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STANDARD METHODS FOR THE IOWA STATEWIDE FLOODPLAIN MAPPING

PROGRAM

by

Nicholas Wayne Thomas

A thesis submitted in partial fulfillment
of the requirements for the Master of
Science degree in Civil and Environmental Engineering
in the Graduate College of
The University of Iowa

December 2011

Thesis Supervisors: Professor Larry J. Weber
                     Adjunct Associate Professor Nathan C. Young

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CERTIFICATE OF APPROVAL

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MASTER'S THESIS

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This is to certify that the Master's thesis of

Nicholas Wayne Thomas

has been approved by the Examining Committee
for the thesis requirement for the Master of Science
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ABSTRACT

Currently the Iowa Flood Center (IFC) of the University of Iowa is working in conjunction with the Iowa Department of Natural Resources (IDNR) to create statewide floodplain maps. The IFC has set up a four year plan to construct flood inundation maps for 85 of the 99 counties within the state of Iowa, with the final goal of creating maps acceptable by FEMA. High resolution statewide LiDAR information provides a base dataset from which floodplain maps are produced. Stream centerline data is extracted from a DEM produced by the LiDAR dataset. The centerline information is used in both this project and as a replacement for the USGS NHD streamline for the state. Stream flow estimation for a range of annual exceedance discharges are produced through a USGS recommended combination of regional regression analysis weighted by gage influence. Water surface elevations are produced for each of the annual exceedance discharges through the use of a HEC-RAS one dimensional steady flow model. Flood boundaries are the final product created by HEC-GeoRAS though a comparison of a TIN produced from the water surface elevations and the ground surface DEM. Final FEMA acceptable DFIRM's are produce by the IDNR and submitted to FEMA for adoption into the NFIP.

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CHAPTER 1: INTRODUCTION

In 2008 flooding occurred over a majority of Iowa, damaging homes, displacing residents, and taking lives. Governor Chet Culver called the 2008 floods, "the worst natural disaster in the state's history," after 85 of the 99 counties were federally declared disaster areas (Baldwin, 2008). Estimated damages to the state totaled $10 billion (Baldwin, 2008). Nearly one third of the total damage was to the agricultural community, including the inundation of 16 percent of the state's 25 million tillable acres (Baldwin, 2008). Whole towns were underwater causing the evacuation of 40,000 Iowans. This event has left its mark on the residents of Iowa that will not soon be forgotten, see Figure 1.1.

Following the 2008 floods the U.S. Department of Housing and Urban Development (HUD) provided a $15 million grant to the state of Iowa for floodplain mapping in the 85 counties which were declared presidential disaster areas. The Iowa Department of Natural Resources (IDNR) contracted the Iowa Flood Center (IFC), a unit of the University of Iowa's IIHR Hydroscience & Engineering (IIHR), to conduct a pilot project. The study refined the hydrologic analysis, hydraulic analyses, and GIS methodologies to take advantage of improved resolution and accuracy from the statewide LiDAR dataset. The project also quantified the time required to perform the individual tasks to maximize the impact of the provided federal funding. From the pilot project IDNR surmised the IFC would be best suited to complete the floodplain mapping for the 85 declared disaster counties under the supervision of the IDNR. The Iowa Department of Economic Development (IDED) allocated $10 million to the IFC to produce maps that can be accepted FEMA, with the additional $5 million to submit maps to the FEMA approval process. Additional funds have been supplemented by IDNR to complete the mapping of the other 14 non-disaster counties.

Flood mapping procedures are to follow the FEMA guidelines for and approximate analysis. FEMA defines approximate methods as, "Semi-automated hydrologic, hydraulic, and mapping tools, coupled with digital elevation data, allow prediction of the floodplain limits, especially in lower-risk areas. If these tools are used without benefit of any field survey data, the study is an *approximate* study," (National Research Council, 2007). Approximate studies emphasize areas of rural development by expanding mapping projects to cover larger areas with less funding. Before adoption by FEMA the maps are used to identify risks informing policy makers and citizens in the state, and allowing them to better plan and manage land cover and development activities. Mapping will begin in southwest Iowa moving west and north over a four year time period identifying the floodplains in all 85 declared disaster counties, see Figure 1.2.

Figure 1.1: Downtown Cedar Rapids, Iowa during 2008 flood (Olson, 2008)
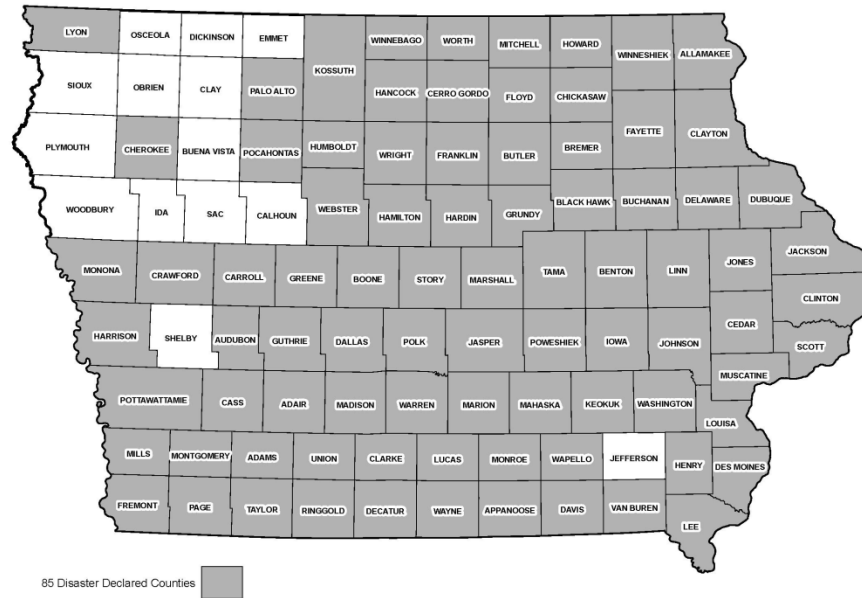
Figure 1.2: Counties with federal disaster declaration post 2008 floods (Ralston, 2010)

The floodplain mapping procedure requires a reliable and accurate ground elevation dataset provided by the 1-meter LiDAR derived DEM. Each procedural component for the Floodplain Mapping (FPM) Project enlists the LiDAR dataset to extract and manipulate elevation data in production of flood boundary maps.

This procedure begins with the identification of the stream network. Through raster manipulation tools imparted on the 1-meter DEM, and aerial photography a stream centerline is digitized manually. The centerline derived from this procedure is to replace the USGS NHD centerline as it is deemed to be more relevant and accurate than the existing information.

Hydrologic modeling procedures are based on IDOT and IDNR standard practices, which use a combination of two regional regression analyses for predicting annual exceedance flow in Iowa streams. Regional regression analyses determine flow by relating measure geomorphic and climatic characteristics. Through raster manipulation techniques applied to the LiDAR derived DEM, drainage areas within the

streams are determined, representing a key geomorphic feature. The hydrologic analysis produces stream flows for eight different annual exceedance discharges.

Hydraulic modeling procedures utilize Army Corps of Engineering tools HEC-GeoRAS and HEC-RAS. Hydrologic Engineering Center tool GeoRAS is utilized to process geospatial data in preparation of use by HEC-RAS. The River Analysis System (RAS) is used to predict water surface elevations based on the standard step backwater method for each of the eight annual exccedance discharges output from the hydrologic modeling procedure.

Floodplain boundaries are identified through use of HEC-GeoRAS. The Army Corps of Engineering program utilizes the water surface elevations from the hydraulic modeling procedure and the LiDAR derived 1-meter DEM to produce the floodplain boundaries. Flood boundaries are adjusted to eliminate artifacts introduced by the DEM. Based on need and funding the developed maps are adopted to be by FEMA and included into the National Flood Insurance Program (NFIP).

CHAPTER 2: BACKGROUND INFORMATION

Prior to the initiation of the Iowa Floodplain Mapping Program a combination of development near bodies of water and natural disasters led to national devastation. The National Flood Insurance Program (NFIP) and Floodplain Mapping (FPM) programs were developed to prevent and recover from flood based disasters. Advancements in technology and a better understanding of flooding encouraged the establishment of new national policies and procedures. A brief synopsis of the nation's history with flood based disasters and the response on a federal, state, local level are documented in the proceeding sections.

2.1 National Flood Insurance Program (NFIP)

The U.S. Congress established the NFIP through the National Flood Insurance act of 1968 (FEMA, 2002). NFIP enables property owners in participating communities to purchase federally subsidized insurance as a protection from flood losses. This act provided an insurance alternative for disaster assistance to meet the escalating costs of repair to buildings and properties caused by floods (FEMA, 2002). Prior to 1968 federal involvement in flood damage mitigation was provided primarily in response to significant events, through the use of structural flood-control projects, such as dams and levees. Despite the billions of dollars invested into structural solutions, the loss of life, property, and the amount of federal assistance continued to increase (FEMA, 2002).

The United States Congress has charged the NFIP with four major responsibilities. Within in participating communities flood risk areas are identified, and communicated to the public. Local and state governments are encouraged to appropriately develop the land identified to be within flood risk areas to minimize damage caused by flooding. Finally, the NFIP makes flood insurance available nationwide allowing individuals to recover from flood losses, mitigate future damages, save lives, and reduce individual and national expenditures.

Initially inclusion of communities and individuals into the federally subsidized flood insurance plan was voluntary (FEMA, 2002). This proved catastrophic as shortly after the conception of the NFIP, Tropical Storm Agnes hit in 1972 causing extensive riverine flooding along the east coast. This disaster caused more damage than any previous disaster in the nation's history (Wright, 2000). As a result, the U.S. Congress passed the Flood Disaster Protection Act (FDPA) of 1973. This prohibited federal agencies from providing disaster assistance to any community within the floodplain which did not participate in the NFIP (FEMA, 2002). NFIP was further amended in 1982 with the Coastal Barrier Resources Act (CBRA), and in 1994 with the Flood Insurance Reform Act (FIRA). The CBRA prohibited federal funds including insurance as aide in designated undeveloped costal barrier islands. The FIRA reduced federal funding to repetitive loss properties through buyouts, elevations, relocations, or flood proofing (FEMA, 2002).

"The National Flood Insurance Act of 1968 authorizes the director of FEMA to establish and carryout a national flood insurance program which will enable persons to purchase insurance against loss resulting from physical damage to or loss of real or personal property" (FEMA, 2002). Flood insurance can be purchased by individuals located in a participating community. Insurance is provided through state-licensed property insurance agents working directly with FEMA, or through private insurance companies involved with the "Write Your Own" (WYO) program. The WYO program enables the private sector to sell flooding insurance on behalf of the NFIP, 95% of flood policies are issued this way (FEMA, 2002). Insurance rates are determined actuarially by flood risk zone, occupancy type, and building type. The NFIP offers subsidized rates to buildings erected prior to 1975 as they were created without the occupants full knowledge and understanding of the flood risk (Wright, 2000). As of March 2002 over $606 billion in flood insurance was covered by the NFIP. The insurance premiums and federal policy fees are collected and stored in the National Flood Insurance Fund (NFIF).

When a flood inundates at least two or more acres over at least two properties of normally dry land, a flood insurance claim is submitted to acquire funds to repair damages.

Flood hazard maps are required for floodplain management regulations, calculating flood insurance premiums, and to determine whether a property owner is required to obtain flood insurance. The 1-percent-annual-chance flood was chosen to illustrate this, on the basis that it provides a higher level of protection while not imposing overly excessive costs on land owners. Before a community is allowed to participate in the NFIP the flood risk zones must first be established. FEMA uses a two approach method to identifying flood risk areas depending on a communities flood hazards. A detailed approach is used to identify flooding sources which affect developed or developing areas. While approximate studies are used for undeveloped or sparsely developed areas. Flood hazard maps have been issued for over 19,000 communities at a cost of over $1.5 billion (FEMA, 2002).

<u>2.2 FEMA Mapping</u>

FEMA splits the mapping efforts through an integrated approach of detailed studies and studies by approximate methods. Each of the three primary periods of FEMA mapping applies a combination of these studies in varying formats and methods.

2.2.1 Early Conventional Flood Maps

Initially, the NFIP relied upon its small underfunded in house staff to map the floodplains for communities new to the NFIP. They utilized base maps provided by the participating communities, which were augmented by flood data generated by federal agencies (FEMA, 2002). The NFIP intended to implement a detailed study for every community before they were allowed into the program identified as a Flood Insurance Rate Map (FIRM), see Figure 2.1. While the study was being conducted a simpler and faster study was performed by approximate methods allowing the community to begin

managing the floodplain and for insurance agencies to produce actuarially sound insurance rates, identified as Flood Hazard Boundary Maps (FHBM), see Figure 2.2.

