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**Hydraulic Fabric: An Information Framework  
for River Channel Cross Section Data**

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**Hydraulic Fabric: An Information Framework  
for River Channel Cross Section Data**

**by**

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**Thesis**

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## **Dedication**

In memory of my grandfather, Jiasheng Zheng, who left me forever last fall when I was pursuing my Master degree on the other side of the earth.

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I would like to thank my advisor Dr. David Maidment for leading me into a wonderful academic world that I have never experienced before. It is my honor to work with the world leader of water resources and GIS research. His insightful guidance and enigmatic enthusiasm always inspire me to move forward.

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May 1, 2015

## **Abstract**

### **Hydraulic Fabric: An Information Framework for River Channel Cross Section Data**

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The translation from discharge to water surface elevation is always an essential issue in flood forecasting and emergency response. To realize this translation, information about river channel is indispensable. In this paper, an information framework named Hydraulic Fabric is designed to store river channel information in a general way for the National Flood Interoperability Experiment (NFIE). Within this framework, cross sections are uniquely located on river network in a percentage form by linear referencing, which is the first attempt of building a national scale cross section dataset. River channel geospatial information and water surface elevation-discharge relationship will be integrated together as a single resource for every cross section in Hydraulic Fabric. A set of customized tools are created to populate Hydraulic Fabric data model, taking river channel data extracted from existing hydraulic models as the input.

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## **Chapter 1: Introduction**

### **BACKGROUND**

From September 2014 to August 2015, the National Weather Service, the academic community, and their respective government and commercial partners will undertake an ambitious collaboration dubbed the National Flood Interoperability Experiment (NFIE). The NFIE will demonstrate a transformative suite of science and services for the next generation of national flood hydrology and emergency response.

This project will create a geospatial data infrastructure for hydrology, containing several water-related, interconnected layers (rivers, catchments, gages, reservoirs, forecast points, inundation polygons, etc.). The creation process will involve integrating existing datasets from different organizations and dividing the natural water flow system of the continental United States into 2.67 million reach catchments. This data infrastructure will comprise a next-generation national hydrologic geospatial fabric. Based on this fabric, a national hydrologic simulation framework, including an atmospheric model for precipitation forecast, a land surface model for flood runoff calculation, and a flood routing model, will be set up. Using the forecast flow data, detailed river hydraulic modeling and flood inundation mapping will be implemented for selected communities and regions. This information will be further developed to improve community resilience and local flood response. If successful, the NFIE will increase the spatial density of flood forecasting locations from approximately 3600 (the present NWS river forecasting system) to about 2.67 million. The increase would transform real-time flood information in the United States. (Maidment 2015)

## **MOTIVATION**

An essential part of NFIE is translating a forest discharge to its corresponding water surface elevation in river channels over the floodplain. Water elevation information is both more understandable and operable to local communities and emergency response organizations. Flood inundation mapping over the floodplain also needs to rely on the translation. In order to realize this translation, two approaches could be considered. One is the experience-based hydrologic approach using the rating curve, a figure or table describing the relationship between water elevation and discharge. Rating curves can be acquired with measured gage height-discharge pairs from stream stations or computed water depth-discharge pairs from hydraulic models. The other option is the physics-based hydraulic approach. In this scenario, hydraulic models are built using classic fluid mechanic equations. Although hydraulic models are applied in both methods, the ways of application are different. In the first approach, the models need to be run only once at the beginning to generate the rating curve. For the second option, hydraulic models will be regularly run in real-time, taking the latest flow data as the input.

For the rating curve approach, an information framework must be defined to standardize the types and formats of dependent and independent variables, which are stored as fields in the rating table. After the framework has been created, some tools also need to be developed to generate the standardized rating curves from the computation results of existing hydraulic models.

Regardless of the NFIE's hydraulic model choice, some fundamental data about river channel geometry are always needed for modeling. This paper will solve the transformation realization between the geospatial information stored in Geographic Information System (GIS) and that utilized by hydraulic models for river channel features.

Although currently hydraulic modeling is usually performed at local scale, cutting-edge researches have revealed the possibility of river modeling at continental scale. (Liu and Hodges 2012) To support hydraulic modeling at such a large scale, a national cross section dataset must be created collecting river channel information for the whole country. Then a concise and efficient information model needs to be designed for the cross section dataset. These cross sections also need to be referenced uniformly on the “blue lines”, the hydrological geospatial framework established as Hydro Fabric.

In summary, cross section is the basic unit to organize river channel data. For each cross section, three kinds of information are needed to represent it completely both in the geographic information system (GIS) and the hydraulic model. They are the geographic coordinates, the cross section geometry, and the discharge-elevation relationship. However, at this moment, there is no data model available to store these three types of data in an integrated way.

#### **OBJECTIVE AND SCOPE**

The purpose of this research is to develop an information framework for river channel cross section data, named Hydraulic Fabric. The inspiration of this name comes from the idea of the National Hydrography Dataset Plus (NHDPlus), which is an integrated water resources dataset Federal Geographic Data Committee (FGDC) built to be the Hydrologic Geospatial Fabric for the United States. (<http://www.horizon-systems.com/NHDPlus/GeoFabric.php>) The NHDPlus stores geographic information of water resources features along the flow direction, but it does not contain river channel information that is perpendicular to the flow direction. This kind of information, which is mainly cross section data, is essential for hydraulic modelling. Hence, we give the name “Hydraulic Fabric” to this cross section information model.

The principle that directs the design of Hydraulic Fabric is that it should become a data model of national cross section repository. Cross section data come from different platforms will be stored in Hydraulic Fabric in a consistent way. In Hydraulic Fabric, all these three kinds of data used to describe cross section features, geographic coordinates, geometry, rating curve, are available, and the exchange among them are easy to realize as shown in Figure 1.

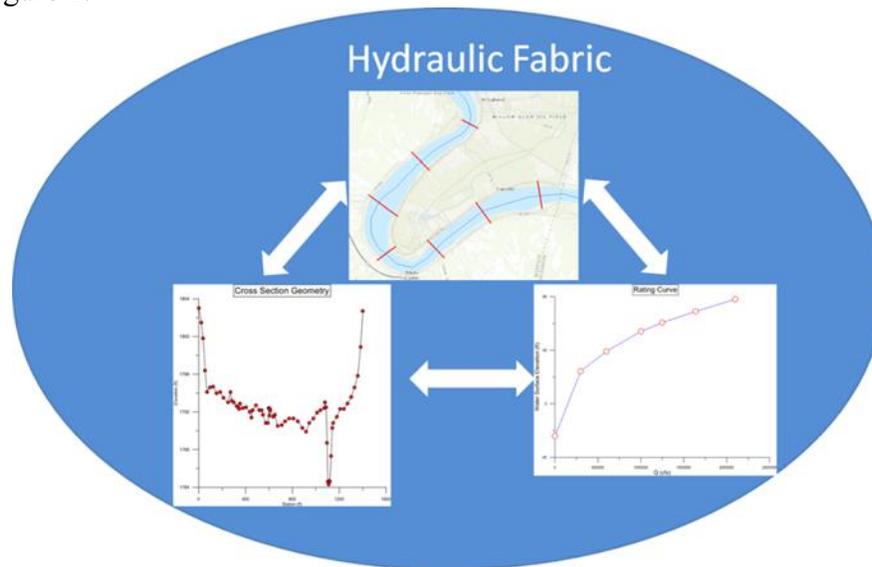


Figure 1 The Role of Hydraulic Fabric

Hydraulic Fabric contains two parts. The first part is a cross section geospatial framework, which is a data model's schema for storing river channel geometry data. Once the data model has been finalized, several tools will be developed to populate required fields in different tables, which are some essential parameters for hydraulic modeling. The interconnection between cross sections and rivers network will also be displayed in this framework. Tools for uniquely identifying the position of cross sections on the river network will also be created. Hence, a national stream addressing system will be set up.

The second part is an information framework to describe water level-discharge relationship. The rating curve type that should be used as a standard template for NFIE will be decided. Then tools will be created for extracting computation results from existing hydraulic models such as HEC-RAS and populating the formal rating curves with these results.

### **THESIS OUTLINE**

This thesis is divided into five chapters. The first provides some background information about National Flood Interoperability Experiment, followed by an overview of the motivation, scope, and objective in implementing the Hydraulic Fabric. The second explains some ideas about National Flood Interoperability Experiment, coordinate systems and rating curves, which are essential for Hydraulic Fabric development. A set of hydraulic modeling software applications and river channel data models are also reviewed in this chapter. The third chapter first presents the schema of the river channel data model at first. Next, it explains the workflow of different tools to populate this data model with a simple input dataset. The framework of rating table and the procedure used to create such tables from HEC-RAS results are elaborated here. The fourth chapter uses a segment of Lower Mississippi River as a case study to test the functionality of these tools described in chapter three and displays the results. The fifth chapter draws conclusions and suggests future work that may be undertaken.

## **Chapter 2: Literature and Technology Review**

### **NATIONAL FLOOD INTEROPERABILITY EXPERIMENT (NFIE)**

National Flood Interoperability Experiment (NFIE) is a one-year collaboration (from September 2014 to August 2015) to demonstrate a transformational suite of science and services for the next generation of national flood hydrology and emergency response between the National Weather Service, its government partners, the academic community and commercial partners. (Maidment, 2015)

During the NFIE, the following questions will be addressed:

- How can real-time hydrologic simulations at high spatial resolutions, covering the nation, be developed using a next generation “HydroFabric” – a framework of open water data services in space and time.
- How can this lead to improved emergency response and community resilience?
- How can an improved interoperability framework support the first two goals and lead to sustained innovation in the research to operations process?

As a result, the NFIE will culminate in a near-real time system capable of characterizing the state of surface water resources, specific to flood or near flood stage on a spatial domain that spans the continental United States, and at a resolution that facilitates decision-making within the emergency management community. (Maidment, 2015)

In order to facilitate the accomplishment of such a complex task as the National Flood Interoperability Experiment, the whole task has been broken down into a series of five components, as shown in Figure 2.

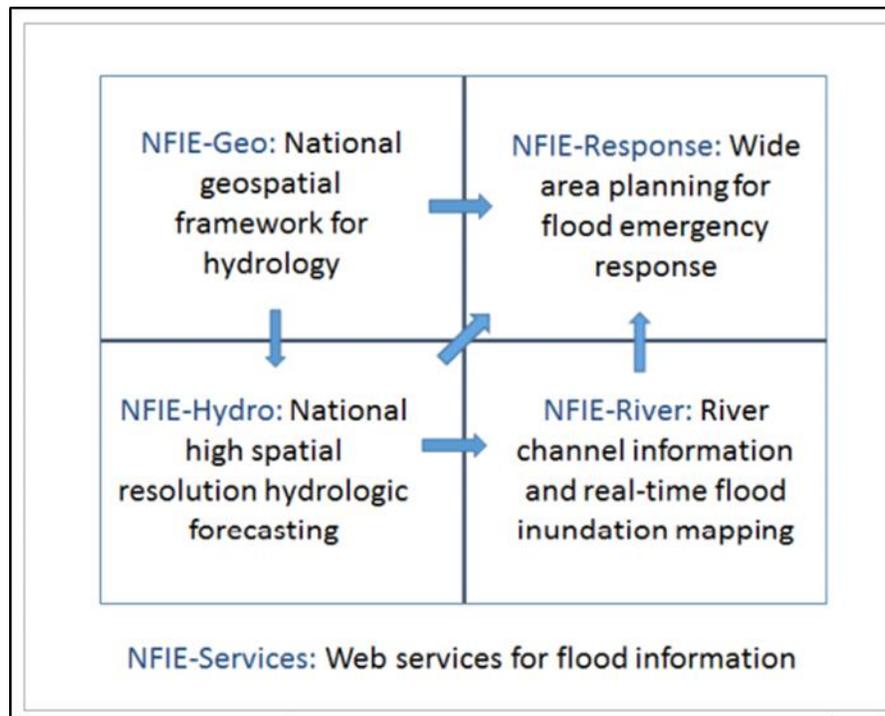


Figure 2 Components of the National Flood Interoperability Experiment (NFIE) (Maidment, 2015)

NFIE-Geo, the first component of NFIE, is a set of vector feature classes of high resolution geospatial information describing the natural water flow system of the continental United States divided into 2.67 million reach catchments connected by a national flow network. It will make up a next generation Hydro Fabric for modeling the nation’s rivers. Then a continental scale hydrologic simulation framework operating on the Hydro Fabric, linking weather forecasts, land-atmosphere modeling and channel flow routing to produce probabilistic flood forecasts for each reach catchment, will be set up named NFIE-Hydro. Because the availability of data and universality of characteristics, these two components can be applied in a uniform pattern nationally, which enables flow to be computed simultaneously throughout the stream network of the continental U.S. On the other hand, for another two NFIE components, NFIE-River and NFIE-Response,

although some general methodology and principles will be developed for the entire continent, local scale system will be built at the level of a county, city, state or water agency that is concerned with flooding within its own region. NFIE-River is a database of river channel information and associated flood hydraulic models that can be used to flood emergency response planning and real-time flood inundation mapping. The reason of local implementation for NFIE-River is that compared to hydrologic models, the more physical-based hydraulic models require more geospatial information about river channel geometry, which cannot be acquired from the continental Hydro Fabric. Therefore a Hydraulic Fabric containing these geospatial details must be developed to solve this problem. NFIE-Response describes a plan for flood response action developed by a local emergency response community. Obviously, the distinctiveness of local conditions of different regions decides that flood response plan must be developed accordingly. NFIE-Response and NFIE-River are intended to support implementation of the NFIE-Hydro flood forecasts to help local flood emergency response and community resilience. All four components mentioned above rest upon a foundation of flood information services called NFIE-Service, which is a set of standardized web services for water and weather observations and forecasts. (Maidment, 2015)

NFIE-Geo is a geospatial information database at high spatial resolution covering the continental United States to support the NFIE. It is a national geospatial data framework for hydrology, which integrates National Hydrography Dataset Plus, FEMA National Flood Hazard Layer, USGS Water Watch Points, NWS Subbasins and Forecast Points. The geospatial data stored in it are for catchments, stream reaches, watersheds, water bodies, floodplains, dams, stream gages, and forecast points. However, none of these datasets contains data about river channels and cross sections.

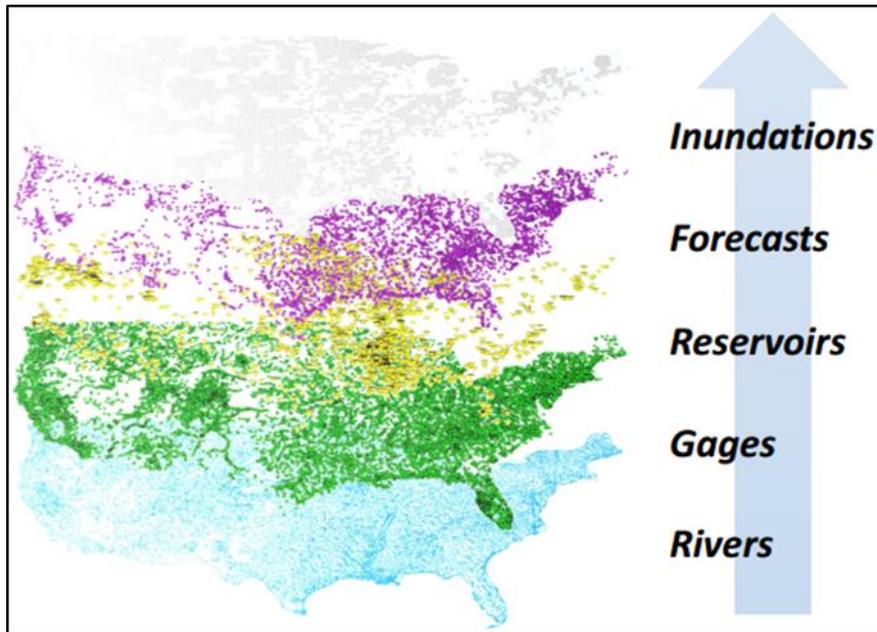


Figure 3 Layers defined within a U.S. Hydro Fabric (Salas, 2015)

The core of NFIE-Geo is the National Hydrography Dataset (NHD), which is a topologically connected flow network across the United States. By combining it with National Elevation Dataset, National Land Cover Dataset, and Watershed Boundary Dataset, a dataset called NHDPlus is created, in which the land surface of the continental United States is subdivided into 2.67 million elementary “reach catchments” where each reach catchment is traversed by a single flow line. Both the reach catchment and its flow line have a common identifier, or COMID, which is uniquely numbered across the nation. Thus the land and water systems of the nation are connected. The COMID forms a solid foundation for a national stream addressing system. By sharing the same COMID with the reach it is located on, and performing linear reference on the reach, the location of the cross section can be determined exactly and uniformly on the stream network of the country.

NFIE-River clarifies the approach to realize the translation from forecast flow to forecast water surface elevation and flood inundation mapping. Two kinds of vertical elevation scales are involved in this process. The first one is stage height that is water surface elevation above river channel bottom. It is used to establish the reference heights for flood warnings, shown in Figure 4. The other one is water surface elevation above geodetic datum, which is used to be compared with elevations in the surrounding landscape for estimating regional inundation and assessing the risk of individual homes being flooded, shown in Figure 5. Both elevation scales are needed to get a complete picture of flood warnings and impacts. So both scales will be considered in the rating curve information framework of Hydraulic Fabric.

