. The joined n-value/NLCD grid code value polygons are stored in a new shape file entitled “n\_lu0.shp.” UTIMS converts this joined n-value shape file into a raster, whose cell values contain the n-values associated with each of the polygons derived from the original clipped NLCD dataset. The resulting n-value raster is entitled “nvalraster0.”

UTIMS utilizes the created “nvalraster0” n value raster and the “euc\_polygons0.shp” shapefile containing the Euclidean allocated polygons to perform a zonal statistics calculation. This calculation considers all the n value cells in the n value raster located within each of the allocated polygons to calculate the areal

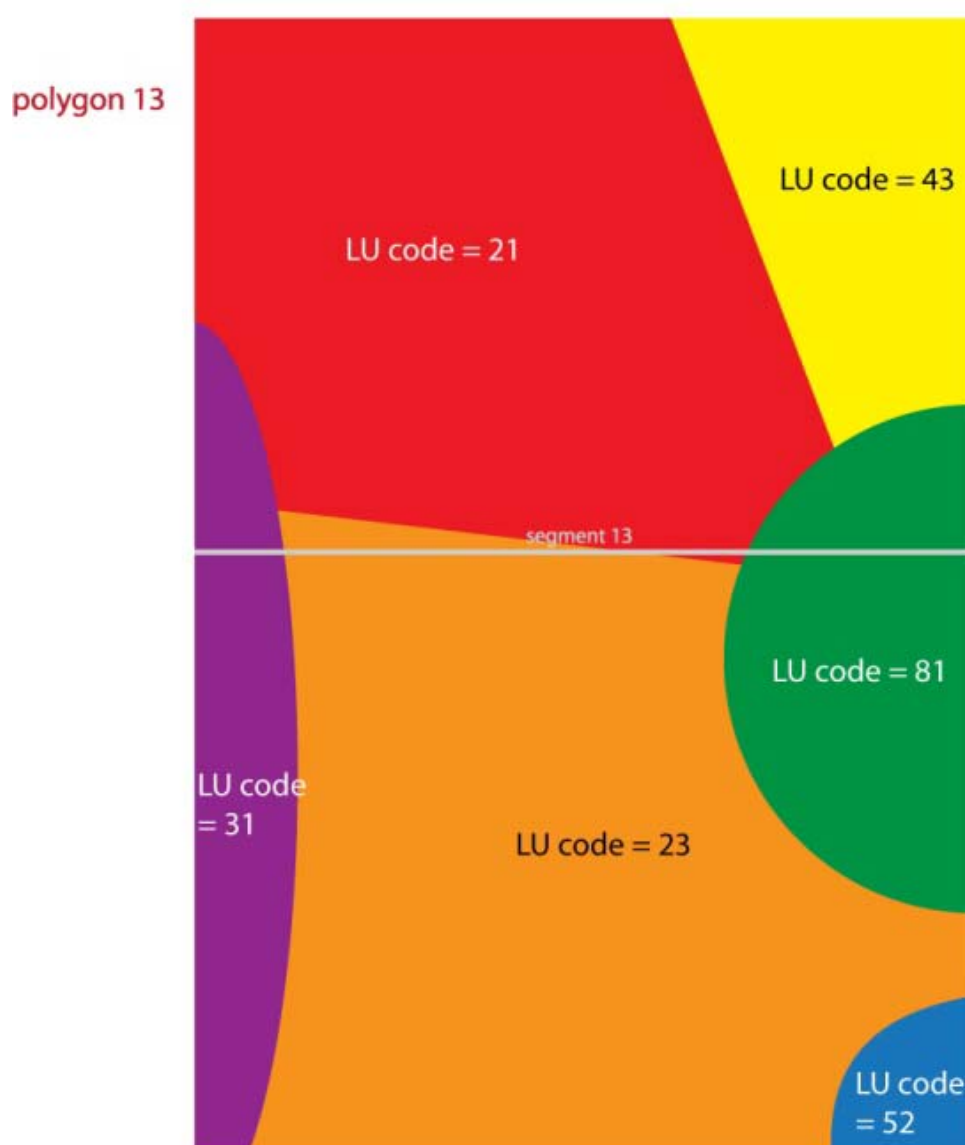


Figure 3-40. Clipped NLCD layer within polygon 13.

averaged n-value within each polygon. For example, for Figure 3-41 the zonal statistics function would ultimately calculate the average n-value within polygon 13. The zonal statistics table generated is stored in the iterative output folder as “zonalstats0.dbf.” Among several other statistical values calculated the zonal statistics function calculates the average n-value within each Euclidean allocated polygon. Equation 3-1 shows how the zonal statistics function calculates the areal average n-value. Table 3-1 displays the values used in defining the areal average n-value for polygon 13. For each land use type located within each Euclidean allocated polygon zonal statistics takes the land use area (specified by n-values in the n value raster) and multiplies each area by its associated n-value, sums these values and then divides by the total area to calculate the areal average n-value.

The polygons which were derived by the Euclidean allocation are joined to their appropriate areal averaged n-value and are stored in a new shapefile entitled “zones0.shp.” These areal average n-value polygons are then converted into a raster format to be easily read when assigning n-values by HEC-RAS. The final n-value raster is stored as “nRaster0” in the iterative output folder.

Therefore, as explained above, the process of determining areal averaged n-values relies upon the cross sections being utilized and the standard NLCD layers to calculate areal averaged n-values. These n-values more reasonably describe the land use and associated n-values because standard land use data is utilized and the assigning of n-values takes into account the extent of each segment of a cross section to which n-values are assigned.

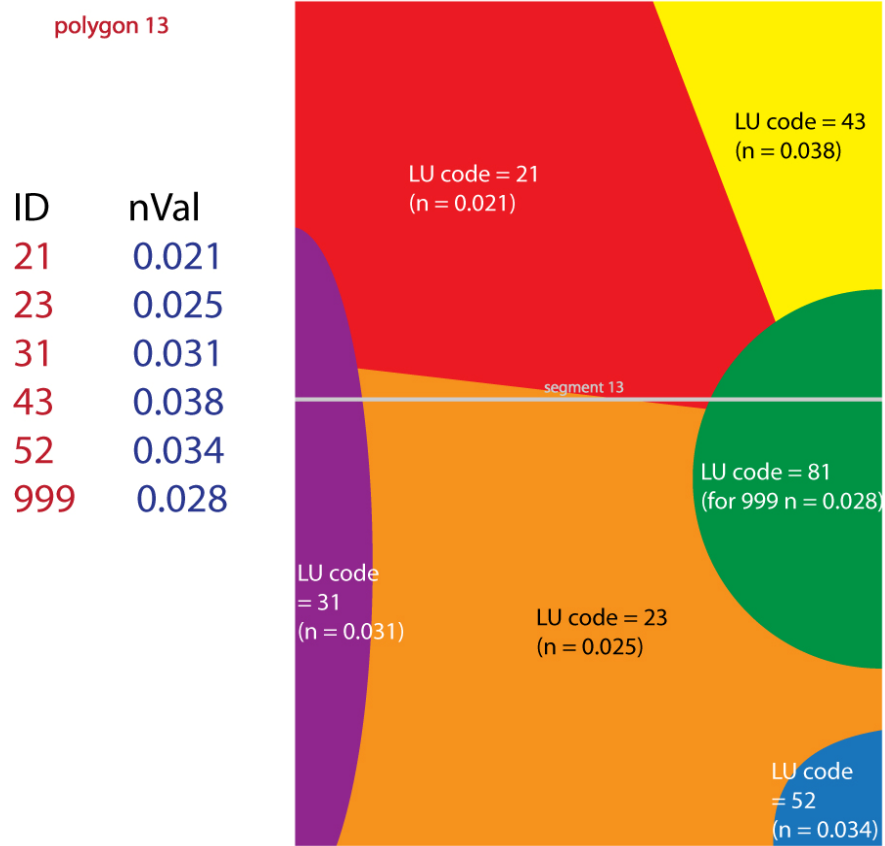


Figure 3-41. Joined land use code – n value polygon shapefile.

$$\text{Average } n \text{ Value} = \frac{1}{\text{Area}_{\text{Total}}} \sum_{i=0}^{n-1} n\text{Value}_i * \text{Area}_i \quad (1)$$

where n is the number of land use types within a Euclidean allocated polygon.

Table 3-1. Average n-value calculation

NLCD Grid Code Value	n Value	Area (m2)	(n-Value)*Area
21	0.021	25	0.525
23	0.025	40	1
31	0.031	10	0.118
43	0.038	10	0.38
52	0.034	5	0.17
81	0.028	<u>10</u>	<u>0.28</u>
Sum of Area = 100			
Sum of (n-Value)*Area = 2.473			
Average n Value = 2.473/100 = 0.0247			

### Comparison of Softwares with UTIMS

The comparison of the various softwares' capabilities is displayed in Table 3-2.

The various software capabilities are compared under following headings.

#### Runs within ArcMap

The ability for softwares to operate within ArcMap provides robustness to the data preparation and analyzing within floodplain mapping. The softwares GeoRAS, AFG and UTIMS provide similar data preparation and loading capabilities for working with river networks. These three allow a user to load pre-existing river centerlines into



the software to be utilized to create cross sections, etc., and then pass that information on to HEC-RAS. UTIMS and AFG allow users to directly supply the shapefiles containing river centerlines to be handled. GeoRAS, however, requires users to either digitize by hand, or load the data within ArcCatalog, which can take extra time to perform, as recorded earlier in this report this step took five minutes for one stream centerline, this time could be much larger depending on the reach length and the stream network. UTIMS and AFG both allow for easy integration of the river network shapefiles into use to be modeled. The WISE and WMS systems perform all of their viewing and data handling within their own GIS framework. While this is similar to working within ArcMap, this may hinder the number of functionalities usable in modeling data preparation and interpreting which ArcMap does provide.

#### River network handling

As has just been noted, GeoRAS, AFG and UTIMS allow for river networks to be uploaded easily from shapefiles. The WISE system also allows for easy integration of shapefiles with hydraulic modeling. The WMS system, though, requires users to digitize river centerlines. A user digitized river centerline may not provide the required detail of a river network into HEC-RAS. Seamlessly loading pre-existing river networks is not only time efficient and convenient but also avoids any loss of resolution introduced by the manual digitization.

#### Develop flood specific centerlines

The UTIMS software is the only software package which develops flood

specific flow paths. The other softwares require users to modify cross sections by digitizing, rather than delineating a new river centerline/flow path centerline from HEC-RAS output. This process of developing flood specific flow paths gives UTIMS its iterative nature.

#### Automated cross section placement

As placement of cross sections is pivotal to floodplain mapping, automated cross sections should not be placed blindly, and the automation process should be carefully monitored. All the softwares, besides WMS, allow for automated cross section placement. GeoRAS allows for users to specify the interval and width of cross sections. This is simple, but the process can create cross sections that overlap each other and cross other river centerlines, which may be outside the study reach. In the time required to develop cross sections earlier in this document it was recorded that the process took 90 minutes. Most of this time was spent deleting and checking for overlapping cross sections. Then additional cross sections were digitized to make up for the deleted cross sections. Therefore GeoRAS is helpful, but is not the most efficient in placing cross sections. The WISE, AFG and UTIMS systems create spatially independent cross sections (both from other cross sections and other river centerlines). Both UTIMS and WISE allow users to specify specific point at which cross sections are to be placed. UTIMS accepts as input a point shapefile to determine where to place cross sections. WISE allows users to provide survey data for cross section profiles. WISE also allows for users to specify distances from confluences to place cross sections. This is important when modeling confluences.

The WMS system requires users to digitize cross sections and will not automate cross section placement.

#### Flood specific clipped cross sections

The only software which provides the ability to clip flood specific cross sections is UTIMS. UTIMS allows users the ability to specify for each river reach the interval between cross sections and their initial widths. Flood specific cross sections are created by using a trial upstream depth and trial downstream depth to capture the expected extent to which cross sections are required to represent the terrain for the flow under consideration. The cross sections are clipped using the linear interpolated trial depth and the terrain to capture the extents of flow footprints expected. This extends UTIMS capabilities into easier and faster delineation of cross sections, as the trial flood depths puts a modeler in the range of extent of cross sections required to pass the flood.

#### Land use n-value polygon development

The GeoRAS, WISE, WMS and AFG softwares extract “n” values based on user-defined land use polygons. As this is simple enough, the user defined land use polygons may not accurately describe the n-value for the area that the cross section itself represents. UTIMS, in contrast, develops its land use polygons automatically from NLCD layer data, with n-values associated to NLCD grid code values. These aerially averaged n values calculated by UTIMS more accurately represent the n values for the area that the cross sections represent themselves. When working with

GeoRAS the process took 20 minutes to perform which was a quick approximation of various land types, and was not developed in any standard method. UTIMS provides a more realistic approach for developing n values.

#### Effective data management

To maintain model order some method of data management must be utilized to store shapefiles and information regarding HEC-RAS model development. The GeoRAS, WISE, AFG and UTIMS systems have various methods of data management. The WMS system does not create shapefiles or manage output from HEC-RAS. GeoRAS, WISE and AFG manage data in somewhat of an iterative process. These three allow users to develop and store both input geometries, to be passed to HEC-RAS, and flood polygons, passed back out from HEC-RAS. Therefore WISE, AFG and GeoRAS use a geographic feature base, which can be modified by the user in light of what the flood polygon looks like from HEC-RAS. UTIMS goes through a different route in developing new geometries. UTIMS starts with a base set of geographic data, but then creates new features to be worked with in a set of “Data” and “Run” folders which hold iterative information. WISE, AFG and UTIMS store project specific data in their own file system such as layer paths and parameter values.

#### Progress display

All the softwares provide progress display in some fashion. GeoRAS, WISE and WMS only show when processes are completed. The AFG and UTIMS systems progress display shows major and minor progress levels showing the main process and

the sub-process being performed.

#### River connectivity checked/completed

To correctly describe a river network within HEC-RAS a user must ensure river connectivity. WISE, AFG and UTIMS will check and complete river network connectivity. GeoRAS will only tell a user if a river network is complete and leaves completing network connectivity up to the user.

#### Generalization of river centerline

The generalization of river centerlines is done to cut down the time in extreme flow cases. UTIMS and WISE are the only softwares which performs this function. WISE utilizes a “maximum distance to remove” in removing meanders. UTIMS, though, utilizes this maximum distance to remove as well as a “line of sight” analysis in removing meanders. This is due to the emphasis that it places on helping modelers iteratively define the flood polygon. The other softwares essentially require users to modify the river centerlines by hand to fit the expected river centerline.

#### Point specific cross section placement

UTIMS and WISE are the only systems which allow users to identify specific points at which to place cross sections without digitizing by hand. UTIMS allows users to provide a shapefile containing points at which to place cross sections, which may be for example critical locations at which the user wants to monitor convergence. WISE allows users to provide survey data, assuring the specific placement of cross sections.

### Automated banks/flow paths creation

GeoRAS, WISE, and WMS require users to supply digitized bank and flow path geometries by digitizing by hand. UTIMS is the only software that provides the capability of automating the creation of bank and flow path geometries. Initially when using GeoRAS the time taken to develop the bank lines and flow paths required 20 minutes. This was done by copying and offsetting the river centerline to develop the two bank lines and three flow path lines. Without being able to load the features in a feature class the process would have taken significantly longer to digitize by hand. UTIMS development of the bank lines and flow path lines significantly cuts down the time to develop these lines. UTIMS essentially makes this process automatic as it takes over in offsetting the river centerline to create the bank lines and the user only needs to provide offset distances in the river reach specific data area of the input interface. To create flow path lines UTIMS uses the center line of the flood polygon and centroid of the left and right overbanks.

### Writing HEC-RAS files directly

By directly writing HEC-RAS files and not working with interchange files a system can add more detail to HEC-RAS files when they are created in an automated fashion. GeoRAS and WMS exchange data back and forth between themselves and HEC-RAS completely with interchange files. UTIMS directly writes HEC-RAS geometry and project files. Though UTIMS does not automate the writing of flow and plan files, but once these are created UTIMS uses them for subsequent iterations of the HEC-RAS models. The WISE and AFG systems automate the complete hydraulic

model setup by writing geometry, project, and flow and plan files.

#### Use of multiple DTM data

The use of multiple sources of terrain data allows a modeler to merge base digital terrain model (DTM) data with more accurate data such as survey data in the development of cross sections. GeoRAS allows for modelers to utilize multiple DTM data sources, but will not import survey data. WISE is the most versatile in this area as it allows for several DTM sources along with survey data. This capability lends itself to blend multiple terrain data sources and get a more accurate terrain representation. The higher resolution provided by the surveyed data is more appropriate in case of in-stream flow modeling, while the UTIMS focus is more on extreme (overbank) flow modeling.

#### Convergence analysis

UTIMS is the only software which provides complete aid in monitoring convergence. This is particularly due to its unique feature of keeping track of past iterations and the change in water surface elevations at specific point locations. This feature may be very useful in fine tuning the results for specific critical locations such as population centers, road crossings, etc. The other softwares allow for somewhat of a convergence analyses by allowing users to modify base data for a re-run within HEC-RAS, but do not keep track of past iteration results for key locations.

#### Structures placement and parameters

GeoRAS and WISE are the only softwares which provide users the ability to

design hydraulic structures to be included within a geometry file outside of the HEC-RAS geometry editor. GeoRAS allows users to specify lateral structures (levees, etc.) and inline structures (bridges, etc.). WISE allows users to provide data on bridges, culverts and dams to be included in the writing of the geometry files for HEC-RAS.

#### Cross section view

When creating cross sections it is helpful to be able to see the cross section profile when placing cross section cutlines. GeoRAS, WISE and AFG provide the ability to see the cross section profile when placing cross sections. This allows users the ability to ensure that cross sections correctly represent a complete cross section and not a sloping profile that does not contain a true thalweg.

#### Cross section to confluence distance use in placing cross sections

This value is helpful in the automated placement of cross sections when there are confluences being analyzed. This value represents the distance upstream and downstream from a confluence on a river centerline to place cross sections. WISE is the only software package that allows for the setting of this value.

#### Displays flooding extent polygons

A software's ability to accurately map flood polygons allows modelers to determine the extent and depth of flooding in analyses. All the softwares discussed here display the flood polygon from the output of HEC-RAS. This allows users the ability to develop the important inputs for dam safety to evaluate the risks posed by



specific dam breach scenarios, and to develop maps for emergency action plans etc.

### Main channel shape defined

This ability is especially important for in-stream types of studies. The AFG system is the only software that allows users to specify channel type.

Table 3-2. Softwares comparison

Software Capabilities	UTIMS`	GeoRAS	WISE	WMS	AFG
Runs within ArcMap	Yes	Yes	No	No	Yes
Load River Network Automatically	Yes	Yes	Yes	No	Yes
Develop Flood Specific Centerlines	Yes	No	No	No	No
Automated Cross Section Placement	Yes	Yes	Yes	No	Yes
Flood Specific Clipped Cross Sections	Yes	No	No	No	No
Land Use Polygons Defined by:	Automatic	User	User	User	User
Easily Understood User Interface	Yes	Yes	Yes	Yes	Yes
Effective Data Management	Yes	Yes	Yes	No	Yes
Checking/Completing Network	Yes	No	Yes	No	Yes
Generalization of River Centerlines	Yes	No	Yes	No	No
Point Specific Cross Section Placement	Yes	No	Yes	No	No
Automated Banks/Flow Paths Creation	Yes	No	No	No	No
Writes HEC-RAS Project Files	Yes	No	Yes	No	Yes
Writes HEC-RAS Geometry Files	Yes	No	Yes	No	Yes
Writes HEC-RAS Flow Files	No	No	Yes	No	Yes
Writes HEC-RAS Plan Files	No	No	Yes	No	Yes
Use of Multiple DTM Data	No	Yes	Yes	No	No
Convergence Analysis	Yes	No	No	No	No
Structures Placement and Parameters	No	Yes	Yes	No	No
Cross Section View	No	Yes	Yes	No	Yes
Cross Section to Confluence Distance	No	No	Yes	No	No
Use in Placing Cross Sections					
Displays Flood Polygons	Yes	Yes	Yes	Yes	Yes
From HEC-RAS					
Main Channel Shape Defined	No	No	No	No	Yes

### Programming Tools

ESRI ArcObjects are the tools which GIS developers use to enhance the GIS experience. This set of tools allows developers to internally handle geographic information, allowing an expanded use of the tools to develop applications within ArcGIS. ArcObjects is an object-oriented toolset which consists of several object models. These object models graphically show the abstract classes, coclasses and classes along with their properties and methods, which can be instantiated to control many of the processes within ArcGIS. For example these instantiations allow GIS designers the ability to define and store new geometries and control how those geometries are displayed by ArcMap.

