RESEARCH REPORT 1738-4

GIS FOR FLOODPLAIN MAPPING IN DESIGN OF HIGHWAY DRAINAGE FACILITIES

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CENTER FOR TRANSPORTATION RESEARCH
BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

AUGUST 1998

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-99/1738-4		

4. Title and Subtitle	5. Report Date
GIS FOR FLOODPLAIN MAPPING IN DESIGN OF HIGHWAY DRAINAGE FACILITIES	August 1998
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
David Maidment, Eric Tate, and Francisco Olivera	1738-4
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Center for Transportation Research The University of Texas at Austin 3208 Red River, Suite 200 Austin, TX 78705-2650	11. Contract or Grant No. 0-1738
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Texas Department of Transportation Research and Technology Transfer Section/Construction Division P.O. Box 5080 Austin, TX 78763-5080	Research Report (9/97 – 8/98)
	14. Sponsoring Agency Code

15. Supplementary Notes

Project conducted in cooperation with the Federal Highway Administration.

16. Abstract

Since the 1960s, civil engineers have employed a variety of computer models for stream floodplain analysis. HEC-2 and its Windows counterpart, HEC-RAS, have been the principal models used for such analyses. A significant deficiency of these programs is that the location of structures impacted by floodwaters, such as roads, homes, and businesses, cannot be effectively compared to the floodplain location. This report presents straightforward approaches to processing HEC-RAS output to enable two- and three-dimensional floodplain mapping in a geographic information system (GIS). The methodology was applied to a segment of Waller Creek in Austin, Texas. The HEC-RAS stream geometry and flood elevation data were imported into ArcView GIS, in which the cross sections were mapped along a digital representation of the stream. A planimetric view of the floodplain was developed using a digital orthophotograph as a base map. An approach to three-dimensional floodplain visualization through the integration of HEC-RAS stream cross-section data into a digital terrain model of the study area is under development. The results indicate that GIS is an effective environment for floodplain visualization and analysis.

17. Key Words	18. Distribution Statement
Hydraulic modeling, HEC-RAS, Geographic Information Systems, GIS, floodplain mapping	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	36	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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by

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Research Report Number 1738-4

Research Project 0-1738
System of GIS-Based Hydrologic and Hydraulic Applications for Highway Engineering

Conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the

U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

August 1998

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ACKNOWLEDGMENTS

The authors acknowledge the support of TxDOT Project Director Anthony Schneider (DES) and former Project Director Peter Smith. Also appreciated is the assistance provided by T. D. Ellis (PAR).

Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

TABLE OF CONTENTS

CHAPTER 1. BACKGROUND 1
OPEN CHANNEL FLOW THEORY 1
Flow Classification 1
Flow and Conveyance 2
Energy Equation 4
HEC-RAS 5
HEC-RAS Parameters 6
Water Surface Profile Computation 7
GEOGRAPHIC INFORMATION SYSTEMS 8
PREVIOUS WORK 10

CHAPTER 2. METHODOLOGY 13
DATA IMPORT FROM HEC-RAS 13
STREAM CENTERLINE DIGITAL REPRESENTATION 16
CROSS-SECTION GEOREFERENCING 17

CHAPTER 3. PRELIMINARY RESULTS 21

REFERENCES 23

INTRODUCTION

Much of the cost of most highway projects is attributable to drainage facilities, including storm drains, highway culverts, bridges, and water quality and quantity control structures. Design of these facilities involves hydrologic analysis to determine the design discharge and hydraulic analysis of the conveyance capacity of the facility. In this report, a geographic information systems (GIS) approach for floodplain mapping to aid in the design of drainage facilities is presented. The methodology was developed to reduce the analysis time and to improve its accuracy by integrating spatial stream geometry with hydraulic analysis. The Texas Department of Transportation (TxDOT) has existing procedures for hydrologic and hydraulic analysis in the Texas Hydraulic System (THYSYS). Each THYSYS application requires the computerization of the description of the watershed and the stream channel using data extracted manually from maps and cross sections contained in paper drawings. In developing a GIS approach for floodplain mapping, the extraction of data and application of design procedures becomes more efficient.

In a relatively short time, GIS has gained widespread use in a variety of engineering applications. Originally envisioned (and used) as a geographic mapper with integrated spatial database, GIS is increasingly being used in modeling applications, where geographic data can be readily accessed, processed, and displayed. Historically, GIS has been implemented primarily by large entities, such as federal, state, and local government agencies, predominantly for mapping and management of spatial data. However, there is increasing interest in the potential application of GIS in engineering design and analysis, especially in hydrology and hydraulics.

The principal objective of the hydraulic model research is to develop a procedure that can take a set of computed water surface profiles and construct an associated GIS floodplain map. The work consists of geographically referencing hydraulic modeling output and forming an integrated terrain model combining data on the general landscape with data for stream channel morphology. These tasks are described in detail in the following chapters.

CHAPTER 1. BACKGROUND

This chapter introduces concepts and associated terminology that formed the backbone of the work completed for this project. The discussion includes open channel flow theory, the HEC-RAS hydraulic model, and GIS.

OPEN CHANNEL FLOW THEORY

Open channel flow is defined as the flow of a free surface fluid within a defined channel. Typical examples include flow in natural streams, flow in constructed drainage canals, and flow in storm sewers. The development of plans to effectively manage floodplains requires that hydraulic engineers understand the hydraulics of open channel flow, which depend on the flow classification, flow and conveyance, and the energy equation.

Flow Classification

Open channel flow is classified based on changes in time, space, and flow regime:

- **Time**. *Steady flow* describes conditions under which depth and velocity at a specific channel location do not change with time. In contrast, *unsteady flow* refers to flow conditions that change with time at a given location.