Flood Categories (in feet)	
Major Flood Stage:	24
Moderate Flood Stage:	20
Flood Stage:	17
Action Stage:	15

Figure 4 Flood Categories of Onion Creek at Highway 183 in Austin, Texas

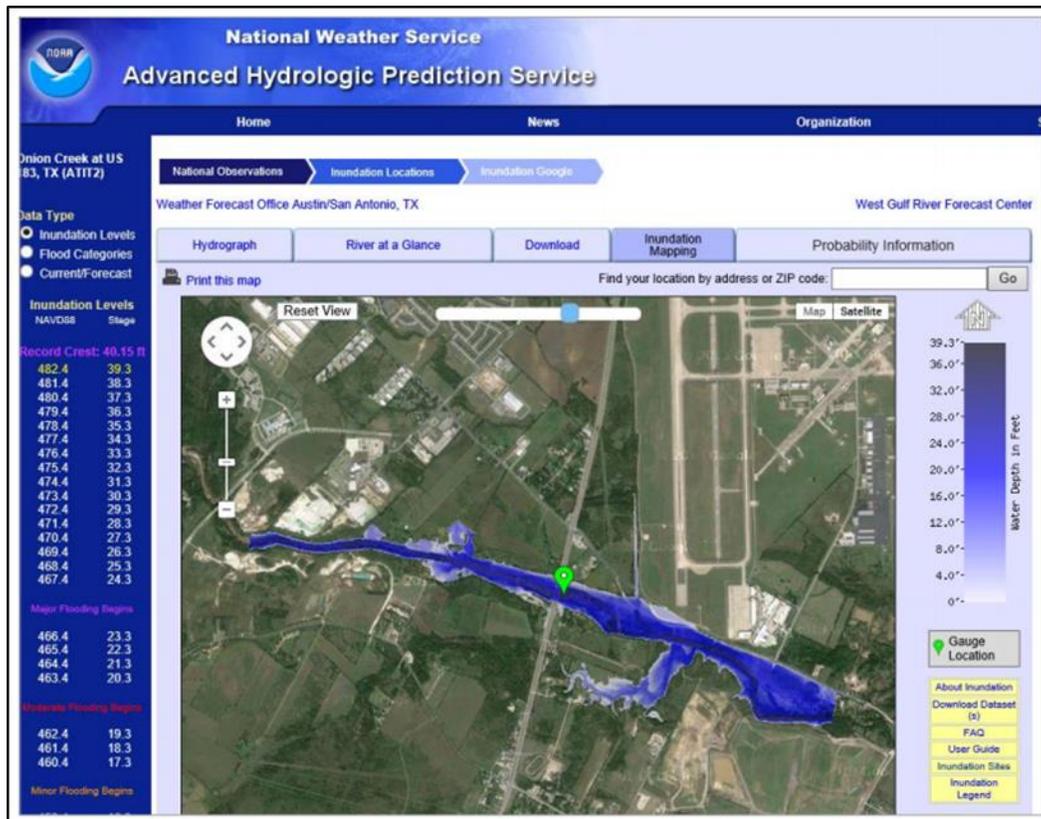


Figure 5 Flood inundation mapping on Onion Creek at Highway 183 in Austin, Texas

## COORDINATE SYSTEMS

In previous work, two coordinate systems are adopted for deciding river channel geospatial information, Cartesian coordinate system and curvilinear orthogonal coordinate system. Three dimensional Cartesian coordinate system is the well-known (x,y,z) coordinate system. In this system, the position of a point is identified by the signed distances from the point to three fixed perpendicular directed lines. Usually river channel geometry data are stored using this system in field survey, remote sensing, and GIS. The most significant advantage of Cartesian coordinates is its universality. River channel information can be combined with geographical data of other spatial features harmoniously within Cartesian system. The curvilinear coordinate system (n,s,z) assigns

coordinates to the point in a river channel with reference to the horizontal river centerline and a vertical datum.  $s$  represents the distance along the centerline, which starts from 0 at the end of the flow line.  $n$  represents the distance perpendicular to the centerline, positive on the left-hand side of the centerline facing downstream.  $z$  represents the vertical distance to the datum. Curvilinear system is good for tracing feature relative position in the river network and absorbing cross section data into hydraulic models. In most case,  $s$  coordinate of points on cross is modified as station for hydraulic modeling, which means the distance to the start point of the cross section, usually the left end of the cross section line facing downstream.

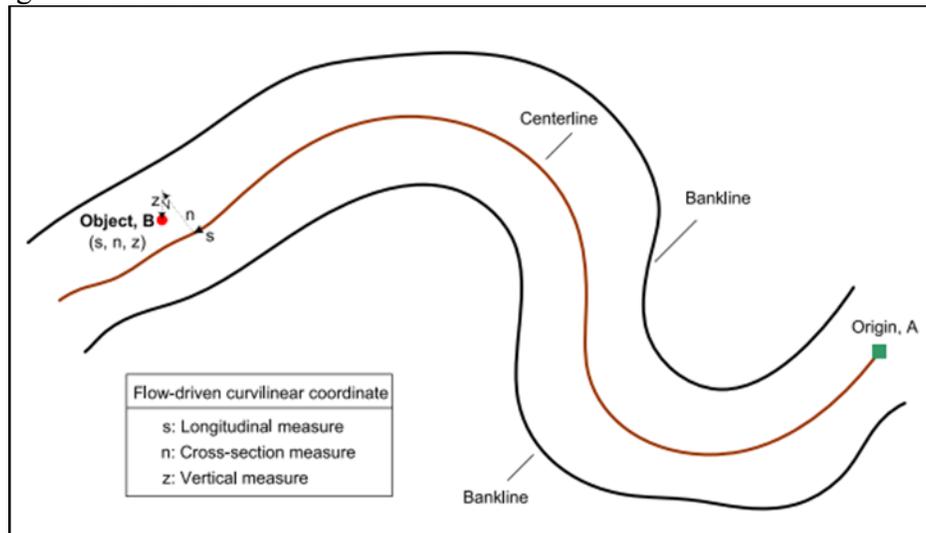


Figure 6 Three-dimensional curvilinear flow-oriented coordinate system (Kim, 2015)

## RATING CURVE

Rating curves are relations between dependent and independent hydrologic variables. For instance, a rating curve expressing the mathematical or graphical relation between stage (independent variable) and discharge (dependent variable) is referred to as a stage-discharge relation. Different variables utilized in the relation lead to different kinds of rating curves. A number of rating curve types are available for the processing of surface-water records. Following is a brief description for each type. (Sauer, 2002)

*Station-discharge relation:* This is a relation between water-surface gage height and the rate of flow of the stream.

*Stage-area relation:* This is a relation between gage height and area for a standard cross section of the stream.

*Velocity-index and mean velocity relation:* This is a relation between an index velocity (electromagnetic, acoustic, and others) and the mean velocity for a standard cross section of the stream.

*Stage and velocity factor relation:* This is a relation between gage height and an adjustment factor used in the velocity-index method of computing discharge.

*Stage-fall relation:* This is a relation between gage height and the water-surface fall between the base gage and an auxiliary gage.

*Fall ratio and discharge ratio relation:* This is a relation between the fall ratio,  $F_m/F_r$ , and discharge ratio,  $Q_m/Q_r$ , as used in the slope method of computing discharge.

*Stage-1/USc relation:* This is a relation between gage height and a flood-wave factor,  $1/USc$ , and is used in the rate-of-change in stage method of computing discharge.

*Elevation and reservoir contents relation:* This is a relation between the water-surface elevation of a reservoir and the contents of the reservoir. (Sauer, 2002)

The processing of most surface-water records requires the application of one or more rating curves. They are an integral part of the computation of most streamflow records, and become a part of the permanent records for each station. Rating curve information required for defining the relation between the independent and dependent variables, such as gage heights and discharges, can be entered into the database using various methods, including tabular, equation, and graphical methods. *Tabular entry* is the use of a table of descriptor data pairs, each representing a specific location of the rating curve. *Equation entry* is the use of a mathematical expression to define the rating curve algebraically. *Graphical entry* is to store the rating curve as a picture directly. A peculiarity of most rating curve plots is that the parameters plotted along the ordinate and abscissa scales are interchanged from the standard engineering practice. For rating curves where gage height is the independent variable, gage height always is plotted as the ordinate, and the dependent variable as the abscissa. This designation allows gage height, which is measured in a vertical direction, to be plotted in a vertical direction. (Sauer, 2002)

In this paper, rating curve is only used to refer to the elevation (station)-discharge rating curve for cross section. Some other auxiliary information may be added to help to describe this relation. However, station-discharge rating curve for control structures, such as spillways, gates, turbines, and other flow conveyances, or rating curve of other types will not be discussed here.

## **DATA MODEL**

### **Arc Hydro**

Arc Hydro is a GIS-based data model that generally represents geospatial and temporal data structure for surface water resources on the basis of the ESRI relational geodatabase technology to support hydrologic or hydraulic simulation models. It was collaboratively developed by ESRI and the Center for Research in Water Resources at the University of Texas at Austin in 2002. The Arc Hydro data model focuses on natural surface water systems and has been widely accepted as a common data model for water resources by various national agencies, such as the National Hydrography Dataset in the USGS, EPA, and US Army Corps of Engineers.

Arc Hydro is a connected set of objects and features built on top of ArcObjects. ArcObjects are a set of generic ArcGIS object classes used for building geodatabase models. There are three kinds of ArcObjects: (1) object—data tables storing only attributes; (2) features—data tables storing both spatial coordinates and attributes (points, lines, and areas); (3) network features—special points and lines called junctions and edges whose data tables store the connectivity between the junctions and edges, in addition to their attributes and spatial coordinates. The term “class” denotes a group of objects with similarly defined attributes and behaviors. In Arc Hydro, the part that stores and manages channel information consists of two feature classes and one object class.

The feature classes are CrossSection and ProfileLine, which are derived from the ChannelFeature abstract class, which inherits properties from the HydroFeature class. The object class CrossSectionPoint is derived from ArcGIS object. (Maidment, 2002)

In Arc Hydro, the ChannelFeature class gathers attributes that are common to channel features such as thalweg and cross section. Its attributes are ReachCode and RiverCode. All channel features derived from this abstract class automatically inherit these attributes. ReachCode is an identifier that tags each water feature uniquely within the drainage systems. RiverCode is another identifier of the river, defined by the river name or by the concatenation of the latitude and longitude of its outlet location. CrossSections are linear features that define the shape of the channel transverse to the direction of river flow. A CrossSection line has vertical measure (z-coordinate) and linear measure (m-coordinate) values at each vertex. Vertical measure (z-coordinate) represents the elevation of channel bottom with respect to a datum such as mean sea level. Linear measure (m-coordinate) represents the distance of each vertex along the cross section. Usually distances measured from the left end of a cross section facing downstream. CrossSectionPoint object class stores traditionally surveyed cross sections for which the m- and z-values are known but the x,y locations of the points are not know. A CrossSectionPoint class is relationally connected using CSCode to a CrossSection line feature. The longitudinal view of a channel is represented as ProfileLines. ProfileLines are linear features that define the longitudinal profile of the channel parallel to the direction of flow. (Maidment, 2002)

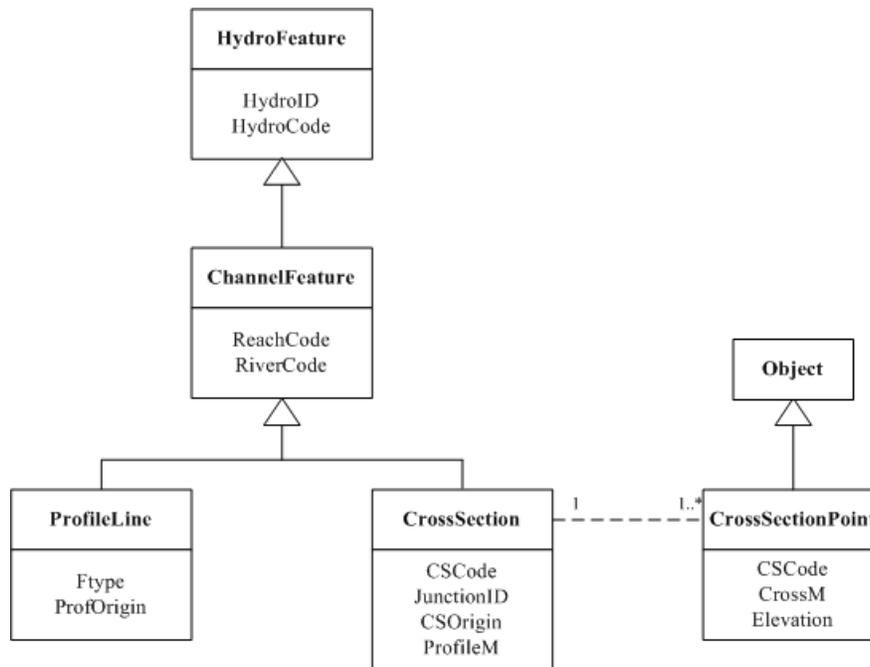


Figure 7 Channel Representation in Arc Hydro (Maidment, 2002)

### Arc River

Arc River is a river data model currently under development intended to extend the capabilities of Arc Hydro to facilitate descriptions of river features and processes using hydraulic/hydrologic terminology. Essential elements of the data model diagram for Arc River are shown in Figure 8.

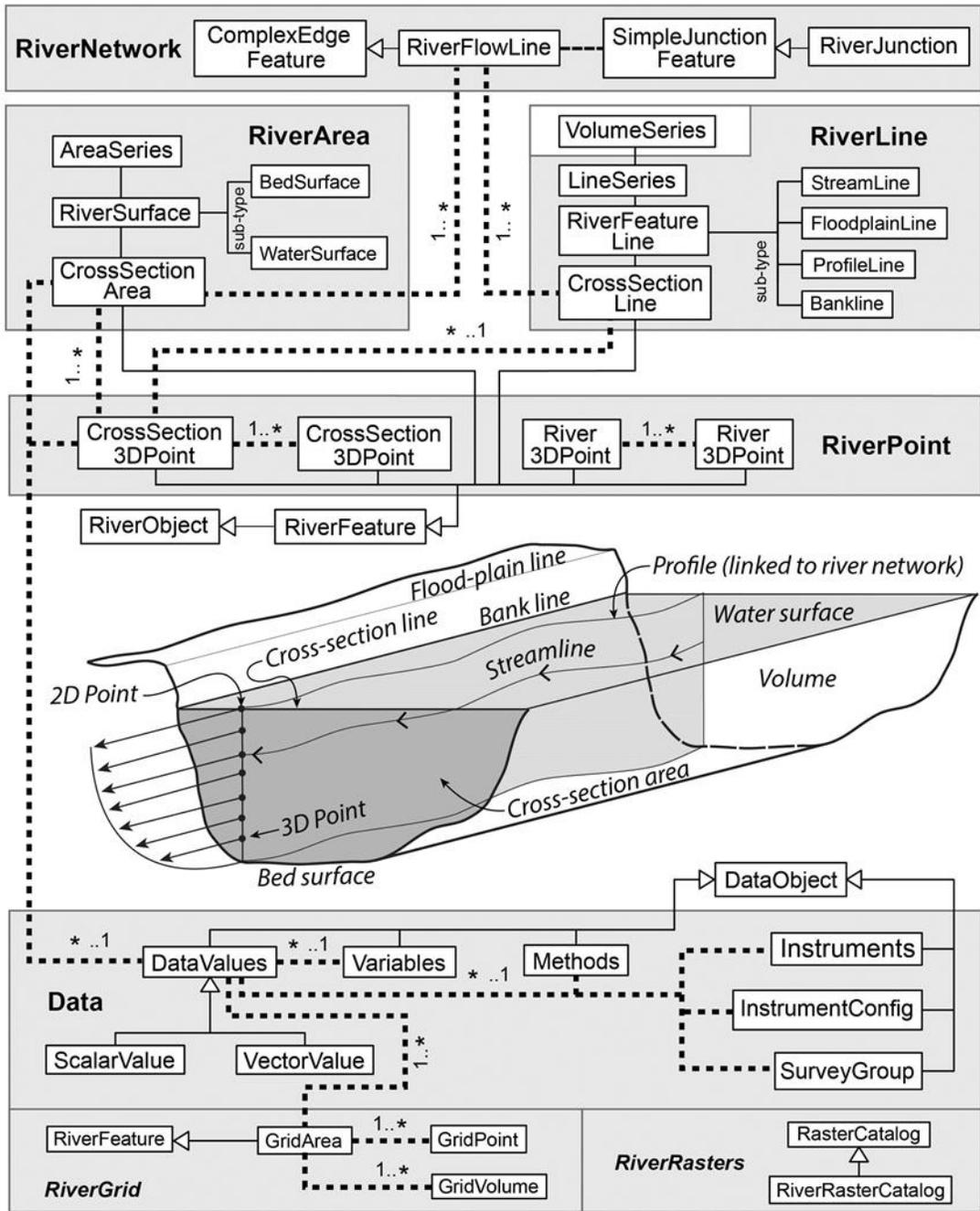


Figure 8 Classes and their relationships in the Arc River data model framework (Kim, 2008)

Because it is designed not only to store river geometry data, but also flow data measured by the new generations of river instruments, such as Acoustic Doppler Current Profilers (ADCP), the structure of Arc River is too complex for the requirement of NFIE-River. Arc River stores data for a three dimensional volume, while Hydraulic Fabric geospatial component only deals with data for river bed surface, which is a three dimensional surface. Adopting Arc River in its entirety is not the proper option for NFIE-River, but some pieces of Arc River will be absorbed in the process of Hydraulic Fabric model design.

## **HYDRAULIC MODEL**

### **HEC-RAS**

#### ***Overview***

One of the most widely used hydraulic analysis software programs is the Hydrologic Engineering Center's (HEC) River Analysis System (HEC-RAS), which is a product of the U.S. Army Corps of Engineers (USACE). It is accepted as a reliable hydraulic model by federal agencies including the Federal Emergency Management Agency (FEMA), the National Weather Service (NWS), the Natural Resource Conservation Service (NRCS) and the U.S. Army Corps of Engineers. Over the last decade, more than \$2 billion has been spent on FEMA floodplain mapping, which may be the largest civilian mapping program in the world. During this process, there are hundreds of HEC-RAS and other hydraulic models that have been created to support regulatory flood mapping at many locations in the nation, and also for hydraulic modeling of the large main stem rivers such as the Missouri, Mississippi and Ohio rivers. The inputs and outputs of these models are precious resources for continental flood modeling. So it is very necessary to check more details about HEC-RAS. (Goodell, 2014)

### ***Geometric Data***

Geometric data consist of establishing the connectivity of the river system (River System Schematic), entering cross-section data, defining all the necessary junction information, adding hydraulic structure data (bridges, culverts, dams, weirs, etc.) and cross section interpolation. In Hydraulic Fabric, because the NHD flow line system is adopted as the river network, so river connectivity and junction definition have already been set up. Hence we will focus on entering cross-section data here. Hydraulic structure and cross section interpolation problems will be discussed in future research.