UTIMS primarily utilizes the geometry object model to process geographic information and to create new geometric features. The geometry object model defines the attributes and methods by which new geometries are created such as polygons, polylines and points, along with their spatial reference which defines how the geometries are to be displayed appropriately in ArcMap to depict their actual spatial location. These are defined as high level geometries and are supported by the creation of lines and segments. UTIMS also utilizes ArcObject models to create new feature classes and rasters.

Several programming languages can be used to control ArcObjects. UTIMS utilizes Visual Basic for Applications (VBA) to handle ArcObjects. VBA is an easily understood yet powerful programming language.

### User Input

The UTIMS interface is simple to use and operate. There are several input text boxes, drop down menus and buttons to select and identify appropriate data for use by UTIMS. Figure 3-42 displays the main user interface for UTIMS. There is one page available upon startup of UTIMS. Depending on the number of river reaches located in the original river network to be analyzed UTIMS will appropriately create several more pages for user input. The different sections of the main user interface allow for the selection of a digital terrain data, river network and monitoring points, land use data, data file management, units, and several values UTIMS uses in its processing. There are several buttons on the main screen which allow for various steps in developing geographic data with UTIMS. Indication is also made as to where data output is to be stored and which iteration UTIMS is currently working on.

Figure 3-43 displays a second page which lists various values, which will be discussed at a later point, which UTIMS uses in developing geographic data. Depending on the number of river reaches in a river network UTIMS creates extra pages to hold twelve rivers per page. This allows for easy dynamic data entry for many river reaches in a river network. For each river centerline feature within the river network UTIMS will display the name of the river and the reach name as directed by the user on selecting the appropriate fields within the river network identifying these names.

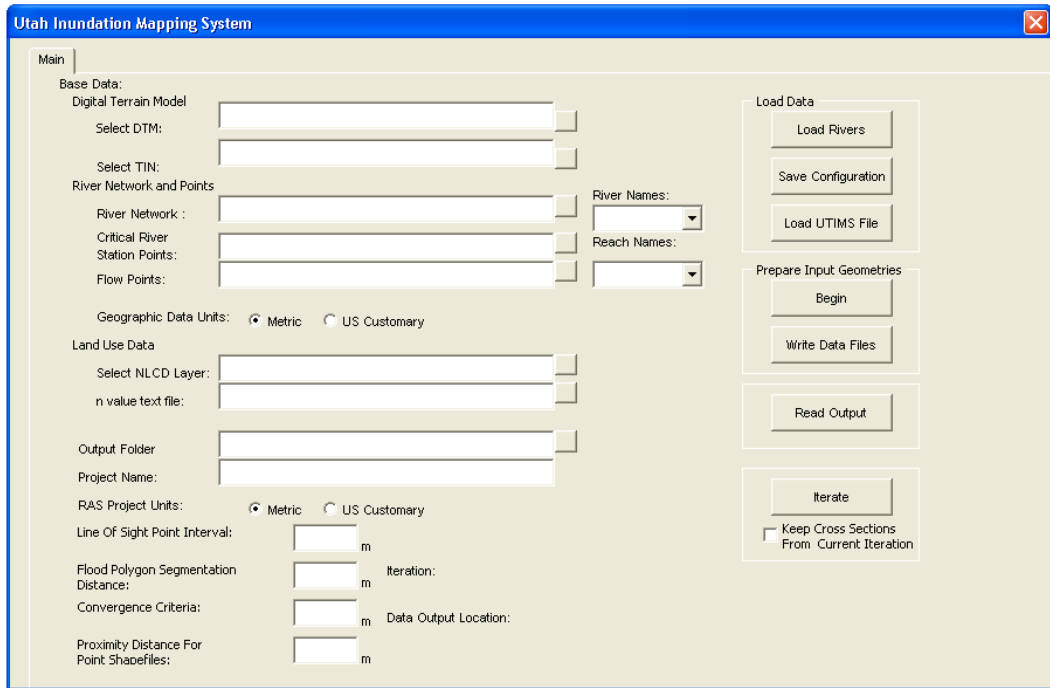


Figure 3-42. Main UTIMS interface.

Units: Meters	Meander Correction	Trial Flood Depths		Offsets	Cross Section Handling			Dog Leg Information (Optional)	
River, Reach		U/S	D/S	Banks	Distance Between XS	XS Width	# Land Use Segments	Length	Angle (deg)
River, Reach	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

Figure 3-43. River reach specific data interface.

UTIMS also verifies input data as part of the input process. The various data inputs and buttons will be discussed in the immediately following pages describing what types of data files can be utilized and what values can be input into UTIMS.

### Digital elevation data

Beginning with the first two text boxes and buttons on the main UTIMS interface UTIMS allows a user to specify a raster/GRID and a triangular irregular network (TIN) model for digital terrain models. A raster/GRID format utilizes a pixel block within ArcObjects, whereas TINs are surfaces therefore the ISurface interface is used to obtain surface elevation values. Surfaces are more representative of the actual terrain, so a TIN is more desirable as an input for terrain data. Due to terrain data models being the main source of profile data for cross sections only high resolution digital terrain data should be used. Upon selecting the appropriate digital terrain model data UTIMS places the full path and name of the digital terrain model in the appropriate text boxes.

The reason that both a grid and TIN layer format are required is that UTIMS utilizes these two data formats for different purposes. UTIMS utilizes the grid formatted data in raster calculations, whereas UTIMS utilizes the TIN layer for cross section profile development for use by HEC-RAS. This is due to the fact that TIN layers will create more uniform cross section profiles for use in writing geometry files used by HEC-RAS.

### River network

The next portion of the user interface allows a user to select appropriate river and point shapefiles. The buttons immediately to the right of the text boxes allow for users to identify the location of the shape files to be used by UTIMS. The river network describes the actual centerline of each of the rivers and reaches desired to be studied in the floodplain delineation. The river network input must contain a continuous river network containing rivers, with appropriate reaches, including tributaries to be studied. The point shape files function in the same manner by identifying the points along a river network where UTIMS automatically places cross sections for either critical location observation purposes or flow change locations.

The shape file containing the river network must be of polyline type and contain two fields identifying firstly river names and secondly reach names. Correct orientation (going in the downstream direction) of reaches is also checked within the processing of the river network. The connectivity of the river network is also checked in the pre-processing of the river network before any action is taken to define cross sections. The connectivity of the river network ensures that cross sections placed accurately describe the terrain over which the modeling will be taking place. Upon finding any non-connective segments of the river network the program queries the nearest point on the main river channel and connects the tributary. Users can ensure that the correct river network paths are laid out by carefully inspecting the river network and connectivity before proceeding with the pre-processing of the river network.

Upon selecting a river network by navigating to its location, UTIMS loads all

the names of the fields located in the river network shapefile. UTIMS allows a user to select the appropriate fields which hold the river name and reach name in developing complete geometric files for use by HEC-RAS.

#### Critical river station points

Critical river station points located in the critical points shapefile provide UTIMS points at which a user defines for a cross section to be placed to monitor convergence. A user may choose not to provide point shapefile for the critical points. This feature class is used primarily in cases of extreme flow modeling where the process of convergence upon a final flood polygon is to be employed. This feature class is important because it allows users to monitor the change in water surface elevations at specific points along the river centerline such as large population centers. UTIMS will store the water surface elevations in a table located in the main data output location for each of the points in this shapefile.

#### Flow points

To allow users the ability to specify any flow change locations in a river network, other than the uppermost cross section on a river reach, UTIMS allows users to specify a shapefile holding points representing the location along a river at which to place a cross section to allow a user to specify within HEC-RAS a flow change at a specific location.

#### Geographic data units

To aid in converting units from one unit system to another in passing data back

and forth between UTIMS and HEC-RAS UTIMS requires that the user select the base geographic units which represent the units of the raster data and river network, etc.

#### Land use data

UTIMS allows users to select grid formatted layer representing the land use data grid defined as an NLCD layer. Upon selecting the NLCD layer UTIMS places the path name and file name of the NLCD layer in the appropriate text box. The NLCD dataset is available for download in the public domain from the USGS (<http://seamless.usgs.gov>).

#### Land use – n-value table

UTIMS provides a text box and a button to the side of it to select the appropriate text file holding a tab delimited relationship of NLCD grid values and associated n-values for use in assigning n-values to segments of cross sections. This text file must hold four different critical features. First, the first column in the file must be entitled with a short title for the grid code values such as “ID.” Second, the second column should be spaced one tab away on the same first line of the text file and must have a short title for n values such as “nValue.” UTIMS uses these column headings to assign appropriate n-values to associated grid cell values in the NLCD dataset. The third critical feature is that the second line of the file must contain an NLCD grid cell value followed by a tab and then an associated n-value. Other rows may follow, but they must each start with a grid cell value in the NLCD grid scheme followed by a tab and then the associated n-value. The fourth and last critical feature



of the text file is that the last “ID” value must be “999.” UTIMS utilizes this value as the default value for any grid cells encountered in the n-value assignment which are not specified in the n-value text file. The “999” must then be followed by a tab and then a default n-value desired for use in the n-value assignment process.

### Output folder

UTIMS allows users to specify an output folder location, in which UTIMS will save all output. A new folder will be created in the specified output location to hold data output. The button provided in the main user interface allows users to specify the desired output location.

### Project name

The project name text box allows a user to specify the name of the output folder to be created within the location specified in the output folder text box. This project name also becomes the name of the HEC-RAS project and geometry files. If a new UTIMS process is started and the same output folder is detected then UTIMS will ask if the user would like to overwrite the existing data files. If yes then UTIMS will delete the existing output folders and begin the iterative processing. If, however, the user does not select to overwrite the pre-existing output folders, then UTIMS allows a user to select a new project name, and thus a new project output folder.

### RAS project units

The RAS project units are also available to be selected in the main user interface window. These units represent the units which define the units of the HEC-

RAS geometry and project files to be written by UTIMS.

#### Line of sight point interval

The line of sight point interval text box allows a user to specify the distance to place points along a river centerline in the line of sight analysis. The number provided by the user can be of type double. An appropriate distance depends upon the resolution of the digital terrain model being used and the impact that possible tributary areas may pose in the generalization process. A suggested value for this interval, though, is three to four digital terrain model grid cell lengths.

#### Flood polygon segmentation distance

The flood polygon segmentation distance text box allows a user to determine the distance to be utilized in determining the flow path centerline of a flood polygon both in the initial sloping plane river centerline process and the iteration nature of UTIMS where new river centerlines are derived from HEC-RAS output data. A small value may cause a long processing time, whereas a large value may not capture enough details of a flood polygon. If a large value is entered, over generalization may take place, misrepresenting the accurate shape of the original river centerline. The polygon segmentation factor is of double type. A suggested value is two to three times the raster grid cell height, but the value should be small enough to represent the accurate centerline of flood polygons.

#### Convergence criteria

The convergence criteria text box allows a user to specify the resolution which

the program uses to identify whether sufficient convergence has been reached.

UTIMS monitors the change in water surface elevations at user defined points to determine when convergence has taken place in extreme flow studies. . If UTIMS finds that successive HEC-RAS computations cause a change in water surface elevations at a critical station cross section smaller than the criteria specified by the user UTIMS will alert the user to the fact that convergence has occurred. A user can then review the convergence table to view the actual difference in the water surface elevation at the critical cross-sections and may discontinue the iteration process.

#### Proximity distance for point shapefiles

In determining where to place cross sections at critical station points or at flow change locations along a river centerline UTIMS allows a user to specify the maximum distance a user specified point can be away from the desired river centerline line. This value ensures that the right points are associated with the correct river centerline despite a user digitizing a point and not getting the point directly on the desired river centerline. This value should be large enough to account for any user error in digitizing the critical station point on the original river centerline. A suggested value is the user supplied raster's grid cell height.

#### Load rivers button

The button titled "Load Rivers" utilizes the shapefile specified as the river network in the river network text box and loads all the features into new pages within the user interface. Figure 3-43 displays the new page available within the user

interface when the “Load Rivers” button is pressed. UTIMS places twelve rivers on a page, therefore if the specified river network contains fourteen river reaches then two additional pages will be created to hold the data for the first twelve rivers on the first page and the remaining two rivers on the next page. Pressing the “Load Rivers” button displays several values which UTIMS utilizes when creating new geographic features for use in writing the HEC-RAS geometry file.

The various fields presented in the “Rivers” pages of the UTIMS interface, when the “Load Rivers” button is pressed, provide the values which UTIMS requires to complete the geographic feature development. They include: meander correction, trial upstream and downstream depths, bank line offset distance, distance between cross sections, cross section widths, the number of segments to divide cross sections into when assigning n-values, and the optional dog-leg information of angle and length of dog-leg extensions.

#### Save configuration button

To allow users to save a UTIMS configuration including specified geographic feature layers to use and values in deriving geographic features. UTIMS saves all the values and file information within a UTIMS “\*.uif” file which is specified on the main user interface along with all the river network information which a user denotes in the additional “Rivers” pages. The saved file is titled the same name as the project name specified in the main user interface. Users can load a UTIMS file upon saving it.

### Load UTIMS file button

UTIMS allows users the ability to load a pre-existing UTIMS file for use in UTIMS computations. When pressed this button will load all the locations and values of all the feature layers specified when the user saved the UTIMS file earlier. The loading of data in the UTIMS file includes river network information, as shown in Figure 3-42.

### Prepare input geometries

The button titled “Begin” initiates the process of creating geographic feature with which to write the HEC-RAS geometry file. This button initiates the UTIMS processing of the river network by verifying river connectivity, performing any generalization processes on the river network, creating cross sections, and creating bank and flow lines.

### Write data files

The button titled “Write Data Files” begins the process of writing the geometry file to be used by HEC-RAS. This process begins initially with UTIMS verifying that each cross section only crosses one river centerline and does not cross other cross sections. UTIMS also checks that cross sections cross their appropriate bank and flow path lines once. Upon verifying that cross sections are appropriate to proceed UTIMS begins the process of determining the areal average n-values, as described earlier in this document. Upon completing this process UTIMS writes the geometry file along with the project file for use by HEC-RAS. When the iteration label reads more than

one, meaning that the user has iterated the process, UTIMS will copy the flow files from the previous iteration into the new “Run” folder holding the geometry and project files. UTIMS changes the stations for boundary conditions, though, taking the furthest upstream and furthest downstream stations to assign to the appropriate upstream and downstream boundary conditions.

### Read output

The button titled “Read Output” directs UTIMS to read the GIS output file from HEC-RAS containing water surface profile information to be imported back into the GIS environment. UTIMS identifies the output location of the GIS output file from HEC-RAS and creates the flood polygons as described by the output file. This button also initiates the process of UTIMS approximating the flow path centerline of each profile found within the HEC-RAS output file. These features are stored in the appropriate “Data” folder for the current iteration. Upon viewing the output geometries and noticing something from the HEC-RAS model output seems awry a user can make changes within their hydraulic model and press the “Read Output” button again. This allows a modeler to interactively change their hydraulic model to ensure they have the newest and best hydraulic data output going from iteration to iteration. If the read output button is pressed a second time UTIMS verifies with the user that they do indeed wish to delete the geometries just created and reload data from HEC-RAS to prohibit any errant deleting of created geometries.

### Iterate

The button titled “Iterate” directs UTIMS to begin a new iteration of the UTIMS process. UTIMS takes the flood polygon flow path centerlines and create new cross section lines and new left and right overbank lines. New output folders titled “Data” and “Run” will be created in the specified output location with appropriate iteration numbers at the end of each folder name for effective data management. An option to keep the previous iterations cross sections is also available to be selected.

### River reach parameters

UTIMS allows users to specify parameters for each river reach being considered in creating geometries to be used by HEC-RAS. As shown in Figure 3-43 they include: meander corrections, trial upstream and downstream depths, bank line offset values, distances between cross sections, cross section widths, number segments to divide cross sections into, and the optional dog-leg parameters of angle and length.

The meander correction value is a critical value in developing accurate geographic features for use by HEC-RAS. This is due to the fact that the meander correction value indicates to UTIMS whether extreme flows are expected, thus inducing the sloping plane analysis to be performed, otherwise in-stream flows are expected for the river reach. If the user enters a “0” (zero) in the meander correction text box for a river then UTIMS will not alter in any way the path of the original river centerline which may be appropriate for in-stream flow modeling. If, however, a user enters a value greater than “0” (zero) then UTIMS performs the operations on the river centerline to approximate a flood magnitude specific flow path centerline to be used in

creating cross sections. For in-stream as well as extreme flow cases bank lines are created by offsetting the initial river centerline a user specified distance. Also for in-stream as well as extreme flow cases the left and right flow path lines are created utilizing the bank lines and the iteration specific cross sections to create overbank area centroid representative overbank lines. The iteration specific flow path centerline is utilized as the main channel flow path line. The meander correction value can be of double type. A suggested value for the meander correction value is a value that is representative of the floodplain flow path in question. For large open floodplains a half a mile may be appropriate, however, for quite meandrous portions the meander correction may be quite a bit smaller.

The trial upstream and downstream depths represent for each river the increase in elevation from the thalweg point elevation for the creation of geographic features. A user must enter values greater than zero for both the upstream and downstream trial depths, even if extreme flow handling is not to be performed on a river centerline, because UTIMS uses the trial upstream and downstream depths to linearly interpolate an increase in elevation when clipping cross sections into a digital terrain model, therefore an overestimation is preferred. Trial upstream and downstream depths can be of double type, and be approximated by taking into account the peak flow to be modeled and the cross-sectional area and slope of the river reach under consideration.

The bank offset values represent the distances away from the actual river centerline to place left and right bank lines. These values can be of double type. A suggested value for bank offset values is 50 feet for large open floodplains and a value of 10 feet for quite meandrous reaches.



The distance between cross sections value for each river reach define the interval at which UTIMS places cross sections along a river centerline. This distance is also utilized by UTIMS in the sloping plane analysis as the distance at which to place query thalweg points along the river centerline in identifying an initial flood polygon in extreme flow cases. The distance between cross sections can be of double type.

The cross section width value (“XS Width”) available to be specified on the additional pages for river reach parameters defines the main body length of cross sections to be placed. The widths for cross sections define the extent of terrain data to be utilized in defining profile data for use by HEC-RAS. The cross section width value also defines the distance used in creating the buffer zone used to clip digital terrain data in the sloping plane analysis. The cross section width defines how far away from the river centerline to create a buffer which is utilized in the sloping plane analysis to identify contour lines at specific elevations in creating the initial flood polygon for extreme flow cases. The cross section width value can be of double type. A suggested value for the cross section width value is a value much longer than expected for meandrous reaches and for large open floodplains a value which is two-thirds the width expected where flow could go so that dog-legs can be attached appropriately.

The optional dog-leg parameters are used by UTIMS to create dog-legs at the end points of cross section lines to aid in the one-dimensional flow modeling of flows when for flows being modeled may fan out into a wide expanding floodplain. Dog-legs are created in a convex downstream orientation and are created at an angle to the

upstream face of a cross section at an angle and distance as specified by the user in the river reach specific parameters page. Additional information concerning the creation of dog-leg portions of cross sections will be discussed in the cross sections handling section. Dog-leg values should extend the cross section well past the expected flood polygon width so the clipping process can define the extent of the flow appropriate cross sections.

For further information concerning the input values and how to operate UTIMS the reader is referred to UTIMS user manual (Stevens and Chauhan, 2009).