- **Space**. The term *uniform flow* denotes fluid flow, in which depth and velocity are constant with distance. Uniform flow conditions require the channel to be straight, with constant cross-sectional geometry, and a water surface that is parallel to the base of the channel. In *varied flow*, water depth and velocity change with distance along the channel.

- **Flow regime**. The dimensionless Froude number is used to classify flow type:

$$Fr = \frac{V}{\sqrt{gy}} \tag{1.1}$$

where: Fr = Froude number
V = mean fluid velocity (m/s)
g = gravitational acceleration (m/s^2)
y = water depth (m)

Subcritical flow (Fr < 1) refers to laminar flow, in which fluid particles move along smooth paths in layers, with one layer gliding smoothly over an adjacent layer (Ref 1). *Supercritical flow* (Fr > 1) is a description of turbulent flow in which small flow fluctuations occur over time for a given point. *Critical flow, critical depth, and critical velocity* are defined at the point where the Froude number equals 1.

In order to determine water surface profiles at different cross sections in a channel, the flow characteristics must be known or assumed. For river hydraulic analysis, a steady, gradually varied flow assumption is often used for both subcritical and supercritical flow regimes. Steady, gradually varied flow applies to flow in which changes in depth and velocity occur gradually over a considerable length of channel (Ref 2).

Flow and Conveyance

The continuity equation for steady flow relates flow to velocity and area. The equation states that flow must be conserved between adjacent cross sections:

$$Q = V_1A_1 = V_2A_2 \tag{1.2}$$

where: Q = flow rate/discharge (m^3/s)

V_n = average velocity at cross-section n (m/s)

A_n = area at cross-section n (m^2)

For open channel flow, the momentum equation is expressed in the form of the Manning equation:

$$Q = K\sqrt{\overline{S_f}} \tag{1.3}$$

$$K = \frac{1}{n} A R^{2/3} \tag{1.4}$$

where: K = conveyance ($m^{5/3}$)

S_f = average friction slope

n = Manning roughness coefficient

R = hydraulic radius (m)

The Manning coefficient is a parameter that measures the effect of the roughness of the channel on the flow of water through it. The values, which vary based on channel terrain, are published in most hydraulic engineering books. The hydraulic radius is calculated by dividing the cross-sectional area by the wetted perimeter.

For prismatic river channels, flow rate is typically known based on either field measurements or stream-specific rating curves. Conveyance for these channels is usually determined using area-hydraulic radius curves. With the flow and conveyance known, the average friction slope between two adjacent cross-sections can be calculated:

$$\overline{S_f} = \left(\frac{Q_1 + Q_2}{K_1 + K_2} \right)^2 \tag{1.5}$$

When the Manning equation is applied to uniform flow, the average friction slope is replaced by channel slope (S_o).

Energy Equation

For open channel flow, the total energy per unit weight (energy head) has components of elevation head, pressure head, and velocity head (Figure 1.1):

$$H = y + z + \frac{\alpha V^2}{2g} \tag{1.6}$$

where: H = energy head (m)

z = base channel elevation (m)

α = velocity weighting coefficient

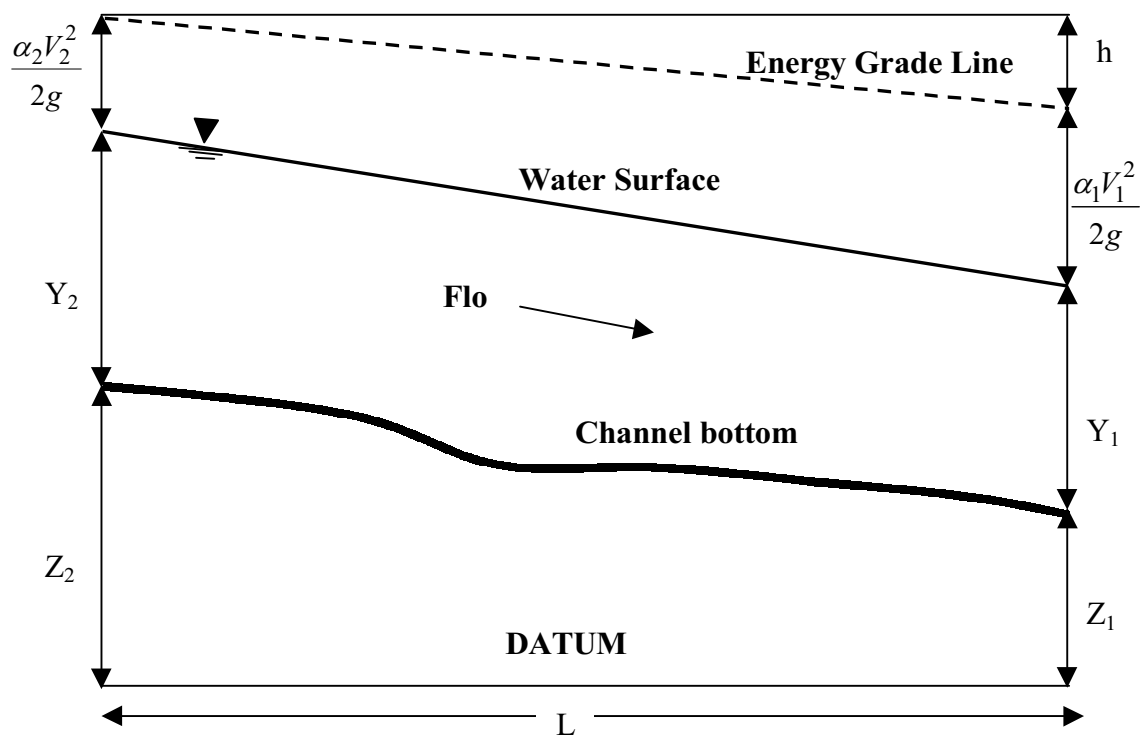


Figure 1.1 Energy equation parameters for gradually varied flow

Based on these parameters, the water surface elevation is the sum of y and z.