HEC-RAS uses a River-Reach-River Station system to identify the location of a cross section. River and reach define which reach the cross section is located in, and river station defines the distance from the cross section to the downstream end of the reach it is located in along the reach. To decide the shape for each cross section, HEC-RAS offers a Cross Section Coordinates table, which is used to enter the station and elevation information for the cross section. The cross section stationing (x-coordinates in Figure 9) are entered from left to right looking in the downstream direction, usually starting from 0. It must be in increasing order. Downstream reach lengths are also geometric data HEC-RAS needs for modeling. It describes the distance between the current cross section and the next cross section downstream. Cross section reach lengths are defined for the left overbank, main channel, and the right overbank. Then the main channel bank stations must be given to define what portion of the cross section is considered the main channel and what is considered left and right overbank area. The bank stations must correspond to stations entered on the cross section X & Y coordinates table. (Brunner, 2010)

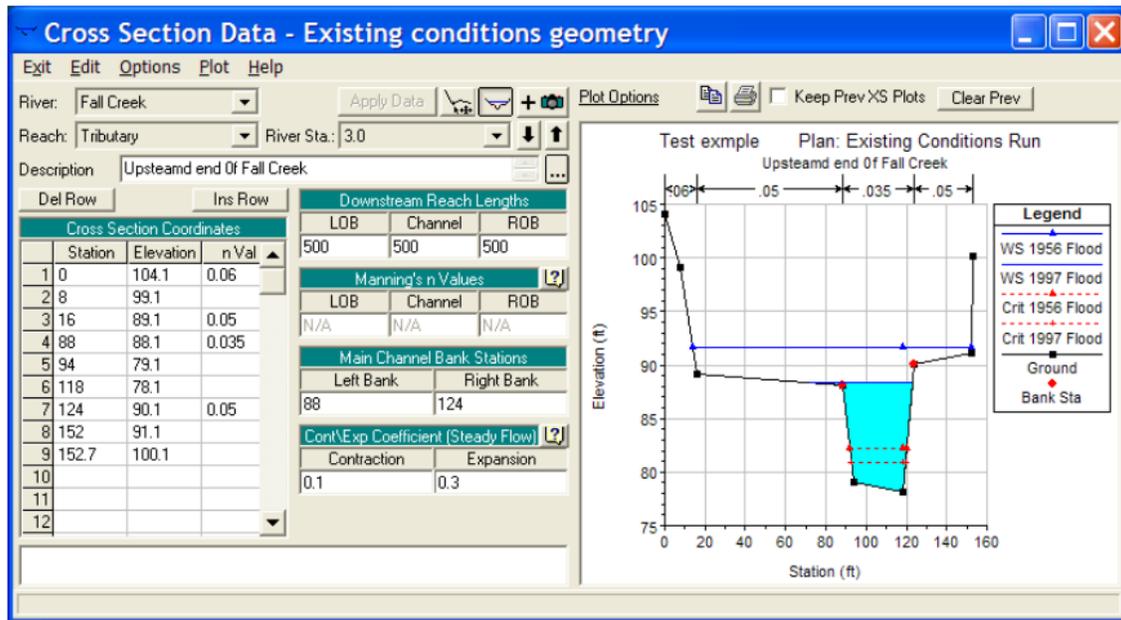


Figure 9 HEC-RAS Cross Section Data Editor

### ***Georeferencing***

Georeferencing is the process by which real-world coordinates are assigned to an HEC-RAS model to reference it to other data. It enables the geospatial information used in a HEC-RAS file to be stored and visualized together with other GIS layers. Additionally, floodplain maps can be developed if the cross sections in HEC-RAS are georeferenced. To draw the stream centerlines, cross sections, and storage areas on the schematic in a georeferenced river framework requires that they must have GIS coordinate information. Since for NFIE, NFIE-Geo provides the river schema using NHD flowline system. Our discussion will focus on cross section part. (Brunner, 2010)

HEC-RAS use a (x, y) coordinate pair to establish the location of RAS objects like river reaches and cross sections. When the river system is hand drawn on the screen, the default coordinate system, which is used in the geometric data editor interface, is a simple 0.0 to 1.0 range for both the X and Y direction. As cross sections are entered, they

are automatically scaled based on the coordinates of the river reach line and the main channel distance between cross sections. Each cross section is drawn as a straight line perpendicular to the river reach schematic line. In order to get the actual geospatial location of a cross section line, real world coordinates must be entered. Each cross section schematic line, which is also called “XS Cut Line”, must have the (x,y) coordinates of at least two points, a start and an end. Coordinates of additional points need to be added if the “XS Cut Line” is a multi-segmented line.

### ***Rating Curve***

For the same river segment, HEC-RAS calculates water surface elevations under different flow conditions, which is called “profile” under HEC-RAS environment. With these discharge-water surface data value pairs, HEC-RAS can generate a rating curve for each cross section. The rating curve plot and figure can be copied to Clipboard and used out of HEC-RAS environment individually for every single cross section. Or rating tables for all cross sections in one hydraulic study can be exported to a Hydrologic Engineering Center Data Storage System (HEC-DSS) database file with a “.dss” extension as a whole. But a problem exists here is that HEC-DSS file can be only recognized by HEC software family. Hence exporting rating curves from HEC-RAS interface in bulk, and writing them into a generic, human readable format file is a question to be solved in this thesis.

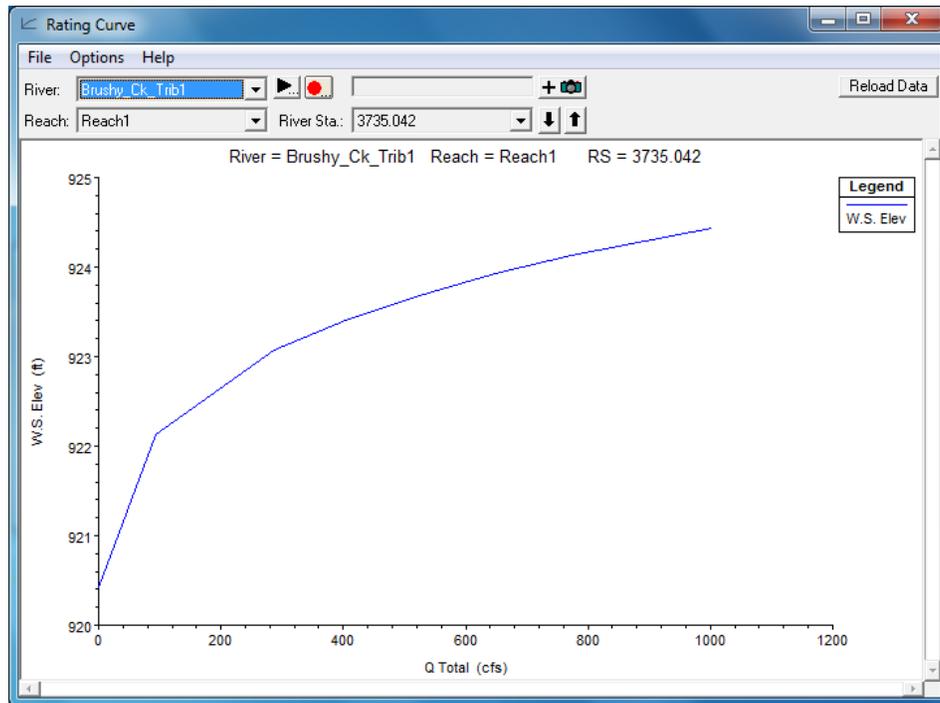


Figure 10 Rating Curve Viewer in HEC-RAS

### ***Data Format***

HEC-RAS input files are stored as ASCII (American Standard Code for Information Interchange) text files, which can be opened and edited in any text editor software application. Furthermore, this allows users to read and write HEC-RAS input files using built in statements like Open, and Line Input in a common programming language such as Visual Basic. The geometry input of HEC-RAS is stored in file with a name of “\*.g###”. Every bit of geometry input data that a user can see in the HEC-RAS GUI also resides in this text file. Most of the lines in the geometry file include some text followed by an equal sign (=), followed by some numbers or some text (or both). Typically, the text on the left of the equal sign is a “key”-an identifier for HEC-RAS to recognize what type of data is present on the right side of the equal sign. The data on the right side of the equal sign can be numerical, strings, dates, etc. Comma delimitation or

constant spaces delimitation (field of 8 or field of 16) is used for multiple values stored in one line. If what the key on a given line of text means can be deciphered, then the succeeding data can be understood. Furthermore, any geometry data present in the geometry file can be retrieved and stored. (Goodell, 2014)

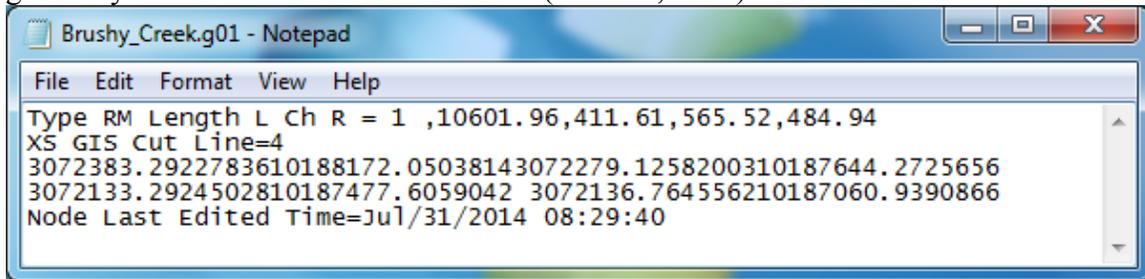


Figure 11 HEC-RAS Geometry Input File

One HEC-RAS output format we are concerned about in this paper is HEC-DSS file. HEC-DSS database files are "direct-access" binary files with no published format. Only programs linked with the HEC-DSS software library can be used to access HEC-DSS files. HEC-DSS uses a block of sequential data as the basic unit of storage. Data is stored in blocks, or records, within a file and each record is identified by a unique name called a "pathname". Pathname is the key to the data's location in the database. It is separated into six parts (delimited by slashes "/") labeled "A" through "F", as follows:

/A/B/C/D/E/F/

To facilitate the ability of application and utility programs to work with and display data, standard record conventions were developed. These conventions define what should be contained in a pathname, how data is stored, and what additional information is stored along with the data. The naming convention for pathname parts is listed in Table 1:

Table 1 HEC-DSS Pathname Parts Naming Convention

Part	Description
<b>A</b>	Project, river, or basin name
<b>B</b>	Location
<b>C</b>	Data parameter
<b>D</b>	Starting date of block, in a nine-character military format
<b>E</b>	Time interval
<b>F</b>	Additional user-defined descriptive information

For HEC-DSS files storing rating curve data exported from HEC-RAS, the naming convention of pathname parts should be:

/River Reach/River Station/ELEV-FLOW///Plan Short ID/

For example, in Brushy\_Creek.dss file, all the water surface elevation-discharge data pairs for the cross section with a river station 61330 (unit: foot) on reach1 of Brushy Creek will be stored in a record with a pathname as

/BRUSHY\_CREEK REACH1/61330/ ELEV-FLOW///BRUSHY\_CREEK/

Number	Part A	Part B	Part C	Part D	Part E	Part F
427	BRUSHY_CREEK REACH1	61330	ELEV-FLOW			BRUSHY_CREEK
428	BRUSHY_CREEK REACH1	61373.07	ELEV-FLOW			BRUSHY_CREEK
429	BRUSHY_CREEK REACH1	61419.61	ELEV-FLOW			BRUSHY_CREEK

Ordinate	ELEV	61330 FLOW 61330
Labels		61330
Units	FEET	CFS
Type	ELEV	FLOW
1	600.87	7380
2	605.69	18714
3	607.61	26255
4	608.79	32468
5	609.15	34476
6	610.54	45239
7	611.41	53729
8	613.13	74924

Figure 12 Rating Table of Brushy Creek Reach 1 Station 61330 Stored in HEC-DSS

Once the way how rating curves are stored in HEC-DSS database files has been fully understood, the next problem to solve is how to extract these data from HEC-DSS and to be stored in a simple, human readable, and program recognizable file format. HEC-DSS Command-Prompt utilities are a suite of applications that allow users to access, manipulate, and view data stored in HEC-DSS files. Among these utilities, the DSS Utility Program (DSSUTL), which provides a means of performing utility functions on data stored in the HEC-DSS including tabulating, editing, and copying data, and listing, renaming, deleting and copying records in a DSS file, is the one we need to solve our problem.

### ***Control***

As water science advances, more data are collected and more models are built up. Therefore, the demand for hydraulic modelling automation becomes more and more urgent. For HEC-RAS, the possibility can be realized through HECRASController. The HECRASController is part of an HEC-RAS application programming interface (API); a collection of programming classes that contain HEC-RAS-specific functions and subroutines that can be called within programming code during run time. The current version of HECRASController has a wealth of procedures that will allow a programmer to manipulate HEC-RAS externally by setting input data, retrieving input or output data, and performing common functions such as opening and closing HEC-RAS, changing plans, running HEC-RAS, and plotting output. With the HECRASController, real-time modeling is possible.

### **MIKE11**

MIKE 11 is a one-dimensional river model developed by Danish Hydraulic Institute (DHI). It is also a hydraulic model approved by FEMA, which can be used in

National Flood Insurance Program. Hence learn about the geometry data MIKE11 needs for modelling and consider its requirement in our data model design will improve the universality of our framework.

In MIKE11, a river network is made up of connected branches. A branch is made up of points with coordinates and river chainage. Every branch knows its upstream and downstream connected branch and the river chainage of the connection point.

Definitions

Branch Name: CALI    Topo ID: 1989    Upstr. Ch.: 0    Downstr.Ch.: 108080    Flow Direction: Positive    Maximum dx: 10000    Branch Type: Regular

Connections

Upstream:     Chainage:

Downstream:     Chainage:

Overview

	Name	Topo ID	Upstr. Ch.	Downstr. Ch.	Flow Direction	Maximum dx	Branch Type	Upstr.Conn. Name	Upstr.Conn. Ch.	Downstr. Conn. Name	Downstr. Conn. Ch.
1	CALI	1989	0	108080	Positive	10000	Regular				
2	OLD_CALI	1989	0	95075	Positive	10000	Regular	CALI	108080		
3	NEW_CALI	1989	0	113901	Positive	10000	Regular	CALI	108080		

Figure 13 Branch Information in MIKE11

Definitions

X-Coordinate: 2500    Y-Coordinate: 40500

Attributes

Branch: CALI    Chainage: 0

Chainage Type: User Defined

Overview

	X Coord.	Y Coord.	Branch	Chainage Type	Chainage
1	2500	40500	CALI	User Defined	0
2	3300	39200	CALI	User Defined	6290
3	5400	38300	CALI	User Defined	15730
4	6800	37500	CALI	User Defined	22580
5	8200	35400	CALI	User Defined	32210
6	8800	35000	CALI	User Defined	35220
7	10100	33900	CALI	User Defined	41720
8	11300	32900	CALI	User Defined	51160
9	13500	33100	CALI	User Defined	55970
10	15200	33100	CALI	User Defined	62640
11	17200	32000	CALI	User Defined	72640
12	19100	31400	CALI	User Defined	80980
13	19800	30800	CALI	User Defined	85050
14	21200	30100	CALI	User Defined	90790
15	20800	27900	CALI	User Defined	100970
16	20100	25500	CALI	User Defined	108080
17	20100	25500	OLD_CALI	User Defined	0
18	20300	24600	OLD_CALI	User Defined	4200

Figure 14 Point Information in MIKE11

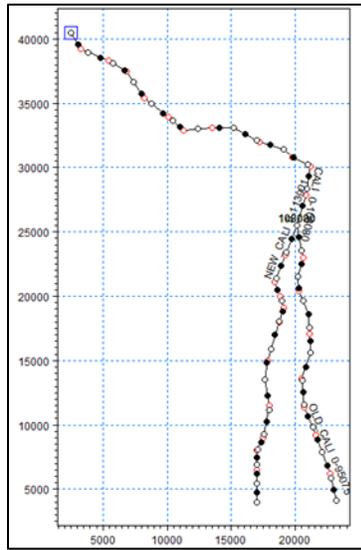


Figure 15 River Network in MIKE11

The cross section shape is described using a group of (x, z) data pairs and a number of markers. The markers are set to define the transformative positions on a cross section such as lowest point, low flow bank, and levee bank.

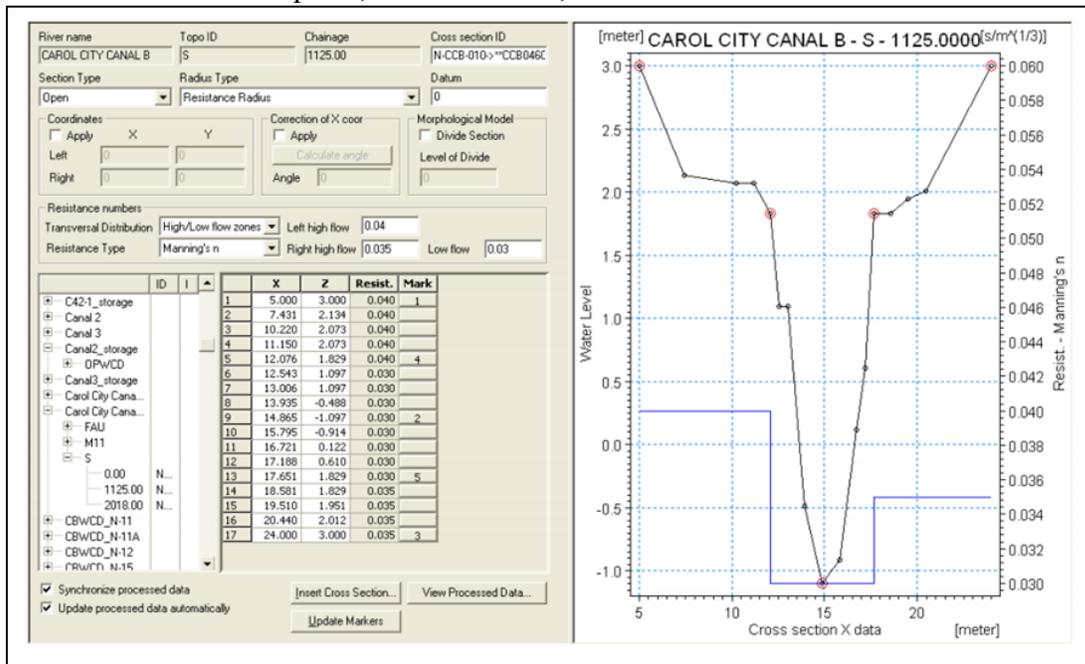


Figure 16 Cross Section Data in MIKE11

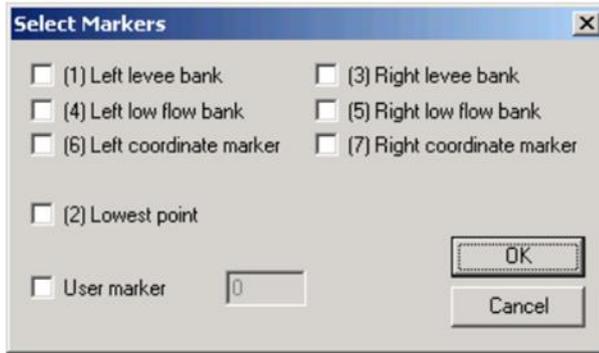


Figure 17 Available Marker Options in MIKE11

## SPRNT

SPRNT (Simulation Program for River Networks) is a dynamic river network simulation software tool, which can solve the full nonlinear Saint-Venant equations for one-dimensional (1D) unsteady flow and stage height in river channel networks with non-uniform bathymetry at a continental scale.