The approximate limits were delineated on topographic maps. At first the flood prone areas were identified in a rectilinear fashion following easily identifiable landmarks. In 1973 with the FDPA the FHBMs needed to be more accurate (Wright, 2000). Curvilinear flood boundaries which followed contour maps became the new ideal. Techniques involving contour interpolation, from USGS 7.5 minute contour maps were typical flood estimation processes. Topographic maps, soils maps, aerial photography, and early HEC models with few cross sections were among the common components included in the early flood boundary identification techniques. With the increased need for actuarial boundaries NFIP focused on producing maps by approximate methods to fulfill the incoming requirements.
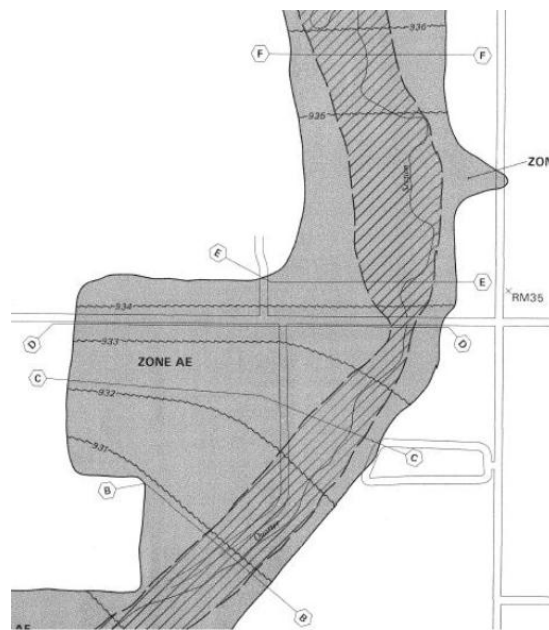
Figure 2.1: Paper FIRM identifying cross section locations, elevation changes, flood boundary, and political features (Ralston, 2010)
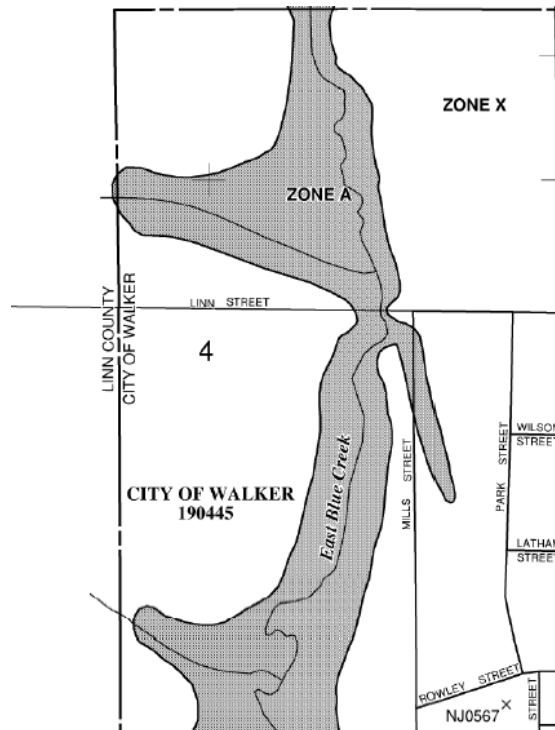
Figure 2.2: Paper Special Hazard Boundary Map produced through approximate methods identifying the flood boundary and political features (Ralston, 2010)

2.2.2 Map Modernization

The Flood Map Modernization Program is a multiyear process undertaken by FEMA to provide a technology based, cost effective, long term process, for updating maintaining, storing, and distributing flood hazard and risk information (FEMA, 2007). Conventional flood maps involved paper-based cartographic methods provided limited accuracy in a quickly changing physical environment. Through a lack of funding in the 1980's and 1990's for flood hazard mapping, most NFIP maps began to age, representing flood inundation poorly (FEMA, 2010). FEMA typically uses the prevailing map production techniques. With advancements in GIS technologies and digital production processes, the long used paper processes began to make way for a digital production.

The five year plan beginning in 2003 was to convert the entire flood map inventory to a digital format, see Figure 2.3. In the digitization process, current maps were upgraded with new information when possible. Additionally, over 13,000 new digital map panels would be created for flood prone communities without maps (Wright, 2000).
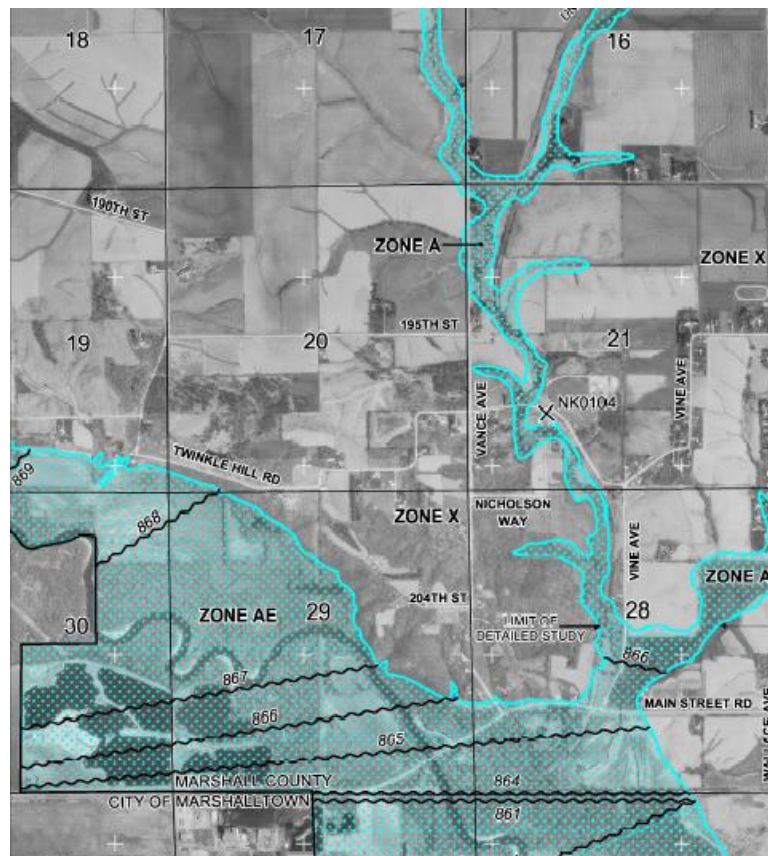
Figure 2.3: Digital Flood Insurance Rate Map (Ralston, 2010)

Using GIS based methods, new approximate flood area delineations were developed for areas not having a detailed study. In this time period approximate studies were no longer performed by interpolation techniques. Peak flow transfer, regional regression, or the rational formulas are implemented to identify the 1 percent-annual-

chance-flood. Normal depth calculations though Manning's equation or highway culvert nomographs were used to identify the flooding height. HEC-2, HEC-RAS, Quick-2, and HEC-SSP are among the computer programs accepted by the NFIP to identify discharges or water surface elevations.

As a part of Map Modernization, a program called Cooperating Technical Partners (CTP) enabled local communities, states, and regional agencies to integrate into the mapping process. The program allows partnering entities to perform all of the data collection, mapping tasks, and management (FEMA, 2002). With a more local approach, specialized procedures can be tailored to areas containing unique conditions, which wouldn't be identified by a federal overview.

Through Map Modernization, 100,000 of the nation's flood maps were made accessible through a digital platform (FEMA, 2009). Improved accuracy, relevancy, and accessibility of flood risk maps were made available.

2.2.3 Risk MAP

Risk Mapping, Planning, and Assessment (Risk MAP) is a five year program beginning in the fiscal year of 2010. It is built on the foundation of Map Modernization through a continuation of map updating and public awareness. The program invested itself into improving elevation data, mapping procedures and databases, risk management, and community involvement and coordination.

FEMA is investing $20 million annually into elevation data acquisition, targeting areas of high flood risk (FEMA, 2010). Accurate topographic data is the most important factor in determining water surface elevations, and flood extents in riverine areas (National Research Council, 2009). LiDAR technology is significantly changing the way the surface of the earth and buildings, vegetation and other features are mapped (FEMA, 2009). Improvements in LiDAR technology and rapidly declining costs are quickly making this the preferred form of elevation data.

Watershed based mapping and coordination is among the new concepts realized by Risk MAP. Watershed based coordination facilitates communities functioning together in discussion of joint risks and consequences. Mapping completed by watershed is also a more intuitive approach compared to the previously accepted by political boundary based mapping.

Risk MAP's approach to risk management is through an integrated approach, providing a suite of decision making tools for development of land, capital improvements, and transportation systems. To enable improved risk comprehension, risks are to be delivered to communities in terms of probabilities and consequences, encompassing the social impacts of flood risk. Programs have been created to integrate flood, earthquake, and hurricane wind risks together allowing individuals a comprehensive understanding of total risk.

The NFIP has identified that sound and reliable flood risk information is a necessary component of useful risk analysis. The dynamic nature of the floodplain requires periodic map updating to maintain a reliable inventory. Risk MAP ensures by 2014 that 80% of the nation's flood hazard maps are current through creating, updating, or validating hazard maps (FEMA, 2009). FEMA will utilize engineering and mapping contractors along with CTP's to ensure that progress made through Map Modernization does not go to waste.

Mapping procedures although systematically similar to the Map Modernization procedures are identified by FEMA mapping requirements with an alternative nomenclature. Previous DFIRMs contained detailed studies, limited detailed studies, and approximate studies. The flood hazard studies are now identified as either a base study or an enhanced study. This better identifies the methods used to produce the maps. Enhanced studies are identified by a continuum of enhancements directly related to the incorporated modeling procedures. Secondary datasets are to be produced improving an individual's understanding of risk. These products include, an image of flooding depth

for the all annual exceedance discharges, and 50, 20, and .05 percent annual exccedance flows with the corresponding flood boundaries (FEMA, 2011).

Throughout history FEMA and the NFIP have altered their approach to floodplain mapping. The early conventional maps were paper based cartographic estimations of flooding extents, using topographic information to identify the floodplain. Map Modernization Program aspired to create a full inventory of Digital Flood Insurance Rate Maps (DFIRM), while updating maps where it was needed through new hydrologic and hydraulic models. Risk MAP's vision is to deliver a product in a manner that increases public awareness, an action that will reduce risk.

2.3 Statewide Mapping Projects

States and other large communities have begun to produce and manage the floodplain mapping within their political boundaries. The CTP, Map Modernization, and Risk MAP programs provide funding through FEMA for digitization of paper maps and new mapping projects. North Carolina, West Virginia, Indiana are primary examples of the FEMA mapping programs.

2.3.1 North Carolina Statewide Mapping Project

North Carolina faces extreme hazards often occurring in short intervals. Since 1989 the state has had over 25 federally declared disasters, while 95 of the 100 counties were affected (State of North Carolina, 2008). Limitations of the state's current risk management became evident over this time period. Many of the flood hazard maps were identified to be irrelevant. As a result North Carolina established a statewide remapping program and became the first Cooperating Technical State (CTS) within FEMA's CTP program in 2000. To date North Carolina has allocated more than $128 million towards the project $60.6 million coming from FEMA (State of North Carolina, 2008). The state updated the flood hazard maps for all communities with digital maps by 2008.

Through a combination of LiDAR data collection and field surveys, topographic information was taken for the entire state. Through the post processing of the LiDAR data 20-foot DEM's and bare earth break lines used as stream centerlines were developed. A basin wide approach using regional regression equations and gage weighting where appropriate output the peak flows. Detailed hydraulic studies were performed for 3,000 stream miles using a HEC-RAS standard step-backwater method. Field survey data for bathymetries of the river was coupled with LiDAR surface data to create detailed cross sections. Limited Detailed studies were performed for 17,000 stream miles using HEC-RAS and cross sectional data extracted from the LiDAR information only. Six thousand stream miles of hazard maps were redelineated using previous FIS to fit the data to the new base map. Approximate analyses were performed for the remaining 2,000 stream miles only the flood hazard areas were identified through a HEC-RAS model. Costal analyses were performed for the 212 miles of coast line along the eastern state line, including storm analysis, and wind, tidal and wave models.

In total the North Carolina Statewide Floodplain Mapping Project completed over 28,000 river miles of analysis and redelineation. State contractors and state government offices completed flood maps for the entire state in eight years. To date the project has spent $128 million to restudy, map, and to increase awareness of the flooding issues. North Carolina led the way for other states to take control of the flood hazard mapping, and risk assessment.

2.3.2 Other State Projects

Through FEMA funded Map Modernization and Risk MAP programs states and local agencies have begun to include themselves into the mapping process. Currently over 115 states and agencies have been recognized by CTP program alone (FEMA, 2002).

FEMA has allocated over $500 million to West Virginia from 1996 to 2004 in flood assistance (West Virginia Conservency Agency, 2011). Many of the state's flood hazard maps were created using studies performed in the 1980's, which lack sufficient detail to easily identify at risk properties. Stemming from this time period the West Virginia Conservancy Agency along with other local agencies identified a need for a new statewide flooding plan. LiDAR will become a key component of the future hazard mapping. The funding for the project is to come from multiple sources within the state, and the CTP, and Map Modernization programs. The state of West Virginia is increasing the knowledge of risks and risk management techniques associated with flooding.

Other states such as Indiana and the associated Department of Natural Resources aim to become a part of the Map Modernization mapping effort through the CTP program. Indiana is to digitally remap, update, and complete new FIS for the entire state over a five year time period (Indiana Department of Natural Resources, 2004).

The state of Louisiana looks to aid the Map Modernization mapping effort, though not involved with the CTP or CTS programs. Mapping firms complete hazard maps in the coast parishes prone to the largest flood risks (LaMP, 2007). The Louisiana Mapping Project specifically acts as an intermediate between FEMA and the public, offering technical help to mapping partners and aiding in public outreach.

Mapping efforts through coordination with states and local agencies are becoming increasingly common as it streamlines the map coordination process and offers a single point of contact for FEMA. North Carolina, West Virginia, and Indiana among others are leading the way in state wide mapping efforts.

2.4 Chapter Summary

The NFIP was established in response to the escalating financial burden put on the taxpayers by natural disasters. Privatization of flood risk was the major aim in the

initialization of the flood insurance program. Amendments to the National Flood Insurance Act strengthened and focused the purpose of the NFIP.

The one percent annual chance flood was identified as the measure of a significant event. Mapping the one percent flood can be completed by either an approximate study or a detailed study. Mapping technologies and procedures have been altered throughout history reflecting the knowledge of the day. Map Modernization, Cooperating Technical Partners, and Risk MAP each have influenced the current FEMA mandated procedures and technologies.

Through these mapping programs many states and large communities have begun identify flood risks within their jurisdiction. North Carolina is the primary example of this with the completion of a statewide mapping effort in eight years, receiving nearly $60 million in funding from FEMA programs. Inclusion of local communities into the mapping process streamlines mapping procedures.

NFIP, Map Modernization, and Risk MAP are among the FEMA based programs advancing the mapping standards and procedures. Enabling FEMA to keep up with current technology, research, and risk management. Current mapping procedures and technologies mandated by FEMA have been honed over time though trial and error enabling the creation of relevant flood hazard maps.

CHAPTER: 3 FEMA METHOLOGY

Inundation maps are employed as a flooding estimation tool. Combinations of hydrologic and hydraulic modeling with stream gage history, stream geometry data, and a comprehensive LiDAR based elevation dataset aid in the completion of statewide floodplain maps. The process utilizes computer modeling paired with GIS mapping to provide accurate estimations of flooding in varying flow scenarios. Inundation mapping can be divided into four major processes hydrographic delineation, hydrologic modeling, hydraulic modeling, and mapping. Each is described in detail in the following sections.