The change in energy head between adjacent cross sections is equal to the head loss:

$$H_1 = H_2 + h_L \tag{1.7}$$

where: H_1 = energy head at cross section 1 (m)

H_2 = energy head at cross section 2 (m)

h_L = energy head loss (m)

The head loss between the two cross sections is the sum of friction head loss and flow contraction/expansion head loss. Friction losses result from shear stress between the water and channel bottom:

$$h_f = L\overline{S_f} \tag{1.8}$$

where: h_f = friction head loss (m)

L = distance between adjacent cross sections (m)

Contraction/expansion head losses can occur as a result of the formation of eddies wherever there is a contraction or expansion of the channel (Ref 2):

$$h_o = C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right| \tag{1.9}$$

where: h_o = contraction or expansion head loss (m)

C = contraction or expansion coefficient

HEC-RAS

HEC-RAS is a hydraulic model developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers. In 1964, HEC released the HEC-2 computer model to assist hydraulic engineers in stream channel analysis and floodplain determination. HEC-2 quickly became the standard stream hydraulic analysis program; its

capabilities were expanded in the ensuing years to provide for, among other things, bridge, weir, and culvert analysis. Although HEC-2 was originally developed for mainframe use, it can currently operate on personal computers (in DOS mode) and on workstations (Ref 3). In response to the increased use of Windows-based personal computing software, HEC released in the early 1990s a Windows-compatible counterpart to HEC-2 called the *River Analysis System* (RAS). HEC-RAS is intended for one-dimensional steady flow water surface profile computations, unsteady flow simulation, and movable boundary sediment transport calculations. The system is capable of modeling subcritical, supercritical, and mixed-flow regimes for streams consisting of a full network of channels, a dendritic system, or a single river reach. The model results are typically applied in floodplain management and flood insurance studies to evaluate floodway encroachments (Ref 4).

HEC-RAS Parameters

HEC-RAS uses a number of input parameters for hydraulic analysis of the stream channel geometry and water flow. These parameters are used to establish a series of cross sections along the stream. Each cross section is divided into segments of left floodway, main channel, and right floodway, as illustrated in Figure 1.2.

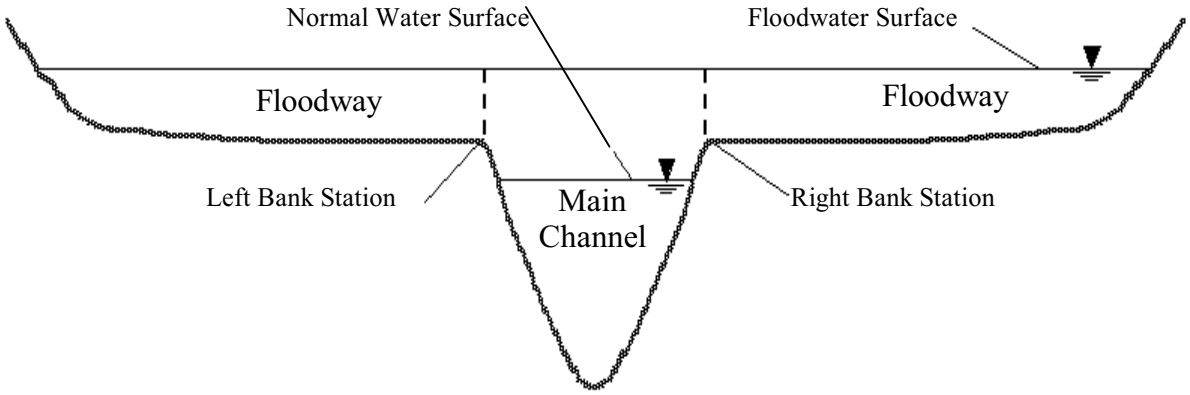


Figure 1.2 Typical HEC-RAS stream cross section

At each cross section, several geometry parameters are required to describe shape, elevation, and relative location along the stream:

- River station (cross section) number
- Lateral and elevation coordinates for each (dry, unflooded) terrain point
- Left and right bank station locations
- Reach lengths between the left floodway, main channel, and right floodway of adjacent river stations (The three-reach lengths represent the average flow path through each segment of the cross section pair. As such, the reach lengths between adjacent cross sections may differ owing to bends in the stream.)
- Manning's roughness coefficients
- Contraction and expansion coefficients
- Geometric description of any hydraulic structures (bridges, culverts, weirs, etc.)

At each cross-section line, HEC-RAS assumes that energy is constant and that the velocity vector is perpendicular. As such, care should be taken to ensure that the flow through each selected cross section meets these criteria. After defining the stream geometry, flow values for each reach within the river system are entered. The channel geometric description and flow rate values are the primary model inputs for the hydraulic computations.

Water Surface Profile Computation

For steady, gradually varied flow, the primary procedure for computing water surface profiles between cross sections is called the *standard step method* (HEC-RAS also supports the momentum, WSPRO bridge, and Yarnell methods). The basic computational procedure is based on the iterative solution of the energy equation. Given the flow and water surface elevation at one cross section, the goal of the standard step method is to compute the water surface elevation at the adjacent upstream or downstream cross section,

depending on the flow regime. The procedure is summarized below. (The numbers in parentheses represent equations previously given in this chapter.)