In SPRNT, a river network is partitioned into multiple branches, each of which is called a “reach”. Each reach is represented by multiple computational nodes. A computational node reflects a position along a river channel where the river physics behaviors computed, in another word, one computational node is one cross section. To run SPRNT, a topology relationship needs to be built for cross sections to decide the connectivity between them on the river network. Geometry information needed by SPRNT includes river length between adjacent cross sections, slope of the reference slope line (a smooth thalweg), and cross section shape information. For cross section type information, three types are supported in SPRNT: rectangular, trapezoidal, and tabulated station-elevation. For a rectangular cross section, only a bottom width parameter is needed. For a trapezoidal cross section, a bottom width parameter and a side slope parameter are needed. When the station-elevation table is used as the cross section type,

the elevation is the river bed height above minimum channel elevation of that cross section. In SPRNT, the description of the river network is specified in a “netlist”. Each netlist consists of the specifications of nodes, segments, branches, forcing terms, lateral flows, downstream boundary conditions, as well as options which are directives on how the simulation should be performed. Figure 20 shows the way how geometric data of one cross section is stored in SPRNT netlist file.

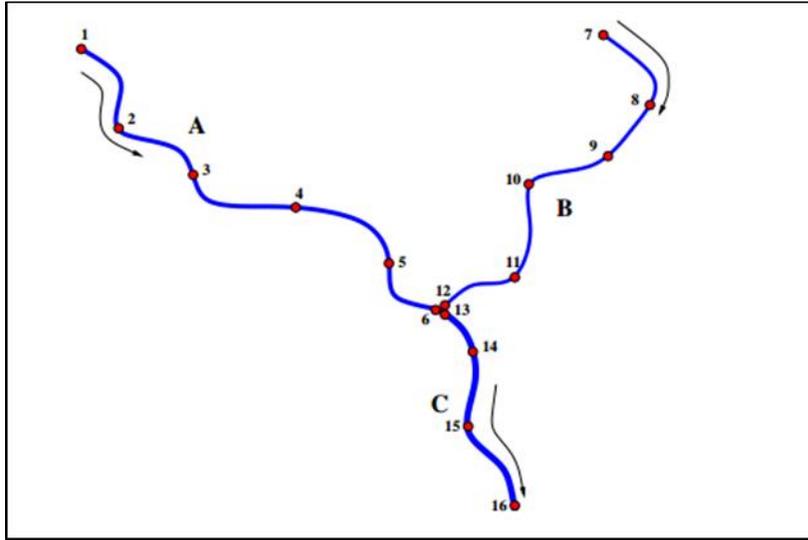


Figure 18 SPRNT River Network

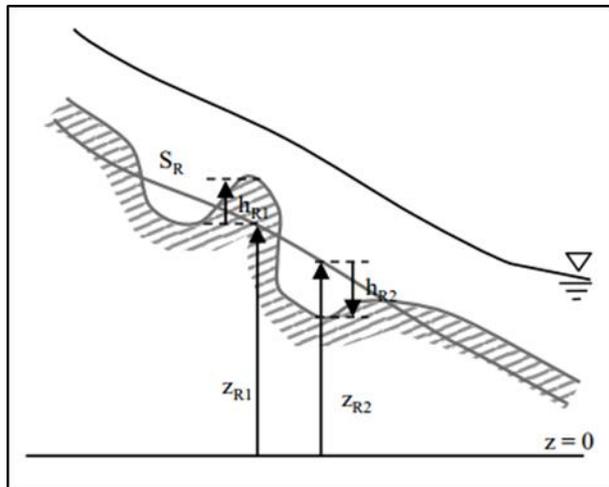


Figure 19 SPRNT Reference Slope

```
def node id=node_1 sr=0.0083 n=0.04 zr=707.23 hr=0.0 xcoord=123.45 ycoord=567.89
  def xy
    x=0.0 y=6.0
    x=2.5 y=1.0
    x=3.5 y=1.0
    x=6.0 y=6
  end
end
```

Figure 20 Cross Section Data Stored in SPRNT Netlist File

From the discussion above, we can see that, the difference between current widely-used hydraulic models and SPRNT is mainly about the modelling scale. Hydraulic models like HEC-RAS or MIKE11 cannot solve the full Saint-Venant equations for river networks larger than  $O(10^3)$  elements, while the computation ability of SPRNT has been demonstrated to do one-dimensional hydraulic computation for river networks of  $O(10^5)$  elements hundreds of times faster than real time on a desktop computer. (Liu and Hodges 2014) It changes the scale of hydrodynamic modelling from local to continental. However, although some differences do exist in data format for different hydraulic models, the cross section geometric information needed by them for modelling is essentially the same, which confirms the necessity and feasibility of creating a cross section data model containing all the cross section geometric data in a unique pattern. The creation of such a data model will facilitate the data integration and exchange from different sources developed using different method. It will also offer the opportunity for building a national scale cross section dataset. To support the visualization and geo-reference, this cross section data model must also be GIS-supported. These are some considerations involved in the design process of Hydraulic Fabric framework.

### **Chapter 3: Methodology**

The Hydraulic Fabric is designed based on GIS concepts. The whole information framework is stored as a geodatabase. The data dictionary of the Hydraulic Fabric is shown as Figure 21. Four feature classes and one table are stored in the geodatabase, namely, **Flowline**, **XSLine**, **XSIIntersection**, **XSPoint**, and **XSRating**. Four relationships, **FlowlineIntersectsXSLine**, **XSLineHasXSIIntersection**, **XSLineHasPoint**, and **XSLineHasRating**, establish connectivity between the feature classes and the table. In order to be explained more clearly, the whole information framework is divided into two components. One is about the geographic and geometric information of cross sections named Hydraulic Fabric-Geo. The other deals with the rating curve information of cross sections named Hydraulic Fabric-Rating. Each one of them will be discussed individually in this chapter.

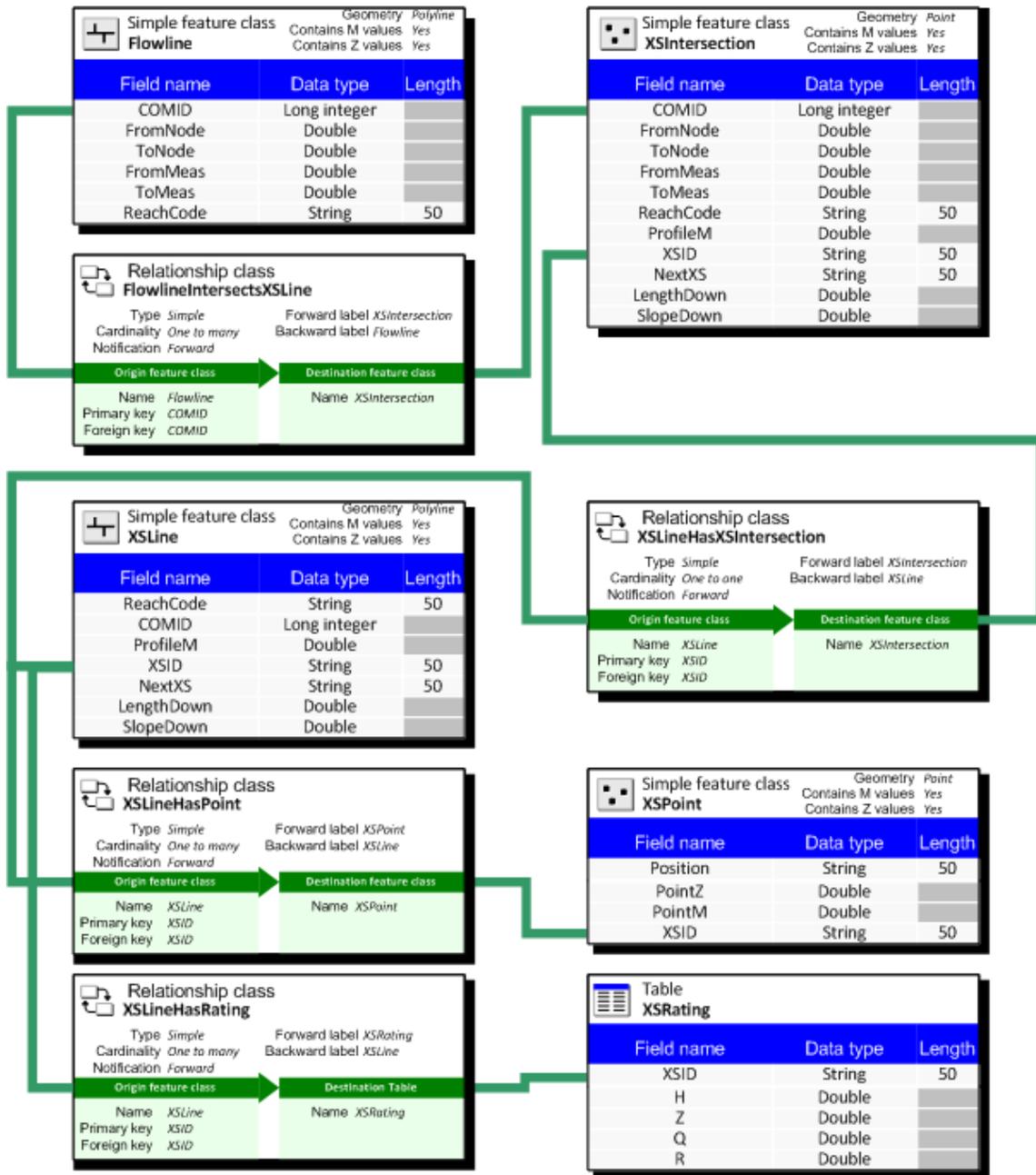


Figure 21 Hydraulic Fabric Data Dictionary

## HYDRAULIC FABRIC-GEO

In this section, the geospatial component of Hydraulic Fabric, which is the geospatial framework used to describe cross sections, is introduced. This framework is developed by adopting and adapting existing river channel data models. For this component, different tools have been created to populate attribute fields. Operating principles of these tools are also explained here.

### Information Framework

#### *Flowline*

Description: Lines representing the river network as shown in plan or map view

Note: Flowlines are similar in concept to a river segment or reach. A reach could be comprised of a single flowline. However, it is also possible for several flowlines to be included in a single reach. Then several features may have the same ReachCode. Thus, a reach is an organizing unit whose definition depends upon the dataset or application. For example, in the National Hydrography Dataset, a reach is “a continuous piece of surface water with similar hydrologic characteristics” ([http://nhd.usgs.gov/nhd\\_faq.html#q106](http://nhd.usgs.gov/nhd_faq.html#q106)). Flowlines include route measure values to enable linear referencing. The route measure value is 100 at the upstream end of a reach, and 0 at the downstream end of a reach.

Table 2 Flowline Fields

<b>Field Name</b>	<b>Description</b>
COMID	Unique identifier of the feature
ReachCode	Identifies the reach to which the feature belongs
FromNode	Unique identifier for the upstream end of the feature
ToNode	Unique identifier for the downstream end of the feature
FromMeas	Route percentage measure (m-value) at the downstream end of the feature
ToMeas	Route percentage measure (m-value) at the upstream end of the feature

Table 2 shows fields within the Flowline feature class. FromNode and ToNode define the topology relationship between different Flowlines. If the ToNode attribute of one Flowline feature shares the data value with the FromNode attribute of another Flowline, connectivity and flow direction between these two Flowlines is established.

***XSLine***

Description: The cross section lines on river channels as shown in plan or map view

Note: Cross section lines are normally drawn transverse to the flow. Each cross section line can only intersect one Flowline and only cross the Flowline once.

Table 3 XSLine Fields

<b>Field Name</b>	<b>Description</b>
COMID	Identifier of the Flowline feature on which the cross section is located
ReachCode	Identifies the reach to which the Flowline feature belongs
XSID	Unique identifier of the XSLine feature
NextXS	XSID of next downstream XSLine feature
ProfileM	Route percentage measure (m-value) at the intersection between the XSLine feature and the Flowline feature
LengthDown	River length between the XSLine feature to its next downstream XSLine feature
SlopeDown	Bed slope of the river segment between the XSLine feature to its next downstream XSLine feature

The key point of the XSLine feature class is using the intersection between cross section and Flowline to identify cross section location on river network. The shared COMID achieved from the intersected Flowline defines which reach the cross section is location on. Route measure value of the intersection along the intersected Flowline combined with the ReachCode decides the exact position of the cross section on that reach. It is displayed in a 0 to 100 percentage format so that it will be consistent with the

linear referencing measure system of Flowline feature class. The premise of this point, the uniqueness of the intersection, must always be satisfied. By giving the NextXS attribute to each cross section, the topologic relationship between cross sections is established. Important river network parameters, river length and river bed average slope between adjacent cross sections, are also provided to facilitate hydraulic modelling.

***XSIntersection***

Description: Intersection points between Flowlines and cross section lines as shown in plan or map view

Note: Intersection point feature inherits all the attributes from both intersected Flowline and cross section line. It is a marker for information attached on the Flowline and the cross section line.

Table 4 XSIntersection Fields

<b>Field Name</b>	<b>Description</b>
COMID	Unique identifier of the feature
ReachCode	Identifies the reach to which the feature belongs
FromNode	Unique identifier for the upstream end of the feature
ToNode	Unique identifier for the downstream end of the feature
FromMeas	Route percentage measure (m-value) at the downstream end of the feature
ToMeas	Route percentage measure (m-value) at the upstream end of the feature
XSID	Unique identifier of the XSLine feature
NextXS	XSID of next downstream XSLine feature
ProfileM	Route percentage measure (m-value) at the intersection between the XSLine feature and the Flowline feature
LengthDown	River length between the XSLine feature to its next downstream XSLine feature
SlopeDown	Bed slope of the river segment between the XSLine feature to its next downstream XSLine feature

### ***XSPoint***

Description: The points on cross sections, i.e., stations

Note: The starting end of the cross section is defined on the left, where left is interpreted by looking in the downstream direction of flow in the channel.

Table 5 XSPoint Fields

<b>Field Name</b>	<b>Description</b>
XSID	Identifier of the XSLine feature on which the XSPoint is located
PointZ	Z coordinate of the point
PointM	The distance along the cross section line from the beginning of the line to the XSPoint
Position	The profile the point is on, left bank, right bank or centerline

Table 5 describes fields in the XSPoint feature class. PointM and PointZ are provided to express the point location in a station-elevation table which is widely used in hydraulic modelling. The position field provides the profile information about the cross section point. The possible value of this field can only be “left” (left bank), “center” (thalweg), “right” (right bank), or NULL. In that way, if the points with the same attribute “center” are connected from upstream to downstream, the thalweg profile of the river is generated. Similar procedure can be repeated for the left bank and right bank.

## **Tools**

The start point of the tools in this section is a geodatabase composed of three feature class. The first one is a flowline polyline feature class. The attributes mentioned in Table 2 must already be presented in its attribute table. The second one is a cross section polyline feature class. The only pre required attribute for this feature class is a unique identifier XSID given to every cross section line. The third one is a cross section point point feature class. The pre required attribute of this feature class is also the XSID to identify which cross section line the point is located on.

### ***Locating Cross Sections on River Network***

Cross sections are usually given as lines along a river segment. Both straight lines and polylines are possible forms. To use Hydraulic Fabric, users need to provide geospatial information about their cross sections including the coordinate system and coordinates for each line.

To locate a cross section on a river network, the first step is to intersect the cross section line with the river flowline. This generates the XSIntersection point feature class. For each cross section, only one intersection is allowed to be stored in the intersection dataset.

While it is possible in hydraulic modelling practice such as HEC-RAS that a cross section may have more than one intersection with one or more flowlines, the existence of multiple intersections will cause ambiguity to identify the cross section location. When multiple intersections appear, excess ones must be removed from the XSIntersection feature class. This removal is likely to be a manual process due to the higher level decision making involved in choosing the best intersection point.

Then flowlines along the path from the most upstream cross section to the most downstream cross section will be selected from the original river flowline dataset and

written into the Hydraulic Fabric Flowline feature class. In other words, only the subset of river features pertinent to establishing connectivity between cross sections is retained. A percentage curvilinear axis, which is called a route in linear referencing, will be set up along every feature. The coordinates of the start point and end point are assumed to have already been assigned for every Flowline feature. The next step is to locate the intersection of each XSIntersection point along that route and to get its coordinate.

Finally, by joining the XSLine table and XSIntersection table using the same XSID, the COMID of the intersected flowline and the measure value of the intersection will be written to the XSLine table as COMID and ProfileM. At this point, the location of the cross section on the river network has been identified clearly. A flowchart of the whole process is shown as Figure 22.