3.1 Source Data

Hydrographic, hydrologic, and hydraulic analysis require established datasets to extract information and complete the corresponding modeling procedures. Published information produced by the Iowa Department of Natural Resources (IDNR), United States Geological Survey (USGS), Environmental Protection Agency (EPA), and other sources are input into the modeling scheme to produce flood inundation maps. LiDAR derived rasters, NHD streamlines, NLCD land use products, USGS stream gage information, and hydrologic zone shapefiles are of the used products discussed in the following section.

3.1.1 LiDAR

Light Detection and Ranging (LiDAR) is a mapping technology that determines the distance to an object or surface by measuring the travel time of laser pulses (Sanborn, 2011). An airplane mounted LiDAR device sends thousands of pulses per second, receives the reflected information and outputs a point cloud of elevation data over a given flight path. With the addition of inertial measurement units, aerial GPS, and ground based GPS units, the pitch, roll, and location of the aircraft are measured multiple times

per second, see Figure 3.1. In unison the devices effectively position and correct all of the LiDAR elevation data.
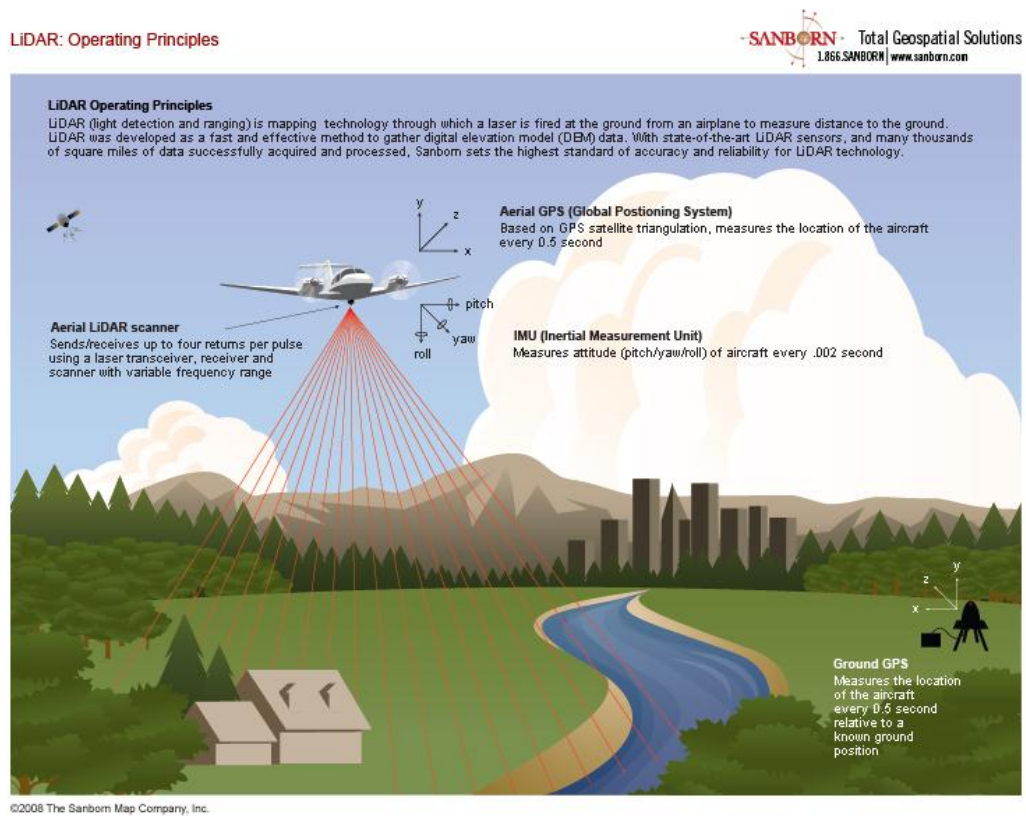
Figure 3.1: Airplane based LiDAR measurement apparatus (Sandborn, 2011)

The primary product of the LiDAR imaging is a one meter Digital Elevation Model (DEM). This is a three dimensional representation of the bare ground surface. An ArcGIS extension called LP360 is applied to analyze 3-D point cloud datasets. LiDAR collection devises measure multiple returns of the laser signal. The first reflection data returned to the tool is off the higher surfaces, trees and buildings. The last returns are off the lowest points, typically the ground surface, see Figure 3.2. LiDAR flights for bare earth datasets are recorded only during leaf off and no snow periods reducing error

introduced from environmental sources. LP360 separates the bare earth points from the others to produce the DEM. The point cloud dataset of the terrain is divided into one meter grid cells. The points are averaged to produce a single elevation in each grid space, outputting the one meter DEM.
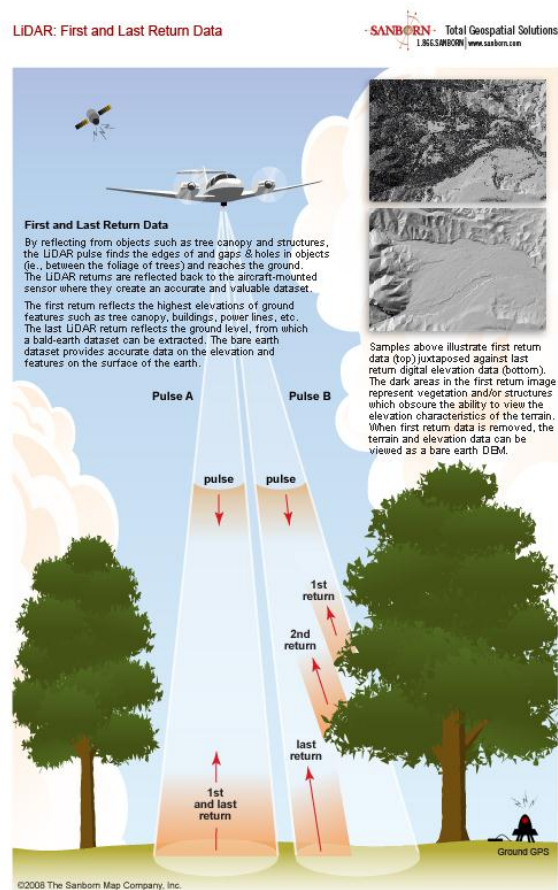
Figure 3.2: LiDAR data measurement, first returns come from the tree tops and last data returns reflect of the ground surface(Sandborn, 2011)

Before the implementation of LiDAR technology other techniques were applied to create lower resolution rasters. The IDNR previously used 30 meter USGS Level 1 and 2 DEMs (Kollasch, 2011). These DEMs are derived from 7.5 minute contour information

by photogrammetric or manual profiling techniques, see Figure 3.3b. Errors in this dataset are permitted up to 50 meters in the vertical direction (US Department of the Interior 1998). For better watershed management capabilities IDNR developed a pilot study on LiDAR based informatics over 5 watersheds across Iowa approximately 1% of land area. Through multiple funding sources LiDAR datasets were created for the entire state of Iowa flown from 2007 to 2010 with the ability to produce one meter resolution DEMs.
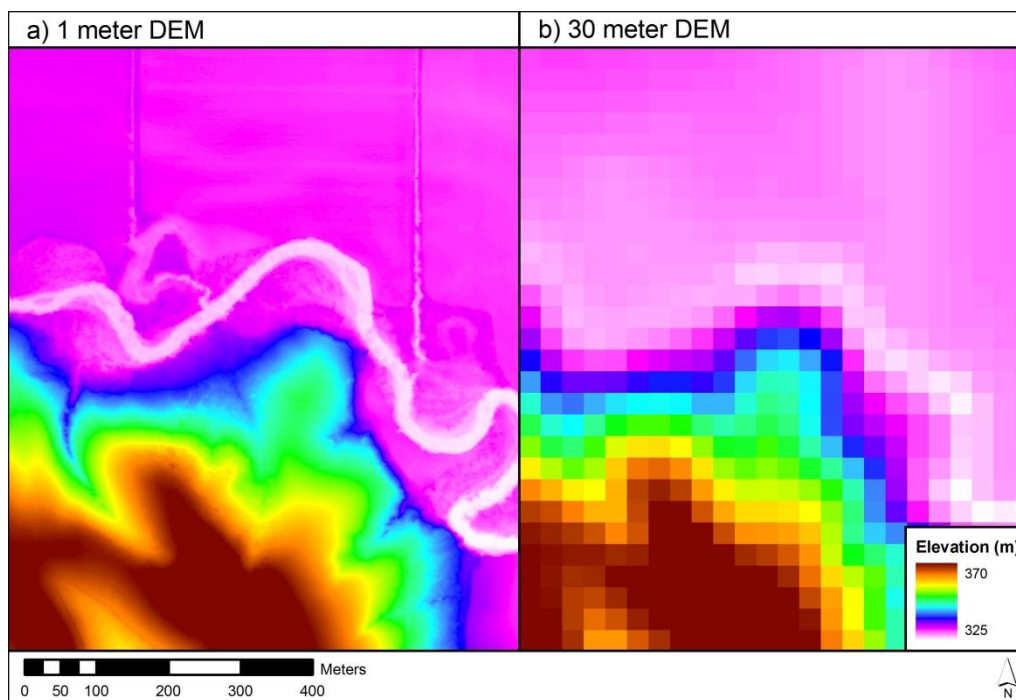
Figure 3.3: 1 meter and 30 meter DEM resolution comparison

Note: a) LiDAR derived 1 meter DEM b) National Elevation Dataset 30 meter DEM

LiDAR based DEMs for the state of Iowa are divided into 185 blocks, see Figure 3.4. Each dataset has an 18.5cm root mean square vertical precision increasing to 37cm in

dense vegetation. Removal of 95% of vegetation, 90% of artifacts, 95% of outliers, and 98% of buildings is required of Sandborn data each exceeding the FEMA product specifications. At the project start date this dataset incurred the highest point resolution offered (Giglierano, 2009).
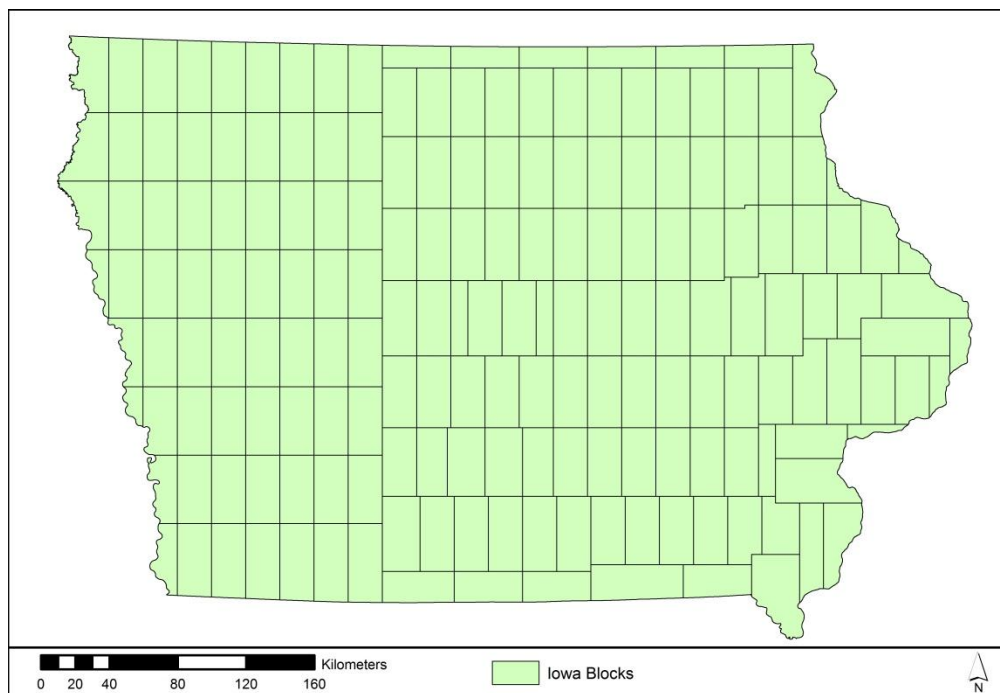
Figure 3.4: LiDAR dataset distribution by blocks for the state of Iowa

The original purpose for a state wide DEM update was to increase the utility of the dataset for watershed management. Through a partnership with the IDNR the more accurate datasets have become available to the Floodplain Mapping Project. The LiDAR derived DEM is a required dataset for each of the four major mapping processes. In the Hydrography section, DEMs are necessary to produce the ArcHydro and fill difference DEM datasets. Also it acts as a guide to visually inspect and manually digitize the stream centerlines, Section 3.3. The DEM is required to calculate the drainage area in the

streams for the Hydrologic Analysis, Section 3.4. To complete the Hydraulic Analysis the DEM is used to create the model geometry, and elevation data is extracted to produce the water surface elevations. Finally, the DEM is used as the ground surface from which the water surface TIN is subtracted. This creates the inundation area and water depth raster, Section 3.5. New and accurate topographic information is a requirement to produce relevant flood inundation predictions.

3.1.2 National Hydrography Dataset (NHD)

The National Hydrography Dataset is a comprehensive spatial dataset identifying various surface water features, see Figure 3.5. NHD includes naturally occurring and constructed bodies of water, paths which water flows, and other related items. Examples of water bodies include lakes, rivers, ponds, dams, and canals. Information regarding classification, delineation, geographic name, position, direction of water flow, and reach code are encoded in the dataset. NHD streamlines support map making, modeling surface water flow, and for use in maintaining and updating datasets (USGS, 2011).