(a) Assume a water surface elevation at the upstream cross section (or downstream cross section if flow is supercritical).
(b) Determine the area, hydraulic radius, and velocity (1.2) based on the cross-section profile.
(c) Compute the associated conveyance (1.4) and velocity head values (1.6).
(d) Calculate friction slope (1.5), friction loss (1.8), and contraction/expansion loss (1.9).
(e) Solve the energy equation (1.6) for the water surface elevation at the upstream cross section.
(f) Compare the computed water surface elevation with the one assumed in step (a).
(g) Repeat steps (a) through (f) until the assumed and computed water surface elevations are within a predetermined tolerance.

GEOGRAPHIC INFORMATION SYSTEMS (GIS)

GIS is defined as "computer systems capable of assembling, storing, manipulating, and displaying geographically referenced information" (Ref 5). Originally developed as a tool for cartographers, GIS has increasingly been used in engineering design and analysis, especially in the fields of water quality, hydrology, and hydraulics. GIS provides a setting on which to overlay data layers and perform spatial queries, thus creating new data. The results can be digitally mapped and tabulated, facilitating efficient analysis and decision making. Structurally, GIS consists of a computer environment that joins graphical elements (points, lines, polygons) with associated tabular attribute descriptions. This characteristic sets GIS apart from both computer-aided design software (geographic representation) and databases (tabular descriptive data). For example, in a GIS view of a group of rivers, the graphical elements would represent the location and shape of the rivers, whereas the attributes might describe the stream name, length, and flow rate. This one-to-one

relationship between each feature and its associated attributes makes the GIS environment unique. In order to provide a conceptual framework, it is necessary to first define some basic GIS constructs.

Geographic elements in a GIS are typically described by one of three data models: vector, raster, or triangular irregular network. Vector objects include three basic elements: points, lines, and polygons. A point is defined by a single set of Cartesian coordinates *(x, y)*. A line is defined by a string of points in which the beginning and end points are called nodes and intermediate points are called vertices (Ref 6). A straight line consists of two nodes and no vertices, whereas a curved line consists of two nodes and a varying number of vertices. Three or more lines that intersect to form an enclosed area define a polygon. Vector feature representation is typically used for linear feature modeling (roads, lakes, etc.), cartographic base maps, and time-varying process modeling.

The raster data structure consists of a rectangular mesh of points joined with lines, creating a grid of uniformly sized square cells (as shown in Figure 1.3). Each cell is assigned a numerical value that defines the condition of any desired spatially varied quantity (Ref 6). Grids are the basis of analysis in raster GIS and are typically used for steady-state spatial modeling and two-dimensional surface representation. A land surface representation in the raster domain is called a digital elevation model (DEM).

78	**72**	**69**	**71**	**58**	**49**
74	**67**	**56**	**49**	**46**	**50**
69	**53**	**44**	**37**	**38**	**48**
64	**58**	**55**	**22**	**31**	**24**
68	**61**	**47**	**21**	**16**	**19**
74	**53**	**34**	**12**	**11**	**12**

Figure 1.3 Raster data structure

A triangular irregular network (TIN) is a triangulated mesh constructed on the *(x, y)* locations of a set of data points (as shown in Figure 1.4). To form the TIN, a perimeter around the data points — called the *convex hull* — is first established. To connect the interior points, triangles are created with all internal angles as nearly equiangular as possible. This procedure is called *Delaunay triangulation.* By including the dimension of height *(z)* for each triangle vertex, the triangles can be raised and tilted to form a plane. The collection of all such triangular planes forms a considerably detailed representation of the land surface terrain.

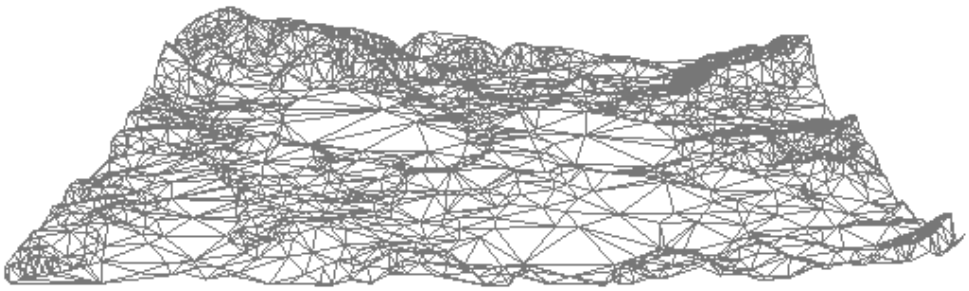


Figure 1.4 Triangular irregular network surface representation

Additional elevation data, such as spot elevations at summits and depressions and break lines, can also be included in the TIN model. Break lines represent significant terrain features like a lake or cliff that cause a change in slope; TIN triangles do not cross break lines. TINs are often used for three-dimensional surface representation and modeling because the TIN model requires a much smaller number of points than does a grid in order to represent the surface terrain with equal accuracy.

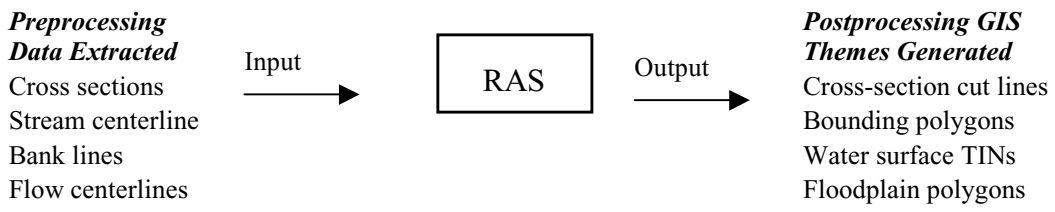
PREVIOUS WORK

Given that the use of GIS for hydraulic modeling is in its early stages, the engineering community has had only limited exposure to the field. Mark Beavers and Dean Djokic performed some of the first work connecting hydraulic modeling and GIS at The University of Texas (Ref 3). They were the principal developers of ARC/HEC2, a GIS-