### Geometry Handling and Creation

#### Effective folder/data management

UTIMS effectively creates and manages the geographic information created in order to monitor the stepwise progression that it takes to convergence in a flood study. On the initial user interface users may specify an output folder which will hold all output and the accompanying HEC-RAS project. This allows users the ability to go back to a set of geographic information and continue with the iterative process or carefully monitor the progression the iterative process took to completion. For each launch of HEC-RAS from within UTIMS a new project is created, taking the name of the project title called for in the initial user interface.

For each run of creating geographic information in developing the geometric input file for HEC-RAS, UTIMS creates a new folder within the output folder specified. This new folder holds such items as the shapefiles which holds all created

geometries along with the rasters and tables created. This allows a user to carefully investigate the process UTIMS takes by analyzing the stream centerlines, cross sections, land use data and n-value proximity maps to clearly see where geographic information has come from. This new folder is called “Data $i$ ” where  $i=1$  for the first run and increases by one for subsequent runs.

For each hydraulic computation of HEC-RAS a new geometric output file is created and is stored in a new output folder. This new folder is called “Run $i$ ” where  $i=1$  for the first run and increases by one for subsequent runs. Thus for a “Run $N$ ” where  $i = N$ , the user can review the data and the associated output in “Data $N$ ” and “Run $N$ ” folders, respectively.

### River centerline

The river network handling by UTIMS is performed in two manners – either to perform the sloping plane analysis or to use the actual river centerlines as the flow path centerlines to be used in placing cross sections and determining flow path lines. UTIMS can handle any size of river network for floodplain mapping purposes. In the process of river network handling UTIMS verifies river network connectivity, and if necessary completes any missing river network connectivity. UTIMS also completes any river non-connectivity issues in the iterative process a user goes through to final convergence.

As discussed previously in the section describing the sloping plane analysis UTIMS has the ability to modify a river centerline to approximate the flow path centerline in cases of extreme flow modeling. UTIMS modifies a river centerline

using trial upstream and downstream depths and the topography to better approximate a flood specific river centerline to be utilized in extreme flow cases. UTIMS also performs a line of sight analysis on all river features which pass through the sloping plane analysis. This is done in an attempt to smooth out any portions of a sloping flood polygon centerline which may have kinks because of tributary areas influencing the sloping flood polygon centerline.

### Bank lines

Bank lines are used to define bank stations along a cross section profile. UTIMS allows users to specify an offset value for bank lines for each individual river reach. Bank lines are created utilizing the actual river centerlines supplied by the user in the river network. The actual river centerlines are used to create the bank lines, in contrast to any derived flow path centerline, to aid users in knowing where the actual river centerline thalweg is located along a cross section profile. Therefore, for example, in the third iteration the bank lines are created using the bank lines from the first iteration. Bank lines are determined by offsetting the actual river centerline at a user specified distance. This is done by creating a buffer zone around the river centerline, at the user specified distance. Figure 3-44 displays a river centerline and a buffer created around the river centerline which has been cut into several segments by the upper and lower most cross sections.

UTIMS creates bank lines by querying lines normal to the upstream and downstream portions of the centerline on both the left and right sides. UTIMS cuts the boundary of the buffer polygon and identifies the left and right bank lines from the cut

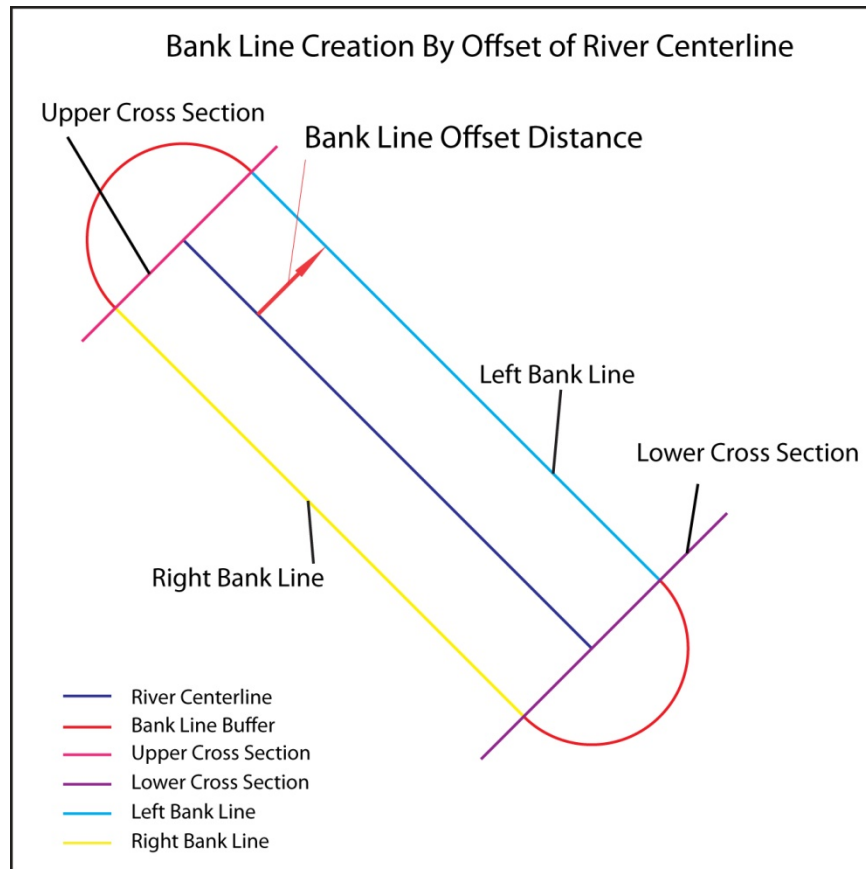


Figure 3-44. Left and right bank lines determination.

portions of the buffer polygon. Figure 3-44 displays how UTIMS identifies the left and right bank lines.

UTIMS creates internal cross sections to “cut” the buffer to create left and right bank lines. In this manner bank lines are created in such a way to ensure no bank line overlap, specifically in meandering reaches

### Flow path lines

Flow path lines represent the approximate path of flow for each of the three main portions of a cross section, i.e. the left overbank, main channel and right

overbank areas. These flow path lines are used to calculate the distances between subsequent cross sections. The flow path centerline is utilized as the main channel flow path line. The left and right overbank flow path lines are created to represent the location of the centroid of the overbank areas in both the left and right overbank areas. Figure 3-45 displays the cross section areas of left overbank, main channel, and right overbank areas.

As seen in Figure 3-45 the thalweg point lies at the lowest point in the cross section with bank station points dividing the left and right overbank areas from the main channel area of the cross section. The flow paths within the left and right overbank areas should represent the approximate path of flow within these areas of

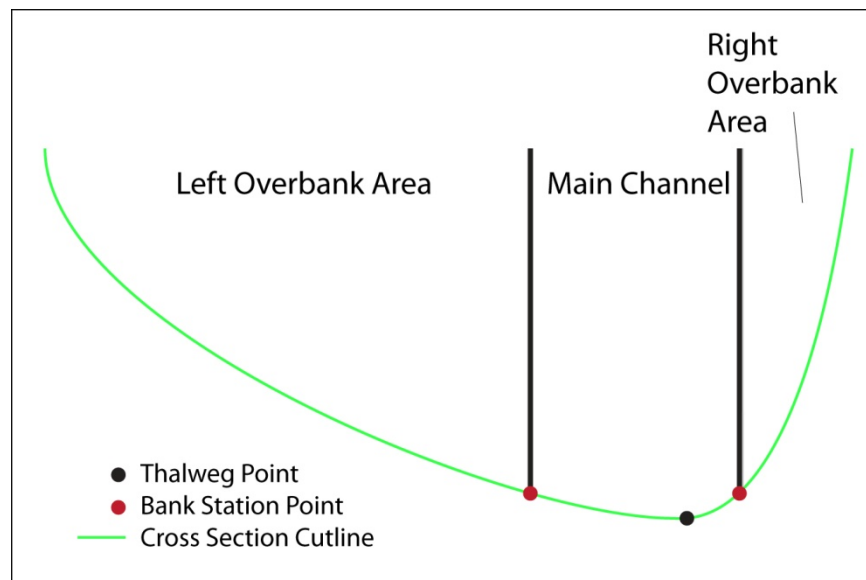


Figure 3-45. Identification of left overbank, main channel, and right overbank areas.

the cross section. Therefore UTIMS approximates the location of the vertex of the flow path lines within the cross section as the point which best represents the centroid of the area within the left and right overbank areas. To identify the centroid of the overbank areas UTIMS divides the left and right overbank areas into slices as shown in Figure 3-46.

The distance between the slices that UTIMS uses in splitting the overbank areas is the dimension of the cells from the digital terrain grid data supplied to UTIMS. This distance was chosen to take into account each pixel cell under the cross sections. As seen in Figure 3-47 UTIMS utilizes each slice within an overbank area to calculate the centroid of the area. Equation that UTIMS utilizes in calculating the

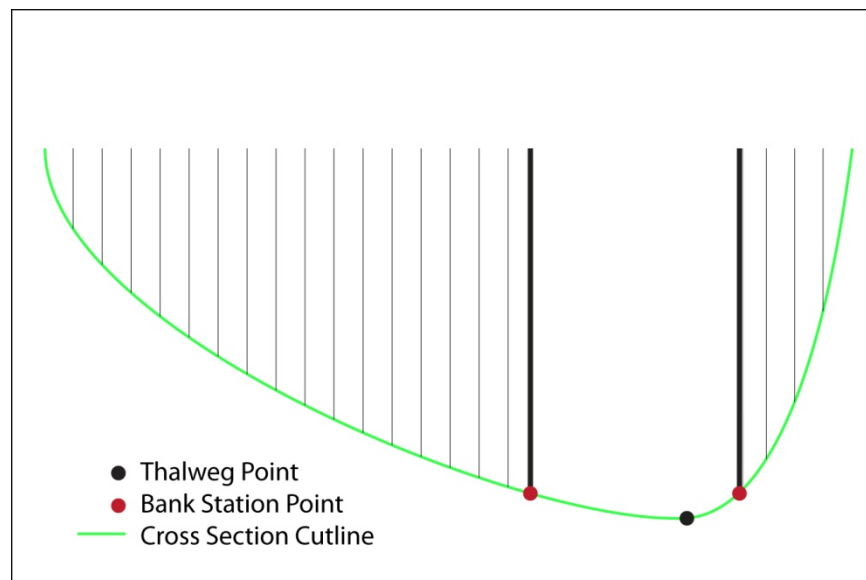


Figure 3-46. Slicing of overbank areas for flowpath centroid calculations.

centroid of each overbank area is shown as Equation 2. As shown in equation 2 for each slice UTIMS multiplies the change in elevation from the interpolated trial flood depth for the cross section to the terrain elevation (elevation change) by the distance the query point is away from the respective bank point (x). Figure 3-47 displays an example slice from the left overbank area where for a slice the change in elevation from the top of the interpolated trial flood depth for the cross section to the terrain elevation underlying the query point and the distance away from the left bank point are identified.

Using equation 2 UTIMS calculates the distance away from the appropriate bank point where the area's centroid is located. Figure 3-48 illustrates where the thus

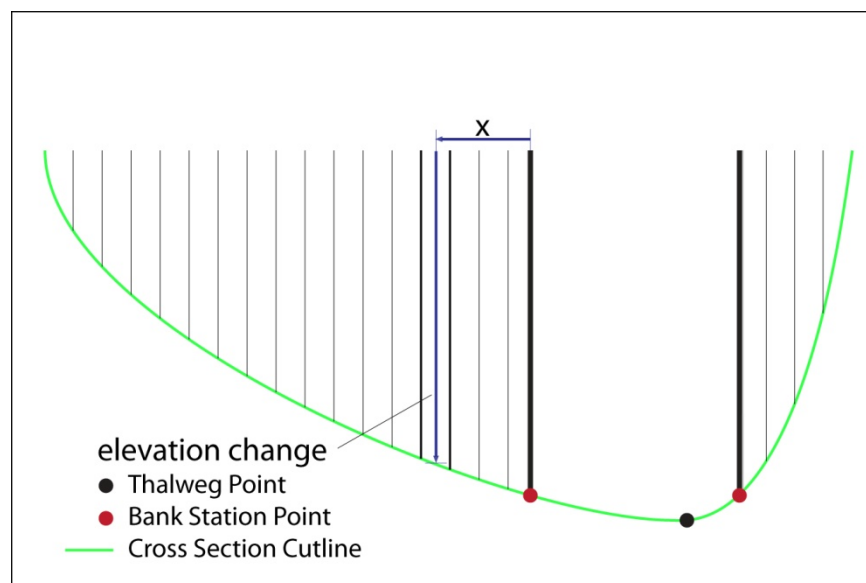


Figure 3-47. Centroid identification calculation.



$$\bar{x} = \frac{1}{\sum_{i=0}^{n-1} \Delta Elevation_i} \sum_{i=0}^{n-1} \bar{x}_i * (\Delta Elevation_i) \quad (2)$$

computed

centroid points would lie for the overbank areas. Figure 3-48 also shows the centroid points projected onto the terrain surface. Thus performing this process for each cross section there will be one vertex for each cross section in each overbank area

for the flowpath features. The lengths of these flowpaths are likely to be shorter than the main channel flow line, as they more reasonably describe the location of the path of flow lines within the overbank areas than manually digitizing the flow path lines within GIS.

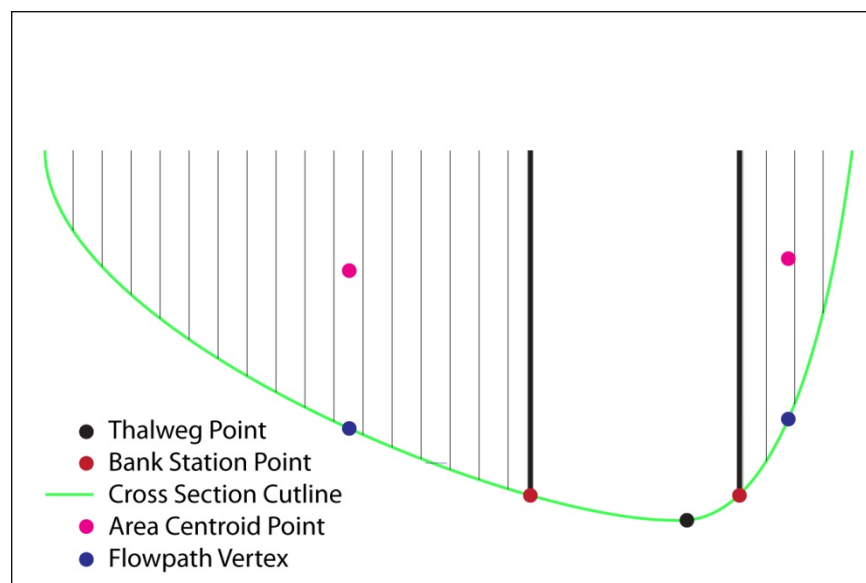


Figure 3-48. Centroid placement and projection.

### Cross sections

Cross sections represent the basis for hydraulic modeling within HEC-RAS. UTIMS allows users the ability to automate the placement of cross sections as well as the ability to modify any cross sections which have been automatically placed before UTIMS writes the HEC-RAS geometry file. There are two ways with which UTIMS allows users to specify the placement of cross sections. The first way is by utilizing the critical river station point or flow point shapefiles, which identify specific stations along the river centerline at which to place cross sections. The second way is by specifying the distance between cross sections along the flow path centerline.

Cross sections are placed perpendicular to the flow path centerline oriented left to right when looking in the downstream direction (which is a requirement of HEC-RAS). Cross sections are created at a length equal to the user specified “XS Width” distance located in the additional rivers pages of the user interface. If dog-legs are called for by the user they are placed after placing the cross section normal to the flow path centerline. Figure 3-49 displays how a cross section is placed perpendicular to the flow path centerline.

Cross sections are clipped, or shortened, to “fit” within the confines of the terrain, which creates cross sections that UTIMS utilizes in determining areal average n-values for segments of cross sections. Figure 3-50 displays how cross sections are clipped to fit within the confines of the terrain specified by a digital terrain model. UTIMS begins at the cross (intersection) point between the cross section and the flow path centerline. UTIMS identifies the elevation defined by the digital terrain model at the cross point and adds the interpolated trial flood depth (by linearly interpolating an

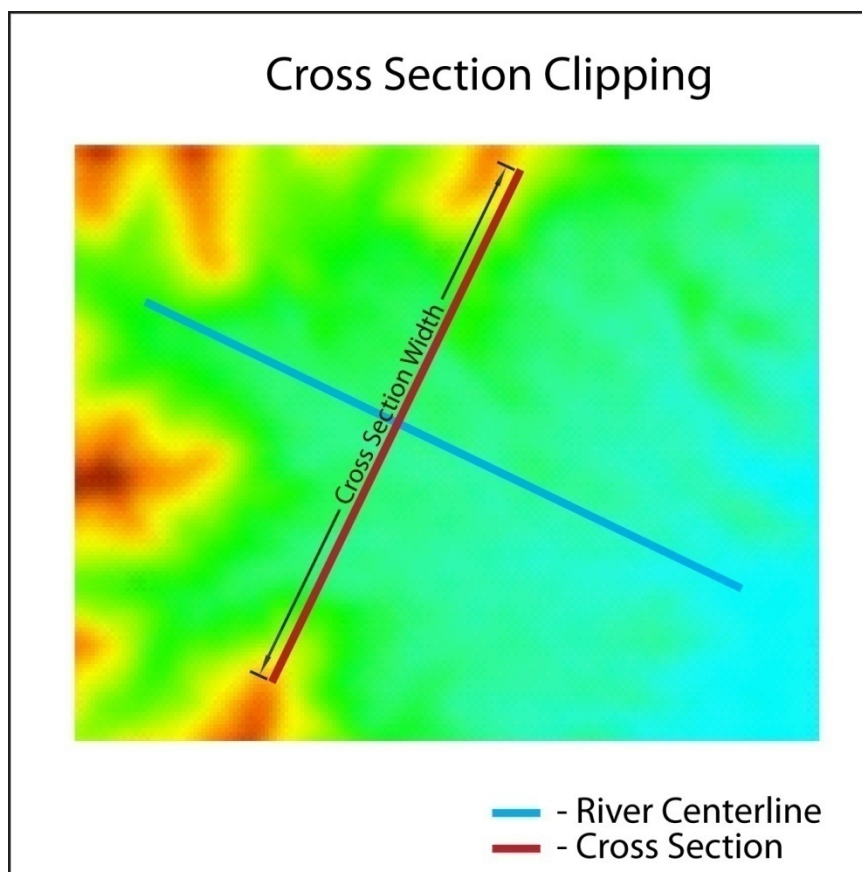


Figure 3-49. Cross section placement.

increase in elevation for the cross section along the actual river centerline based upon the trial upstream and trial downstream depths specified by the user) to define the maximum elevation that any point along the cross section can have. This maximum elevation is termed the threshold elevation by UTIMS.

UTIMS begins searching first on the left side of the cross section from the cross point out away from the river centerline to identify the point at which the point elevation along the left side of the cross section goes above the threshold elevation and uses that point as the new cross section's left point. UTIMS then performs the same

type of search on the right side of the cross section.

Once UTIMS identifies the new left and right points for a cross section it creates the new cross section line by connecting those points. If dog-legs are specified internal vertices are also kept. Figure 3-51 displays the clipped cross section.

By using trial upstream and downstream depths to clip cross sections it is important to realize how these depths may affect the modeling process within HEC-RAS. In HEC-RAS if flow exceeds the maximum extent of the cross section then it assumes that it can continue to fill the cross section using the end points of the specified cross section as vertical walls. In this case where flow exceeds the capacity of a cross section the cross section needs to be further extended into the overbank areas so that the flow being modeled is fully contained within the specified cross section.