The NHD serves primarily as a naming convention and reach identification tool. From the Hydrologic analysis streams draining more than one square mile and longer than 0.5 miles are modeled. In a vast majority of locations the NHD streamline corresponds with a centerline identified in the Hydrography Section 3.2, and the Hydrologic Analysis Section 3.3. In these locations the NHD naming conventions are applied to the Hydraulic model if the DIRM names are unavailable, Section 3.4. Per request an update of the NHD centerlines and classifications are to be included in the Hydrography Section 3.2 of the procedure, increasing the relevancy and consistency of the dataset.
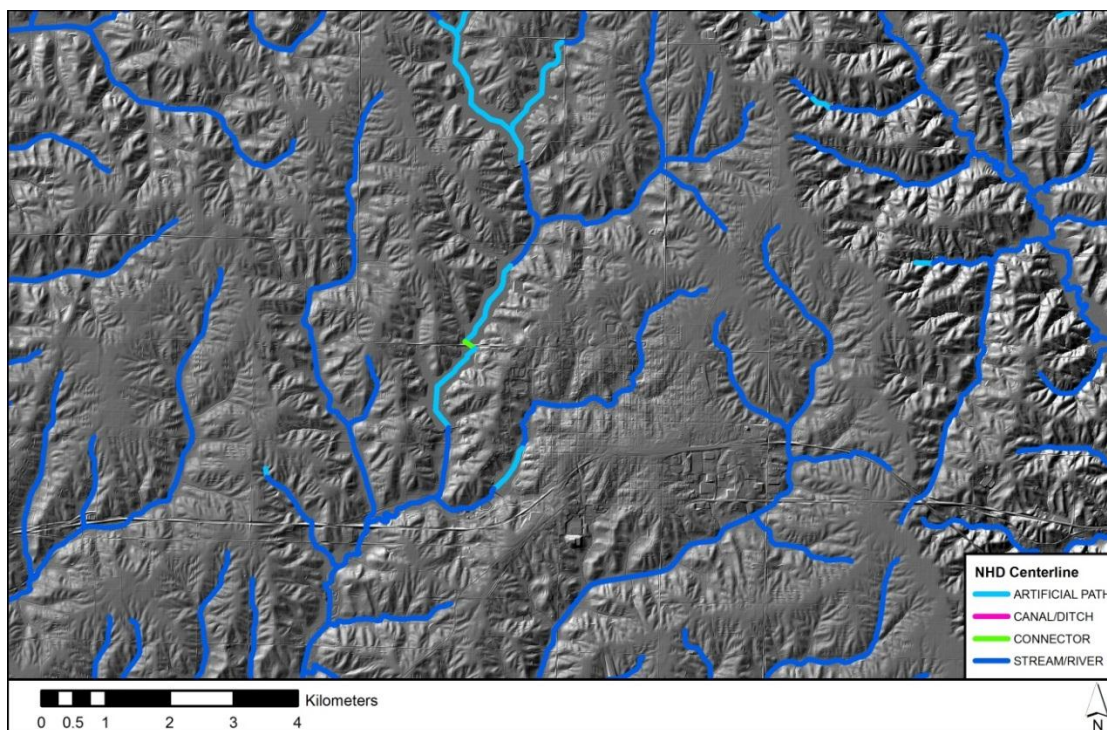
Figure 3.5: NHD stream centerline dataset with 1 meter hillshade background

3.1.3 National Land Cover Database (NLCD)

The National Land-Cover Database (NLCD) provides relevant and consistent land cover information over the entire United States. Landsat 5 and Landsat 7 satellite scenes from the spring, summer, and fall describe the early, peak, and late greenness periods. By incorporating ancillary DEM data into the analysis 29 different land cover classifications are able to be identified and manually corrected (Homer, 2004), see Figure 3.6. Regression tree cross validation produced accuracies ranging from 70.5% to 77.2% and standard errors ranging from 1.2% to 2.1% (Homer, 2004). Constant change in the distribution of land uses over the United States, advancements in satellite technology, and procedural improvements, offer adequate motivation for periodic analysis of the land cover.

The NLCD is primarily used in the Hydraulic Analysis Section 3.4, as a source of roughness information. A direct conversion from land use classification to Manning's n roughness coefficient is performed creating a dataset, which encompasses the entire state of Iowa with overland flow resistances.
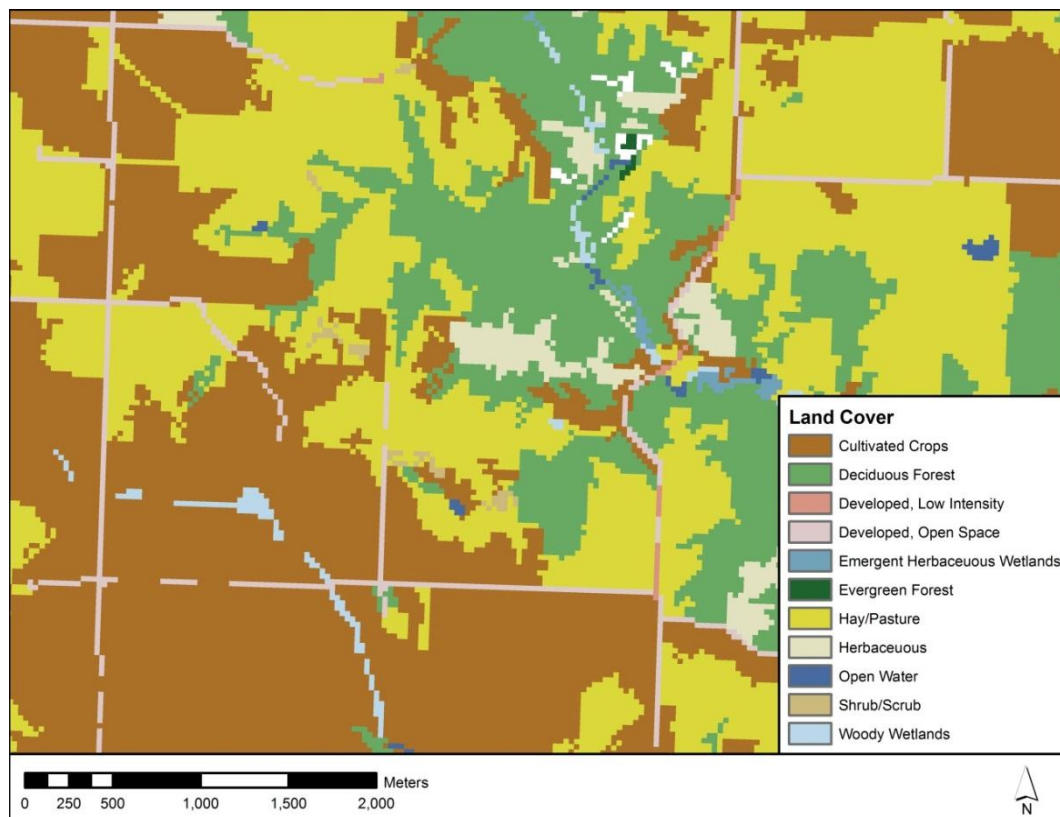
Figure 3.6: 2001 NLCD data contained in an Iowa watershed

3.1.4 United State Geological Survey Stream Gage Locations

The United States Geological Survey (USGS) currently operates and maintains over 23,000 stream gages nationwide (USGS, 2011). Stream gages are located on streams, lakes, reservoirs or other bodies of water. They record hydrologic observations and produce stream discharge estimates. Locations of the gages are identified by a GIS

dataset, including both gages in operation and historical gage locations. Information regarding the gage name, location, drainage area at the site, and dates of operation accompanies the spatial identification. Within the state of Iowa almost 400 current and historical gages are on record, see Figure 3.7.

Gage location information is applied to the Hydrologic Analysis Section 3.3. Relevant information regarding the gages annual peak flow data identifies locations which are acceptable for use in a gage-weighted regional regression analysis. The information is used to perform a Bulletin 17B Frequency Analysis, identify gage influence areas, and properly weight the regional regression analysis to include the historical gage information.
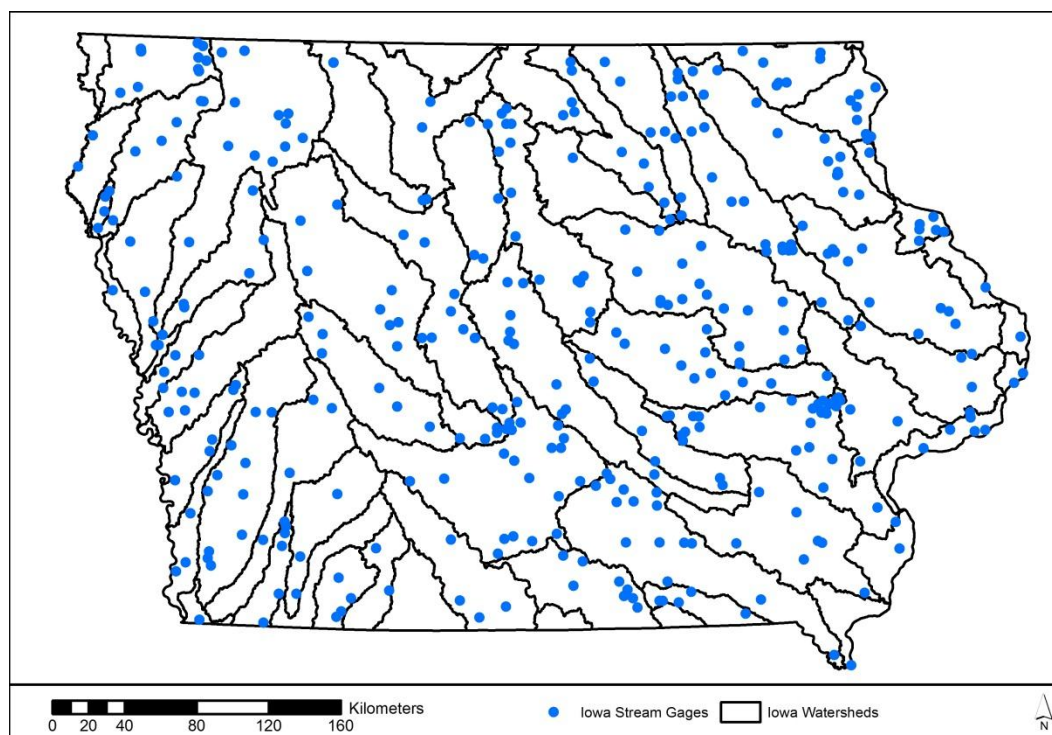
Figure 3.7: USGS stream gage locations in Iowa

3.1.5 Hydrologic Zones

Regional regression analyses are a simplified procedure of estimating peak flows for various flood frequency events. This form of hydrology splits the land surface into varying regions based on geologic and topographic features. The hydrologic regions have been defined for both the Eash and Lara analyses aiding in flow calculation for the Hydrologic Analysis, Section 3.3, see Figure 3.8.
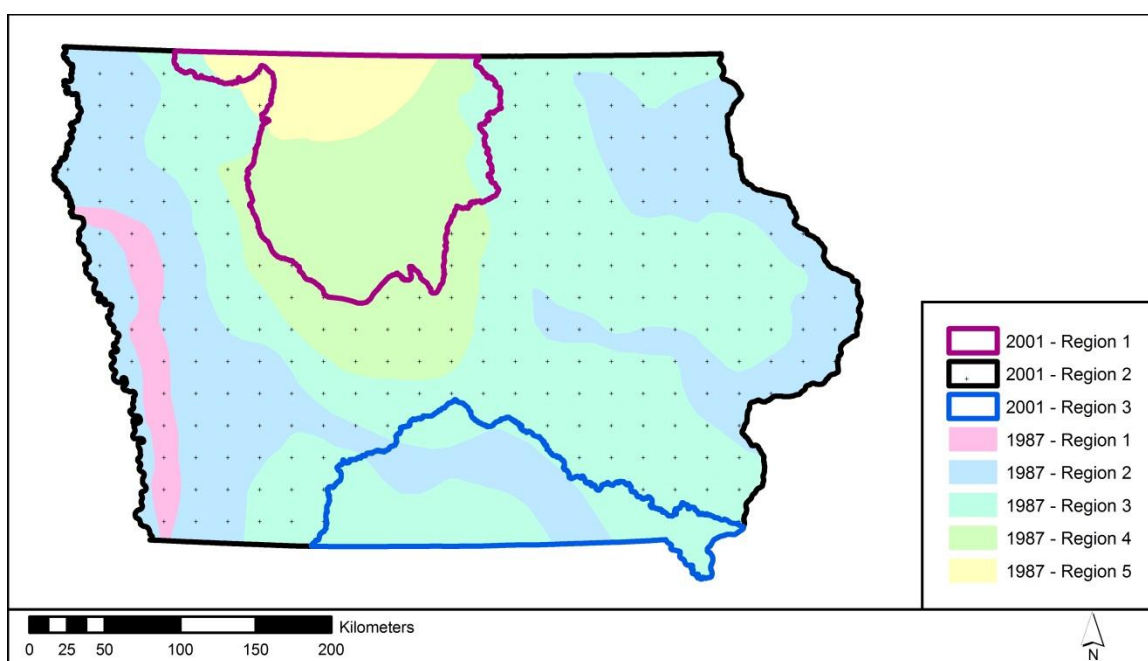
Figure 3.8: Hydrologic regions for Lara (1987) and Eash (2001) regression analyses

3.1.6 Section Summary

Established and relevant datasets are capable of producing reliable mapping products. Datasets discussed in the Source Data Section 3.1 are important aspects within the modeling procedure. Each set of data is employed in the Hydrography, Hydrology, Hydraulics, or Mapping portions of the FEMA Methodology.