based tool designed to assist hydrologists in floodplain analysis. ARC/HEC2 is a set of Arc/Info Macro Language scripts (AMLs) and C programs, which work to extract terrain information from contour coverages, insert user-supplied information (such as roughness coefficients, or location of left and right overbanks), and format the information into HEC-2 readable data. Following HEC-2 execution, ARC/HEC2 is capable of retrieving the HEC-2 output (in the form of water elevations at each cross section) and creating an Arc/Info coverage of the floodplain. This process allows the resulting floodplain to be stored in a coverage format that can be readily accessed by users who wish to use the floodplain information in conjunction with other Arc/Info coverages. ARC/HEC2 requires that a terrain surface be generated so that accurate cross-section profiles are provided to HEC-2. These terrain surfaces, in the format of TINs or grids, are created within Arc/Info based on contour lines, survey data, or other means of establishing terrain relief. The accuracy of the surface representation is crucial for accurate floodplain calculations.

In the years following the release of ARC/HEC2, many hydrologists began to switch from HEC-2 to the Windows-based HEC-RAS hydraulic model. RAS differed from the HEC-2 model in that it supported import and export of GIS data. Version 2 of HEC-RAS gives the user the option to import and utilize three-dimensional river reach and cross-sectional data from a general-purpose data exchange file.

In 1997, Tom Evans of HEC released a series of AMLs that serve both as a pre- and postprocessor for HEC-RAS. The preprocessing AMLs create a data exchange file consisting of stream geometry description extracted from a triangular irregular network (TIN) model of the land surface. In HEC-RAS, the user is required to provide such additional data as Manning's *n,* contraction and expansion coefficients, any hydraulic structures (e.g., bridges, culverts), and bank stations and reach lengths (if they are not included in the exchange file). After running the model, RAS can export the output file into the digital-exchange file format. A TIN of the water surface can be created from the exchange file using the postprocessing macros:



In function, Evans' work was quite similar to the work completed by Beavers, albeit more sophisticated. Execution of the AML code produces a set of utilities that allows preparation of GIS data for HEC-RAS input and formatting of model output for GIS display.

The migration to the Windows environment became nearly complete by early 1998 with ESRI's limited release of the ArcView extension AVRAS. AVRAS was created by translating Evans' AML code into Avenue (ArcView's scripting language). AVRAS is scheduled for full release as a commercial product in November 1998, under the trade name *Stream Analyst.*

The three approaches described above are all rather sophisticated methods for GIS-based pre- and postprocessing for hydraulic modeling. Unfortunately, each of the techniques requires the user to provide a number of stream parameters in HEC-RAS. More importantly, a TIN model of the landscape is required as input. However, many practicing engineers already have established HEC-2 and HEC-RAS models for floodplain analysis. The methods described above are not as effective if the hydrologist has no TIN surface model and wishes only postprocess (map the floodplain) the hydraulic model results. The research presented in this report offers an alternative approach to GIS floodplain mapping in such a scenario.

CHAPTER 2. METHODOLOGY

The methodology detailed in this section describes approaches to processing HEC-RAS output to enable two- and three-dimensional floodplain mapping and visualization in ArcView GIS. The approaches are based on the assumption that the RAS cross sections are not geographically referenced. The methodology was applied to a segment of Waller Creek in Austin, Texas. The HEC-RAS stream cross section and flood elevation data were imported into ArcView, in which the cross sections and floodplain were mapped along a digital representation of the stream. A planimetric view of the floodplain was developed using a digital orthophotograph as a base map. An approach for three-dimensional floodplain visualization is currently under development.

The methodology for planimetric floodplain visualization consists of three primary steps:

- Data import from HEC-RAS,
- Stream centerline digital representation, and
- Cross-section georeferencing and floodplain polygon generation.

These steps are discussed in detail in the following subsections.

DATA IMPORT FROM HEC-RAS

In order to move into the GIS environment, the output data from HEC-RAS must be extracted. The first step toward this end is the creation of an output report using an HEC-RAS menu option. The report is a text file containing input data regarding cross-sectional geometry and flow descriptions, and output data describing water surface profiles. A computer program written in ArcView's scripting language, Avenue, was developed for this project to read the RAS output text file and write key stream parameters to ArcView. The parameters vary between cross sections and include the following:

- Station number
- Location of the minimum channel elevation
- Bank station locations
- Water surface elevation
- Terrain-water surface interface locations

Figure 2.1 presents a graphic of a typical HEC-RAS cross section in which these parameters can be seen. For each cross section, the location (x and z) of all points are read and stored. The locations of the floodplain boundaries and minimum channel elevation are subsequently calculated. If there are multiple points possessing the same minimum channel elevation, the location of the channel center is calculated by averaging the x-coordinates of points with the minimum elevation. The remaining parameters imported into ArcView are the locations of the bank stations, the river station number, any text description of the cross section, and the flood elevation.