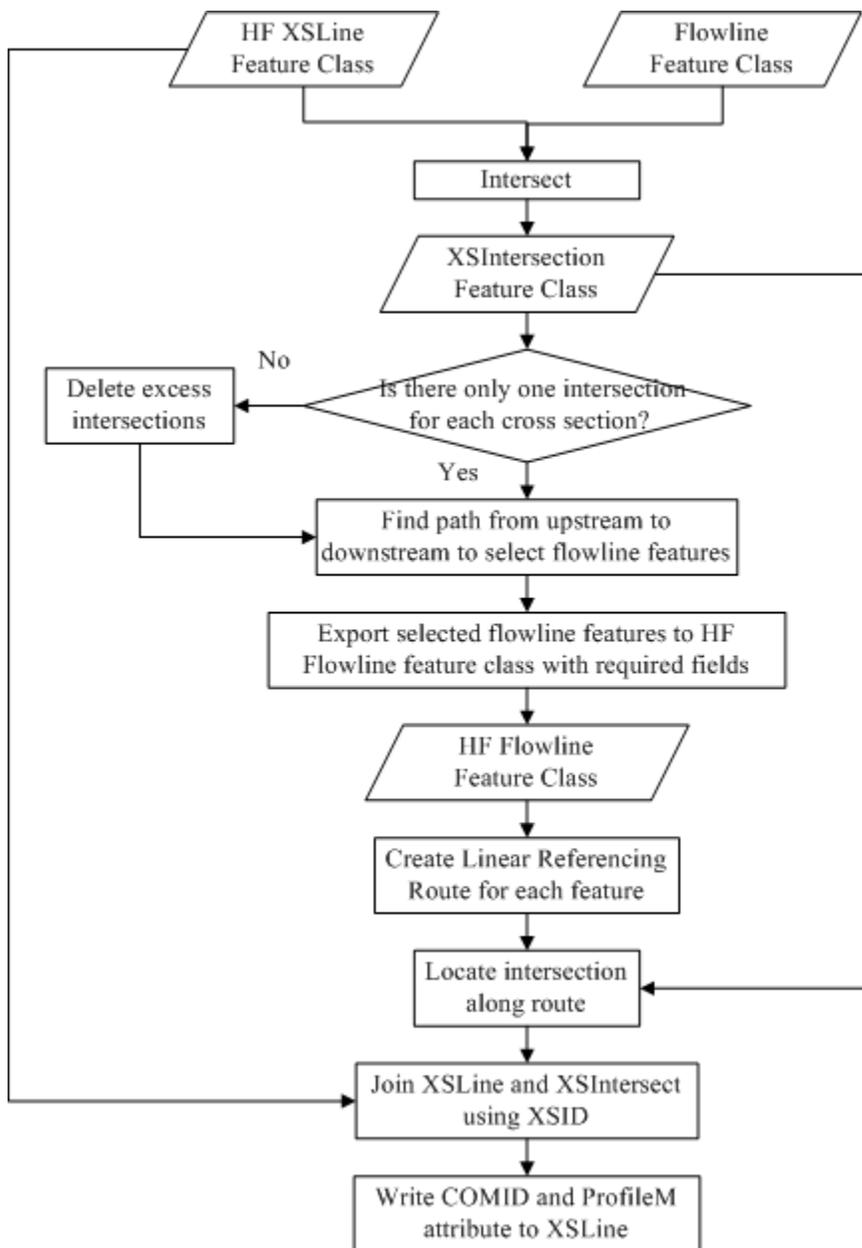


Figure 22 Flowchart of Locating XSLine

### ***Populating Remaining XSLine and XSPoint Attributes***

The XSLine attributes COMID and ProfileM were assigned in the process of locating XSLine features on the river network. The next step is to populate the remaining fields in XSLine as well as fields in XSPoint.

To calculate NextXS, LengthDown, and SlopeDown attributes for cross section lines, the Flowline features must be split using the intersection created by last tool. Then a geometric network is constructed using the split flowlines and the intersections so that the intersection topological relationships can be determined and the river length between neighboring cross sections calculated. To get the mean slope of river segment between two cross sections, the minimum elevation values from the related cross section points are used along with the calculated river length. The minimum elevation value for all points with the same XSID is used as the minimum elevation of each cross section line.

To make a raw cross section points feature class compliant with the Hydraulic Fabric XSPoint feature class, several attributes must be computed if not already present. PointX, PointY, PointZ attributes can be computed using standard GIS tools such as the Calculate Geometry tool in ArcGIS. If XSPoint does not already include an attribute linking each point to its cross section line, then it must be computed. If cross section points are spatially coincident with cross section lines, a spatial join intersecting the two datasets can be used to link them. If cross section lines are straight lines drawn arbitrarily among a “cloud” of channel survey points, distance between cross section points and lines must be calculated. Point that falls into a preset range around a certain line will be given the same XSID attribute as the cross section line.

Once the minimum elevation has been decided using either cross section line data or cross section point data, river segment mean slope between two adjacent cross

sections, dividing the elevation difference between upstream and downstream cross sections by river length. The flowchart of the whole process is shown in Figure 23.

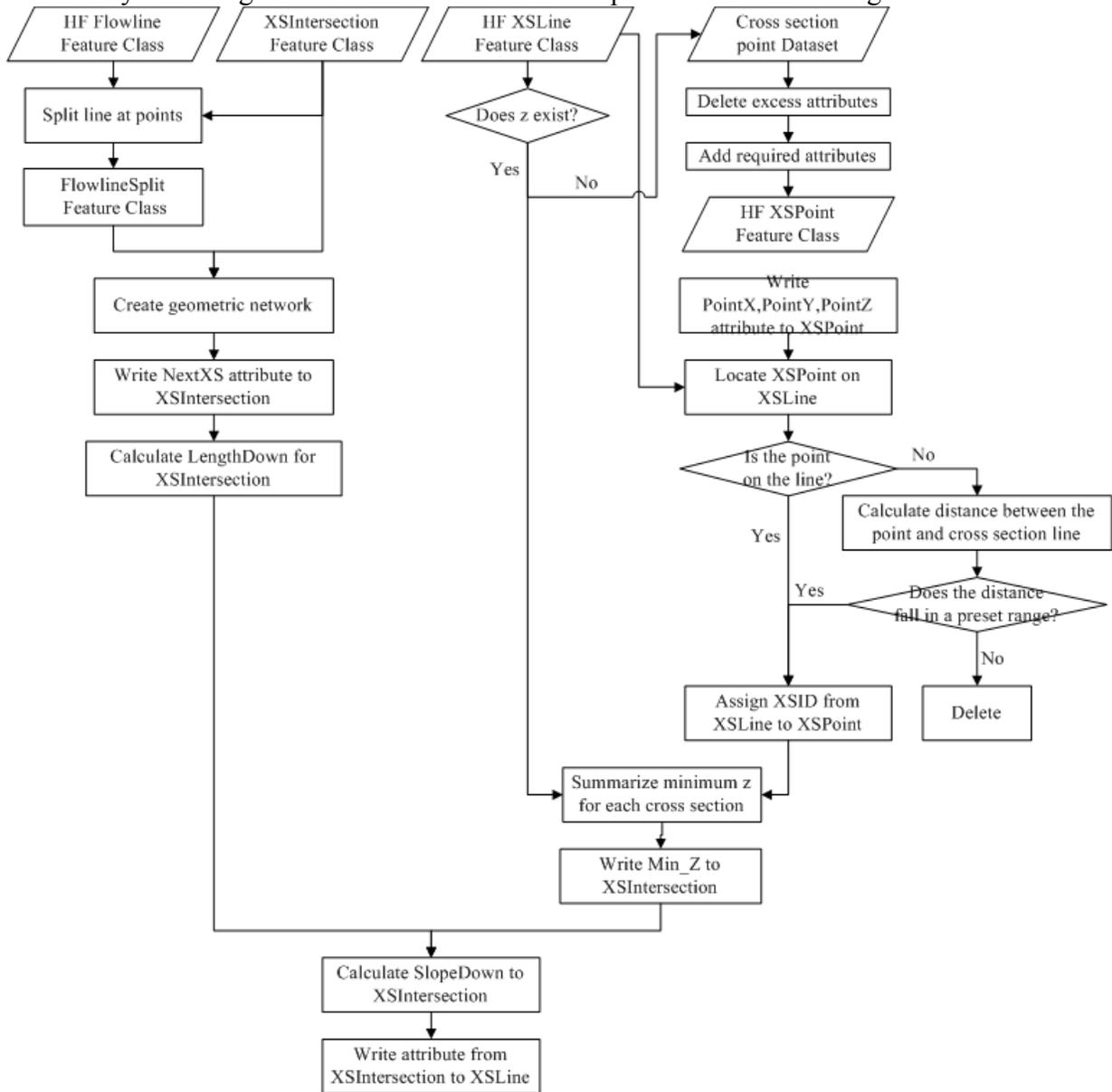


Figure 23 Flowchart for Populating XSPPoint and XSLine attributes

### ***Locating Cross Section Points on Cross Section***

The process to locate cross section points on a cross section line is very similar to that of locating cross section lines on the river network. The only difference is at the beginning of this process, the digitized direction of cross section lines needs to be checked to make sure each line follows the convention of lines being drawn from left to right when facing downstream. This is required for proper linear referencing of points on cross section lines. If the cross section direction is opposite the predefined direction, then it must be flipped. Then a linear referencing route is set up for every cross section line with its first vertex as the origin. The route measures being with zero and end with the length of the cross section polyline.

To locate cross section points on the line, one must consider whether the point is spatially coincident with the line. If the point falls exactly on the line, its measure coordinate is its distance to the beginning of the line along the line. Otherwise, the nearest location on the line from the point location is used to compute the measure coordinate. The flowchart of this process is shown in Figure 24.

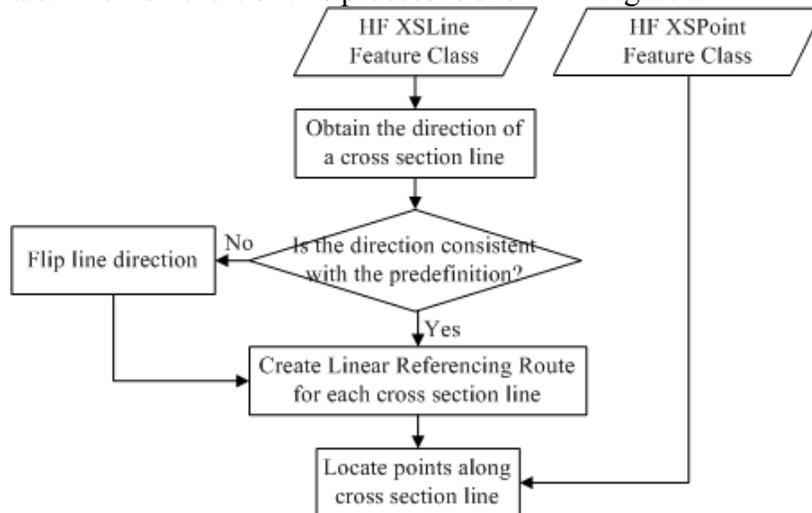


Figure 24 Flowchart for Locating XSPoint

### ***Transform HEC-RAS Geometry Data into Hydraulic Fabric***

Since HEC-RAS is widely used by the engineering community for local hydraulic modelling, putting HEC-RAS river channel data into the framework of Hydraulic Fabric is a good use case for Hydraulic Fabric implementation.

In HEC-RAS, all cross section line data in a project can be exported to a shapefile, a popular geospatial vector data format for GIS software. Then it can be transformed into Hydraulic Fabric XSLine feature class following the steps described in “Locating Cross Sections on River Network” section. One thing needs to be emphasized here is that most of the attributes in the original table of these shapefiles will be deleted or recalculated. Because these hydraulic models are developed by different organizations separately, each of them may have individual requirements for the fields appearing in their cross section table. It is impractical to keep values of these attributes in a universal data framework. For example, there are nineteen hydraulic models just for the part of Onion Creek Watershed in Travis County (Figure 25). Both the name and meaning of attributes in the Williamson Creek cross section line table and the Onion Creek cross section line table are quite different from each other (Figure 26). Hence unnecessary attributes will be deleted. However, the information stored in these fields still can be derived using the geometry data stored in Hydraulic Fabric following the workflow like the “Populating XSLine and XSPoint Attributes” tool.

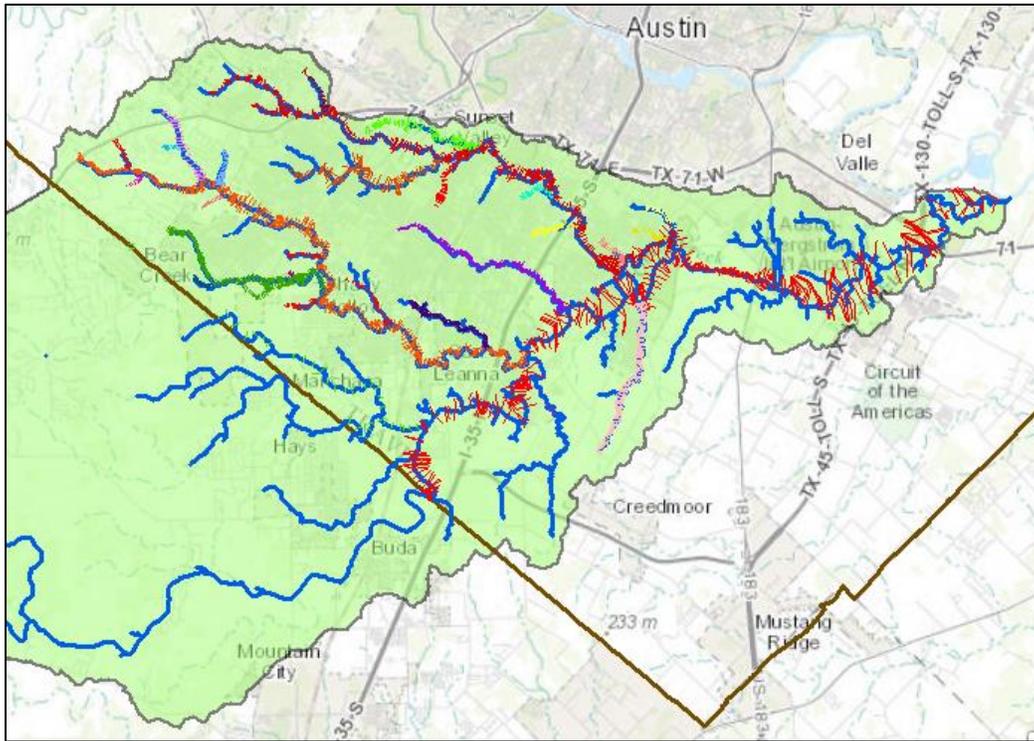


Figure 25 Cross Sections Extracted from Available Hydraulic Models for Onion Creek Watershed in Travis County

Fields in Williamson Creek Cross Section Table	Fields in Onion Creek Cross Section Table
<input checked="" type="checkbox"/> OBJECTID	<input checked="" type="checkbox"/> OBJECTID
<input checked="" type="checkbox"/> Shape	<input checked="" type="checkbox"/> Shape
<input checked="" type="checkbox"/> STREAM_ID	<input checked="" type="checkbox"/> FID_1
<input checked="" type="checkbox"/> REACH_ID	<input checked="" type="checkbox"/> SID
<input checked="" type="checkbox"/> SR_ID	<input checked="" type="checkbox"/> SRSID
<input checked="" type="checkbox"/> INTERP	<input checked="" type="checkbox"/> Length
<input checked="" type="checkbox"/> STATION	<input checked="" type="checkbox"/> River
<input checked="" type="checkbox"/> Shape_Length	<input checked="" type="checkbox"/> Reach
	<input checked="" type="checkbox"/> RiverStatioC
	<input checked="" type="checkbox"/> LBank
	<input checked="" type="checkbox"/> RBank
	<input checked="" type="checkbox"/> Shape_Length

Figure 26 Fields in Cross Section Table from Two HEC-RAS Models

For cross section point points, HEC-RAS has no option to get the coordinates for every cross section station point. So the only way to create HF XSPoint features from HEC-RAS cross section station points is to combine the geospatial information of the cross section line and the station-elevation table of that cross section, and then interpolate locations along the line.

HEC-RAS uses coordinates of “control points” to georeference a cross section line. For instance, knowing the geographic (x, y) coordinates of two points, the start and the end, is enough to locate a straight cross section line. If the length of the cross section line is equal to the station value of the farthest station point, the (x, y) coordinates of every station point in the station-elevation table can be determined by interpolating between the coordinates of the start and the end. If the cross section line length is different from the largest station value, the ratio between them is multiplied with the station values to extend or compress the station-elevation table to fit the actual length of the cross section. A similar process can be carried out for multi-segmented lines. If the station value falls into the range between cumulative segment lengths of two neighboring control points, the coordinates of that station point will be interpolated using these two points.

## **HYDRAULIC FABRIC-RATING**

In this section, the rating curve component of Hydraulic Fabric is described, which is an information framework to store the rating curve information for cross sections. The operating principle of a tool, which is designed to export rating curve data from HEC-RAS and put them into Hydraulic Fabric-Rating framework, is also expounded.

### **Information framework**

As mentioned in Chapter Two, there are three methods popular for storing rating curve information: table, equation, and graphic. In Hydraulic Fabric, a single rating table will be created for each cross section. Several reasons support the table option instead of equation or graphic. First, a table is a much more common format used in data management. Second, there are a number of equation formats that can be used to fit the rating curve, such as power function and parabolic function. However, none of them meets the requirement that the Hydraulic Fabric should be universally applicable to all cross sections. Also, the data model, and in particular table fields, would likely need to be customized for different fitting function types. Third, a table is compatible with how rating curves are stored in other systems like HEC-RAS. It is more straightforward for implementation to transfer the data stored in one table to another table.

Below is the design of Hydraulic Fabric-Rating:

Table 6 Hydraulic Fabric-Rating Table Fields

<b>Field Name</b>	<b>Data Type</b>	<b>Description</b>	<b>Minimum Value Required</b>
XSID	String	Unique identifier of the XSLine feature	--
H	Double	Water surface elevation above river bed (gage height)	Zero
Z	Double	Water surface elevation above geodetic datum (mean sea level)	No limit
Q	Double	Discharge	Zero
R	Double	Return Period	--

To link the rating component to the geospatial component, XSID is adopted as the rating table name. There are four fields in the table. Two kinds of vertical elevation are kept in this table. Gage height (water surface elevation above river bed) is useful for local flood warning and flood damage evaluation, while water surface elevation above geodetic datum (mean sea level) is useful for flood inundation mapping over a large area. Return period is also added here to connect water surface elevation and discharge together with hydrologic frequency analysis results, and help people have a better understanding of the flood scale they are facing. Gage height and discharge data are required to start from zero so that the lower boundary of the interpolation is fixed, and unreasonable values can be avoided.

## Tools

### *Exporting HEC-RAS Rating Curve to Hydraulic Fabric*

A HEC-RAS plan composed of several profiles (flow conditions) will generate a rating table and a corresponding rating curve for each cross section by sorting elevation-discharge data pairs of that cross section calculated under different flow conditions in ascending order. Values in these tables can be copied from the HEC-RAS user interface individually for each cross section. Or rating tables for all the cross sections in one plan can be exported to a HEC-DSS (Hydrologic Engineering Center Data Storage System) database file with a “dss” extension.