3.2 Hydrography

Stream centerline data is required to complete the hydrologic and hydraulic analyses. Stream centerlines are utilized to modify the DEM and ensure that flow is allowed to pass through drainage structures such as bridges and culverts, or artificial obstructions in the DEM, such as fence lines and other features. Existing USGS NHD stream centerline data is available, but the dataset was created using a product with a lower resolution than the LiDAR derived DEM. A comparison between the two shows a division between the existing centerline data and the LiDAR based stream channels, see Figure 3.9. New stream centerlines were developed to take full advantage of the LiDAR elevation data and update the existing NHD data. To aid in the update of the USGS NHD waterway dataset, the new stream centerlines will include information regarding its uses. Specifically, main channels, lakes, and culverts are to be differentiated, giving the user a more informative description.
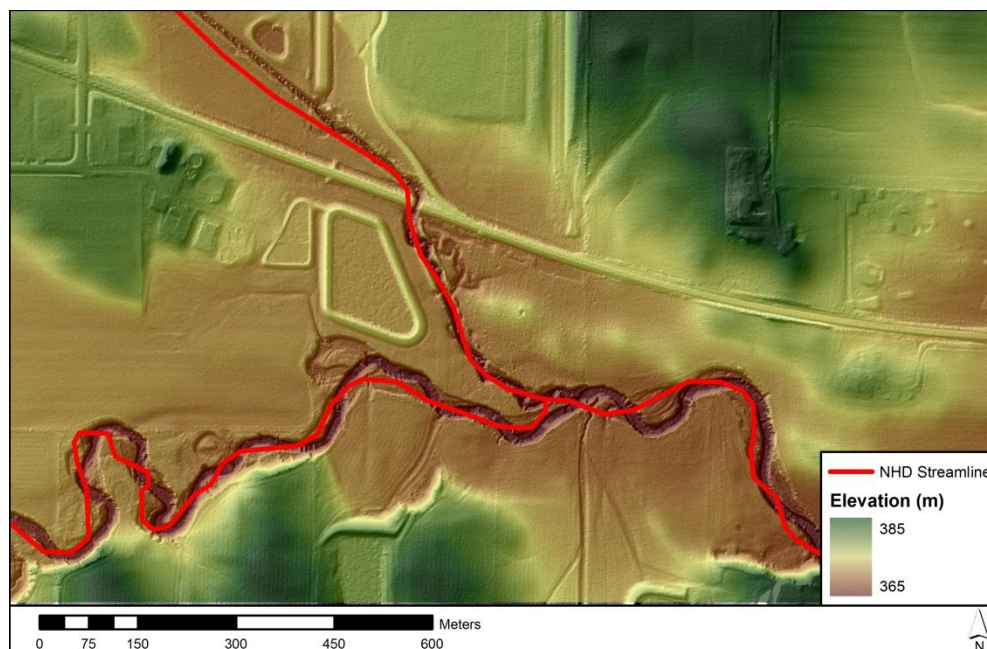
Figure 3.9: NHD stream centerline compared to the 1-meter LiDAR derived DEM

3.2.1 Definitions

"The National Hydrography Dataset (NHD) is a comprehensive set of digital spatial data that encodes information about naturally occurring and constructed bodies of water, paths through which water flows, and related entities" (USGS, 2011). As indicated by the USGS, each stream is given a specific classification describing how it interacts with water. The NHD classifications identified within this study include a stream or river designation, culvert, artificial path, and connector. A stream classification identifies a continuous unbroken stretch of water contained in a river reach. Culverts designate locations of stream flow through a culvert or under a road connecting two stream segments. The artificial path and connector classifications ensure that the hydrographic network is complete. Artificial paths represent a flow of water through features which are delineated by areas, serving as a centerline. Connectors fill gaps in the delineation where the other three classifications don't fit creating a continuous flow. Together the classifications serve as a link between digitized lines and the respective hydrologic applications, see Table 3.1.

Table 3.1: Classification of stream features based on NHD specifications

Classification	Definition
Stream/River	Stream or river reach
Culvert	Bridge overpass or roadway culvert
Artificial Path	Pond or Lake
Connector	Connects a pond or lake to a stream or river

3.2.2 Implementation

Generation of stream centerlines is broken into two major categories small stream and large stream, based on bank width. Small stream data consists of reach containing bank widths of less than seven meters wide. Digitization and classification of each stream segment is required to complete the dataset. Large stream digitization is performed on streams wider than seven meters. Manually digitizing a large stream centerline accurately is difficult. A process which identifies both banks and applies ArcGIS tools to the bank lines forming an unbiased stream centerline is used. A stream centerline is a necessary component of a floodplain map. Creating an accurate centerline will aid in limiting errors introduced into the model as the dataset is an input for multiple processes in the mapping procedure.

3.2.2.1 Small Stream Digitization

Small stream reaches are most often located in the rural areas of Iowa. Accurate digitization and classification ensures the creation of a robust dataset useful for many tasks. The process of building a small stream centerline is done primarily using ArcGIS and the corresponding suite of analysis tools. The most instrumental datasets used in identifying the centerline location include the ArcHydro streamline, LiDAR derived DEM, hillshade, and aerial photos. Scrutinizing the data allows a user the ability to manually digitize and classify the stream centerline accurately.

The ArcHydro toolbox consists of a series of ArcGIS raster manipulation tools. It is employed to find the ArcHydro stream centerline. Correctly applying the tools to the LiDAR derived DEM allow the definition of the ArcHydro centerline representing the most likely flow path. ArcHydro streamlines are created using the process shown in Figure 3.11 and are essential in locating stream ends and channel centerlines. The DEM is submitted to the ArcHydro process, which converts a DEM into a streamline using a logic based assessment of each raster set. The final product is a polyline illustrating a

flow path starting at a user established minimum threshold. The process is defined in the proceeding section.

The ArcHydro streamline process is time intensive. For this reason the 1-meter LiDAR derived DEM is condensed into a 3-meter DEM using the Spatial Analyst extension "Aggregate" tool. The tool generates a reduced resolution raster by averaging the cells, see Figure 3.10. The raster contains $1/9^{th}$ the data points, producing a decrease in detail and files size, allowing for increased ArcGIS performance.
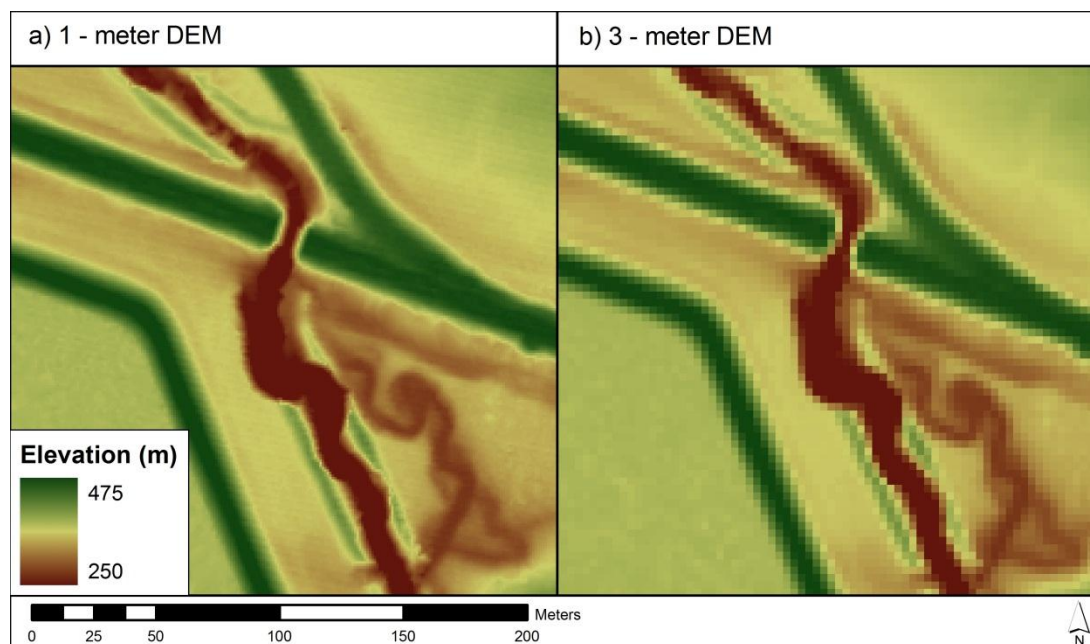
Figure 3.10: Aggregate tool applied to the 1 meter DEM to produce a 3 meter DEM

Note: a) 1-meter DEM b) 3-meter DEM produced from the Aggregate tool

DEMs contain depressions which are artifacts from manipulation of the LAS point dataset to generate the DEM. The depressions are referred to as sinks, which can pool water and confuse identification of continuous flow paths through the raster area.

The ArcHydro Extension "Fill Sinks" tool is used to fill sinks within the input DEM. The "Fill Sinks" tool iteratively scans the DEM to identify depressions, alter the elevations, and create a DEM with no inner depressions, allowing for continuous flow downstream to the basin outlet. The tool iterates until all sinks within a user-defined threshold are removed. The result of the tool is a filled DEM containing no inner depressions that is capable of continuous flow, see Figure 3.11a.

The filled DEM is input into the ArcHydro extension "Flow Direction" tool to calculate the corresponding direction of flow for each cell. The tool determines the elevation difference from a specific cell to each of the eight cells surrounding it. Assuming that water flows in the steepest direction, the tool assigns a number indicating the direction of flow. The result of the tool is a grid denoting the direction which each cell flows, see Figure 3.11b.

The flow direction grid is input into the ArcHydro extension "Flow Accumulation" tool to determine which cells contain the highest flow values. The tool counts the number of cells draining to each location on the grid. The result of the tool is a grid with high flow accumulations in the valleys and low accumulations in the hills, see Figure 3.11c.

The flow accumulation grid is input into the ArcHydro extension "Stream Definition" tool to calculate the flow path. The tool identifies a flow path using the high flow accumulation within the valleys. The result of the tool is a grid containing a value in the locations of the flow path and no values all other cells. The stream definition grid is then converted into a line file using the conversion tools extension "Raster to Polyline" tool resulting in a polyline following the grid path created in the stream definition process, see Figure 3.11d.
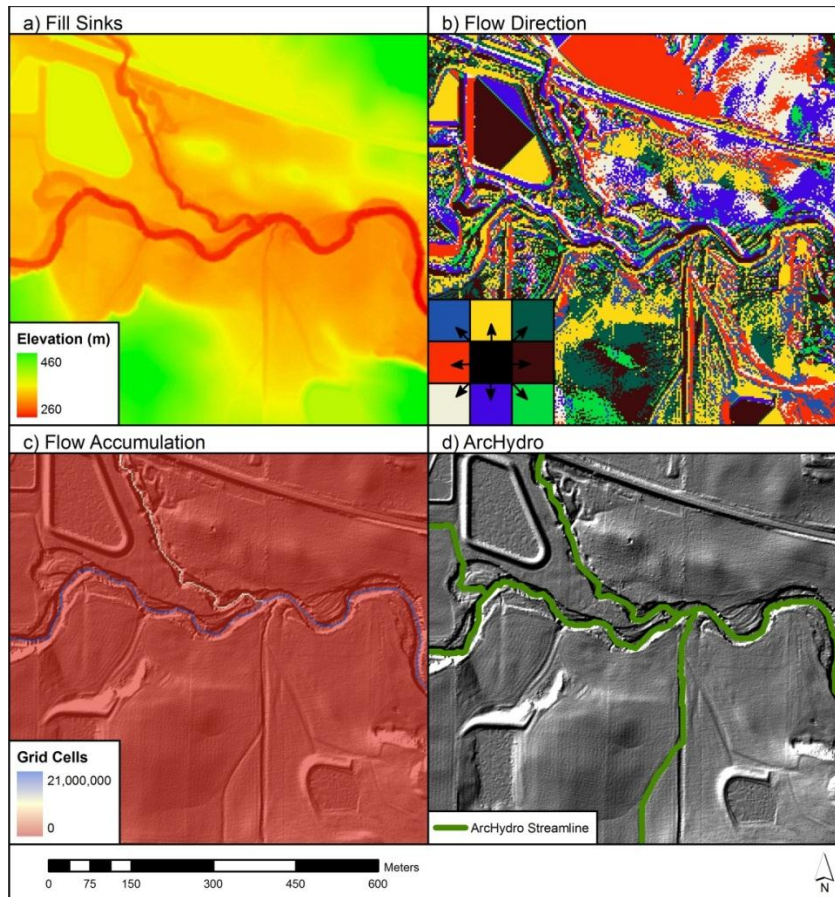
Figure 3.11: ArcHydro Processes used to create the ArcHydro centerline

Note: a) DEM raster after Fill Sinks tool is applied creating seamless flow through the watershed b) DEM raster after the Flow Direction tool is applied identifying direction of flow c) DEM raster after the Flow Accumulation tool is applied identifying the amount of cells flowing to each stream grid cell d) Final ArcHydro centerline after all of the process have been completed.

The accuracy of the flow path is directly dependent on the DEM under manipulation. The centerline loses accuracy in areas of dense vegetation cover under bridges, or culverts. In each of the examples LiDAR data reflects off the higher surfaces covering the water. In the ArcHydro process this forces the defined stream to exit the banks and flow around the high areas. Manual digitization of the centerline must correct for these errors.

Manual digitization is the primary technique employing the ArcHydro centerline as the principal tool. The dataset employed to display and digitize the centerline is the 1-meter LidAR derived DEM. Stream centerlines are visually identified through inspection of the 1-meter DEM. During digitization, a broad spectrum color map with strong color contrasts is used to reveal the most terrain detail.

A 1-meter hillshade grid is created to enhance detail within the 1-meter DEM data. The hillshade grid is created using the Spatial Analyst extension "Hillshade" tool. The "Hillshade" tool creates a grid by considering an illumination angle and shadowing effects. The 1-meter DEM is overlain onto the 1-meter hillshade grid with partial transparency, this combination displays more detail in the surface, see Figure 3.12. A majority of the digitization is completed using these two data sets.
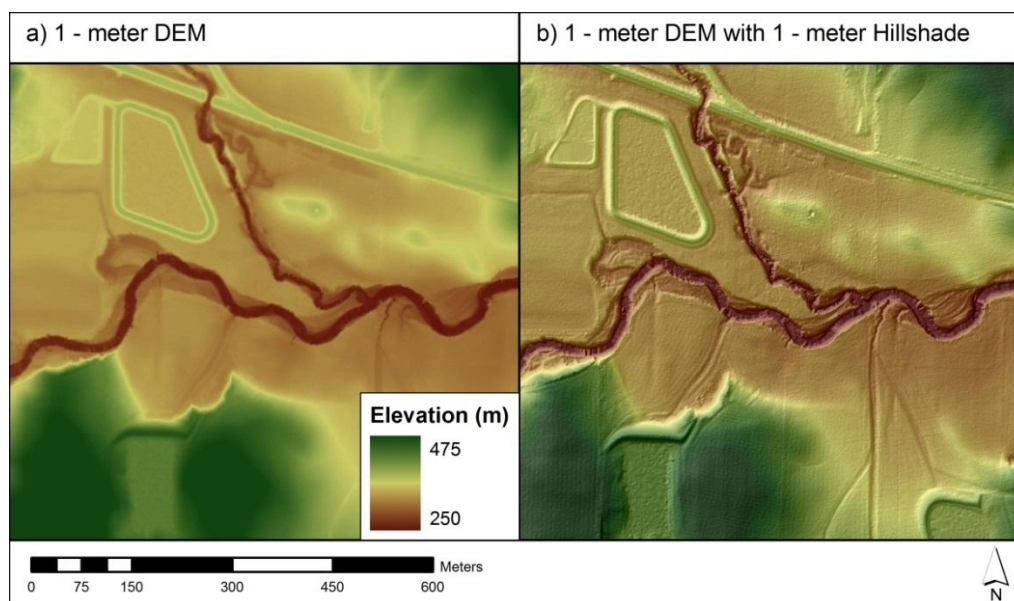
Figure 3.12: Comparison of DEM with and without DEM derived hillshade

Note: a) 1 meter grid DEM b) 1 meter grid DEM overlaying a 1 meter grid hillshade with partial transparency

Aerial photography is used as an alternative to the 1-meter DEM and hillshade combination in areas where vegetation and structures (bridges, culverts, and dams) mask the stream banks. In cases containing culverts and bridges, streamlines can be assumed, as the path under the bridge or through the culvert is typically obvious. In areas of dense vegetation, the stream often creates a visible separation of the vegetation. If the channel can be located then it is digitized.