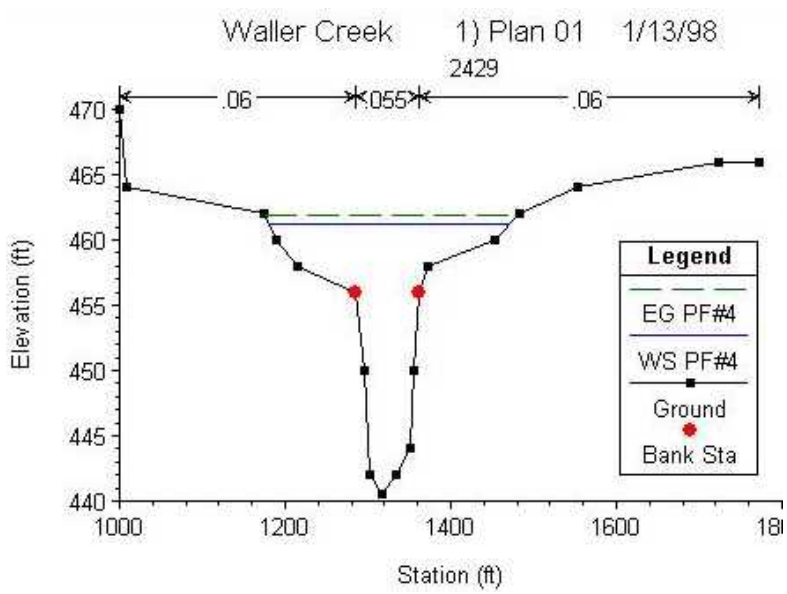


Figure 2.1 Typical HEC-RAS cross section

After the stream information is read from the output text file, it is subsequently written to a table readable by ArcView. Figure 2.2 shows an example of the stream geometry table in ArcView. The columns titled "Station No." and "Flood Elevation" are self-explanatory. The "Location" field contains short descriptions of the cross section location that were input in the original RAS geometry file for certain cross sections. The "Channel Y" column includes the reach lengths between cross sections along the stream, as measured from the upstream end. The remaining columns contain data describing the left and right widths of the floodplain and bank stations, as measured from the center of the stream.

RAS Geometry

Station No.	Location	L Flood X	L Bank X	Channel Y	R Bank X	R Flood X	Flood Elevation
32093		46.1	26.5	0.0	11.9	34.9	680.7
31961		26.3	28.3	132.0	18.0	223.9	678.7
31806		14.8	16.2	287.0	34.1	236.9	677.2
31576		30.8	32.5	517.0	20.0	228.1	675.6
31485		30.8	36.0	608.0	11.0	114.0	674.0
31249		19.4	20.0	844.0	24.0	22.2	671.4
31166		97.6	12.8	927.0	25.3	77.5	671.4
31136	Denson Drive on Waller Creek		12.8	986.0	25.3		
31107		12.4	12.8		25.3	24.9	669.7
31057		21.6	27.0	1036.0	19.0	480.9	670.3
30812		21.5	27.0	1281.0	19.0	19.0	668.7
30442		7.8	8.0	1651.0	33.0	259.8	665.8
30157		84.2	18.0	1936.0	24.0	31.1	662.7
29987		161.2	23.0	2106.0	21.0	234.7	662.4
29962		180.4	23.0	2131.0	21.0	252.0	662.4
29955	Skyview Footbridge on Waller Creek		23.0	2145.0	21.0		
29948		151.7	23.0		21.0	231.9	662.0
29717		196.8	25.0	2376.0	15.0	171.1	660.6
29307		259.8	26.0	2786.0	13.0	29.0	656.9
28912		197.1	24.0	3181.0	17.0	44.0	653.8
28847		267.6	25.0	3246.0	25.3	179.1	653.9
28811		277.4	25.0	3282.0	25.3	196.9	653.9
28779	2222/Koenig Lane on Waller Creek		25.0	3346.0	25.3		
28747		254.6	25.0		25.3	173.6	653.6

Figure 2.2 ArcView stream geometry table

Because the table is saved in database format (dbf), it could be opened in Excel and Access in addition to ArcView. However, all that has been done in this step is to transform HEC-RAS output into a format readable by ArcView. The cross sections still must be geographically referenced.

STREAM CENTERLINE DIGITAL REPRESENTATION

The next step was to link the RAS stream to the same stream in digital form. There are two primary ways to obtain a digital representation of a stream:

1. *Reach Files.* Reach files are a series of national hydrologic databases maintained by the U.S. Environmental Protection Agency (EPA) that uniquely identify and interconnect the stream segments or "reaches" that comprise the country's surface water drainage system. The databases include such information as unique reach codes for each stream segment, upstream/downstream relationships, and stream names. The latest release, reach file 3 (RF3), consists of attributed 1:100,000-scale digital line graph hydrography. The data are available from EPA's BASINS Website at http://www.epa.gov/OST/BASINS/gisdata.html.

2. *Digitize the Stream.* Using either digital orthophotographs or digital raster graphics as a base map, the stream can be digitized using tools in ArcView. Digital raster graphics are digitized topographic maps. Geographically referenced digital raster graphics and orthophotos for the state of Texas can be obtained from the Texas Natural Resources Information System (TNRIS) Website at http://www.tnris.state.tx.us/gispage.html.

Both digital data sources were evaluated for this project. In the end, digital orthophotos were found to provide a representation of the Waller Creek study area superior to that provided by RF3. As such, 1-meter resolution orthophotography for the Austin East 7.5-minute quadrangle was obtained from TNRIS. In ArcView, the image was used as a base map to digitize Waller Creek.

CROSS-SECTION GEOREFERENCING

The first step toward georeferencing the cross sections is to compare the definitions of the RAS stream and its digital counterpart. It's entirely possible, for example, that the digital stream is defined to a point farther upstream than the RAS stream, or vice versa. Hence, it's necessary to delineate the upstream and downstream boundaries of the RAS stream on the digital stream. To this end, an Avenue script was developed, with which the upstream and downstream boundaries can be established with a click of the mouse. Intermediate stream definition points corresponding to important RAS cross sections, such as bridges or culverts, can also be defined. When a point is clicked, the script determines the nearest point along the stream centerline and snaps the point to the digital stream. Often, the boundary points are more easily pinpointed by comparison to the location of existing structures (e.g., roads, buildings, etc). As such, a base map theme of roads was used in addition to the digital orthophoto to assist in the point-selection process (see Figure 2.3, page 19). As the number of defined points increases, so does the accuracy of the resulting floodplain.