Cross sections are clipped based upon their station and interpolated trial depth. Therefore in order to extend the cross section either it must be moved to a different location along the stream or the trial depth must be increased. Thus underestimation of trial depths within UTIMS may cause misrepresentation of flooding extents within the HEC-RAS model if the flow being modeled exceeds the capacity of the cross section. On the other hand, an overestimation of these trial depths may result in unreasonably wider overbank flow path centerlines for the first iteration, but it is not as limiting in nature as underestimation of the trial depths. Therefore if a user is to err on one side then overestimation of the trial depths is to be chosen. In subsequent iterations of UTIMS the flood polygon obtained from HEC-RAS output is used to compute flow path centerlines thus the error introduced by over estimation of the trial

flood depth by the user in the first iteration is nullified. This allows users the ability to automate the capture of cross section extents required by expected flow depths for a given flood magnitude.

UTIMS allows users the ability to specify dog-leg information for the creation of dog-legs on the ends of cross sections to approximate the flow modeling by HEC-RAS (one-dimensional model) in situations where the flow fans out in a floodplain. Placing dog-legs is optional, and is only suggested when they are warranted in a flood study. Figure 3-53 displays how dog-legs are created. Users can specify the length of

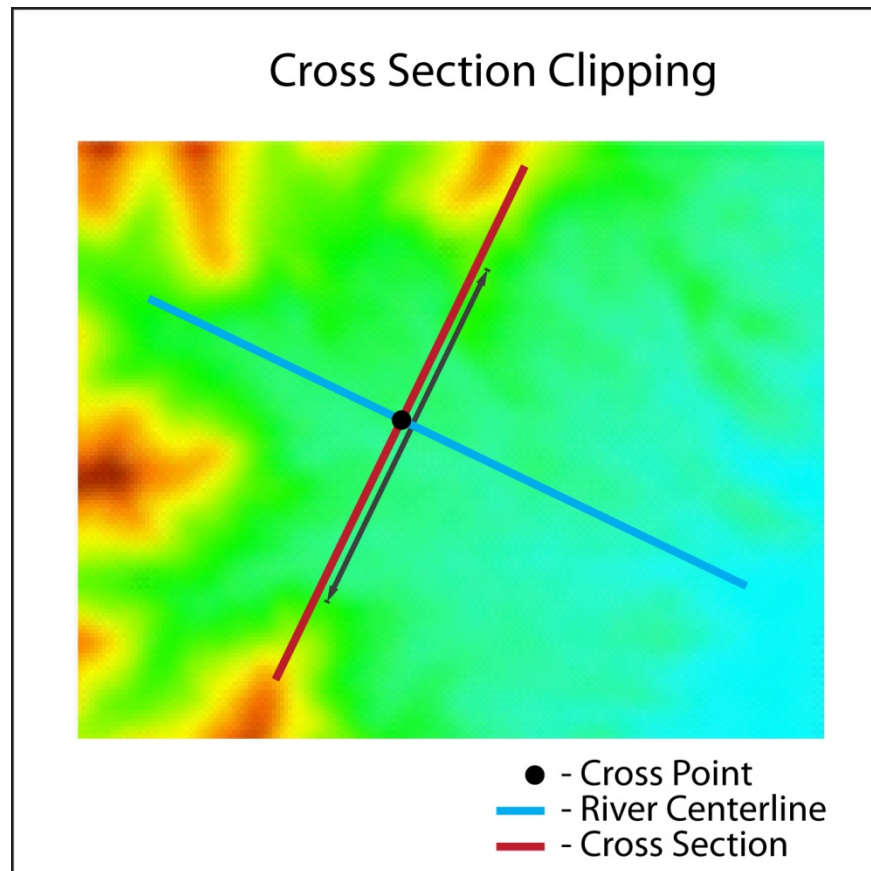


Figure 3-50. Clipping cross section.

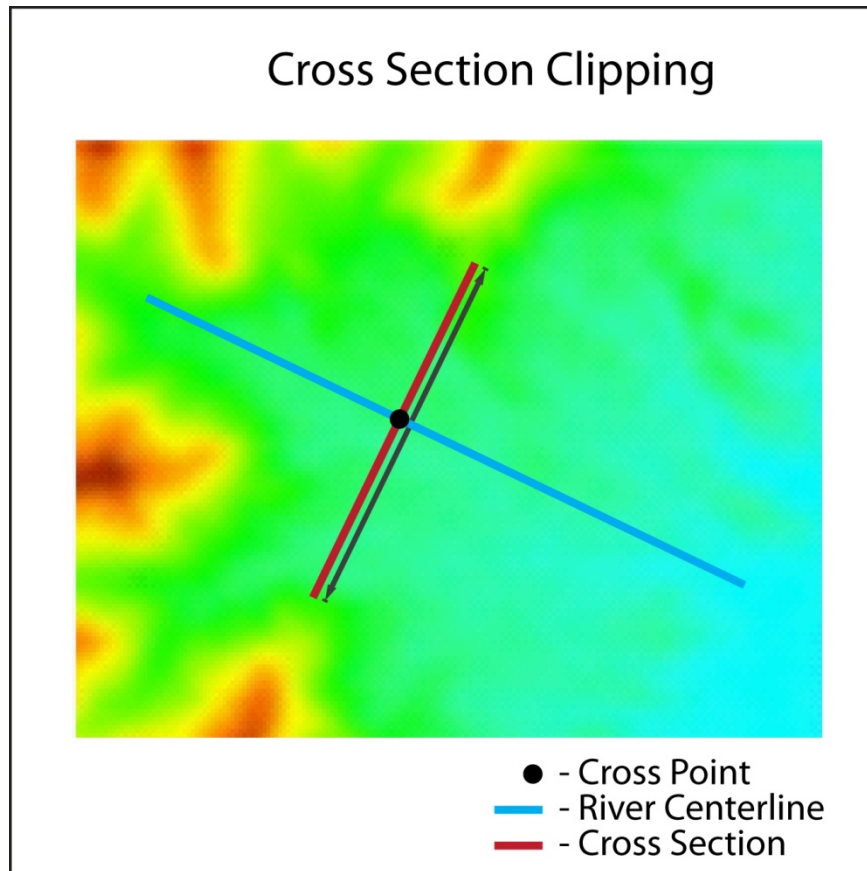


Figure 3-51. Clipped cross section.

the extension for dog-legs and also the angle from the main portion of the cross section from which to orient the dog-legs.

Upon completion of placing cross sections automatically by UTIMS the control of UTIMS is passed back to the user. Upon which a user can inspect the cross sections created to verify if they sufficiently represent the path of flow. This allows for easy placement of cross sections, thus cutting down the time required to digitize each and every cross section by hand, while still providing the user an opportunity to inspect and modify the cross sections, if required.

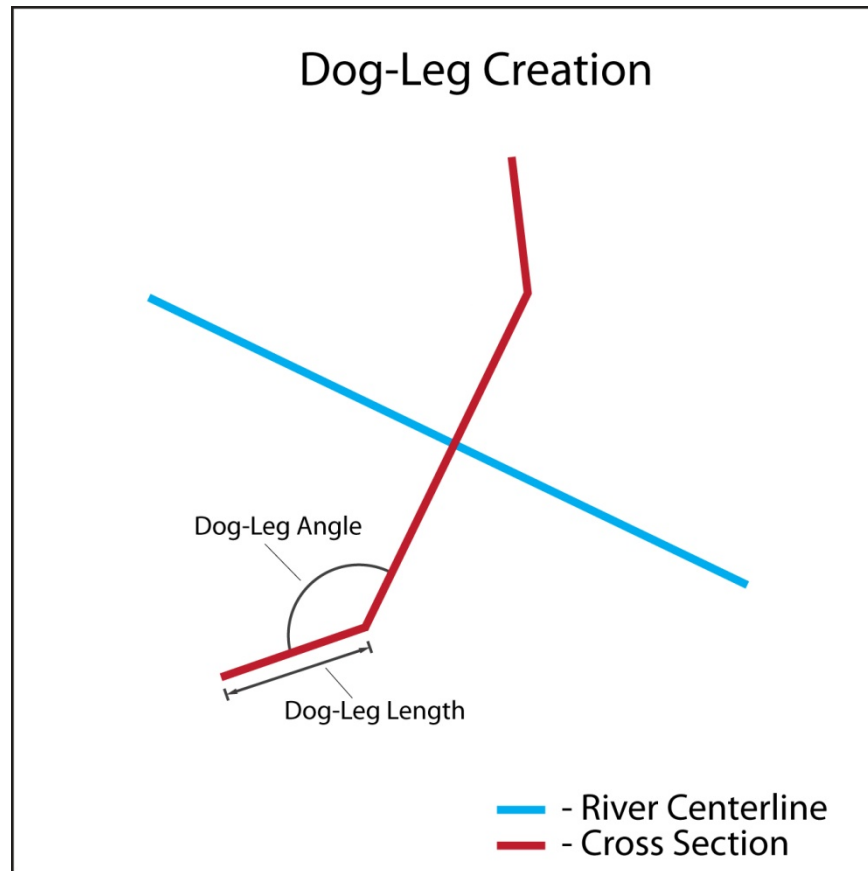


Figure 3-52. Dog-leg placement.

UTIMS verifies that cross sections do not overlap any other cross section, cross a river centerline only once and cross their appropriate bank and flow path lines. If any of these problems are identified UTIMS informs the user of the cross section causing problems and allows the user to modify any of the geographic features so that accurate and complete geometry files can be constructed for use by HEC-RAS.

#### Land use/n-value polygons

Areal averaged n-values are calculated using NLCD layer, NLCD grid code/n-Value table relationship file, and utilizing the cross sections for each river reach under

consideration in a flood study. The specific methods and output schemes and names are described in the earlier section titled Areal Averaged n-Value Assignment.

### UTIMS Output

#### Flood polygons

The GIS output file from HEC-RAS (“\*.RASexport.sdf”) contains water surface profile data, which is used to develop the flood polygons within GIS. UTIMS constructs three-dimensional flood polygons for each profile found in the GIS output file from HEC-RAS. For each time a user selects the “Read Output” button on the UTIMS main user interface UTIMS creates a new shapefile entitled “Flood Polygons” in the appropriate “data” output folder. Appropriate name for the flood polygon, defined by the name of profiles in the output file, is assigned in the created shapefile, as well as the area of the flood polygon is provided. A single flood polygon is constructed for each profile and river found in the GIS output file. These three-dimensional flood polygons can be viewed in ArcScene in three-dimensional space.

#### Flood specific river centerlines

UTIMS approximates the flow path centerline of each flood polygon created when UTIMS reads the GIS output file from HEC-RAS. The process described in the section entitled “Flood Polygon Centerline Approximation” is used to approximate the new flow path centerline for the next iteration. The newly derived flow path centerline shapefile is titled “Flood Polygon Centerlines” and is located in the appropriate



iteration “data” output folder. The resulting centerlines are approximations of the centerline of each flood polygon defined in the GIS output file. Before being stored the flood polygon centerlines are passed through the line of sight analysis to smooth any kinks in the derived flood polygon centerlines.

#### Interpolated cross sections

UTIMS reads interpolated cross sections being passed to UTIMS by HEC-RAS and stores them in the appropriate data output folder in the shapefile titled “Interpolated Cross Sections.” These cross sections allow for a more accurate flood polygon and thus provide a better resolution of the flooding extents.

#### Convergence criteria handling

UTIMS aids modelers in determining when convergence upon a final flood polygon has been achieved. This is performed by monitoring the water surface elevation changes in flood polygons at user specified locations along a river centerline from subsequent HEC-RAS computation iterations. UTIMS monitors the convergence process by holding the “ID” value for each location in the critical point shapefile along with the water surface elevation for the current iteration and the change in water surface elevation between the current iteration and the previous iteration.

When the change in water surface elevation from subsequent iterations of UTIMS is less than the convergence criteria value entered on the main UTIMS user interface page the user will be alerted to the fact that convergence has been achieved . This tracking of changes in water surface elevations from iteration to iteration is stored

in a “\*.dbf” or table file entitled “Elevation Table” located in the main output folder.

A user can easily monitor the changes in water surface elevations from iteration to iteration by inspecting the contents of this table file.

## CHAPTER 4

### INUNDATION MAPPING AUTOMATION PROCESS

A case study was performed to demonstrate the capabilities and functionalities of UTIMS by developing an inundation map for Millsite Dam. The Millsite Dam and Reservoir are located in east central Utah. The Millsite Reservoir is formed by the damming of Ferron Creek which travels 24.8 miles from the downstream of Millsite Reservoir until its confluence with Huntington Creek and Cottonwood Creek to form the San Rafael River. A preliminary breach hydrograph was considered in the study, as an example of an extreme type of flow where flow is expected to flood overbank areas.

The preliminary breach hydrograph, HEC-RAS files, and GIS inundation map files were obtained from NRCS (Todea, 2008). The preliminary dam breach hydrograph was developed by NRCS using the USDA NRCS Technical Release 60 (“Earth Dams and Reservoirs” which can be downloaded from [http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/tech\\_info/TR\\_TP.html](http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/tech_info/TR_TP.html)). The USDA NRCS Technical Release 66 (“Simplified Dam-Breach Routing” which can be downloaded from [http://www.wsi.nrcs.usda.gov/products/w2q/H&H/Tools\\_Models/other/TR66.html](http://www.wsi.nrcs.usda.gov/products/w2q/H&H/Tools_Models/other/TR66.html)) was used by the NRCS to model the breach, and the breach hydrograph was obtained approximately 1000 feet downstream of the dam. The peak flow at the upstream boundary condition was approximately 226,000 cfs. Routing of the breach hydrograph was done for two and a half hours, thus ensuring that the peak flow passed the downstream portions of the Ferron Creek.

The input data for UTIMS was gathered from several online sources supplying GIS data. Digital elevation data in GRID format was downloaded from the Utah Automated Geographic Reference Center (AGRC) for the entire Emery County. The grid cell size was 10 meters. To model with 10 meter grid data makes cross sections non-uniform in shape, therefore a TIN was created using ArcMap's 3D Analyst using a tolerance of 1. The TIN created provided a much better surface to model with. The National Land Cover Dataset (NLCD) data was downloaded from the United States Geological Survey (USGS) site (<http://seamless.usgs.gov>). The grid cell size of the downloaded NLCD data was 10 meters.

River centerlines for the entire Emery County, UT, were downloaded from the AGRC. From the downloaded features Ferron Creek was isolated from the many features supplied by the AGRC. Ferron Creek was then trimmed so that the upstream portion of the actual centerline was downstream of the downstream face of the dam (approximately matching the location of the breach hydrograph obtained from the NRCS) and the furthest downstream portion extended far enough downstream past Ferron, UT, so that the downstream boundary condition did not influence the results at the most downstream location of interest.

The NLCD layer was investigated to identify appropriate critical station points to monitor convergence near Ferron, UT. Three critical station points were placed near Ferron City and two points further downstream to monitor the convergence process along the river centerline. Figure 4-1 shows Ferron Creek along with the critical station points placed along the actual river centerline.

Figure 4-2 shows the NLCD layer for the area surrounding Ferron Creek.

Figure 4-3 shows a close up view of Ferron City with the critical station points placed along the actual river centerline. The critical station points near Ferron City were placed at major road crossings although no bridges or other structures were modeled in this study (same as in the NRCS study) as they were expected to be washed out.

The grid format raster, the TIN layer and the NLCD layer were selected on the main UTIMS screen by browsing for the data sets on the hard drive. Their appropriate paths and file names were loaded into the appropriate text boxes. A river network containing Ferron Creek was loaded and the appropriate field titles were selected in the river name and river reach combo boxes. The appropriate critical river stations shapefile was also selected.

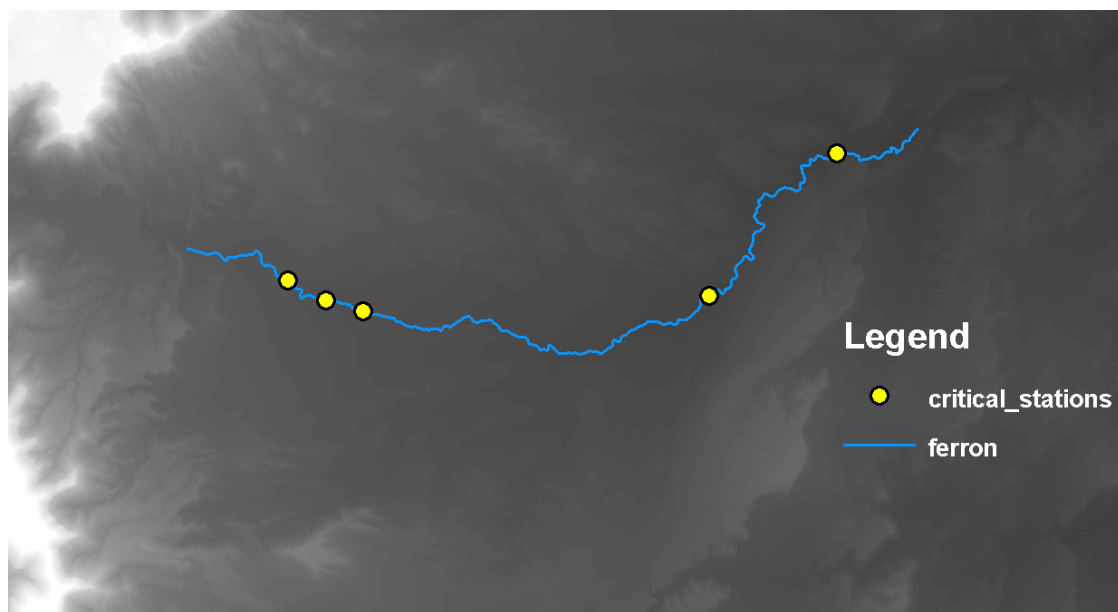


Figure 4-1. Ferron Creek and critical station points.

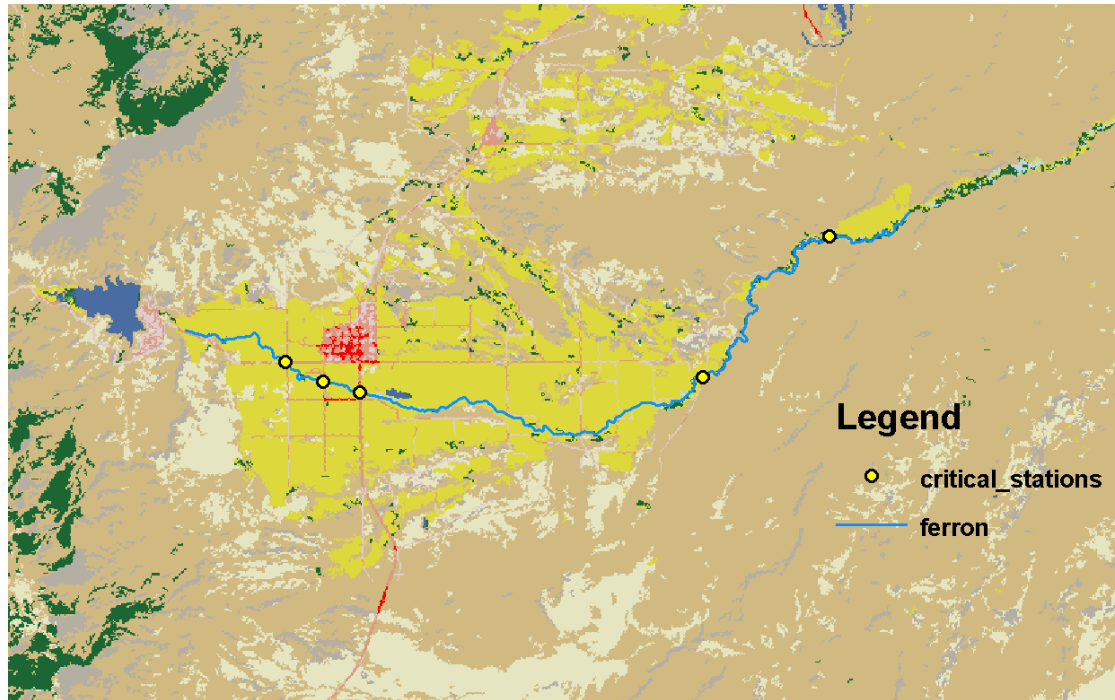


Figure 4-2. NLCD layer surrounding ferron creek.