If vegetation persists or the age of the aerial photography is in question the "FilDEM" is used. This raster is the difference between the fill sinks grid created in the ArHydro process and the 3-meter DEM which created the fill sinks grid. The Spatial Analyst "Raster Calculator" is used to find the difference grid. The difference shows areas of elevation alterations created in the fill sinks method, many of these locations are within the channels and often in areas of vegetation overgrowth. A semitransparent FilDEM is applied to the 1-meter DEM illuminating the areas of blocked streamline.

Digitization of small streams begins at the furthest upstream portion of the watershed. The threshold is determined by a combination of a 1-meter DEM and hillshade. An area must contain both a constant defined channel and an ArcHydro streamline or water must be clearly visible from the aerial photography. Each watershed is manually digitized from the furthest upstream areas of the watershed downstream. Breaks in the centerline occur at locations of a NHD classification change, and at each junction with another stream. Stream centerlines end at the furthest downstream location in the watershed, and at a junction between a small stream and a large stream. At the joining of a large and a small stream, an artificial path is digitized between the edge of the large stream and the estimated centerline of the large stream. A review of the methods used to digitize the centerline are seen in Figure 3.13.
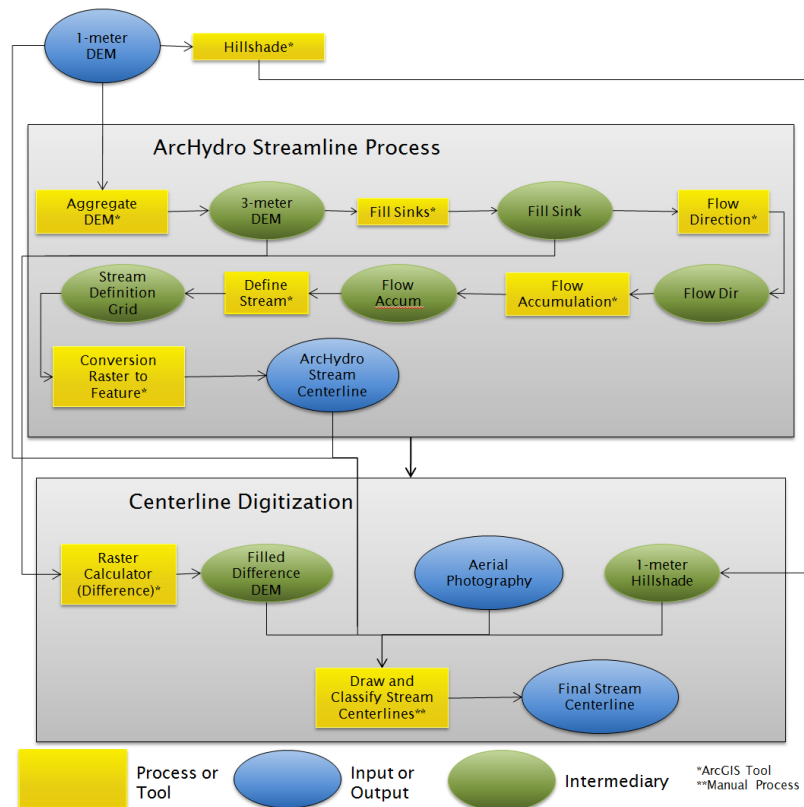
Figure 3.13: Small stream digitization work flow diagram

3.2.2.2 Large Stream Digitization

A large stream is defined as a river demonstrating a width from the edge of bank to edge of bank greater than seven meters wide. Manually digitizing the centerline of a channel becomes less accurate as the channel increases in width. When the channel becomes too wide for manual digitization LP360 is used to define the edge of water on both sides of the channel, average the distance across, and determine a channel centerline.

LP360 allows a user to access raw LAS data files, and integrate the geospatial data into an ArcGIS environment. Within ArcGIS the banks and center islands in a river reach are able to be accurately digitized. Locating the banks of the channel is done in a similar fashion to small stream centerline digitization. The 1-meter hillshade and aerial

photography are used in the same manner to determine an approximate bank line. LAS

data is the root of a DEM, as it contains the same elevation information in a point form.

The "LP360 Sketch" tool is used to edit and digitize the edge of the water surface. The

tool allows the user to see a swath of LiDAR point data based on user defined profile

depth and the current cursor location, see Figure 3.14. Analysis of the pseudo-cross

section allows for the capability to accurately determine the location of the water surface

in relation to the banks. LAS imagery consists of reflections from all surfaces including

buildings, ground, vegetation, and water surface. To more clearly view the edge of

water, the LAS data from only the ground surface is viewed significantly reducing the

data clutter. Both banks of the river are digitized in the same manner from upstream to

downstream.
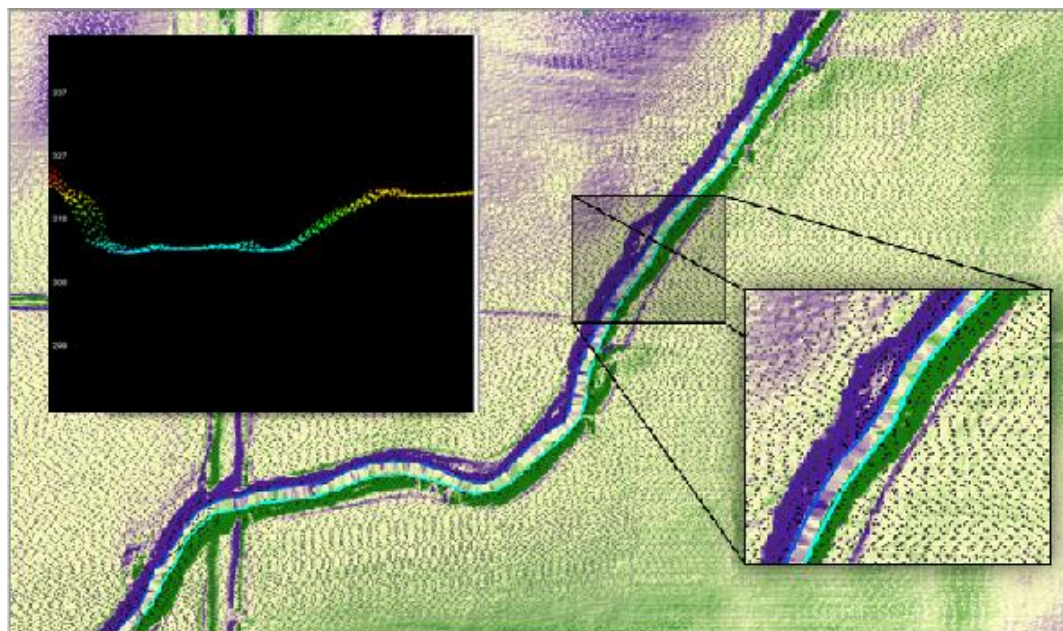
Figure 3.14: LiDAR LAS data points and cross section view for large stream digitization

Note: Left, LiDAR data points in the vicinity of a large stream. Right, pseudo-cross
section view of the LiDAR elevation data in LP360 used to identify the banks

The bank lines are used to determine the stream centerline through the Data Management Toolbox tool called the "Collapse Dual Lines to Centerline". The tool creates a centerline from two near parallel lines within user based width thresholds. The result of this process is a more definitive centerline, see Figure 3.15. The combination of LP360 and the Data Management toolbox allows for increased accuracy in determining a stream centerline within a large channel.
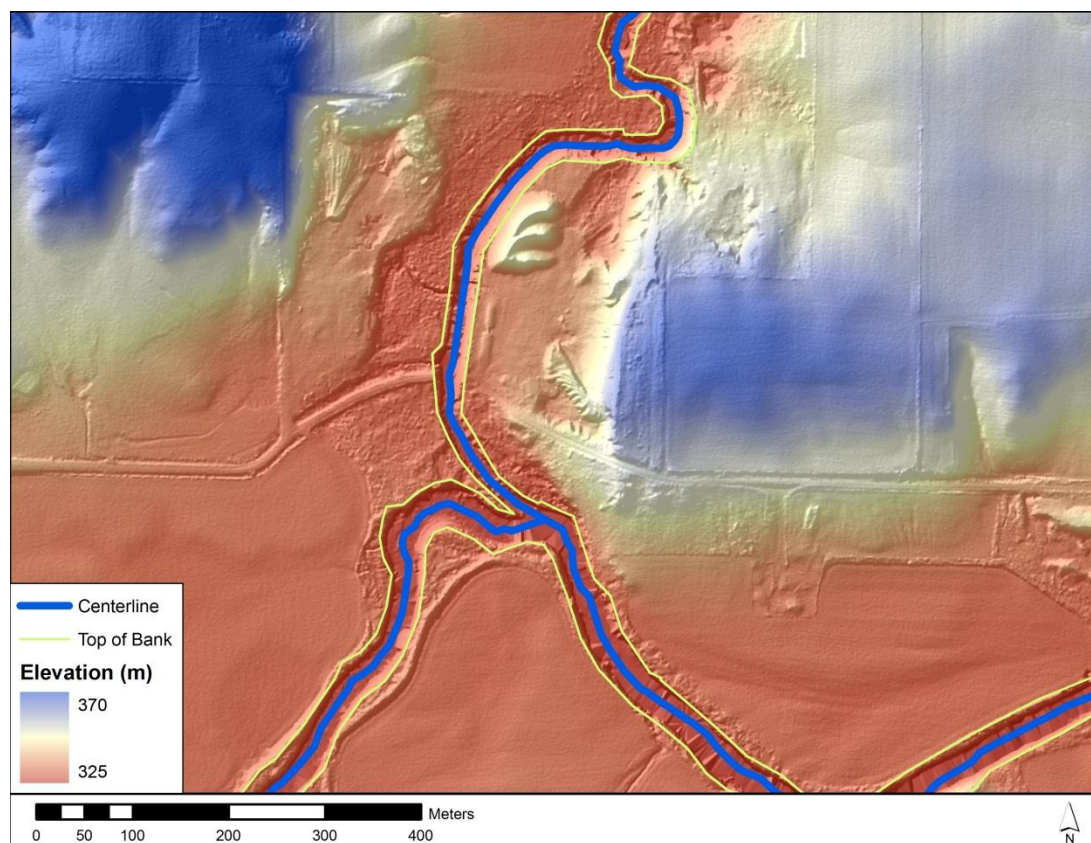
Figure 3.15: Completed large stream digitization with top of bank and collapsed stream centerline

3.2.3 Process Automation

Tools capable of increasing the efficiency and accuracy of centerline digitization have been developed. Small and large stream digitizations are repetitive and time consuming tasks that can be done by computer programs. Programs are employed to complete large and small stream separately as they involve two differing processes.

Small stream digitization is completed using a program produced by Brian Gelder of Iowa State University. Through the use of the LiDAR derived DEM a centerline is digitized by an iterative process involving identification of low lying areas and drainage thresholds. Manual smoothing of the line work and classification of NHD attributes are completed to produce the stream centerline.

Large stream line work is produced through a scripting technique within ArcGIS. Scripting creates a computer code in the language of Python which is an efficient method of automating simple and complex geoprocessess. The process identifies the edge of water of each bank through slope analysis of the LiDAR derived DEM. The output is a file containing two lines identifying the banks which are checked for quality and collapsed into a centerline.

3.2.4 Section Summary

Scrutinizing developed LiDAR data enables the digitization and classification of small streams up to a user based threshold. The identification and digitization of large stream banks ensures the precise location of large stream centerlines. Through the use of LiDAR based informatics and advancements in process automation, centerline data is produced, classified, and prepared for use in the hydrologic and hydraulic analyses efficiently and objectively.

3.3 Hydrologic Analysis

As part of the Iowa statewide floodplain mapping project, stream discharge estimates are calculated to establish hydrologic conditions associated with the 50, 20, 10,

4, 2, 1, 0.5, and 0.2 percent annual exceedance discharges. The United States Geological

Survey developed methods in 1987 (Lara, 1987) and 2001 (Eash D. A., 2001) to calculate

annual exceedance discharges in Iowa steams. The Iowa Department of Natural

Resources (IDNR) and Iowa Department of Transportation (IDOT), through experience

applying the USGS methods in the State, have developed recommendations on use of the

1987 and 2001 equations based upon proximity to stream gages, periods of gage records,

and drainage area. These recommendations have been adopted for use in the statewide

floodplain mapping effort. The methods are summarized in Table 3.2 and discussed in

greater detail in the following sections.

Table 3.2: Summary of methods used to estimate annual exceedance discharges

Site Description	Gage Record (Years)	Drainage Area (Square Miles)	Method	Reference
gaged site			weighted estimates for gaged sites	Eash 2001
ungaged site on a gaged stream	< 25		regression-weighted estimate for ungaged sites	Eash 2001
	≥ 25		area-weighted estimate for ungaged sites	Eash 2001
ungaged site on an ungaged stream		1 - 20	1987 methods	Lara 1987, Eash 2001
		20 - 50	average the 1987 and 2001 methods	Lara 1987, Eash 2001
		> 50	2001 single-parameter regression equations	Eash 2001

Additional information regarding annual peak flow data through USGS stream

gages and variability in the Lara and Eash regional regression analyses allows for the

specialization of methodology in producing annual exceedance discharge estimates.