Once the stream definition points were established, the next step was to add the cross sections between them. To do this, two attributes must be known for each cross section: location along the stream and orientation. An Avenue script was developed to aid in the determination of these attributes. Cross section location was determined using the boundary points; a one-to-one relationship was established between each boundary point and a particular cross section in the table resulting from data HEC-RAS data import (Figure 2.2). Between adjacent boundary points, the ratio of the length of the RAS modeled stream to that of the digital stream is important. If the RAS reach lengths are correct and the boundary points were accurately placed, then the ratio should be nearly 1. If the RAS stream length exceeds the digital stream length, the reach lengths between cross sections will need to be compressed by the ratio. However, if the RAS stream length is less than the

digital stream length, the reach lengths between cross sections should be expanded by the same ratio. In this manner, the proportionality of RAS reach lengths is preserved.

At this point, the cross section locations are known, but not their orientation. To determine this, an assumption was made that the cross sections occur in straight lines perpendicular to the stream flow. This assumption was used because geographically referenced cross-section data are typically not available. This is a key concept of this approach. If the cross sections are "doglegged" instead of perpendicular and straight, this approach will overestimate the floodplain width. An alternative to the assumption of perpendicular and straight-line cross sections might be to digitize the cross sections and attribute them with descriptive data. These data could include such information as stationing numbering and bank station and center points identification so that the cross sections correspond to the RAS geometry data.

The slope of the stream is determined using points located at a user-defined distance upstream and downstream of the cross section. If the resulting cross sections intersect near bends in the stream, the script can be re-run using a higher distance value. As the distance value increases, so does the departure from a true perpendicular cross section. The slope of the cross-section line is determined by calculating the negative inverse of the stream slope. With the cross section locations and orientations now known, a line representing the floodplain at each cross section can be formed. By connecting the ends of each cross section, a polygon representing the floodplain extent is mapped (Figure 2.4).