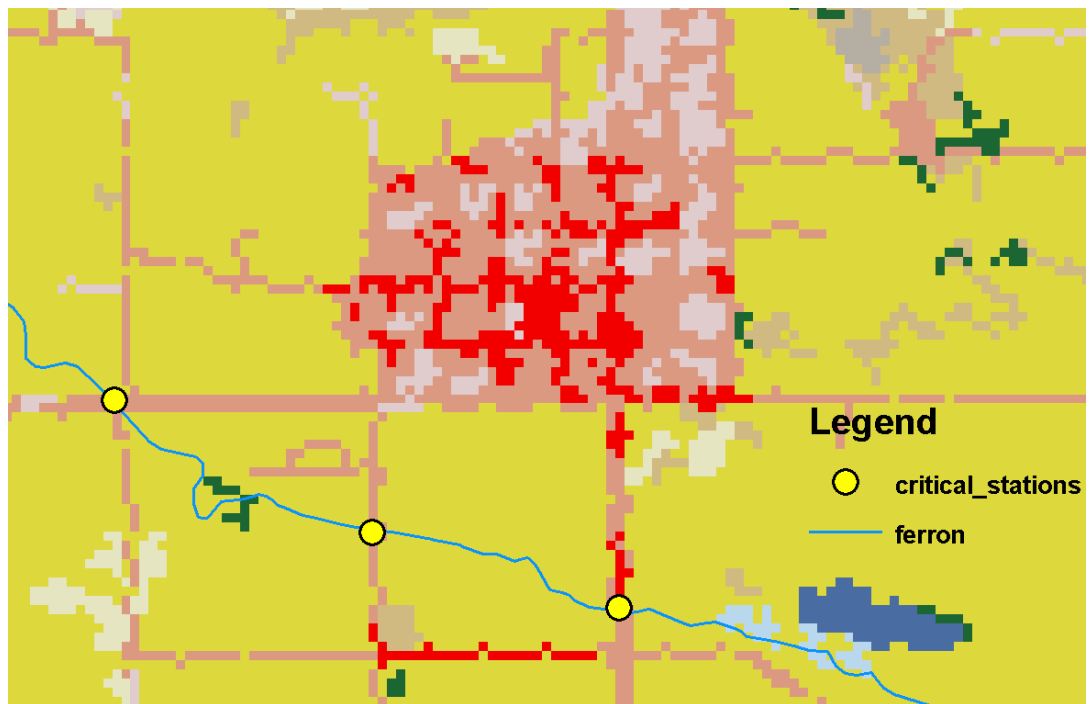


Figure 4-3. Critical station points placed near Ferron, UT.

Geographic data units of “Metric” were selected due to the spatial reference of the geographic layers being loaded into UTIMS. A text file containing two columns containing NLCD grid code values and representative n-values was also selected. The NLCD – n value relationship (Nanadoun, 2005) is shown in Table 4-1. An output folder was browsed for using the output folder button and an appropriate project title was selected. The units selected for this project for use by HEC-RAS were “US Customary” the same as in NRCS study.

A line of sight interval of 20 meters was selected due to it being roughly two times the dimension of the pixel cells within the grid format digital terrain data. A polygon segmentation distance of 10 meters was chosen to develop an accurate flood polygon centerline. A convergence criteria of 1.0 foot was selected as the convergence tolerance. A critical point station proximity distance of 50 meters was selected due to there being one river centerline being modeled. Figure 4-4 displays the main UTIMS interface with the loaded layers and various input values.

The reach of Ferron Creek considered did not exhibit heavily meandrous portions, therefore a rather large value for the meander correction value was chosen at 500 meters.

To investigate trial upstream and trial downstream depths the slope immediately downstream of the most upstream and most downstream cross sections on Ferron Creek were examined. Profile views of the furthest upstream and furthest downstream areas of Ferron Creek were made utilizing the 3D Analyst within ArcGIS. The friction slope for the downstream boundary was approximated by observing the profile view. Then using approximate peak flow ( $Q_{\text{peak}} = 145,000$  cfs at downstream

Table 4-1. NLCD grid code – n value relationship

NLCD Grid Code	n-Value
11	0.035
21	0.06
22	0.08
23	0.11
31	0.025
32	0.04
33	0.04
41	0.12
42	0.15
43	0.1
51	0.07
61	0.055
71	0.035
81	0.035
82	0.05
83	0.04
85	0.045
91	0.1
92	0.01
999	0.07

from the NRCS study) the normal depths were calculated for both the upstream and downstream portions of Ferron Creek. The approximated normal depth for the upstream and downstream portions of Ferron Creek were 17.2 meters and 11.1 meters, respectively. Utilizing these values approximate trial depths of 20 and 12 meters were entered on the “Rivers” page in the UTIMS interface.

The user is advised to enter these values based on the approximate peak flow to be modeled at the upstream boundary and the estimated attenuated flow at the downstream boundary. These trial depth values need not be precise, an overestimate is



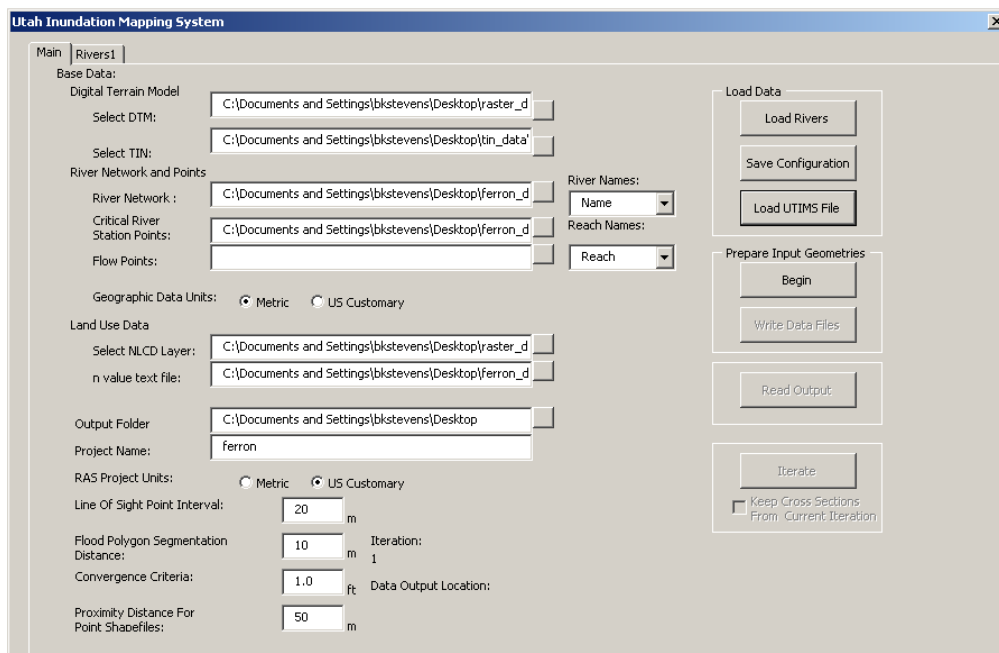


Figure 4-4. Main UTIMS interface loaded.

suggested because as explained earlier these values are used to approximate an initial flood polygon and are also utilized in clipping cross sections.

Bank lines were placed 25 meters away from the actual river centerline. This was due to a relatively open plain that flow must travel through. It is to be noted that for an extreme flow model the precise definition of the stream banks is usually not significant because the area of flow within the stream banks is usually insignificant as compared to the total area of flow.

Cross sections were placed 300 meters apart, which is roughly a fifth of a mile. The main cross section width was approximated around 3000 meters with dog-leg lengths at 1000 meters at 150 degrees. The number of cross section segments for land use n-value polygon development was eight, to allow for interpolation within HEC-

RAS without exceeding the limit of 20 n-values per cross section. Figure 4-5 shows the “Rivers” page holding all the appropriate reach specific parameters. As shown in Figure 4-4 and Figure 4-5 UTIMS is now ready to process the input data. Thus the “Begin” button was pressed. By pressing the “Begin” button UTIMS generates a flow specific centerline, places cross sections, develops bank lines and flow path lines.

Upon completion of the UTIMS processing of the input data, the cross sections were visually examined to investigate if sufficient cross sections were placed to capture the trial flood polygon. Having verified that sufficient cross sections were placed the “Write Data Files” button was pressed.

Upon completing the task of checking the connectivity of the flow path lines and bank lines to cross sections, n-value polygons were developed by UTIMS. The sloping analysis, line of sight analysis, cross section placement, bank and flow path line development and n-value polygon development took about 12 minutes to complete. HEC-RAS was then launched and the geometry file was inspected to see if any bank stations needed to be moved and if any levees needed to be placed. Bank stations coming from UTIMS follow the actual river centerline path, with a simple offset, therefore the placement of bank stations along a cross section indicate where the actual river centerline was located along the cross section, which is helpful particularly if there are multiple dips in the cross section profile.

Utah Inundation Mapping System									
Main Rivers1									
Units: Meters River, Reach	Meander Correction	Trial Flood Depths		Offsets Banks	Cross Section Handling			Dog Leg Information (Optional)	
		U/S	D/S		Distance Between XS	XS Width	# Land Use Segments	Length	Angle (deg)
Ferron, Millsite	500	20	12	20	300	3000	8	1000	150

Figure 4-5. Rivers page values for Ferron Creek.

Upon correcting any bank station placement in relation to the cross section thalweg, dummy levees (with zero heights) were also added to ensure that HEC-RAS placed the flow in the main channel and did not split it unreasonably in a low area captured by the cross sections, unless the elevation at which a dummy levee was placed was exceeded. Flow data was entered and the plan file created. Upon completing hydraulic computations, using an appropriate cross-section interpolation interval (in this case 100 feet) and other computation tolerances and setting, the flood profile and flooding extents were checked for reasonableness of results. Upon verification of the hydraulic computations the “Export GIS Data” was selected from the HEC-RAS File menu dropdown list to export results to GIS. The maximum water surface was exported (titled “MaxWS”) along with the accompanying interpolated

cross sections. Upon pressing this button UTIMS reads the flood polygon extents and stores the interpolated cross sections and the maximum water surface polygon in their respective output shapefiles. UTIMS also derives the flood polygon centerline. This flood polygon centerline is also stored in its appropriate output shapefile. At this time the water surface elevations for the critical point cross sections were stored into the “Elevation Table” in the main output folder. Upon the completion of deriving the flood polygon centerline UTIMS enables the button titled “Iterate” to allow the user to begin a new iteration using the derived flood polygon centerline as the next iteration flow path centerline. New cross sections were desired to better approximate the orientation of the derived flow path centerline, therefore the check box below the iterate button was not checked to keep the previous iterations cross sections and the “Iterate” button was pressed.

By pressing the iterate button UTIMS created new cross sections using the derived flood polygon centerline as the new flow path centerline, therefore cross sections were placed normal to the new flow path centerline. Bank lines were kept from the initial iteration as being offset from the actual river centerline, and flow paths were created using the new cross sections and the banks lines. Again the button titled “Write Data Files” was pressed to create new n-value appropriate land use polygons and write a new HEC-RAS geometry file. The unsteady flow file was copied into the new “Run” folder and a new project file was written. Therefore upon launching HEC-RAS the only data to modify before performing hydraulic computations was to inspect the placement of bank stations for stable computations and the placement of dummy levees.

Upon performing the unsteady flow analysis the flood extent profile was inspected to verify that the computations were performed reasonably. Upon verifying that the computations were performed appropriately the maximum water surface profile was exported along with the interpolated cross sections by pressing the “Export GIS Data” option within HEC-RAS. On the UTIMS interface the “Read Output” button was pressed.

UTIMS read the HEC-RAS output file and created the flood polygon, its appropriate centerline, interpolated cross sections and stored the critical point cross sections water surface elevation. Having read the HEC-RAS output file UTIMS read the “Elevation Table” with values stored for the first two iterations and notified through a message box that convergence was achieved for critical location points one, two and three. Therefore noting that convergence was almost reached and visually inspecting the cross-sections for their reasonableness with respect to the flood polygon, the box for keeping the current iteration cross sections for the next iteration was checked and the “Iterate” button was pressed.

The cross sections from the second iteration were kept for the third iteration and new flow path lines were created by UTIMS based on the new flood polygon output from HEC-RAS. The button titled “Write Data Files” was pressed to develop new land use polygons and to write a new geometry file. Flow files were copied by UTIMS to the new run folder and a new HEC-RAS project file was written.

Again, in HEC-RAS bank station placement was inspected and dummy levees were added. The unsteady flow analysis was completed and water surface extents

were verified for reasonableness. The maximum water surface elevation profile data along with the interpolated cross sections were again exported to GIS.

The “Read Output” button was again pressed on the UTIMS interface to store the interpolated cross sections, flood polygons, flood polygon centerlines, and the critical point cross section water surface elevations in their appropriate files. UTIMS notified through message boxes that convergence had been achieved for all critical point cross sections. Thus the convergence process was completed and UTIMS was exited to view the final output.

## CHAPTER 5

### RESULTS AND DISCUSSION

For the extreme flow modeling case described in chapter 4 the appropriate data was input as discussed in Chapter 4. For the first iteration UTIMS performed the sloping plane analysis, which took the actual river centerline and found the closest points on the terrain to queried trial flood depth points. Combining these points into an initial flood polygon UTIMS constructed an approximation for the flood polygon for the first iteration. Figure 5-1 displays the initial flood polygon along with the actual river centerline for Ferron Creek.

Having constructed the initial flood polygon by the sloping plane analysis

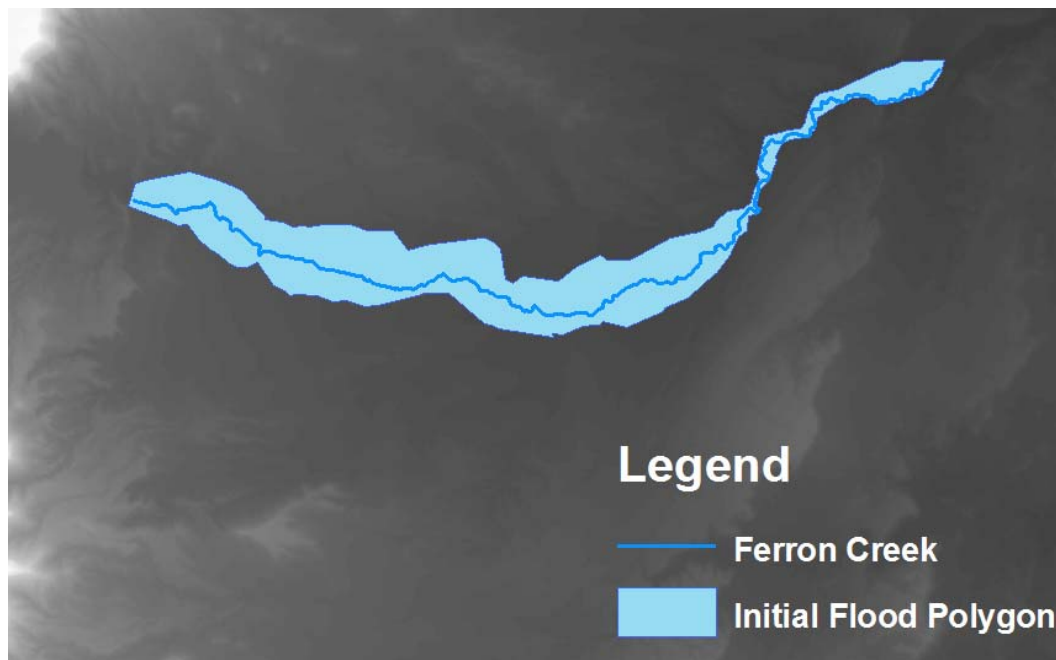


Figure 5-1. Actual river centerline with initial flood polygon.

UTIMS approximated the initial flood polygon centerline by performing the closest point analysis. Figure 5-2 displays the initial flood polygon centerline as derived by UTIMS. The initial flood polygon centerline for the first iteration is held in “Modified Flowpath” shapefile.

Upon deriving the initial flood polygon centerline UTIMS performed the line of sight analysis which in essence smoothes the kinks in the initial flood polygon centerline. Figure 5-3 displays the initial flood polygon with the “Modified Flowpath” and the flood polygon centerline after the line of sight analysis held in the “Complete Flowpath Centerline” shapefile.

Figure 5-4 shows a close up view of a short portion of Ferron Creek.

The flow path centerline smoothed after line of sight analysis is utilized as the

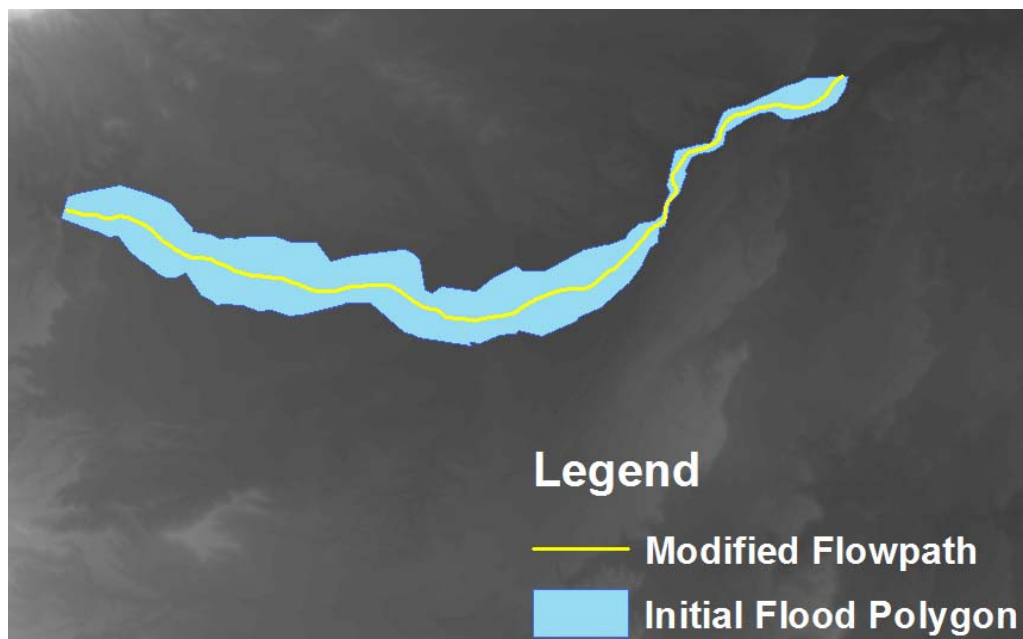


Figure 5-2. Initial flood polygon and flow path centerline.



flow path centerline in placing cross sections and is also utilized as the main channel flow path centerline. Figure 5-5 shows the cross sections which were placed normal to the flow path centerline. Sixty-eight cross sections were placed and clipped by UTIMS.

Figure 5-6 shows the bank lines and flow path lines which were created. The bank lines follow the path of the actual river centerline and the flow path lines were created as approximations of the centroid locations of the overbank areas.

Figure 5-7 shows the land use polygons which were created by UTIMS in assigning n-values for the cross section segments. Labels located on the polygons in Figure 5-7 show the mean value of n-values for the first iterations average n-value polygons in the upper portion of Ferron Creek. The n-values in the final iteration ranged from 0.025 to 0.15.

Figure 5-8 shows the initial flood polygon along with the first iterations flood polygon which was obtained from HEC-RAS. It is to be noted that the initial polygon was intentionally made much wider by overestimating the trial flood depth for the reasons explained earlier under heading "Cross sections" in Chapter 3.

Figure 5-9 shows the flood polygon created from the HEC-RAS output from each of the three iterations.

Figures 5-10, 5-11 and 5-12 display a close up view of the upper, middle and lower portions of Figure 5-9, which shows the polygons from the first, second and third iterations obtained from HEC-RAS.

Figure 5-13 shows the overlaid flood polygon centerlines from each of the three iterations, each derived from the flood polygons obtained from HEC-RAS.

Figure 5-13 also shows the initial flood polygon centerline obtained in the first iteration using the sloping plane and line of sight analysis. The actual river centerline for Ferron Creek is also shown.

Figure 5-14 shows the final flood polygon and flood polygon centerline (i.e. final flow path centerline) which was read from HEC-RAS from the third iteration.