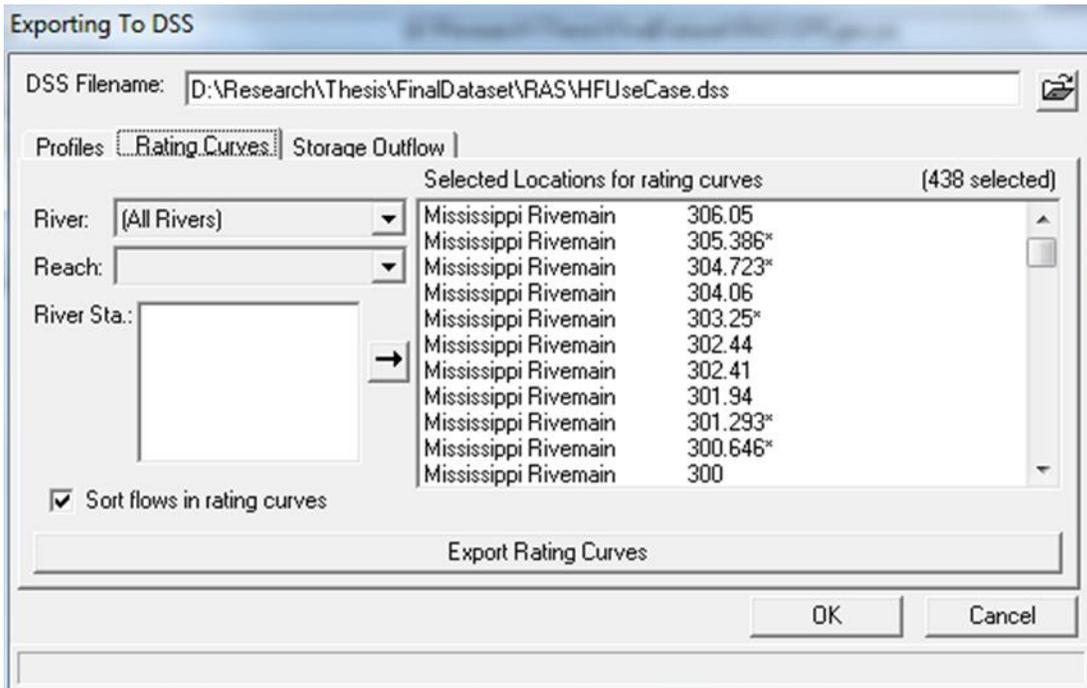


Figure 27 Exporting HEC-RAS Rating Curve to HEC-DSS

For the rating tables stored in HEC-DSS file, there are two fields with default names in each table. The ELEV field represents what is defined as gage height here, and the FLOW field represents the discharge. Since HEC-DSS is not a popular format for

data storage outside of the HEC software system. It is quite necessary to figure out an approach to transform the rating tables in a HEC-DSS file to a more generic data format. An application named DSS Utility Program (DSSUTL) can help to deal with that.

Relying solely on the data available in the DSS file is not enough to create a Hydraulic Fabric rating table. An elevation-discharge pair (0, 0) must be added at the beginning of the stage height-discharge data sequence. Also, since Hydraulic Fabric requires water surface elevation above mean sea level, the minimum channel elevation must be extracted from HEC-RAS for every cross section. To realize this process automatically, the HEC-RAS application program interface (API), HECRASController, must be applied. Then water surface elevation can be calculated for every cross section combining stage height and river bed elevation. For the return periods, HEC-RAS does not need that information for its hydraulic computation, so a hydrologic frequency table or function is another necessary input. In our case, the problem is solved in a simplified way. By naming HEC-RAS profiles using the return periods of those flow conditions, we can obtain that information from profile names and write them into the Hydraulic Fabric rating table.

## **Chapter 4: Implementation Process and Results**

This chapter first introduces some basic information about the working environment and test dataset that are used for implementing the conceptual data model and tools discussed in Chapter 3. Then the implementation process of building the database and the result of customized tools are presented.

### **IMPLEMENTATION ENVIRONMENT AND DATASET**

The GIS platform that is used to implement Hydraulic Fabric data model is ArcGIS. Customized tools are developed combining various programs, including ArcGIS ModelBuilder, Python scripts, and VBA (Visual Basic for Applications). An ArcGIS toolbox named NFIE-River is developed as a collection of these tools.

Cross section lines and points datasets are given by the Coastal and Hydraulics Laboratory of US Army Engineer Research and Development Center. A bathymetric survey cross section dataset and a HEC-RAS model for the same river segment of the Lower Mississippi River from Tarbert Landing to Venice, LA are used as a case study to test the functionality of the data model and the tools. is the map of the study river segment.



Figure 30 is the distribution of bathymetric points on a part of one cross section line. In the bathymetric survey dataset, each cross section line has been assigned a unique identifier. The same identifier is also given to the points on each line to show the connection between line and point.

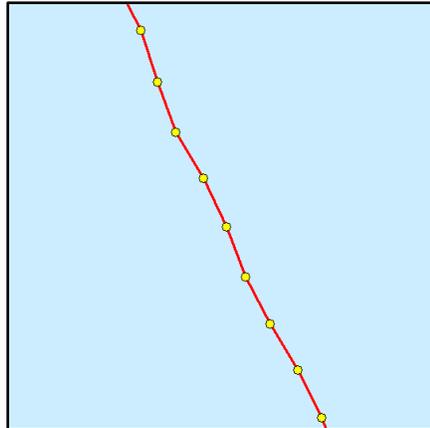


Figure 30 Bathymetric Points on Cross Section Line

For HEC-RAS, there is no cross section point geospatial data available in its I/O information flow. Therefore one of the tasks in this thesis is to find a way to generate these cross section points using the cross section line geospatial information and station-elevation table of the same cross section.

The Flowline feature class used in this case study is the NHDPlus 100K (Medium Resolution) flowline dataset for Lower Mississippi region. Two things need to be pointed out to when Hydraulic Fabric is implemented using NHD flowline dataset. First, all the attributes required by Hydraulic Fabric are available for every flowline in the NHD flowline attribute table. Therefore, they are all shifted directly from NHDPlus to Hydraulic Fabric. Second, instead of calculating river segment average slope between two adjacent cross sections following the workflow described in Chapter 3, the slope attribute of the NHD flowline, which the cross section line intersects with, will be

inherited as the SlopeDown attribute for that cross section line. If the cross section intersection is a confluent point in the river network, the slope of the downstream flowline will be adopted for the cross section line.

## IMPLEMENTATION PROCESS AND RESULTS

### Locating Cross Sections on NHD River Network

When cross section data are collected, the first step when building a Hydraulic Fabric-Geo dataset is to identify corresponding NHD flowlines for these cross sections.

#### *Identify Flowline for Study River Segment*

To identify relevant flowlines, project the cross section line features and NHD flowline features into the same coordinate system, and then run the “CreateIntersection” tool in the NFIE-River toolbox. A point feature class containing all the intersections between the cross section lines and NHD flowlines is created.

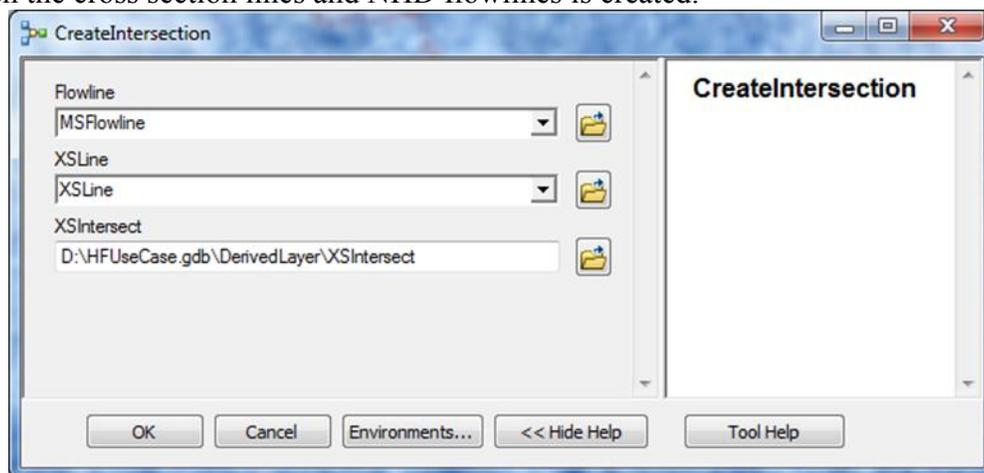


Figure 31 Create Intersection Tool

For 173 cross section lines in this dataset, 186 intersections are created in the intersection feature class.

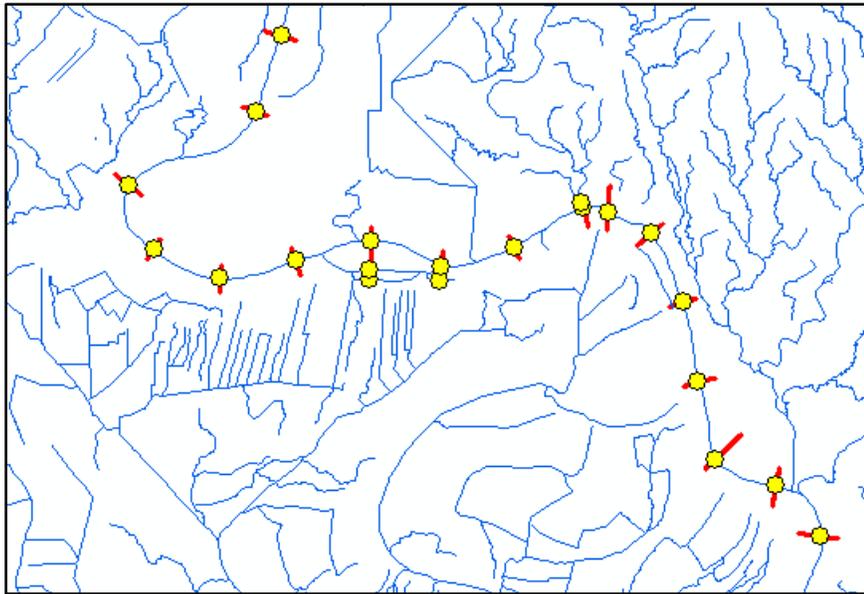


Figure 32 Intersections between Cross Section Lines and Flowlines

When a cross section intersects the flowline dataset more than once, the cross section identifier and the number of extra intersections are reported as an output of this tool.

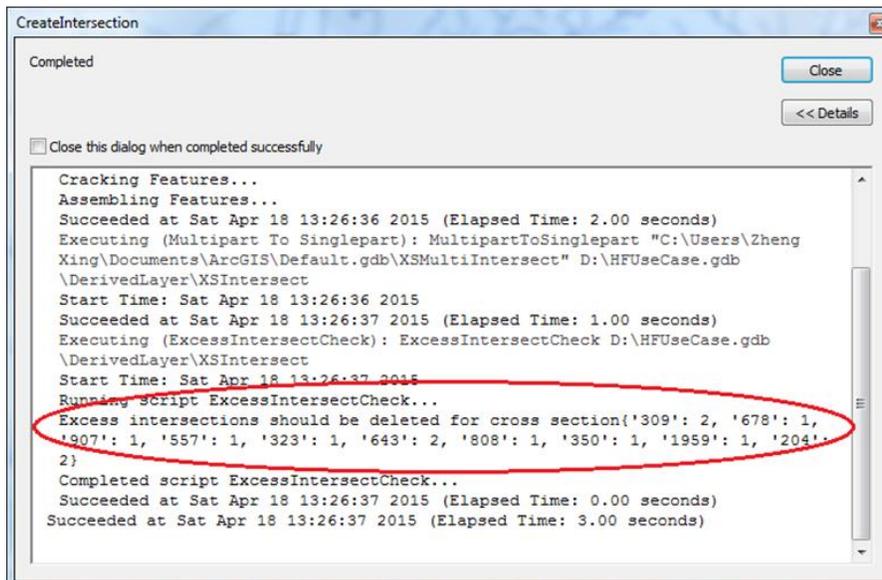


Figure 33 Report for Extra Intersections

Then these extra intersections need to be deleted manually. The reason why this step is not carried out programmatically is that an approach to identify the relevant intersection often requires higher level decision making that is difficult to program. Figure 34 is the implementation of “CreateIntersect” tool using ArcGIS model builder.

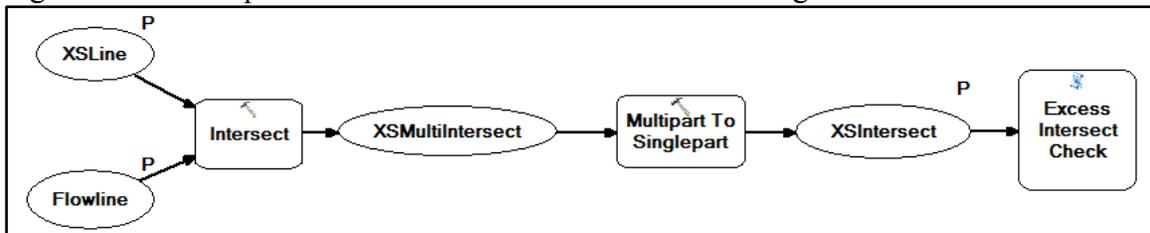


Figure 34 Implementation of CreateIntersection Tool

After the intersections are created, a geometric network is created using original NHD flowlines. Then a “find path” trace task is carried out on this network using intersections as the junction flags to identify the flowlines of the study region. This process is implemented by the “IdentifyFlowline” tool. Results of this tool are shown in Figure 35.

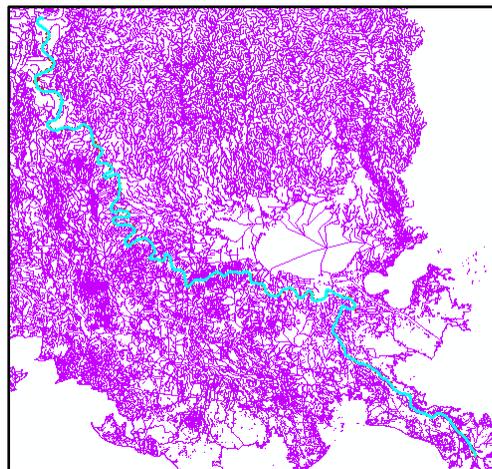


Figure 35 Identified Flowlines

## Hydraulic Fabric-Geo Framework Generation

After the flowlines are identified, they are exported to a new Hydraulic Fabric Flowline feature class. There are a lot of metadata fields in the table of NHD flowline features. In order to simplify the table structure, these original fields are deleted and Hydraulic Fabric required fields are added to the table of the new feature class. A similar process is carried out for the original cross section line and point feature classes. Hence, three tools named “FlowlineAttributeCalculator”, “XSLineAttributeCalculator”, “XSPointAttributeCalculator” are developed. Figure 36, Figure 37, Figure 38, and Figure 39 are the run results of these three tools.

OBJECTID_1	Shape	OBJECTID	COMID	FDATE	RESOLUTION	GNIS_ID	GNIS_NAME	LENGTHK
1	Polyline ZM	61059	2281202	2009/9/21	Medium	1629903	Mississippi River	1.307
109	Polyline ZM	62758	2281446	2009/9/21	Medium			.961000
115	Polyline ZM	62767	2281204	2009/9/21	Medium	1629903	Mississippi River	3.97
116	Polyline ZM	62768	2281203	2009/9/21	Medium	1629903	Mississippi River	8.673
117	Polyline ZM	62769	2281203	2009/9/21	Medium	1629903	Mississippi River	3.526
150	Polyline ZM	76774	2281195	2009/9/21	Medium	1629903	Mississippi River	7.594
249	Polyline ZM	77402	2281463	2009/9/21	Medium	1629903	Mississippi River	7.031
250	Polyline ZM	77403	2281192	2009/9/21	Medium	1629903	Mississippi River	7.023

Figure 36 Attributes Table of NHDFlowline Features

OBJECTID_1	Shape	COMID	FromNode	ToNode	FromMeas	ToMeas	Shape_Length	ReachCode
1	Polyline ZM	22812021	350101423	350101433	0	100	4289.220915	08090100001191
2	Polyline ZM	22814467	350101210	350101209	0	100	3154.790237	08090100001178
3	Polyline ZM	22812041	350101439	350101210	0	100	13030.428936	08090100001205
4	Polyline ZM	22812037	350101433	350101437	28.91894	100	28456.186407	08090100001206
5	Polyline ZM	22812035	350101437	350101439	0	28.91894	11574.520443	08090100001206
6	Polyline ZM	22811951	350101404	350101423	0	35.09404	24918.144229	08090100001207
7	Polyline ZM	22814637	350100710	350101391	67.52728	100	23064.497378	08090100001207
8	Polyline ZM	22811921	350101391	350101404	35.09404	67.52728	23036.925574	08090100001207
9	Polyline ZM	22811923	350101392	350101494	6.24274	21.72263	51345.387072	08090100001208

Figure 37 Attributes Table of Hydraulic Fabric Flowline Features

OBJECTID *	Shape *	XSID *	Shape_Length	COMID	ProfileM	NextXS	LengthDown	SlopeDown
1	Polyline ZM	106	4667.821308	<Null>	<Null>	<Null>	<Null>	<Null>
2	Polyline ZM	354	6132.990851	<Null>	<Null>	<Null>	<Null>	<Null>
3	Polyline ZM	604	4992.129823	<Null>	<Null>	<Null>	<Null>	<Null>
4	Polyline ZM	965	4850.001392	<Null>	<Null>	<Null>	<Null>	<Null>
5	Polyline ZM	1075	3967.767177	<Null>	<Null>	<Null>	<Null>	<Null>
6	Polyline ZM	1175	3860.000504	<Null>	<Null>	<Null>	<Null>	<Null>
7	Polyline ZM	1231	3854.867445	<Null>	<Null>	<Null>	<Null>	<Null>

Figure 38 Attributes Table of Hydraulic Fabric XSLine Feature

OBJECTID *	Shape *	XSID	PointX	PointY	PointZ	PointM	Position
1	Point ZM	106	3179805.050132	898582.599931	43.57	<Null>	<Null>
2	Point ZM	106	3179755.08993	898580.729856	42.37	<Null>	<Null>
3	Point ZM	106	3179738.100135	898580.090093	42.67	<Null>	<Null>
4	Point ZM	106	3179705.119886	898578.849938	45.67	<Null>	<Null>
5	Point ZM	106	3179678.139953	898577.840098	47.77	<Null>	<Null>
6	Point ZM	106	3179655.160012	898576.979863	47.77	<Null>	<Null>
7	Point ZM	106	3179605.189967	898575.099946	47.47	<Null>	<Null>

Figure 39 Attributes Table of Hydraulic Fabric XSPoint Feature

### ***Locating Cross Section Lines on Flowlines***

The flowchart of “locating cross sections on NHD river network” tool will be realized using ArcGIS ModelBuilder, taking the XSLine, XSIntersect, and Flowline feature classes. The user interface of the the “LocateXSAlongFlowline” tool is shown in Figure 40 and Figure 41.