Methods are established for gaged locations, ungaged locations on gaged stream reaches,

and ungaged locations on ungaged stream reaches.

3.3.1 Methodology

Hydrologic Analysis is broken into two major parts, calculating a continuous drainage area within the river channel, and applying the regression analysis formed by Laura in 1987 and Eash in 2001 in concurrence with IDOT and IDNR standards. The drainage area originates from the 1-meter LiDAR derived DEM, and stream centerlines. Drainage areas are calculated through inspection and manipulation of the DEM by applying ArcGIS raster based processes. Application and adjustment of annual exceedance discharges are calculated through Eash 2001 and Lara 1987 regression analyses.

3.3.1.1 Drain Area Calculation

Stream centerline data is required to aid in the hydrologic analysis. DEMs are modified by the final stream centerline dataset, forcing flow into the streams and allowing it to pass through culverts, bridges, or other artificial obstructions within the DEM. To complete the task an ArcHydro extension "DEM Reconditioning" tool is applied. The tool modifies the DEM by imposing the centerline feature into the raster. At the centerline location, the DEM is lowered to a user based threshold. A large enough drop in elevation will cause the flow to pass through the artificial obstructions in the DEM as opposed to around them, see Figure 3.16a.

To determine the drainage area ArcHydro raster manipulation tools are applied to the DEM. Following a similar process used in Section 3.2.1, the fill sinks tool is applied to the reconditioned DEM, which alters elevations allowing for continuous flow to the downstream outlet, see Figure 3.16b. The flow direction tool is applied to the fill sinks grid, which determines the direction of flow in each grid cell by comparing neighboring relative elevations, see Figure 3.16c. From the flow direction grid, the peaks and valleys are located through application of the flow accumulation tool, which is a measure of the area drained to each grid space, see Figure 3.16d.

FEMA requirements indicate floodplain mapping by approximate methods should be performed on areas draining one square mile or greater. The current flow accumulation raster has a grid size of nine square meters matching the DEM from which it was derived. The Spatial Analyst extension "Raster Calculator" is used to change the flow accumulation grid to units of square miles. The "Raster Calculator" is used to set all the points draining less than one square mile to blank fields with the "set null" function. The result of these operations is a raster containing only grid cells draining more than one square mile, see Figure 3.16e. The set null grid is transformed to a point shape file using the Conversion Tools extension "Raster to Point" tool. The tool takes each grid cell with a value and changes it to a point containing the value entrained in the original grid space. The result is a shape file of points running along the valley within the channel banks, referred to as the drainage area points shape file (DA.shp), see Figure 3.16f. Regional regression equations and adjustments employ the DA.shp dataset in the proceeding sections.

The DA.shp is separated into three categories based on the relative proximity to a USGS stream gage location. The categories are gaged locations, ungaged locations on gaged streams, and ungaged locations on ungaged streams. A gaged location refers to the exact location of the USGS stream gage based on USGS location data. An ungaged location on a gaged stream refers to a stream segment both upstream and downstream of a gaged location. At these points gage data will influence the annual exceedance flows. The ungaged location on an ungaged stream refers to areas which are not gaged or within the area of a gages influence. Each category of drainage area requires a varying combination of gage weighting and regression analysis, described in the proceeding sections.
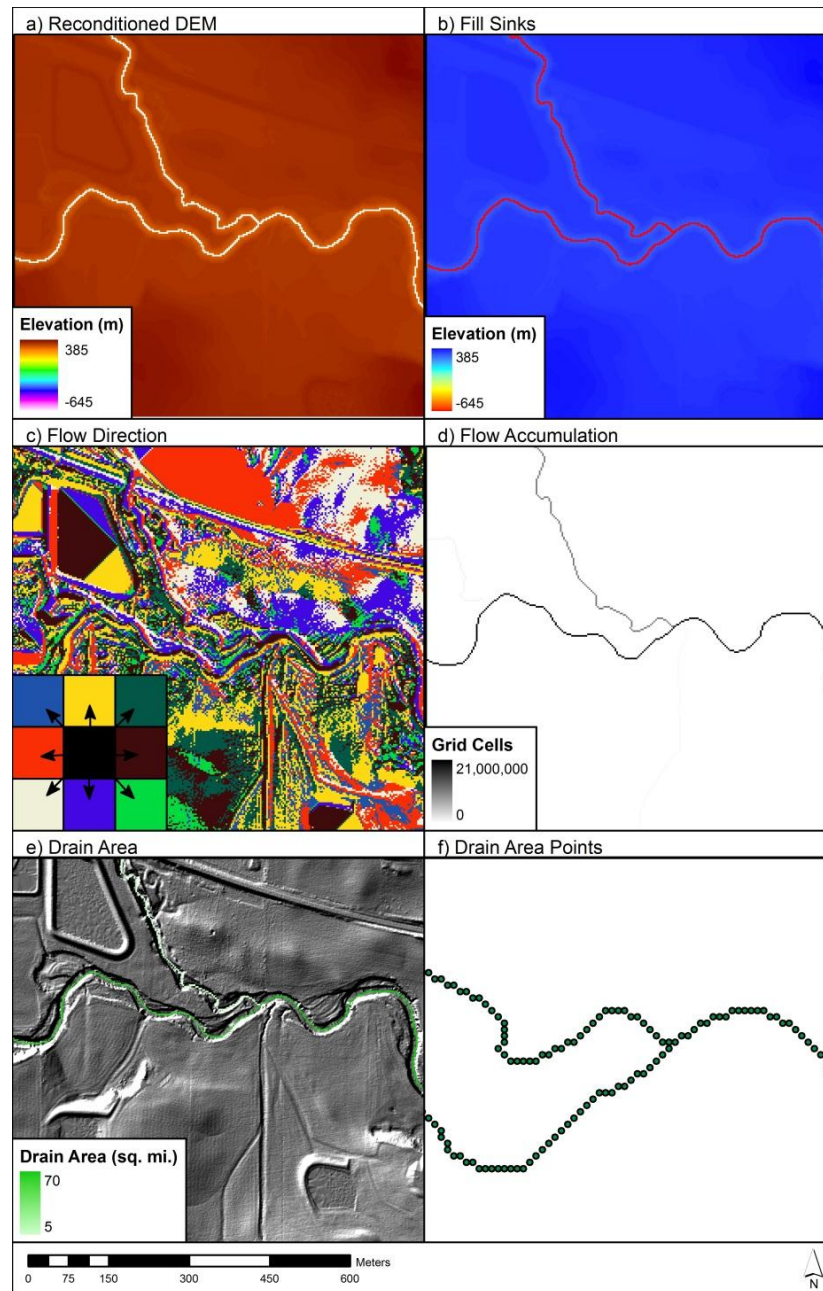
Figure 3.16: Raster process to determine DA.shp from DEM

Note: a) DEM after stream centerline was reconditioned forcing water flow into the streams. b) DEM grid after the Fill Sinks tool was applied creating seamless flow to the outlet. c) DEM grid after the Flow Direction tool was applied, identifying the direction of flow for each cell. d) DEM after the flow accumulation tool was applied summing the total number of cell flow to each stream grid point e) Total drainage area grid converting the grid cells from the flow accumulation grid into square meters. f) Drainage area points showing 1 point containing the drainage area every 3 meters.

3.3.1.2 Gaged Locations

At locations where a stream gage is operated by the USGS or United States Army Corps of Engineers, annual exceedance discharges are estimated by the USGS. A comprehensive analysis of Iowa gages was last conducted by Eash in 2001. Eash recommends adjusting annual exceedance discharge estimates using a regional weighting scheme. Due to 10 additional years of record since publication of (Eash D. A., 2001), annual log-Pearson Type III flood discharge estimates ($Q_{t(pg)}$) are calculated according to USGS Bulleting 17B using the USACE Hydrologic Engineering Center Statistical Software Package (HEC-SSP).

3.3.1.2.1 Implementation

All USGS stream gages are not used in this analysis, as incomplete and abbreviated data sets introduce unnecessary error into the analysis. Gages must have a total record length of at least 10 years, allowing for a sufficient quantity of data. The last recorded year must be within the past 10 years, attributing to the relevancy of the data, and excluding the outdated information. The data associated with a site must not be missing more than 10% of events within the record length, giving completeness to the dataset. If all of the listed criteria are met, then the gage information is accounted for within the study.

The gage locations are compared to the DA.shp, the DA.shp point closest to each gage is assumed to be the drainage area at the gage point. At a location where a USGS gage exists and has been deemed usable for the current analysis, the annual exceedance discharge calculated using the regional regression analysis is adjusted using a weighted scheme. To complete the adjustment the flood-discharge estimate, regional regression discharge estimate, effective record length, and equivalent years of record must be determined.

HEC-SSP is employed in calculating the flood-discharge estimate and the effective record length. The HEC software is used to carry out a Bulletin 17B analysis at the gaged location. Peak annual flow data is imported into the HEC-SSP software from the USGS server. Analyses are performed using each gage's full record of annual peak discharges, regional skew coefficients from table 2 in (Eash D. A., 2001), and a regional skew mean squared error (MSE) of 0.156 from (Eash D. A., 2001). In cases were individual gages are not included in (Eash D. A., 2001), table 3, regional skew coefficients are visually interpreted from Figure 3.17.
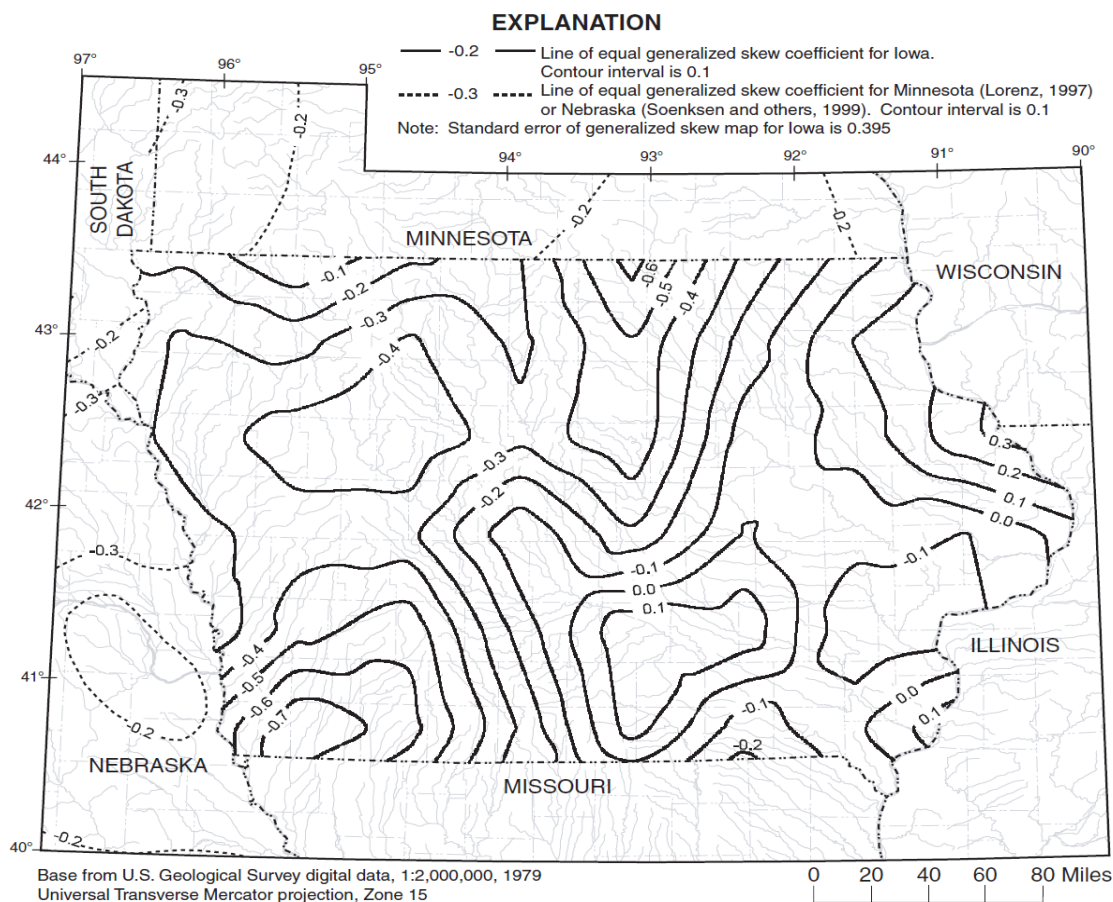
Figure 3.17: Generalized skew isolines for Iowa used to estimate the regional skew coefficients when regional skew coefficients are not identified for the gaged location in (Eash, 2001) table 3

Inclusion of historic data is the final step in the Bulletin 17B Analysis. Historic flood data is defined as information that provides reliable estimates of flood peaks outside of the systematic record. Historic data can be located before or during the systematic data collection period. It defines an extended period during which the largest floods, whether recorded or historic, are known. Data that fits these criteria should be used in the analysis often extending the record of largest events to a period much longer than the systematic record length. The verification of historic data is done using USGS Quality Codes of Annual Peak Flow Data and through visual inspection of plotted data. Information input into an Annual log-Pearson Type III flood discharge estimate according to the USGS Bulletin 17B allow the calculation of the flood-discharge estimate for each return period.

Equivalent record length is an output of HEC-SSP. The value determined by the program is accurate if historic data is not taken into account. If historic data is a factor in the analysis, adjustments to the equivalent years of record are performed shown in Equations 3.1, 3.2, and 3.3.

$$\text{ERL} = \text{LS} + (\text{HST} - \text{LS})a \tag{3.1}$$

$$a = 0.55 - 0.1 \left[\log_e \left(\frac{\text{ph}}{1 - \text{ph}} \right) \right] \tag{3.2}$$

$$\text{ph} = 1.0 - \frac{\text{np}}{\text{HST}} \tag{3.3}$$

Where np is number of historic and extremely large discharge (high-outlier) peaks, LS is the systematic record length of a gaging station in years (the number of water years during which the gaging station was operating), and HST is the historic record length of a gaging station, in years, as used in a Pearson Type-III historical flood frequency analysis, if a systematic flood frequency analysis was performed, HST = LS, and if (HST-LS) > 200, set (HST-LS) = 200.