Figure 5-15 shows the final UTIMS derived flood polygon with the NRCS flood polygon overlaid on top.

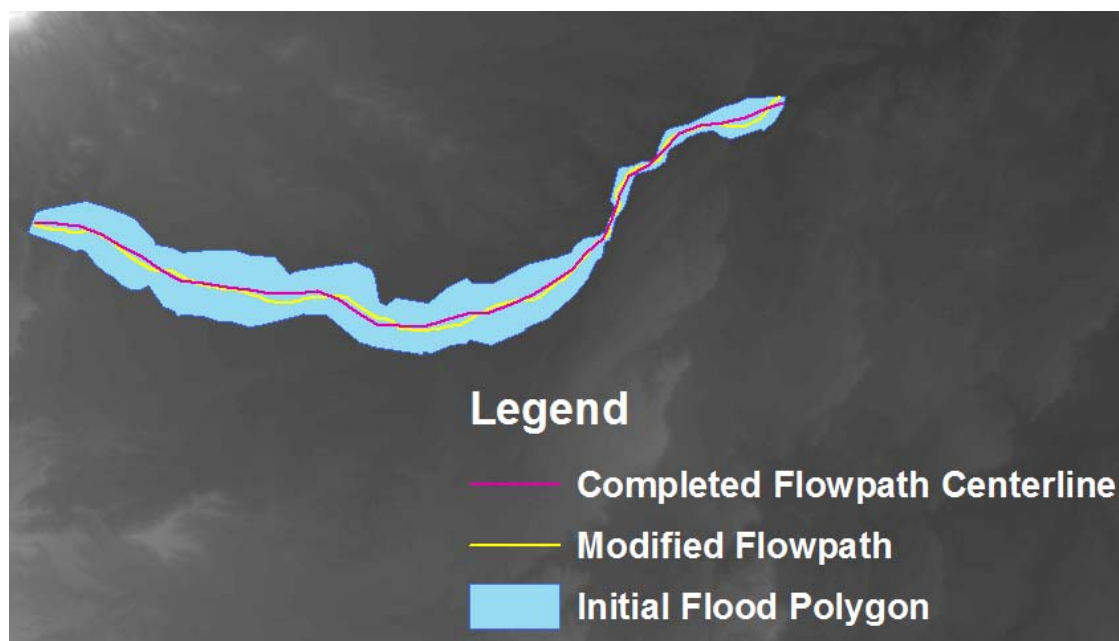


Figure 5-3. Initial flood polygon flowpath centerline and line of sight analysis line.

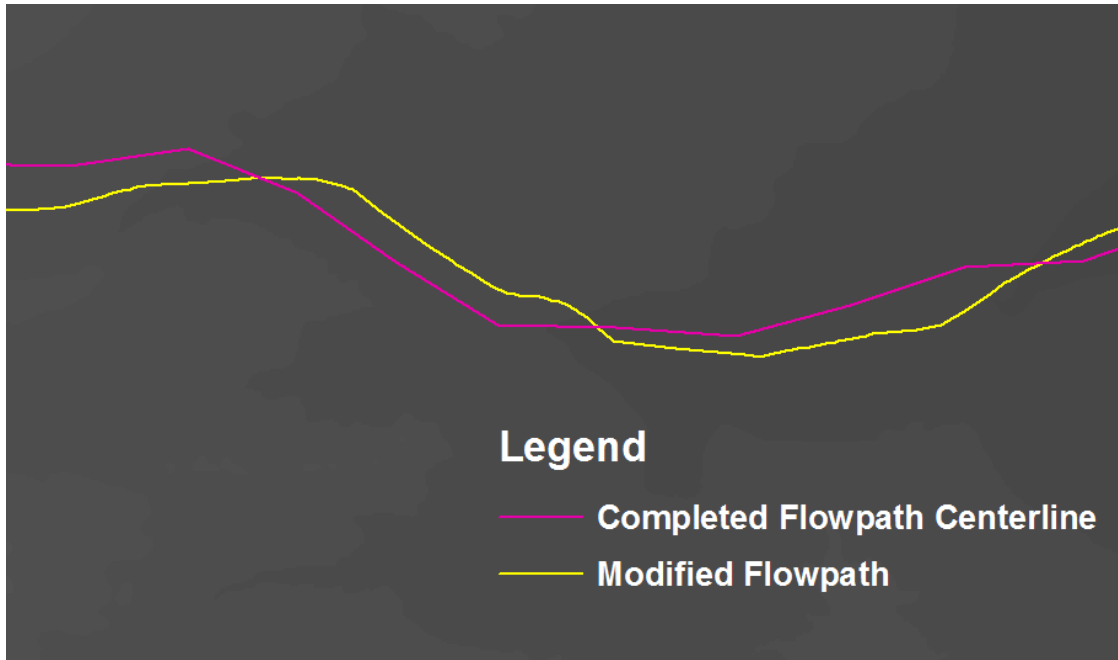


Figure 5-4. Close up view of the initial flood polygon flowpath centerline and line of sight line.

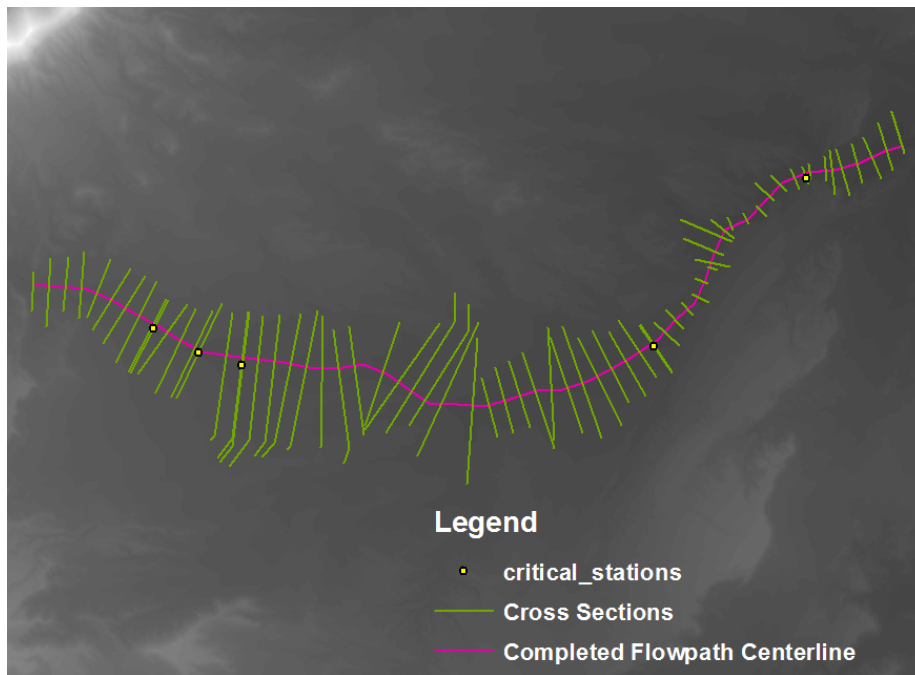


Figure 5-5. Flow path centerline and cross sections.

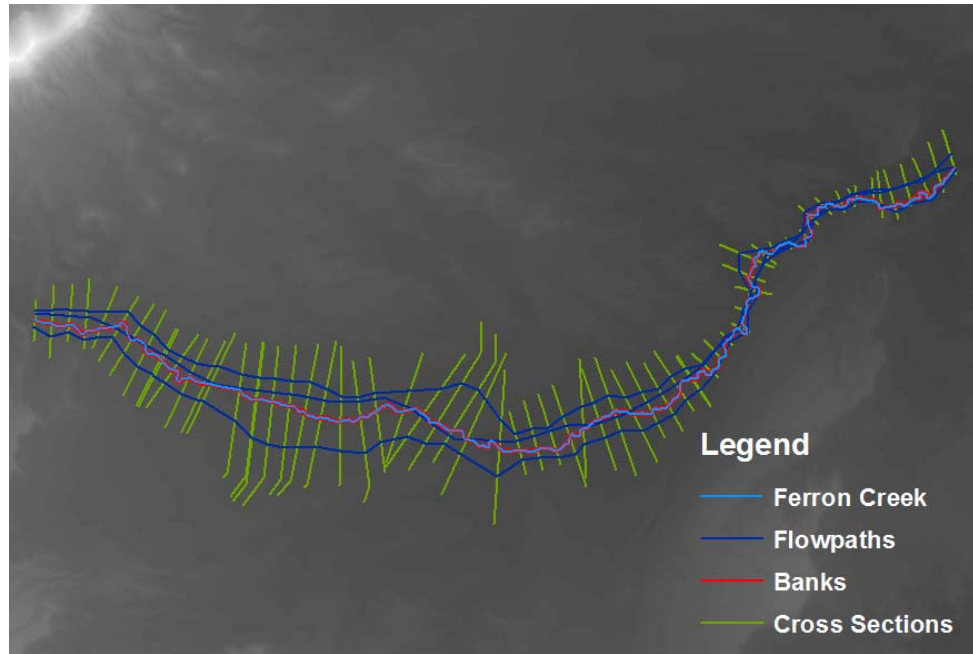


Figure 5-6. Created flow path and bank lines with cross sections.

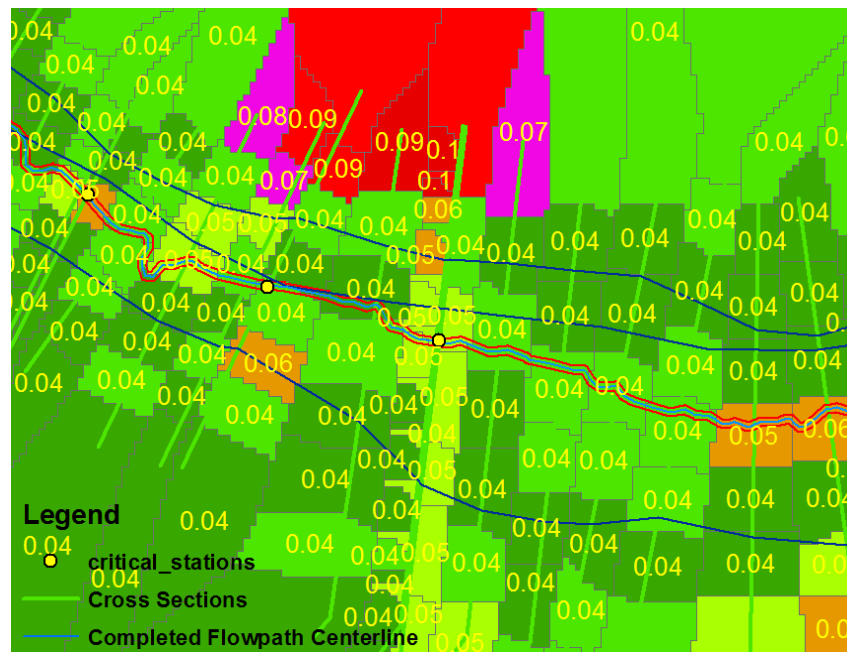


Figure 5-7. Created land use areal averaged n-value polygons.

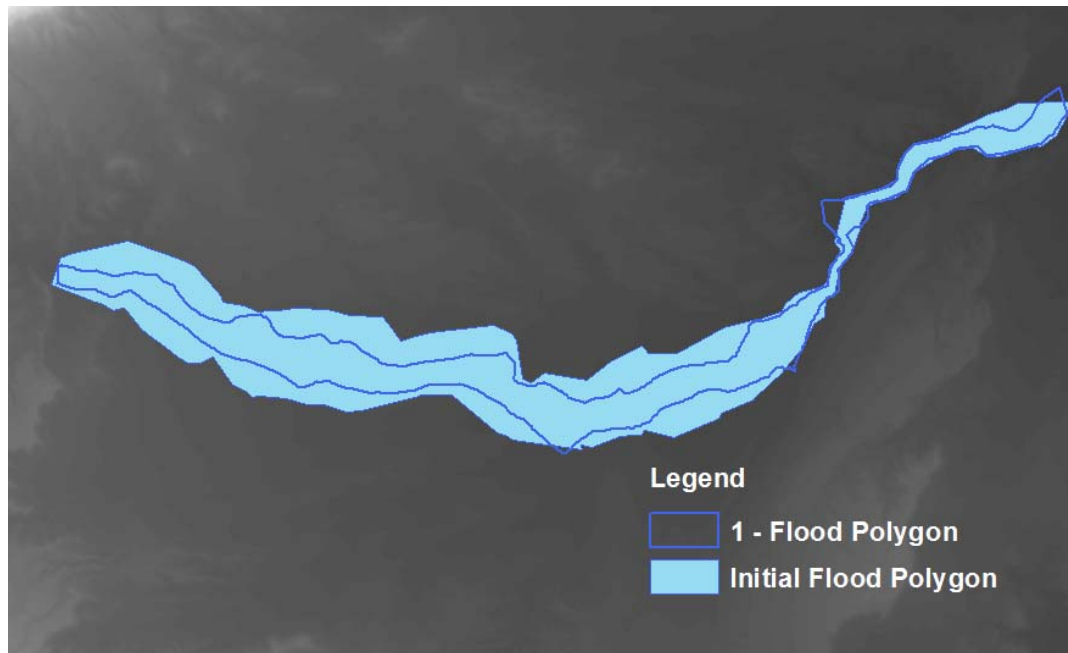


Figure 5-8. Initial flood polygon and first iteration flood polygon.

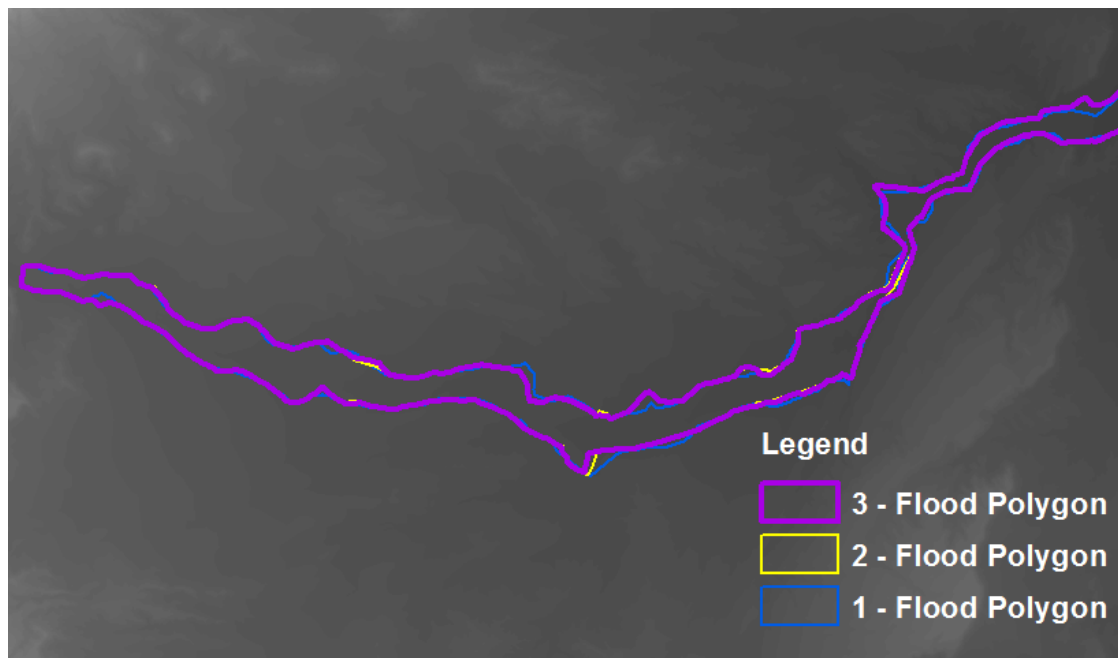


Figure 5-9. Flood polygons from three iterations.

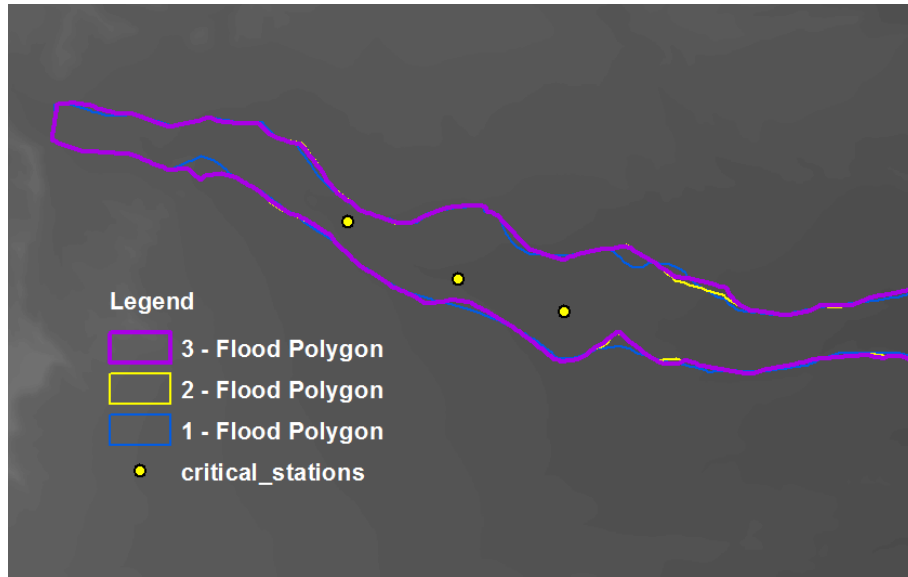


Figure 5-10. Upper portion of overlaid flood polygons from three iterations.

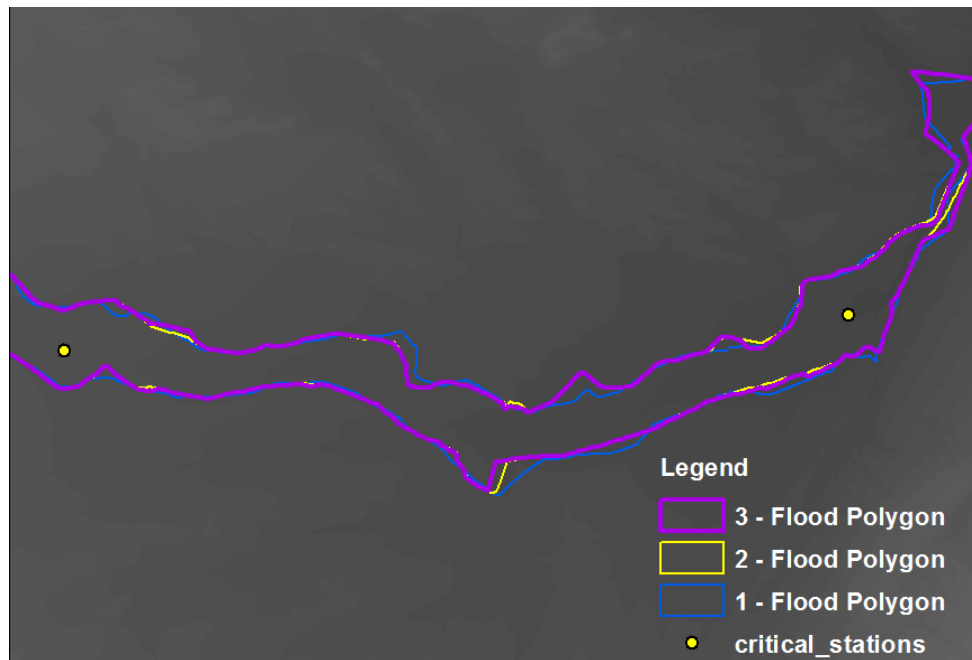


Figure 5-11. Middle portion of overlaid flood polygons from three iterations.