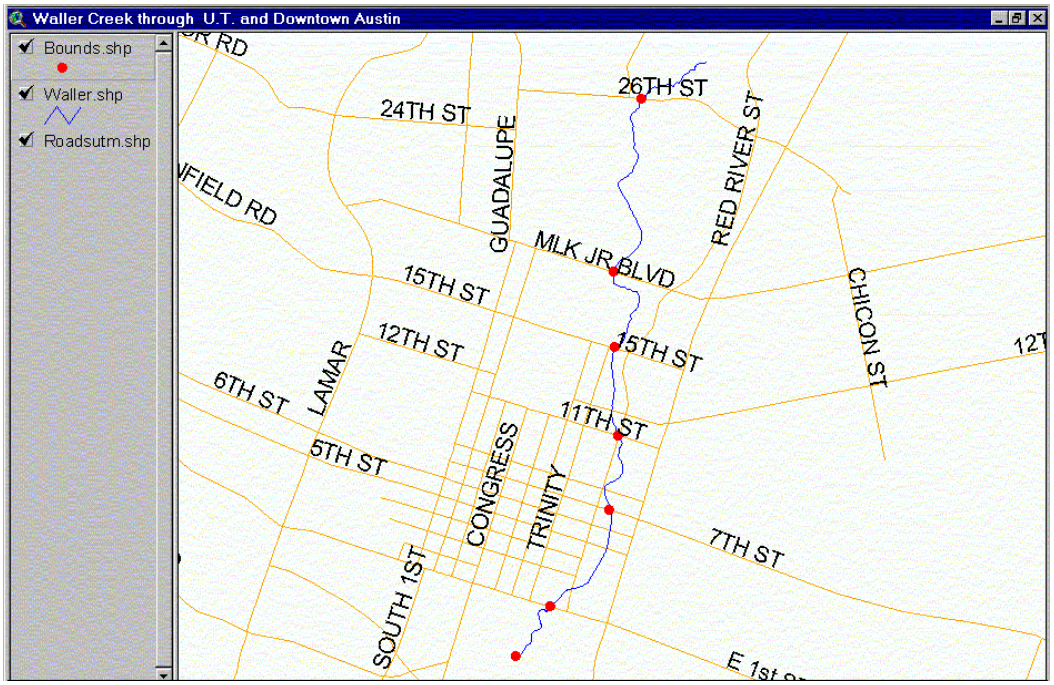


Figure 2.3 Stream boundary and intermediate point definition

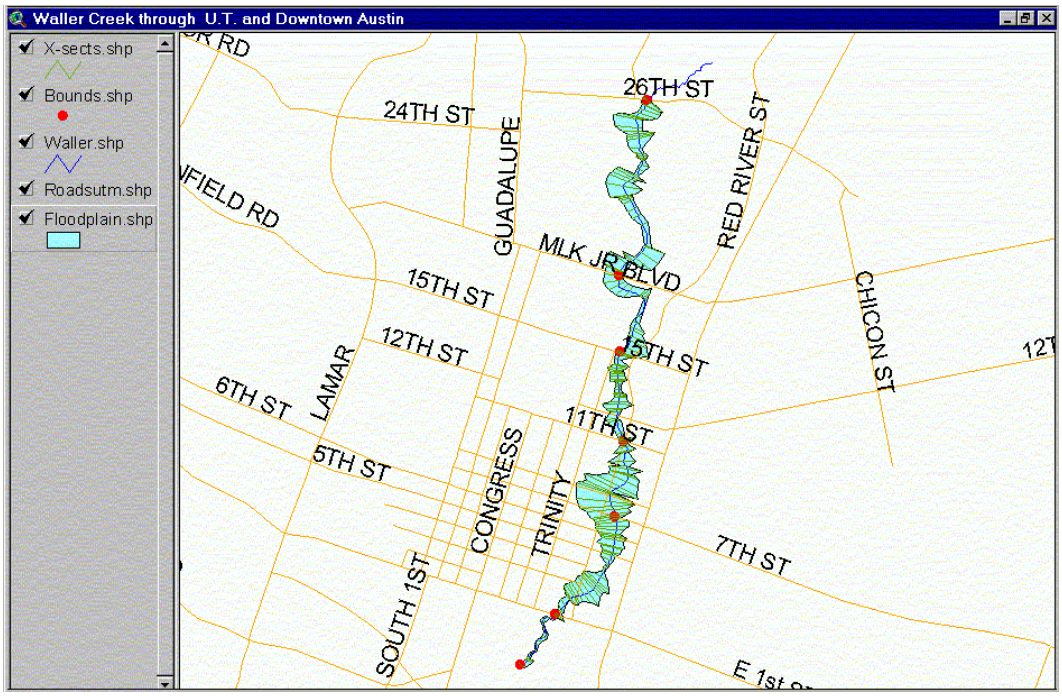


Figure 2.4 Geographically referenced cross sections and floodplain

CHAPTER 3. PRELIMINARY RESULTS

Figure 3.1 offers a view of what can result by following the methodology described in this report. The approach for floodplain mapping in ArcView generates a perspective of the floodplain far superior to that generated by the limited visualization tools offered in HEC-RAS. Using a digital orthophotograph as a base map allows the surrounding landscape to be viewed as it actually appears. With the zoom tools incorporated in ArcView, the user can easily compare the location of the floodplain to that of structures of interest, such as roads and buildings. By clicking on the nearest cross section, the flood elevation can be determined.

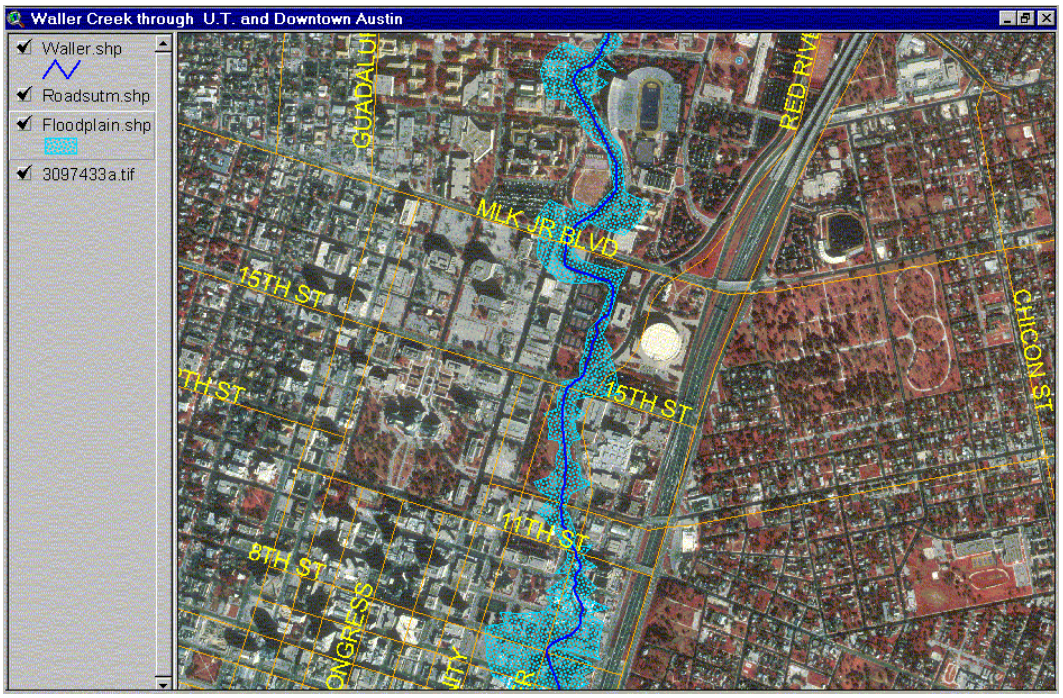


Figure 3.1 Planimetric floodplain view

The procedure is straightforward and the Avenue scripts are simple to use. Hence, users with even limited ArcView experience should be able to quickly map floodplains based on HEC-RAS output and compare floodplains resulting from different discharge scenarios.

Future work on this topic will focus on two areas: refining the two-dimensional floodplain mapping technique described in this report, and developing a procedure for three-dimensional floodplain visualization. In the two-dimensional arena, the City of Austin has digitized the RAS cross sections along Waller Creek and has agreed to share the resulting GIS coverage. Development of a means to map floodwaters using this coverage will eliminate a current limitation of the available data.

For three-dimensional visualization, the principal challenge is to develop a representative TIN model of the terrain. This will require a method to integrate low-resolution digital elevation model (DEM) data with comparatively higher-resolution vector floodplain data. The intended result is a continuous landscape surface that contains additional detail in stream channels. The end method will likely require the following steps:

(1) Use a 30-meter DEM to represent the area terrain.
(2) Vectorize the DEM to create a point coverage of terrain elevations.
(3) Define the channel morphology using the methodology described in this report. However, the HEC-RAS data import script should be edited to extract all points from each cross section (currently only the locations of the center point, bank stations, floodplain boundaries are extracted).
(4) Construct a bounding polygon from the cross-section endpoints.
(5) Eliminate any DEM points that fall within the bounding polygon.
(6) Create a TIN using the DEM and cross-section points as nodes, and the centerline and bank lines as hard breaklines.
(7) Develop an approach to smooth the interface between the DEM and HEC-RAS data.

In this manner a three-dimensional terrain TIN could be constructed such that the stream channel data supersede the terrain data within the area for which it is defined and the terrain TIN prevails elsewhere, with a smooth zone of transition. The final step would then be to overlay a TIN of floodwater profiles on the terrain TIN.

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