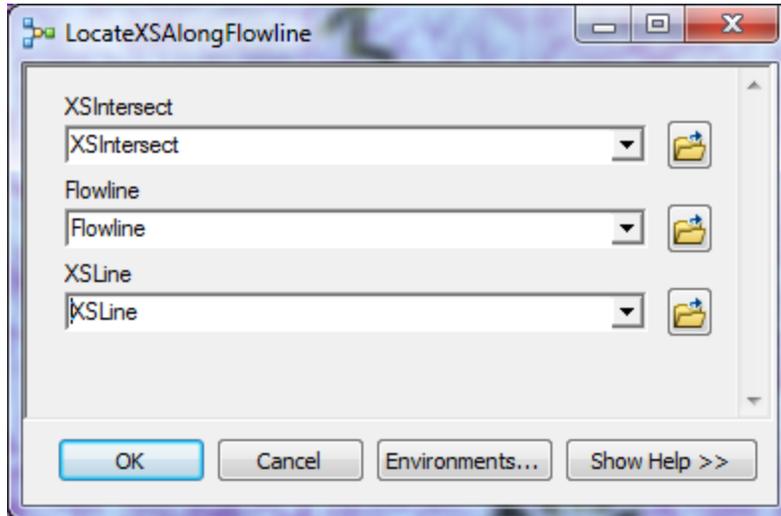


Figure 40 Inputs of Locating XSLine Tool

OBJECTID	Shape	XSID	Shape_Length	COMID	ProfileM	NextXS	LengthDown	SlopeDown
1	Polyline ZM	106	4667.821308	19085399	77.159295	<Null>	<Null>	<Null>
2	Polyline ZM	354	6132.990851	19085479	94.779085	<Null>	<Null>	<Null>
3	Polyline ZM	604	4992.129823	19088319	3.985535	<Null>	<Null>	<Null>
4	Polyline ZM	965	4850.001392	19086175	94.953369	<Null>	<Null>	<Null>
5	Polyline ZM	1075	3967.767177	19088125	57.989476	<Null>	<Null>	<Null>
6	Polyline ZM	1175	3860.000504	19086183	18.234248	<Null>	<Null>	<Null>
7	Polyline ZM	1231	3854.867445	22799303	91.522631	<Null>	<Null>	<Null>

Figure 41 Output of Locating XSLine Tool

Now the COMID and ProfileM fields have been populated for every cross section line. The COMID of XSLine is the same as that of the Flowline it intersects with, and the ProfileM falls in the range between the measure values of the Flowline start and end points. (Measure values increase from downstream end to upstream end.)

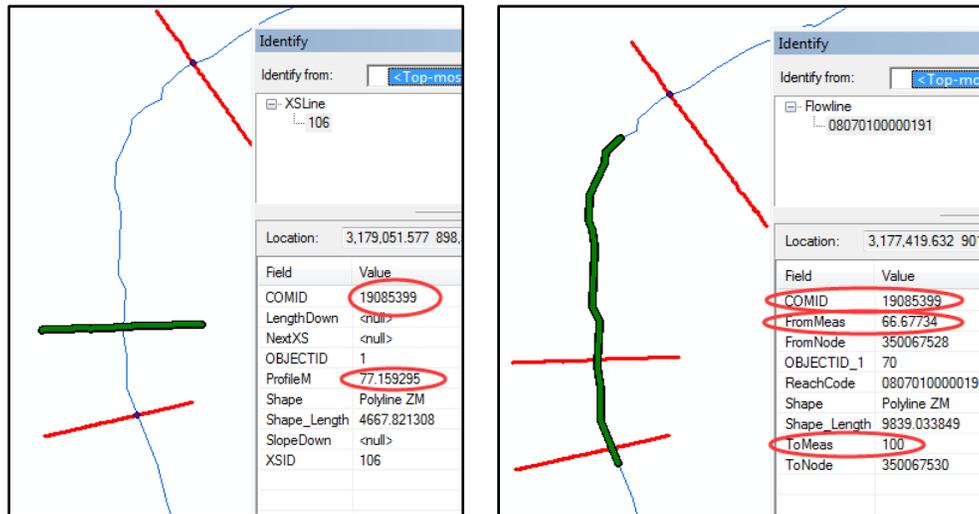


Figure 42 Mapping of COMID and Measure between XSLine and Flowline

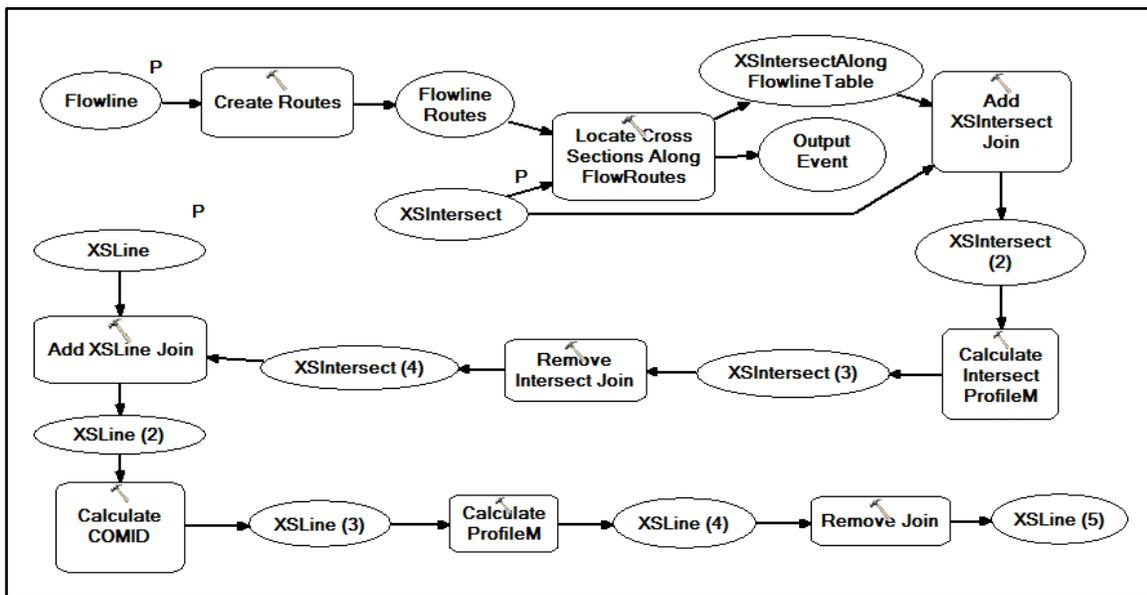


Figure 43 Realization of Locating XSLine Tool in ArcGIS Model Builder

### Populating XSLine Attributes

After the framework of Hydraulic Fabric has been set up and cross section lines have been located on the rivers, the next step is to populate NextXS (XSID of next downstream cross section), LengthDown (river length between two adjacent cross

sections) and SlopeDown (mean river bed slope between two adjacent cross sections) attributes for XSLine features. The first step to calculate them is to split flowlines using the intersections. Then a geometric network is created with the split flowlines as simple edges and intersections as simple junctions. Once flow direction is set, upstream and downstream relationships can be established and river length to the outlet can be calculated for intersections using the Arc Hydro tools. Through a join operation between the XSLine table and the XSIntersect table, NextXS and LengthDown fields will be filled. To obtain the SlopeDown attribute, the minimum elevation value needs to be determined for every cross section. SlopeDown equals the difference of minimum elevation between two adjacent cross sections divided by the river length between them. Output of this tool is shown as Figure 44.

OBJECTID	Shape	XSID	Shape_Length	COMID	ProfileM	NextXS	LengthDown	SlopeDown
1	Polyline ZM	106	4667.821308	19085399	77.159295	109	2631.083298	.000003
2	Polyline ZM	354	6132.990851	19085479	94.779085	364	6786.504844	.000027
3	Polyline ZM	604	4992.129823	19088319	3.985535	607	2653.590435	-.000002
4	Polyline ZM	965	4850.001392	19086175	94.953369	976	9237.574317	.000038
5	Polyline ZM	1075	3967.767177	19088125	57.989476	1080	4992.440436	.000045
6	Polyline ZM	1175	3860.000504	19086183	18.234248	1178	3599.480985	.000004
7	Polyline ZM	1231	3854.867445	22799303	91.522631	1236	5498.618686	.000002
8	Polyline ZM	1351	3920.993143	22799307	27.250292	1356	4908.220748	-.000003
9	Polyline ZM	1424	4200.001209	22814607	6.918456	1426	2051.059354	.000046

Figure 44 Output of XSLine Attributes Populate Tool

### Locating Cross Section Points on Cross Section

Similar to the Locating XSLine tool, the “LocatePointAlongXSLine” tool is also developed using ArcGIS ModelBuilder. The output and workflow steps of this tool are shown in Figure 45, Figure 46, and Figure 47.

OBJECTID	Shape	XSID	PointX	PointY	PointZ	PointM	Position
1	Point ZM	106	3179805.050132	898582.599931	43.57	0	<Null>
2	Point ZM	106	3179755.08993	898580.729856	42.37	49.9952	<Null>
3	Point ZM	106	3179738.100135	898580.090093	42.67	66.997	<Null>
4	Point ZM	106	3179705.119886	898578.849938	45.67	100.0006	<Null>
5	Point ZM	106	3179678.139953	898577.840098	47.77	126.9994	<Null>
6	Point ZM	106	3179655.160012	898576.979863	47.77	149.9954	<Null>
7	Point ZM	106	3179605.189967	898575.099946	47.47	200.0008	<Null>
8	Point ZM	106	3179555.230094	898573.229871	46.47	249.9957	<Null>
9	Point ZM	106	3179505.260049	898571.360124	45.77	300.0007	<Null>

Figure 45 Output of Locating XSPoint Tool

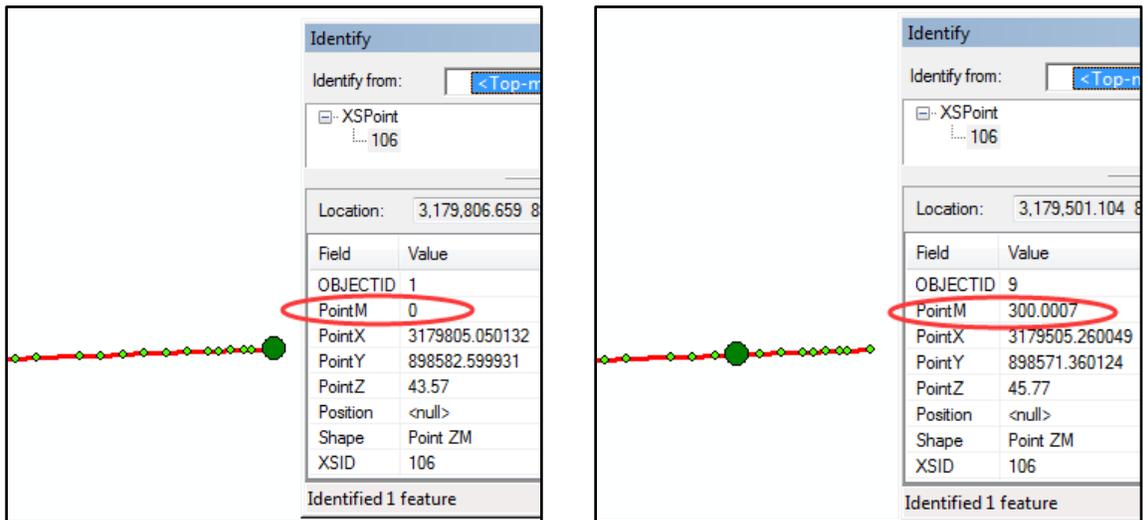


Figure 46 Points' Locations on XSLine

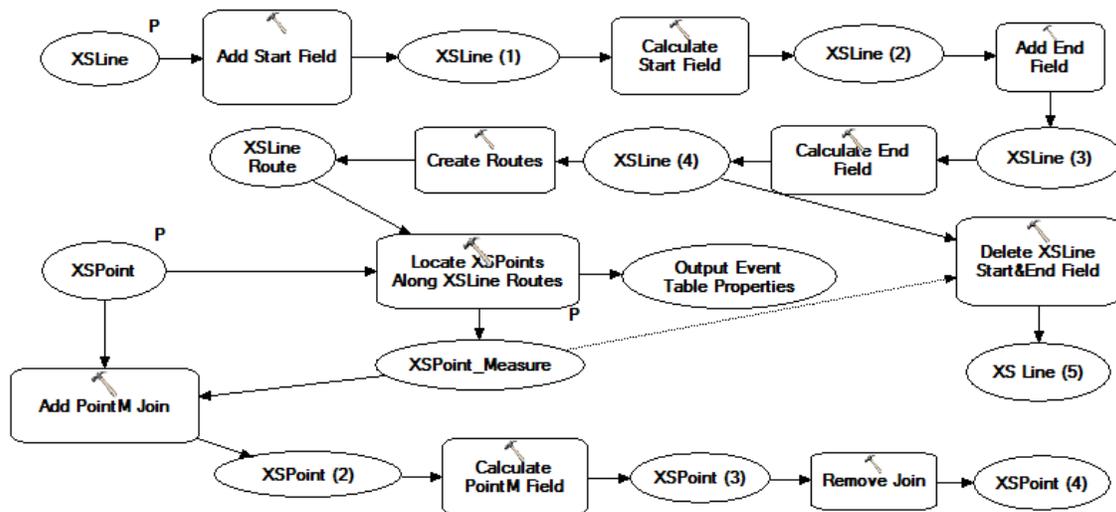


Figure 47 Workflow of Locating XSPoint Tool in ArcGIS Model Builder

### Generating Hydraulic Fabric XSPoint Features from HEC-RAS

Geometric data for every cross section that HEC-RAS uses are all stored in a text file with a name like \*.g0\*, including the geographic coordinates of control points on a cross section line and a station-elevation table.

For example, Figure 48 demonstrates all the geometry data HEC-RAS used for the cross section at river station 306.05 on the Mississippi River. There are 10 pairs of control point (x, y) coordinates in this file describing the location of the cross section line, and there are 60 station points in this file describing the shape of the cross section. The first step of this workflow is to extract this information from a HEC-RAS geometry file, which is done by a VBA module named XSGeometryReader. It takes a RAS geometry file as the input, searches for some predefined keywords to locate these data in the input, and writes them to separate output text files. In this case, a text file named “XSGIS.txt” is generated to store control point coordinates, and another file named “XSGeometry.txt” is generated to store station-elevation tables.

```

Type RM Length L Ch R = 1 ,306.05 ,3784.23,3566.72,3798.47
XS GIS Cut Line=10
3192627.86110057,905052.46691224,3191340.48408216907129,341695488
3189963.70009032909397,1399814043189914,71987332909447,860024318
3189535.42010699910118,4400479943189284,24016316910506,220112324
3188500.07014357911831,9500724083188391,38991474911978,700106993
3188053.90010415912529,5999238193186487,23296191,915121.12098749
Node Last Edited Time=Nov/29/2012 14:23:41
#Sta/Elev=60
0,50.69,165.13,49.79,286.69,59.89,400.78,59.76,636.44,41.69
864.63,47.4,1289.48,48.18,1486.14,41.23,1741.3,48.15,2181.07,43.05
2397.23,47.92,2463.51,40.82,2863.51,43.66,3023.51,48.06,3308.5,49.22
3628.5,47.09,3688.5,43.78,4088.5,42.04,4133.5,48.85,4228.49,43.48
4853.49,47.91,4975.5,51.45,5006.49,39.95,5169.42,5.74,5520.15,-.76
5800.33,7.04,6052.46,7.94,6220.65,3.33,6501.45,2.73,6598.96,6.33
6963.9,-.47,7090.01,1.43,7369.45,-8.47,7481.83,-9.17,7607.53,-3.27
7747.77,-11.27,7776.22,-2.87,7972.1,-8.57,8127.28,-1.57,8197.37,-7.07
8507,-14.08,8633.51,-24.18,8731.86,-15.28,8801.91,-.08,8848.29,29.79
8948.3,45.74,9253.29,47.94,9433.3,52.5,9463.3,60.55,9553.3,47.64
9753.3,43.39,9953.3,45.78,10033.3,51.03,10073.3,38.2,10378.3,49.5
10458.3,70.37,10568.3,51.83,10708.3,48.9,11593.3,46.83,11803.3,44.31
#Mann=3,0,0
0,.17,0,4975.5,.026,0,9463.3,.17,0
Levee=-1,286.69,94.25,-1,10458.3,94.25,Levee 1,Levee 2
#XS Ineff=2,0
0,4947.46,51.65,9456.81,0,60.24
Permanent Ineff=
F
Bank Sta=4975.5,9463.3
XS Rating curve=0,0
XS HTab Starting El and Incr=-23.68,3,100
Exp/Cntr=.37,.014

```

Figure 48 Geometry Data for One Cross Section

XSGIS.txt - Notepad

```

File Edit Format View Help
River Name=Mississippi Rive
Reach Name=main
RiverStation=306.05
XS GIS Cut Line=10
X,Y
3192627.86110057,905052.46691224
3191340.48408216,907129.341695488
3189963.70009032,909397.139981404
3189914.71987332,909447.860024318
3189535.42010699,910118.440047994
3189284.24016316,910506.220112324
3188500.07014357,911831.950072408
3188391.38991474,911978.700106993
3188053.90010415,912529.599923819
3186487.23296191,915121.12098749
RiverStation=305.386*
XS GIS Cut Line=21
X,Y
3189728.69826373,903413.814677745
3189629.61217582,903525.763600826

```

XSGeometry.txt - Notepad

```

File Edit Format View Help
River Name=Mississippi Rive
Reach Name=main
RiverStation=306.05
#Sta/Elev= 60
Station(ft),Elevation(ft)
0, 50.69
165.13, 49.79
286.69, 59.89
400.78, 59.76
636.44, 41.69
864.63, 47.4
1289.48, 48.18
1486.14, 41.23
1741.3, 48.15
2181.07, 43.05
2397.23, 47.92
2463.51, 40.82
2863.51, 43.66
3023.51, 48.06
3308.5, 49.22
3628.5, 47.09
3688.5, 43.78

```

Figure 49 Data Extracted from RAS Geometry File

Next, for each of these two files, separate text files are created such that each file only includes data for a single cross section. The “river-reach-river station” information of that cross section is used as the file name. The curvilinear length from start control point to every control point is also calculated for each cross section.