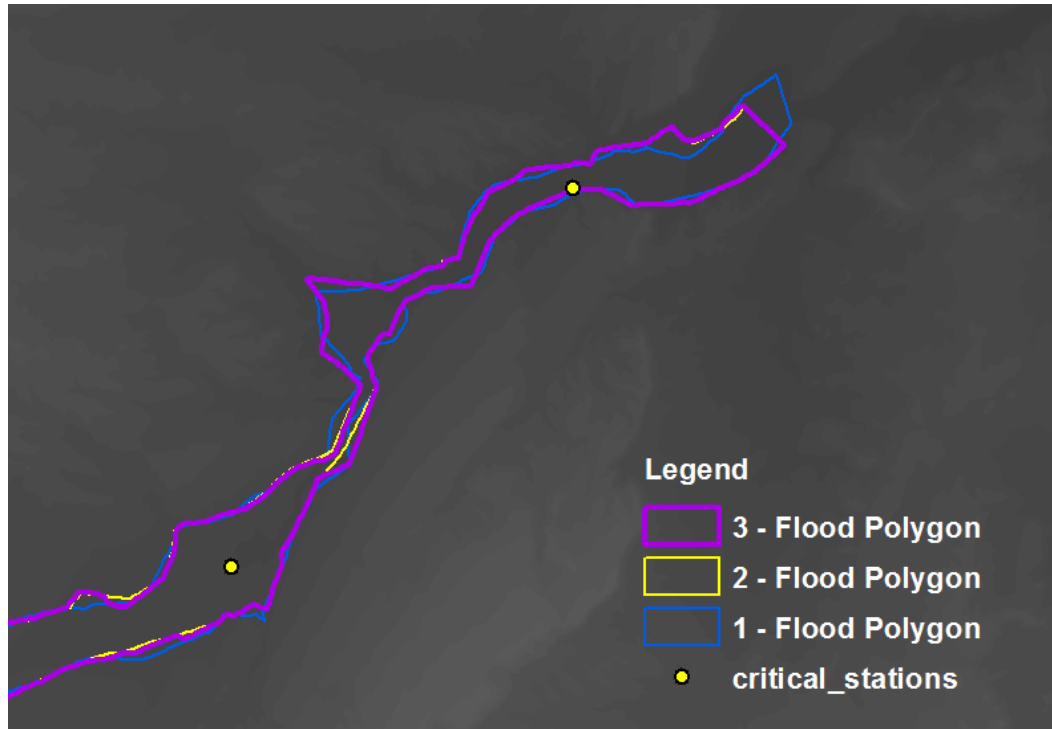


Figure 5-12. Lower portion of overlaid flood polygons from three iterations.

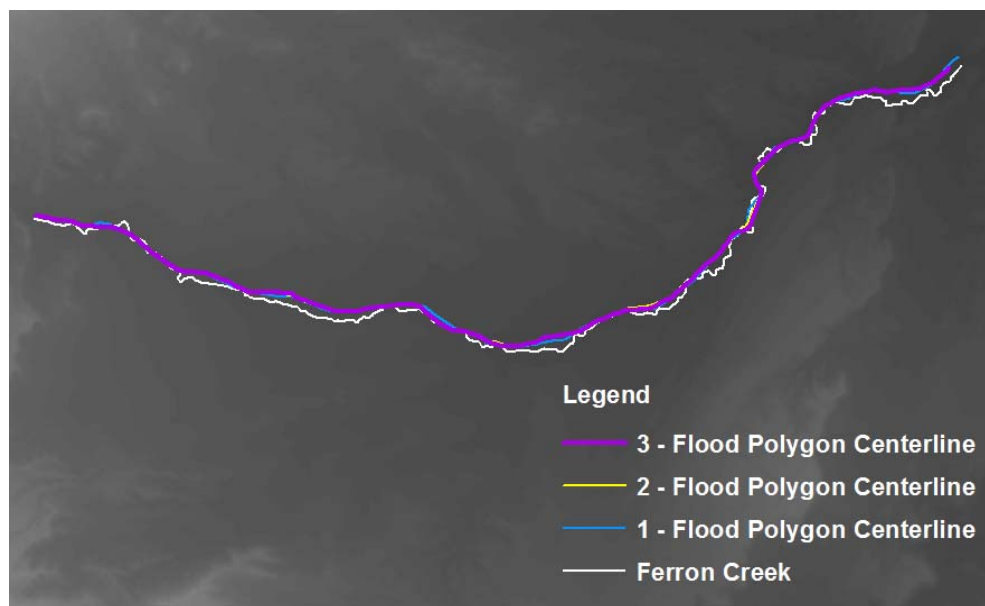


Figure 5-13. Overlaid flood polygon flow path centerlines from three iterations.

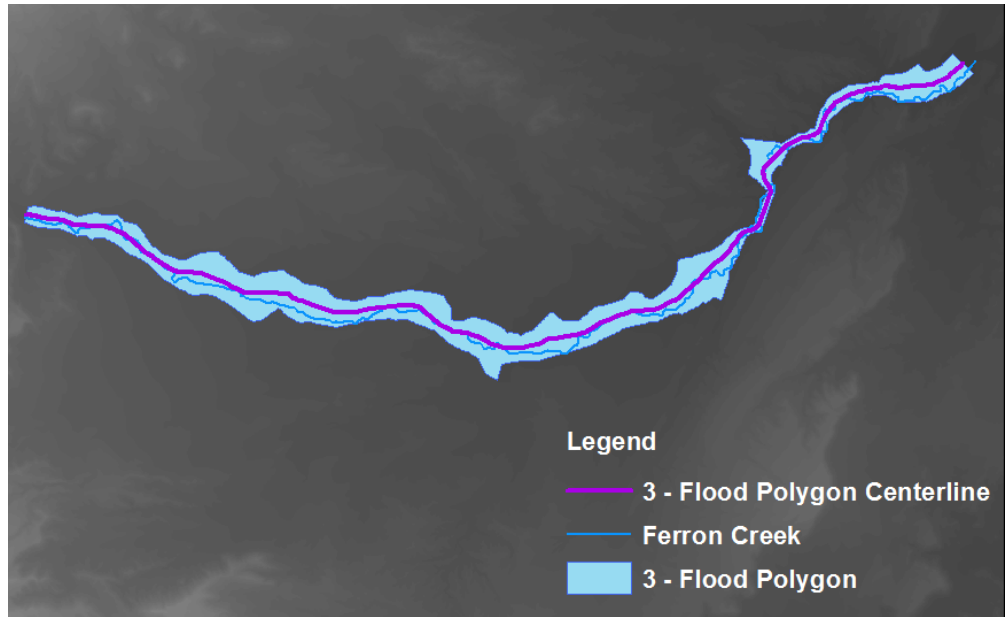


Figure 5-14. UTIMS final flood polygon and overlaid flow path centerline.

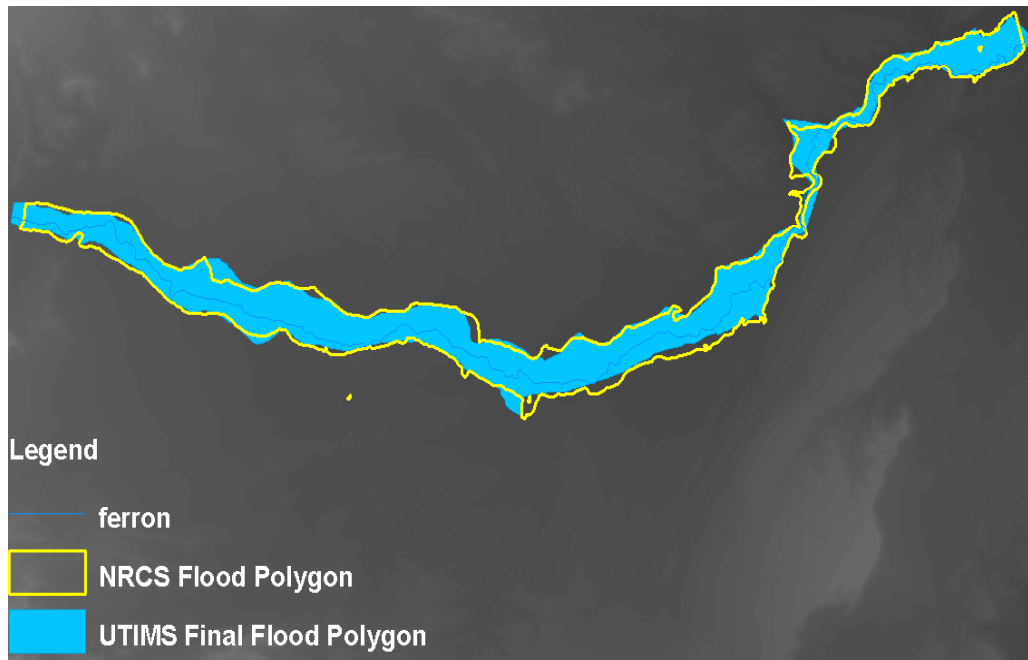


Figure 5-15. UTIMS and NRCS final flood polygons overlaid.



Table 5-1. Attributes of elevation table (units in meters)

ID	River	Reach	Profile	Iteration	WS Elev	Change Elevation
1	Ferron	Millsite	MaxWS	1	1815.72	0
2	Ferron	Millsite	MaxWS	1	1807.47	0
3	Ferron	Millsite	MaxWS	1	1798.49	0
4	Ferron	Millsite	MaxWS	1	1729.86	0
5	Ferron	Millsite	MaxWS	1	1695.95	0
1	Ferron	Millsite	MaxWS	2	1815.65	0.07
2	Ferron	Millsite	MaxWS	2	1807.17	0.30
3	Ferron	Millsite	MaxWS	2	1798.48	0.01
4	Ferron	Millsite	MaxWS	2	1729.35	0.50
5	Ferron	Millsite	MaxWS	2	1695.25	0.70
1	Ferron	Millsite	MaxWS	3	1815.72	0.07
2	Ferron	Millsite	MaxWS	3	1807.18	0.01
3	Ferron	Millsite	MaxWS	3	1798.52	0.04
4	Ferron	Millsite	MaxWS	3	1729.10	0.25
5	Ferron	Millsite	MaxWS	3	1695.45	0.20

Table 5-2. Velocity at critical points (units in feet per second)

Point	UTIMS	NRCS
1	24.28	15.93
2	9.55	12.5
3	8.51	12.14
4	2.6	2.88
5	12.78	14.12

As seen in Figure 5-1 the initial flood polygon mainly contains the actual river centerline supplied to UTIMS. The actual river centerline briefly leaves the initial flood polygon near the bottom of the reach (towards right hand side), which was not expected, but can be explained for two reasons. The intervals at which the sloping plane analysis was done may have been too long to catch that portion of the centerline. A shorter distance for placing cross sections, and thus the sloping plane analysis interval may have caught that problem. The second reason is that UTIMS removes any points from the boundary of the initial flood polygon which goes back upstream when constructing the flood polygon, therefore a point which was placed on the terrain initially may have been removed due to this processing. Overall the initial flood polygon looks adequate and fits the land form well for Ferron Creek and the overbank areas.

Figure 5-2 shows the initial flood polygon with the flood polygon centerline developed. The flood polygon centerline follows the center of the polygon quite well and looks to be a good approximation of the flow path centerlines of the derived flood polygon. As the trial depths were a bit overestimated from the calculated normal depths the flood polygon is expected to be larger than the final flood polygon. Therefore the flow path centerline is expected to change with subsequent iterations, but as shown in Figure 5-2 the initial flood polygon centerline looks to be a good representation of the flow path centerline. As seen in Figure 5-2 the centerline follows the change in width of the polygon quite well and stays in the center of the polygon for the complete length of the flood polygon including in the more open floodplain areas

(in the middle) and in the more narrow neck of the flood polygon (near two thirds the way down the flood polygon).

Figure 5-3 shows the line of sight polyline on top of the derived flood polygon centerline. The line of sight polyline stored in the “Complete Flowpath Centerline” shapefile follows the same general path that the derived flood polygon centerline follows. This is due to choosing a meander correction value of 500 meters. This value seemed to be an appropriate value as overgeneralization did not take place, but the centerline was smoothed to remove small kinks. As seen in Figure 5-4 the line of sight polyline smoothed the kinks in the derived flood polygon centerline. Thus the line of sight polyline provides a much smoother flow path centerline for placing cross sections.

Figure 5-5 shows the placing of cross sections along the flow path centerline. The placement of critical station point cross sections is also shown. As can be seen in Figure 5-5 there is some change in the orientation of the cross sections, but they are all perpendicular to the flow path centerline. Some of the areas were not covered well with cross sections. This is due to the fact that there is a hierarchy of placing cross sections by UTIMS. The hierarchy goes in this order: end points > critical point stations > flow point stations > cross sections placed at intervals. Thus the placement of previous cross sections either based upon the hierarchy or cross sections downstream which overlap cross sections upstream may not be allowed to be stored. Thus a user must inspect the cross sections to see if they sufficiently represent the terrain being described by the cross sections. As was noted in Chapter 4 additional cross sections were added to sufficiently cover the terrain being represented by the

cross sections. The placement of cross sections occurred relatively fast and followed the rule of being oriented normal to the flow path centerline. Thus this is a very big improvement compared to the general technique of looking at contour lines and digitizing cross sections by hand. The sloping plane analysis along with the line of sight analysis approximates the required orientation of cross sections to be normal to the path of flow, thus the automated placement of cross sections was found to be extremely helpful. This feature is likely to be even more useful in case of modeling long reaches.

The placement of bank lines as shown in Figure 5-6 shows that bank lines follow the path of the actual river centerline. This is to help modelers know where the actual river centerline is located in the cross section viewer within HEC-RAS, it is to be noted that the flow path centerline may not lie between the bank lines. Therefore by keeping the bank lines around the actual river centerline modelers can make a good judgment on how to modify bank stations within HEC-RAS.

The development of overbank flow path lines as seen in Figure 5-6 shows how the left and right flow path lines move away from and come closer to the main channel flow path line in relation to the centroid of the overbank areas. As can be seen in Figure 5-6 the left and right flow path lines always lie in the overbank areas. When the cross sections get longer in much wider floodplain overbank areas the flow path lines move away from the flow path centerline when coming into the expanding areas, and return closer to the flow path centerline when the flow path approaches a bottle neck or meandrous areas. This appears to be a good approximation of the expected flow paths in the overbank areas. The main channel flow path line may lie in the

overbank areas because the flow path centerline is not restricted (and not expected) to lie in between the bank lines under extreme flow conditions. As can be seen in Figure 5-6 the main channel flow path line does indeed cross into the overbank areas.

The development of areal averaged n-value polygons is shown in Figure 5-7. As can be seen the constructed polygons truly follow the Euclidean allocation algorithm (also known as Thiessen polygon algorithm) which associates each pixel cell with its closest source cell (here specified as cross section segments). For the first iteration the minimum average n-value for the land use polygons was 0.034 and the highest n-value was 0.15. As seen in Figure 5-7 the more red areas indicate higher average n-values. The areas which are in the left overbank areas near the three most upstream cross section station points are most red, which is in relation to Ferron City being in the overbank areas. Thus the n-values appear to be reasonably derived spatially and by utilizing standard n-values and land use data.

After running HEC-RAS for the first iteration UTIMS created the first flood polygon from the HEC-RAS computations. Figure 5-8 shows the first iteration flood polygon with the initial flood polygon. It has been noted previously that the initial flood polygon is expected to be larger than the flood polygon from HEC-RAS because in the sloping plane analysis liberally higher trial depths were used. Thus as seen in Figure 5-8 the flood polygon derived from HEC-RAS is smaller than the initial flood polygon derived from the sloping plane analysis. The sloping plane analysis did a fairly good job in describing the main shape of the HEC-RAS flood polygon. Thus the sloping plane analysis provides modelers a reasonable first approximation of the general shape for the flow path centerline for a particular magnitude of flows.

Figure 5-9 shows the three flood polygons created from the three iterations of UTIMS. As can be seen the first iteration flood polygon is not much different in shape than the second and third iteration polygon. This indicates that the sloping plane analysis did a reasonable job in describing the flow specific flow path centerline and that the derived flow path centerlines from the HEC-RAS output flood polygons described the expected flow path centerline quite well. The true measure for convergence, though, is if the change in water surfaces does not vary by much from iteration to iteration. Figure 5-9 shows that there is not great change in flood polygon shape from iteration to iteration, indicating that UTIMS has done its job well in aiding a modeler in describing the flood polygon of an extreme flow from iteration to iteration.

Figures 5-10, 5-11 and 5-12 all show a close up view of the flood polygons (Figure 5-9) in the upper, middle and lower portions of the study area. As seen in Figure 5-10 the upper portion of Ferron Creek flood polygons do not vary by much, which is significant due to this being area where Ferron City is located. This shows that convergence is very likely because as can be seen the flood polygons do not change in shape much in the area of the upper three critical station points. The middle portion of the three flood polygons shown in Figure 5-11 shows minimal change in the flood polygon shapes. The greatest change was in the first portions of the flood polygons (on the left hand side of Figure 5-11), but this was not too significant. Near the fourth critical station point the three flood polygons do not change by very much and seem very near identical in shape in that portion of the flood polygons. The lower portions of the three polygons as shown in Figure 5-12 indicate some change in the

flood polygon shapes, but again there is not great change in the flood polygon shapes. This is significant because the process has quickly (from the initial flood polygon to the third iteration flood polygon) provided a user with a representative flood polygon for the dam breach being modeled.

As seen in Figure 5-13 the flow path centerlines change very little after the sloping plane analysis is completed. As shown, the actual river centerline shape is smoothed and moved slightly due to the modeling of an extreme flow case. Once the sloping plane analysis was completed the general shape of the flow path centerlines did not change much. This indicates that convergence was near because there was no great change in shape of the flow path centerline. The flow path centerlines determine the orientation of the cross sections and are also used in calculating the main channel flow path lengths. These influences can alter the general shape of the flood polygon, but as is seen in Figure 5-13 the general shape of the flow path centerlines did not change much from iteration to iteration, thus it was indicated that convergence was close.

Figure 5-14 shows the final flood polygon and flow path centerline, as defined by convergence being reached for all five points. The general shape of the flood polygon and flow path centerline did not change much from iteration to iteration.

The reasonableness of the UTIMS software was verified by comparing the UTIMS derived flood polygon and an independently computed flood polygon by the NRCS. The NRCS supplied along with the breach flow data a preliminary flood polygon for the breach of Millsite Dam. Figure 5-15 shows the overlay of the UTIMS derived flood polygon and the NRCS derived preliminary flood polygon. The general

shapes of the two polygons are very similar and basically mirror each other from the upstream to the downstream portions of the polygons. This is significant because with very little GIS work by the user UTIMS has aided in modeling a fairly long reach and allowed for the bulk of the time used in this study to be spent on hydraulic modeling. The differences in shape of the two polygons are likely due to differences in the modeling techniques and the input data utilized, as discussed below.

1. The first significant difference in developing the flood polygons is that the NRCS utilized different cross sections than the once generated by UTIMS. As was noted previously cross sections play major role in floodplain mapping. Therefore, because different cross sections were utilized the flood polygons are expected to be slightly different.

2. Another factor responsible for any differences in shape is due to manner in which flow path lines are created. UTIMS utilized a centroid approach to identify the center of mass of the overbank areas in placing flow path line vertices. The flow path lengths in the main channel, and left and right overbanks can be significantly different in the final flood polygon than in case of NRCS, thus by utilizing a different approach in developing flow path lines UTIMS' flood polygon may not exactly match the shape of the preliminary NRCS flood polygon.

3. Another factor which influenced the difference in flood polygon shape is the assigning of n-values. UTIMS calculates the areal average n-values for each segment of cross sections. For the third and final iteration UTIMS' n-values for the land use polygons had values ranging from 0.025 to 0.15. The NRCS study utilized a constant value of 0.05 for all the segments of the cross sections utilized. This difference is



significant due to there being an urbanized area in the overbank areas, with likely higher roughness than used in NRCS model. The n-values from upstream to downstream should be representative of the land use and is not reasonable to use a constant n-value throughout. Thus UTIMS has added the spatially difference of land use into the model. As seen in Figure 5-7 the n-values near Ferron City are much higher than in other portions of the overbank areas.

4. Yet another factor which influenced the difference in flood polygon shape is the downstream boundary conditions used. As noted previously in identifying the downstream friction slope used in calculating normal depth, described in chapter four, a friction slope of 0.005455 was used in the UTIMS iterative modeling process. The NRCS friction sloped utilized was 0.005. Thus there was a difference in the boundary condition, which would have definitely impacted the lower portions of the flood polygons shapes.

Table 5-1 shows the convergence path with respect to the actual change in water surface elevation from iteration to iteration. As shown in Table 5-1 the convergence process, for which tolerance was specified as 1.0 feet in this case study, took three iterations to complete. The units in Table 5-1 are in meters, thus convergence is achieved when the change in water surface is less than 0.3048 meter. As seen in the change in water surface elevation from the first to the second iteration for the first three critical point stations convergence was obtained. This helped in the decision to keep the cross sections from the second to the third iteration. When the cross sections were passed from the second to the third iteration care was taken to re-orient any cross section which was not perpendicular to the new flowpath centerline.

In the third iteration convergence was achieved for all five critical point stations and the maximum change in water surface elevation was found to be 0.25 meters, which is about 0.82 feet (i.e. less than the convergence tolerance specified in this study).

Table 5-2 shows the maximum velocity at the critical points of the UTIMS process along with the corresponding point velocities provided in the NRCS model. As can be seen the velocities are similar. As noted earlier the cross sections were not exactly same and the roughness values are different, therefore some differences are expected. The UTIMS approach is more physically based and hence expected to provide more reasonable results. The velocities along with flow depths are critical inputs into consequence (both economic as well as life loss) estimation for dam safety risk assessment studies which require that these should be as reasonable estimate as possible for the given flood magnitude being modeled.

Figure A-1 and A-2 compare the stage hydrographs obtained from the UTIMS and NRCS models for each critical location point. As can be seen in these figures the stages obtained from the two models at these critical location points are very similar. The peaks are almost identical but they are shifted in time with the UTIMS hydrograph peaks occurring about 10 to 30 minutes sooner. This difference is most likely due to the four factors discussed earlier in this section.

Figure A-3 compares the flow hydrographs at the critical location points obtained from the UTIMS and NRCS models. Again the flow magnitudes are very similar but the UTIMS hydrograph peaks occurring 10 to 15 minutes earlier than the NRCS hydrographs..

The first iteration of UTIMS to develop the geometries required by HEC-RAS to develop a flood polygon for Ferron Creek took 12 minutes to complete. In comparison to approximately 2.5 hours (for a person with high level of GIS experience) to develop the required geometries using HEC-GeoRAS. Therefore the use of UTIMS significantly reduced the time required to develop an inundation map. For a user having less familiarity with GIS, the time saving by using UTIMS can be even more significant, particularly if modeling a long river reach.

In conclusion, the general shape of the two flood polygons, developed by using UTIMS and obtained from the NRCS, is similar and the minor differences in shape could be due to the four factors discussed above. The stage and flow hydrographs shapes and peaks at the critical location points also compare well, only with UTIMS hydrographs peaking a few minutes earlier than the NRCS hydrographs. Thus UTIMS has enabled significant time savings on the GIS side of developing the inputs and thus allowing the user to better spend their time on the modeling aspect of developing a flood inundation map.

## CHAPTER 6

### CONCLUSION AND RECOMMENDATIONS

As described in Chapter 5 the output from UTIMS significantly aided the modeling of the dam break flood of Millsite Reservoir. This process was significantly aided by the sloping plane analysis, flood polygon centerline approximation by the closest point analysis, line of sight analysis, automated placement of cross sections, placement of bank lines, placement of flow path lines, areal averaged n-value land use polygon development and the deriving of new flow path centerlines based upon flood polygons imported from HEC-RAS computation.

The sloping plane analysis performed quite well in deriving a flow specific flow path centerline. This process was performed by making an initial assumption that the flood polygon follows a sloping plane down the river corridor. The initial flood polygon was shown to be similar in shape to the flood polygon derived by modeling the breach flow within HEC-RAS. The sloping plane analysis along with the closest point analysis delivered a flow path centerline which was indicative of the final flow path centerline for the extreme flow modeled.

The line of sight analysis created a smooth flow path centerline which was utilized in placing cross sections.

The automated placement of cross sections was performed seamlessly and took very little time and reasonably described the orientation of the flow path. The cross sections reasonably described the extent of overbanking flood waters by UTIMS

clipping the cross sections based upon trial upstream and downstream depths along a river centerline.

The development of bank and flow path lines significantly aided in the modeling process. By utilizing the actual river centerline to develop bank lines UTIMS aided users in knowing where the actual river centerline is located along a cross section profile. This was extremely useful in placing dummy levees and modifying bank station locations to accurately model the unsteady flow. The left and right overbank flow path lines were created by utilizing a computation which identified the centroid of the overbank areas. This significantly aided in the modeling process, by eliminating the need for the user to manually digitize these lines.

Areal averaged n-values were assigned by taking into account the changing land use types from one cross section to the next. This was performed by utilizing a standard land use type source of the NLCD layers and modeling standard n-values for the NLCD grid code values. Thus by automating the development of n-value land use polygons UTIMS significantly aided in the n-value development for land use polygons by accounting for the change in land use.

The flow path centerline in extreme flow cases is ultimately defined by the flood polygon from HEC-RAS, therefore the capability of UTIMs to derive the flood polygon centerline as an approximation of the flow path centerline proved extremely useful.

UTIMS has been demonstrated to be a very useful tool in hydraulic model development. With UTIMS a modeler can significantly reduce the time spent on developing the geometry files to be used by HEC-RAS, and thus utilize this time saved

on HEC-RAS unsteady flow modeling to get an accurate flood polygon. UTIMS adds significant capabilities to the arena of floodplain mapping automation. UTIMS is simple to use, yet provides powerful tools to aid modelers to converge upon a final flood polygon to effectively and accurately manage the flood-plain.

Recommendations for further capabilities to be included within UTIMS will yet increase the modeling aid capabilities which UTIMS already possesses. There are four main recommendations for further development of UTIMS capabilities.

The first is that several terrain data sources should be available to be utilized within UTIMS. Survey data is extremely useful for in-stream flow modeling, so to bolster the strengths of UTIMS for in-stream flow modeling the capability of UTIMS to handle several terrain data sources need to be added.

The second recommendation is also related to increasing capabilities relating to in-stream flow modeling. That is to include the option to specify channel shape such as trapezoidal, rectangle, etc., shapes with corresponding parameters for the channel shape. By utilizing a thalweg and a channel shape the in-stream flow modeling capabilities will be improved.

The third recommendation for UTIMS is in regard to if users wish to keep a selected group of cross sections from one iteration to the next and replace the other cross sections. This would be extremely useful in cases where ineffective flow areas could be retained along with bank station points and other cross section specific parameters for specific cross sections. This would further reduce the time required in inundation mapping as modelers would only need to alter bank station points as

needed, and add ineffective flow areas only for new cross sections from iteration to iteration.

The fourth and final recommendation for UTIMS development is to include a cross section viewer within the UTIMS interface. With a cross section viewer a user can visualize cross section profiles before they are passed to HEC-RAS, thus allowing a modeler to modify cross section orientation to accurately define the path of flow.

By adding these four functionalities UTIMS will further increase its usefulness to enhance the modeling capabilities of professional modelers by reducing their time on geometry file development, and thus allowing them to spend their time where it is needed most – in the modeling of flood waters to effectively manage the risk of flooding and the floodplain itself.

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APPENDIXES

APPENDIX A

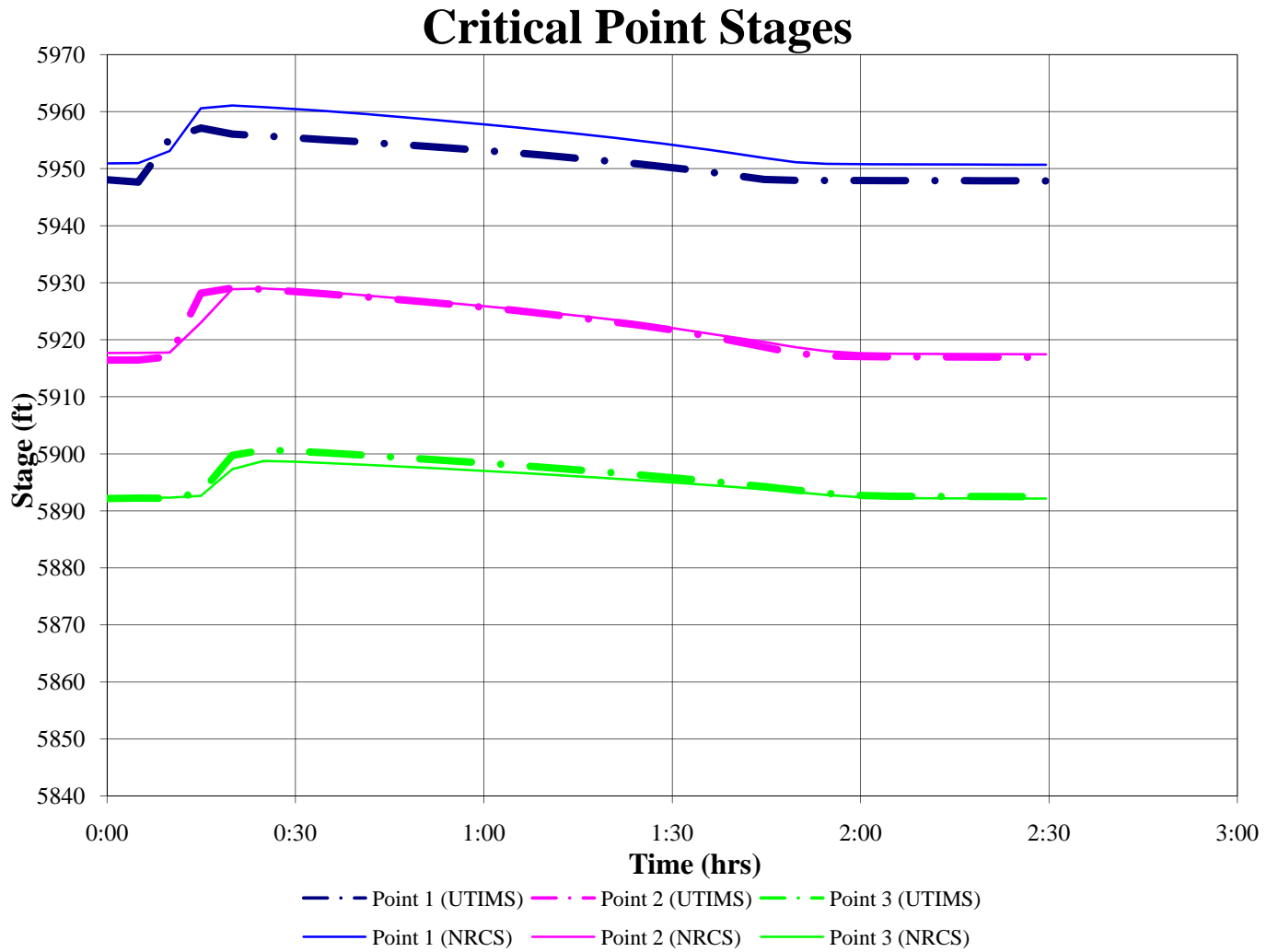


Figure A-1. Critical point stages for points 1-3.

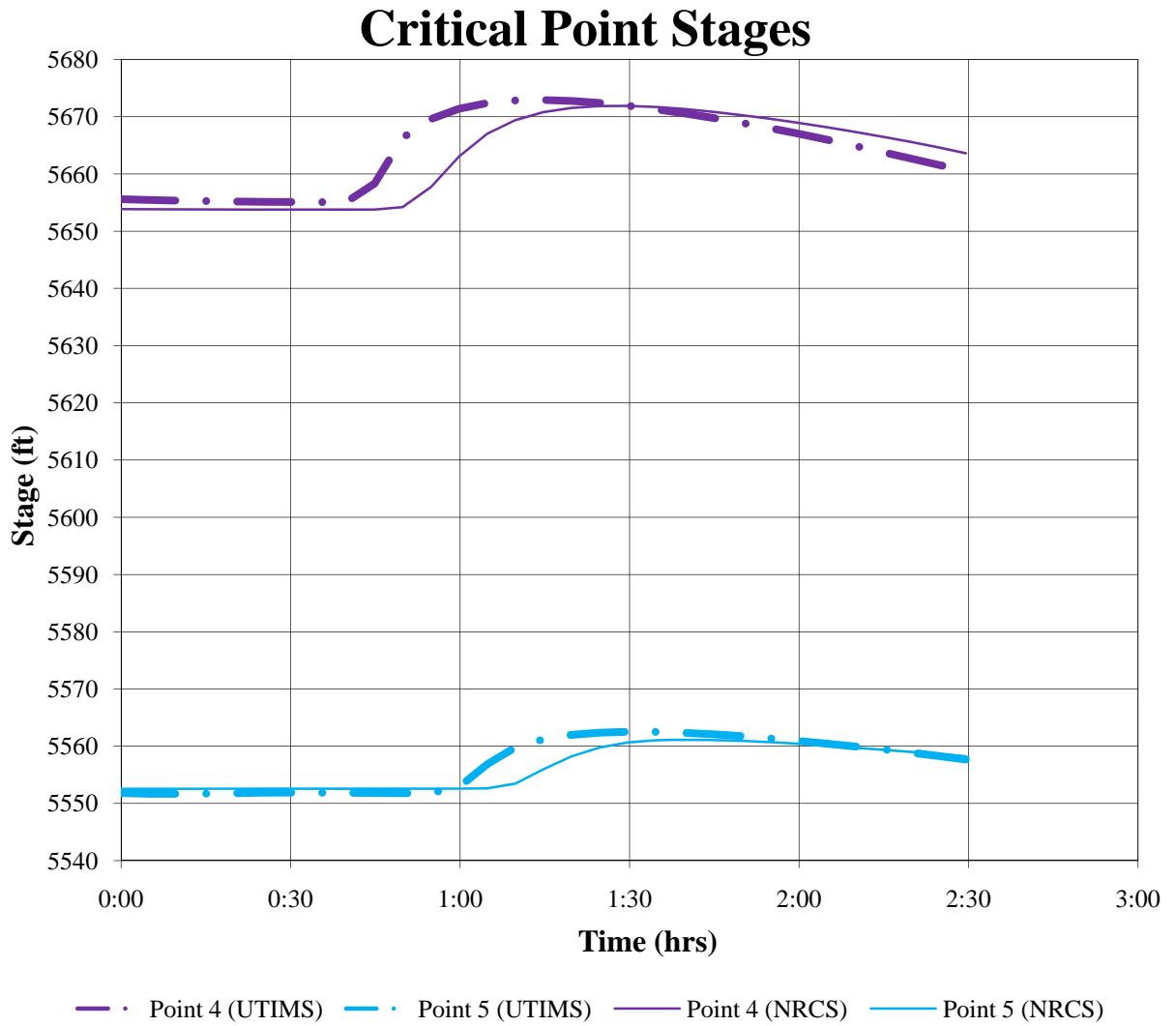


Figure A-2. Critical point stages for points 4-5.

### Critical Point Flows

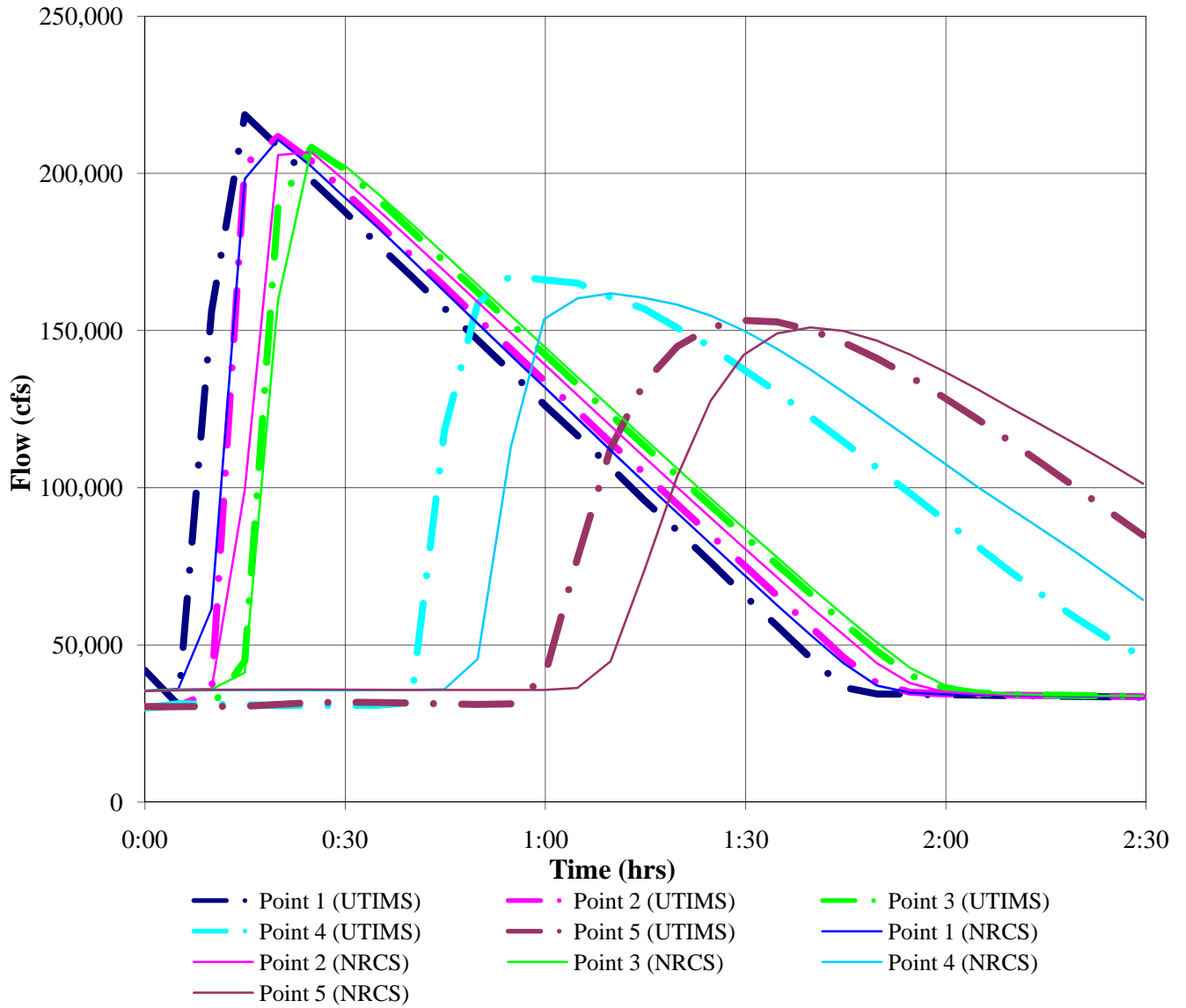


Figure A-3. Critical point flows for UTIMS and NRCS.

## GLOSSARY

## Areal Average n-Value Assignment

A process where UTIMS develops land use polygons which have average n-value of the land use contained within the polygons assigned to them.

## Closest Point Analysis

An analysis where a flood polygon flow path centerline is approximated by querying the left and right sides of a flood polygon to approximate the center line of the polygon.

## Convergence Criteria

A value which designates if convergence has been achieved by monitoring the change in water surface elevation from iteration to iteration.

## Extreme Flows

Magnitude of flows which exceed the capacity of well defined channels and flood into the overbank areas.

## Flood Polygon Segmentation Distance

A distance which is used in the flood polygon centerline approximation process. This distance is added to the station of the last closest point queried on the opposite side of the flood polygon which ensures that the flood polygon centerline determination continues in a downstream direction.

## Flow Path Centerline

Represents the center of flow path. Cross sections are placed perpendicular to the flow path centerline.

## In-Stream Flows

Magnitude of flows which are contained within well defined channels.

## Meander Correction Value

A value which UTIMS uses to designate that an extreme flow is expected and is also utilized as the maximum length of a flow path centerline which can be removed by the line of sight analysis.

Sloping Plane Analysis	An analysis where an initial flood polygon and flow path centerline is developed by utilizing terrain data, trial flow depths and the actual river centerline.
Line of Sight Analysis	An analysis where a flow path centerline is smoothed by removing sections of a polyline by checking for visibility down a flow path centerline