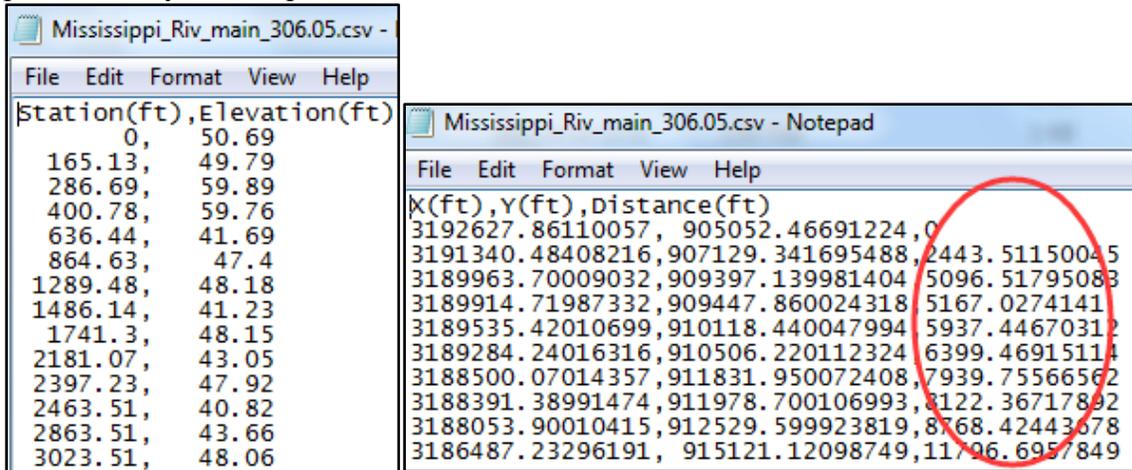


Figure 50 Geometry Data for Each Cross Section

Next the station-elevation table is stretched or compressed to fit the cross section length. Interpolating the control points, so the interpolated PointX and PointY attributes together with the original PointZ and PointM attributes of a HY XSPoint feature have been populated for all the station points on every cross section. The whole process is implemented in a python script named XSPoint.py.

Mississippi_Riv_main_306.05.csv - Notepad				
File Edit Format View Help				
PointX	PointY	PointZ	PointM	
3192627.86110057	, 905052.46691224	, 50.69000000	, 0.00000000	
3192540.86148260	, 905192.81997908	, 49.79000000	, 165.03760601	
3192476.81695065	, 905296.14050719	, 59.89000000	, 286.52959042	
3192416.70802789	, 905393.11187154	, 59.76000000	, 400.55575446	
3192292.54930464	, 905593.41226355	, 41.69000000	, 636.08389733	
3192172.32619058	, 905787.36349182	, 47.40000000	, 864.14621983	
3191948.49171050	, 906148.46686764	, 48.18000000	, 1288.75850658	
3191844.88034448	, 906315.61901519	, 41.23000000	, 1485.30847083	
3191710.44794260	, 906532.49352943	, 48.15000000	, 1740.32570300	
3191478.75278124	, 906906.27823364	, 43.05000000	, 2179.84964167	
3191364.86773660	, 907090.00450342	, 47.92000000	, 2395.88869523	
3191330.10581337	, 907146.43647601	, 40.82000000	, 2462.13161006	
3191122.52486435	, 907488.35773830	, 43.66000000	, 2861.90780096	

Figure 51 HF XSPoint Attributes for All Station Points

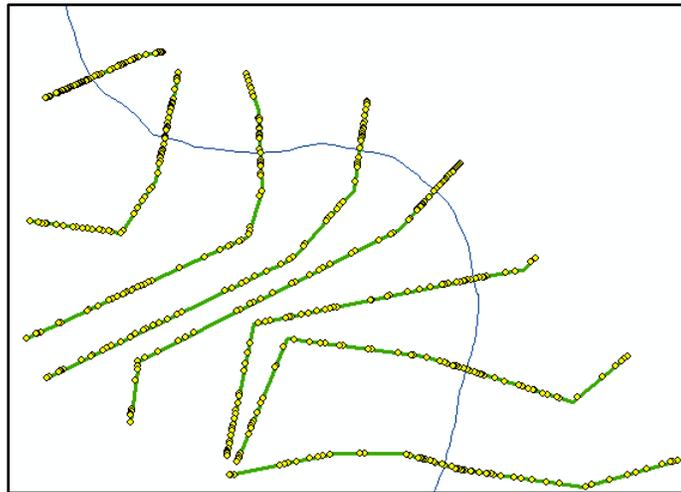


Figure 52 XSPoint Generated Using RAS Geometry Data

### Exporting HEC-RAS Rating Curve to Hydraulic Fabric

As mentioned in Chapter 3, rating curves for all cross sections are stored in a HEC-DSS file.

Number	Part A	Part B	Part C	Part D	Part E	Part F
329	MISSISSIPPI RIVE MAIN	302.44	ELEV-FLOW			HFUC
330	MISSISSIPPI RIVE MAIN	303.25*	ELEV-FLOW			HFUC
331	MISSISSIPPI RIVE MAIN	304.06	ELEV-FLOW			HFUC
332	MISSISSIPPI RIVE MAIN	304.723*	ELEV-FLOW			HFUC
333	MISSISSIPPI RIVE MAIN	305.386*	ELEV-FLOW			HFUC
334	MISSISSIPPI RIVE MAIN	306.05	ELEV-FLOW			HFUC
335	MISSISSIPPI RIVE MAIN	31.3066*	ELEV-FLOW			HFUC
336	MISSISSIPPI RIVE MAIN	31.97	ELEV-FLOW			HFUC
337	MISSISSIPPI RIVE MAIN	32.65*	ELEV-FLOW			HFUC
338	MISSISSIPPI RIVE MAIN	33.33*	ELEV-FLOW			HFUC
339	MISSISSIPPI RIVE MAIN	34.01	ELEV-FLOW			HFUC
340	MISSISSIPPI RIVE MAIN	34.69*	ELEV-FLOW			HFUC
341	MISSISSIPPI RIVE MAIN	35.37*	ELEV-FLOW			HFUC
342	MISSISSIPPI RIVE MAIN	36.05	ELEV-FLOW			HFUC
343	MISSISSIPPI RIVE MAIN	37.005*	ELEV-FLOW			HFUC
344	MISSISSIPPI RIVE MAIN	37.96	ELEV-FLOW			HFUC
345	MISSISSIPPI RIVE MAIN	38.6433*	ELEV-FLOW			HFUC
346	MISSISSIPPI RIVE MAIN	39.3266*	ELEV-FLOW			HFUC
347	MISSISSIPPI RIVE MAIN	40.01	ELEV-FLOW			HFUC

/MISSISSIPPI RIV...			
File Edit View Help			
Ordinate	ELEV	306.05	
		FLOW	
		306.05	
Labels			306.05
Units	FEET		
Type	ELEV	FLOW	
1	24.396	300000	
2	39.211	600000	
3	54.041	1000000	
4	60.578	1250000	
5	69.062	1640000	
6	78.049	2100000	

Figure 53 Rating Curve Stored in HEC-DSS

To read these data from a HEC-DSS file and write them to a text file, DSS Utility Program (DSSUTL) is needed. It is a command-prompt application, and is executed by entering its name. The program responds by asking for the name of the DSS file to access. After the DSS file name has been entered, the program gives the prompt “U>”, where the user enters commands. To terminate the session, the command FI is entered. However, there is a smarter way to manipulate DSSUTL. The commands can be specified in a separate input file, and the program run in a “batch mode”. To accomplish this, the DSS file name and commands are placed into a file. To execute the program with an input command file, enter:

DSSUTL INPUT=file-name

Hence, a python function is developed to create an input command file for DSSUTL, call the command shell, and then run DSSUTL in the shell with the input file.

The output of this function will be a text file holding data for all the rating curves stored in the original HEC-DSS file.

```

HFUseCase_dssoutput.txt - Notepad
File Edit Format View Help
/MISSISSIPPI RIVE MAIN/306.05/ELEV-FLOW//HFUC/
PD Ver: 1 Prog:Undefi LW:16APR15 22:14:08 Tag:T1 Prec:00
1 Curve(s), 6 Ordinates, IHORIZ: 2
First Var. Units: FEET Type: ELEV Second var. Units: CFS Type: FLOW
Label 1: 306.05
24.3961
39.2107
54.0407
60.5778
69.0623
78.0492
300000.0000
600000.0000
1000000.0000
1250000.0000
1640000.0000
2100000.0000
END DATA
/MISSISSIPPI RIVE MAIN/31.3066*/ELEV-FLOW//HFUC/
PD Ver: 1 Prog:Undefi LW:16APR15 22:14:08 Tag:T403 Prec:00
1 Curve(s), 6 Ordinates, IHORIZ: 2
First Var. Units: FEET Type: ELEV Second var. Units: CFS Type: FLOW
Label 1: 31.3066*
4.8993
7.3372
9.2280

```

Figure 54 Rating Curve Extracted from HEC-DSS

Now another function needs to be developed to obtain the minimum channel elevation for each cross section. To realize that, the HEC-RAS API—HECRASController is applied. So this function is written in VBA. The key function used in this process is `Output_NodeOutput`, which returns an output for a given cross section under a given flow condition. By calling this function for every cross section, minimum channel elevations can be extracted and written to another text file.

Location	Elevation (ft)	Channel Elevation (ft)
Mississippi Rive,main	306.05	-24.18
Mississippi Rive,main	305.386*	-33.14
Mississippi Rive,main	304.723*	-42.09
Mississippi Rive,main	304.06	-51.05
Mississippi Rive,main	303.25*	-44.85
Mississippi Rive,main	302.44	-38.64
Mississippi Rive,main	302.41	-39.02
Mississippi Rive,main	301.94	-44
Mississippi Rive,main	301.293*	-44.81
Mississippi Rive,main	300.646*	-45.63
Mississippi Rive,main	300	-46.44
Mississippi Rive,main	299.333*	-40.59
Mississippi Rive,main	298.666*	-34.75
Mississippi Rive,main	298	-28.9
Mississippi Rive,main	297.333*	-24.57

Figure 55 Minimum Channel Elevation for Every Cross Section Extracted with HECRASController

Finally, a python script is created to combine the data in these two text files and generate a rating curve for every cross section following Hydraulic Fabric-Rating data framework.

H(ft)	Z(ft)	Q(cfs)	R(yr)
0	-24.18	0	
48.5761	24.3961	300000	1
63.3907	39.2107	600000	2
78.2207	54.0407	1000000	5
84.7578	60.5778	1250000	10
93.2423	69.0623	1640000	100
102.2292	78.0492	2100000	500

Figure 56 Rating Curve of One Cross Section in Hydraulic Fabric-Rating Framework

## **Chapter 5: Conclusions and Discussion**

### **CONCLUSIONS**

As the title of this thesis indicates, the main contribution of this research is to explore a possible approach to weave the water data fabric for the whole country in a different direction. In the past, water data framework is mainly designed for describing “blue lines”, which are the flowlines following the flow direction of the river. NHDPlus dataset, or NFIE-Geo dataset specifically in NFIE project, is such a hydrologic fabric weaved for the whole country. However, no geospatial information framework exists for cross sections, which is the basic unit to organize river channel geospatial information perpendicular to flow direction. Hence, the hydraulic fabric is weaved up for river channels.

In this paper, we start from the need of such a cross section information framework in National Flood Interoperability Experiment. First, we review existing information models for river channels and figure out their advantages and limitations for implementation at a national scale in our case. Then we examine several popular hydraulic models, learn about their requirements of cross section data, and generalize the core concepts about cross sections, which lurk in various data formats. Depending on the results of harmonization study, we can up with the Hydraulic Fabric data framework shown in Chapter 3, where we put cross section geographic information, cross section geometric information, and cross section discharge-elevation relationship into an integrated system. Next we develop several tools to link the cross sections with the flowlines in river network, to calculate river segment parameters needed by hydraulic modelling, and to fit geometry data used by different hydraulic models into this unique information framework. These explorations will enormously benefit further efforts for creating an integrated cross section dataset for the whole country.

## DISCUSSION

There are several things to be considered for future research.

1. Mapping between Hydraulic Fabric framework elements and elements needed in different hydraulic models to test its functionality.
2. Develop more tools to transform common cross section geometry data format into Hydraulic Fabric framework. Create post-process tools for automatic cross section generation programs like GeoNet to store the cross sections they created in Hydraulic Fabric.
3. Develop tools to create cross sections from LIDAR (Light Detection And Ranging) point cloud dataset, and store them in Hydraulic Fabric.

As we mentioned before, there are several alternatives for the translation from discharge to water elevation. Which one should become the direction of our future research? We start from the classic experience-based rating curve approach, which is most implementable under current condition. Because setting of this method is relative easy, just several gage height-discharge data pairs. However, there are some limitations of this method future researchers must try to resolve. The first one is the complexity of discharge-water elevation relationship. In actual situation, the relationship between gage height and discharge is not unique. Under unsteady flow conditions like water level rising and falling in large floods, the same water level may correspond to various discharge values.

The second thing that needs to be considered is geomorphologic evolution. Major floods can bring dramatic changes to river channel geometries, which means modification and update to existing rating curves in floodplain are very necessary after flood happens. How to make the modification and update in a general and efficient way to the rating curves stored in Hydraulic Fabric is a good question to think about.

Because of the extension of topographic dataset, the advancement of computing capability, and its solid physical foundation, real-time hydraulic modelling is a more potential and reasonable approach to realize the discharge-water elevation transformation in the future. Figure 57 describes the expected workflow of real-time hydraulic modelling. The role of Hydraulic Fabric in this workflow is the data model designed for the cross section database.

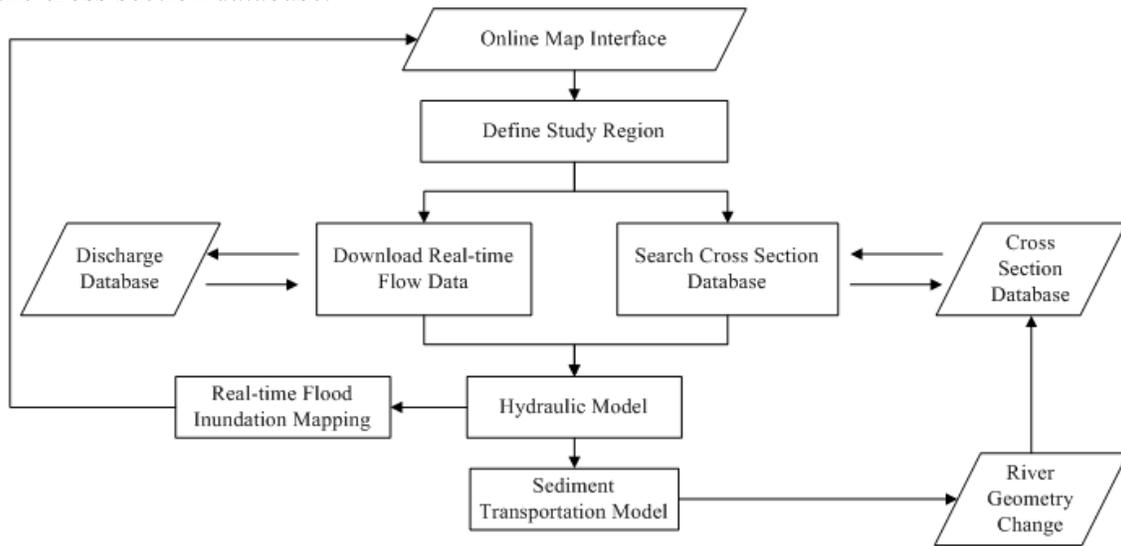


Figure 57 Flowchart of Real-time Hydraulic Modelling

## References

- Brunner G. W., 2010. HEC-RAS river analysis system hydraulic reference manual. US Army Corps of Engineers, Hydrologic Engineering Center
- Goodell, C. R., Breaking the HEC-RAS Code: A User's Guide to Automating HEC-RAS. Portland: h2ls.
- Kim, D. 2008. Arc River-Geotemporal River Hydrodynamic Data Model. ProQuest.
- Kim, D., Muste, M., and Merwade, V. 2015. A GIS-based relational data model for multi-dimensional representation of river hydrodynamics and morphodynamics. *Environmental Modelling & Software*, 65, 79-93.
- Liu, F., and Hodges, B. R. 2012. Dynamic river network simulation at large scale. In *Proceedings of the 49th Annual Design Automation Conference*. ACM.
- Liu, F., and Hodges, B. R. 2014. Applying microprocessor analysis methods to river network modelling. *Environmental Modelling & Software*, 52, 234-252.
- Maidment D. R. et al. 2002. *Arc Hydro:GIS for Water Resources*. Redlands CA: ESRI Press.
- Maidment D. R. 2015. A Conceptual Framework for the National Flood Interoperability Experiment. Austin: The University of Texas at Austin. <[https://www.cuahsi.org/Files/Pages/documents/13623/nfieconceptualframework\\_revised\\_feb\\_9.pdf](https://www.cuahsi.org/Files/Pages/documents/13623/nfieconceptualframework_revised_feb_9.pdf)>
- Salas F.R., et al. 2015. *Building Cyberinfrastructure to Support a Real-time National Flood Model*. Austin: The University of Texas at Austin.
- Sauer, V. B. 2002. Standards for the analysis and processing of surface-water data and information using electronic methods (No. 2001-4044). US Geological Survey.

## **Vita**

Xing Zheng was born in Shangcheng, Henan, China on January 1, 1994. He is the only child of Feng Zheng and Changqiong Xia. After attending elementary and middle school in Shangcheng, he went to Xinyang for his high school study. In 2009, he entered Wuhan University in Wuhan, Hubei, China where he received a Bachelor degree in Hydrology and Water Resources Engineering in June 2013. In August, 2013, he left China for the first time in his life, and became a graduate student of the Environmental and Water Resources Engineering program in The University of Texas at Austin. In January, 2014, he started working as a Graduate Research Assistant at the Center for Research in Water Resources of The University of Texas at Austin.

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This thesis was typed by the author.