The HEC-SSP analysis computes the flood-discharge estimate, effective record length. The equivalent years of record is a known quantity. Using the weighted

discharge scheme in Equation 3.4 annual exceedance discharge estimates are made at gaged locations.

$$Q_{t(wg)} = \frac{Q_{t(pg)}(ERL) + Q_{t(rg)}(EYR)}{(ERL + EYR)} \qquad (3.4)$$

Where $Q_{t(wg)}$ is the weighted discharge estimate for a gaged site for recurrence interval t, $Q_{t(pg)}$ is the flood-discharge estimate (log-Pearson Type III) for a gaged site for recurrence interval t (listed (Eash D. A., 2001), table 2), ERL is the effective record length for a gaged site, in years (equivalent to the systematic record length if historical data are not considered; calculated according to Equations 3.1, 3.2 and 3.3 when historical data are used), $Q_{t(rg)}$ is the regional-regression discharge estimate for a gaged site for recurrence interval t (listed in the flood-frequency discharges (Eash D. A., 2001), table 2, or calculated using the 2001 single parameter regression equations in tables 3-5), and EYR is the equivalent years of record for the regional regression equation used to determine Qt(rg) (Eash 2001, tables 3-5).

3.3.1.3 Ungaged Locations on Gaged Streams

The Iowa Department of Transportation LRFD Manual (IDOT, 2010) makes the following recommendations regarding annual exceedance discharge estimates at ungaged sites located on gaged streams:

> *"If the drainage area at the project site is within 50% of the drainage area of the gage, the gage discharges should be used and transferred to the project site per the method specified in USGS WRIR 00-4233. If 25 years or more of stream gage data is available, the area-weighted estimate for ungaged sites on gaged streams is preferred over the regression-weighted estimate. Stream gage information may be obtained from the USGS in Iowa web site, the U.S. Army Corps of Engineers web site, or from the USGS WRIR 00-4233 publication."*

When a stream gage exists on the stream of interest, the drainage area ratio between the gaged site and ungaged site is used to determine whether it is appropriate to use gage information in estimating annual exceedance discharges. For locations within

gage influence, two methods are applied to weight the annual exceedance discharge. When less than 25 years of information is on record, the discharge is determined using a regression-weighted approach. When more than 25 years of information is on record, the discharge is determined using an area-weighted approach. In areas under the influence of more than one gage a logarithmic averaging scheme described by (Sando, 1998) is applied.

3.3.1.3.1 Implementation

Stream gage influence is based on the relative drainage areas within the stream reach. Applying Equation 3.5 to the drainage points surrounding the gaged location determines the drainage area ratio (DAR). When the DAR is less than 0.5, the location is considered to be on a gaged stream segment.

$$\text{DAR} = \frac{|DA_g - DA_u|}{DA_g} \tag{3.5}$$

Where DAR is the drainage area ratio, DA_g is the drainage area of the gaged location, and DA_u is the drainage area of the ungaged location.

The drainages deemed to be within gage influence are exported from the rest of the dataset and an annual exceedance flow is calculated one of two ways based on Iowa Department of Transportation recommendation (IDOT 2010). For gages with a historical record length of less than 25 years, a regression-weighted estimate is performed, see Equation 3.6. For gages containing more than 25 years of record, an area-weighted discharge is completed, see Equation 3.8.

$$Q_{t(rw)} = Q_{t(ru)}[AF - (2DAR)(AF - 1)] \tag{3.6}$$

Where $Q_{t(rw)}$ is the regression-weighted discharge estimate for an ungaged site on a gaged stream for recurrence interval t, $Q_{t(ru)}$ is the regional regression discharge estimate for an ungaged site for recurrence interval t, determined using the technique

described in (Eash D. A., 2001), and AF is the adjustment factor for the gaged site and is calculated as

$$AF = \frac{Q_{t(wg)}}{Q_{t(rg)}} \tag{3.7}$$

Where $Q_{t(wg)}$ is the weighted discharge estimate for a gaged site for recurrence interval t (from Equation 3.4), and $Q_{t(rg)}$ is the regional-regression discharge estimate for a gaged site for recurrence interval t (listed in the flood-frequency discharges in (Eash D. A., 2001), table 3).

$$Q_{t(aw)} = Q_{t(wg)} \left(\frac{DA_u}{DA_g}\right)^x \tag{3.8}$$

Where $Q_{t(aw)}$ is the area-weighted discharge estimate for an ungaged site on a gaged stream for recurrence interval t, $Q_{t(wg)}$ is the weighted discharge estimate for a gaged site for recurrence interval t (from Equation 3.4), DA_u is the drainage area of the ungaged site, DA_g is the drainage area of the gaged site, and x is the mean exponent for a hydrologic region defined in (Eash D. A., 2001); for Region 1, the mean exponent is 0.665; Region 2, 0.446; and Region 3, 0.403.

In some cases, a location's drainage area ratio is 0.5 or greater for two stream gages. In this case, regression- or area-weighted discharges are calculated using each gage; then the two calculated discharges are averaged using the logarithmic averaging scheme described by (Sando, 1998) see Equation 3.9.

$$Q_{t(wa)} = \log^{-1}\left[\frac{\log Q_{t(w1)} + \log Q_{t(w2)}}{2}\right] \tag{3.9}$$

Where $Q_{t(wa)}$ is the logarithmically averaged discharge for an ungaged location on a gaged stream for which two gages satisfy the drainage area ratio criterion described by Equation 3.5, $Q_{t(w1)}$ and $Q_{t(w2)}$ are regression- or area-weighted discharges calculated using Equations 3.6 and/or 3.8.

3.3.1.4 Ungaged Locations on Ungaged Streams

At sites which are not located on gaged streams, annual exceedance discharges are calculated using regional regression equations. The Iowa Department of Transportation LRFD Manual (IDOT, 2010) makes the following recommendations regarding annual exceedance discharge estimates at ungaged sites located on ungaged streams:

> *"If the project site is not located in a detailed FIS or within 50% of the drainage area of a gage, the USGS regression equations should be used to estimate peak discharges. The Iowa DOT currently recommends that the USGS 87-4132 report be utilized for projects that have drainage areas between 2 and 20 square miles. For drainage areas greater than 20 but less than 50 square miles, the Iowa DOT recommends that both the USGS 87-4132 and 00-4233 reports be used for estimating the design discharges and engineering judgment (possibly averaging both methods) be utilized for determining the peak discharges. If the drainage area is greater than 50 square miles, the Iowa DOT recommends using the USGS 00-4233 report."*

Consistent with these recommendations, annual exceedance discharges for ungaged locations on ungaged streams are estimated using regional regression equations developed by both (Lara, 1987) and (Eash, 2001). Laura (1987) regression equations are applied to drainages of less than 20 square miles, as the report focused on improving accuracy of regression analysis in small, rural unregulated drainages. Eash (2001) regression equations are applied to drainages of more than 50 square miles, as the report focused on larger gaged streams. On drainages between 20 and 50 square miles and an arithmetic average of the two methods is employed to calculate the annual exceedance discharges.

3.3.1.5 Implementation

The exceedance flow at an ungaged location is based on two factors, the drainage area, and the hydrologic region of the stream reach. The drainage area determines which regression analysis is applied. The hydrologic region determines which set of equations

within the proper regression analysis are employed. The drainage area is input into the regression equations to output annual exceedance flows.

Annual exceedance discharges for sites draining between 1 and 20 square miles are calculated using regression equations developed by Lara (1987), see Table 3.3. Regression equations were developed for five hydrologic regions, shown in Figure 3.18 delineated by differences in topography and geology.

Lara (1987) first developed flood regression relations for the 2-, 5-, 10-, 25-, 50-, and 100-year equations by fitting a log-Pearson Type III (LP3) distribution to sample data. Since equations for estimating the 200- and 500-year discharges were not generated by Lara (1987), an approach for extrapolating the 1987 regression relations was developed using the LP3 method. New regional regression equations for 200- and 500-year discharges are shown in Table 3.4.

Table 3.3: 1987 USGS regional regression equations for Iowa

Region 1	Region 2	Region 3	Region 4	Region 5
$Q_2 = 211 \cdot A^{0.62}$	$Q_2 = 196 \cdot A^{0.57}$	$Q_2 = 129 \cdot A^{0.62}$	$Q_2 = 31 \cdot A^{0.77}$	$Q_2 = 30 \cdot A^{0.66}$
$Q_5 = 502 \cdot A^{0.60}$	$Q_5 = 402 \cdot A^{0.55}$	$Q_5 = 265 \cdot A^{0.59}$	$Q_5 = 67 \cdot A^{0.72}$	$Q_5 = 37 \cdot A^{0.71}$
$Q_{10} = 757 \cdot A^{0.60}$	$Q_{10} = 570 \cdot A^{0.55}$	$Q_{10} = 381 \cdot A^{0.57}$	$Q_{10} = 98 \cdot A^{0.70}$	$Q_{10} = 41 \cdot A^{0.74}$
$Q_{25} = 1,140 \cdot A^{0.57}$	$Q_{25} = 821 \cdot A^{0.54}$	$Q_{25} = 555 \cdot A^{0.55}$	$Q_{25} = 145 \cdot A^{0.68}$	$Q_{25} = 45 \cdot A^{0.77}$
$Q_{50} = 1,500 \cdot A^{0.60}$	$Q_{50} = 1,020 \cdot A^{0.53}$	$Q_{50} = 695 \cdot A^{0.54}$	$Q_{50} = 180 \cdot A^{0.66}$	$Q_{50} = 47 \cdot A^{0.79}$
$Q_{100} = 1,880 \cdot A^{0.60}$	$Q_{100} = 1,230 \cdot A^{0.53}$	$Q_{100} = 851 \cdot A^{0.53}$	$Q_{100} = 227 \cdot A^{0.65}$	$Q_{100} = 50 \cdot A^{0.80}$
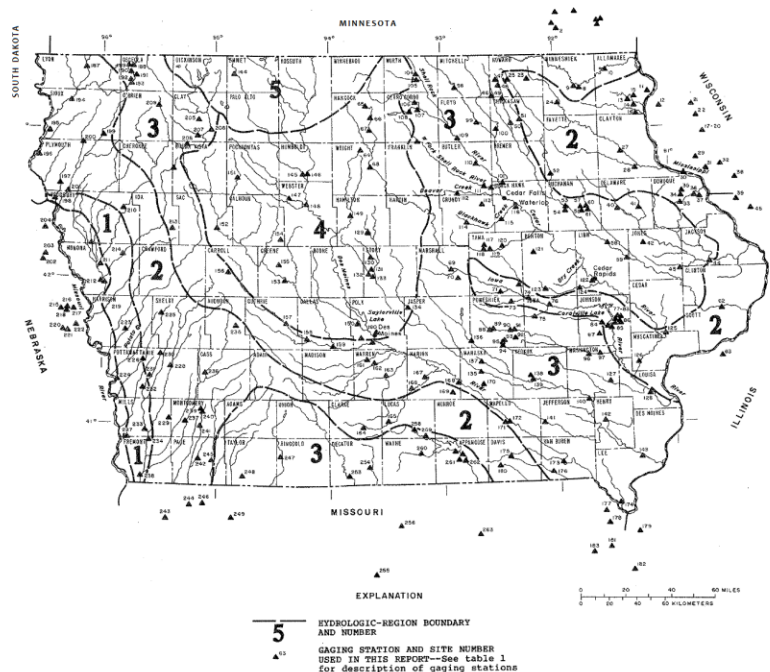
Figure 3.18: State of Iowa hydrologic regions identified by the 1987 regional regression
analysis (Lara 1987)

Table 3.4: Extrapolated 200- and 500- year regression equations by assuming Log-
Pearson Type III Distribution

Region 1	Region 2	Region 3	Region 4	Region 5
$Q_{200} = 2300 \cdot A^{0.60}$	$Q_{200} = 1460 \cdot A^{0.52}$	$Q_{200} = 1020 \cdot A^{0.52}$	$Q_{200} = 274 \cdot A^{0.64}$	$Q_{200} = 52.1 \cdot A^{0.81}$
$Q_{500} = 2910 \cdot A^{0.61}$	$Q_{500} = 1780 \cdot A^{0.52}$	$Q_{500} = 1270 \cdot A^{0.51}$	$Q_{500} = 342 \cdot A^{0.63}$	$Q_{500} = 54.5 \cdot A^{0.83}$

Annual exceedance discharges for sites draining greater than 50 square miles are
calculated using the single-parameter regression equations developed by Eash (2001), see
Table 3.5. The equations were developed for three hydrologic regions, depicted in Figure
3.19, based on variations in topography and geology.

Table 3.5: 2001 single parameter USGS regression equations for Iowa (Equivalent period of record associated with the equations are shown in parentheses)

Region 1	Region 2	Region 3
$Q_2 = 33.8 \cdot A^{0.656}$ (4.2)	$Q_2 = 182 \cdot A^{0.540}$ (3.6)	$Q_2 = 286 \cdot A^{0.536}$ (3.6)
$Q_5 = 60.8 \cdot A^{0.658}$ (5.8)	$Q_5 = 464 \cdot A^{0.490}$ (7.9)	$Q_5 = 737 \cdot A^{0.466}$ (6.9)
$Q_{10} = 80.1 \cdot A^{0.660}$ (7.7)	$Q_{10} = 728 \cdot A^{0.465}$ (13.5)	$Q_{10} = 1,180 \cdot A^{0.431}$ (11.0)
$Q_{25} = 105 \cdot A^{0.663}$ (10.1)	$Q_{25} = 1,120 \cdot A^{0.441}$ (20.5)	$Q_{25} = 1,900 \cdot A^{0.397}$ (17.5)
$Q_{50} = 123 \cdot A^{0.666}$ (11.5)	$Q_{50} = 1,440 \cdot A^{0.427}$ (24.0)	$Q_{50} = 2,550 \cdot A^{0.376}$ (22.2)
$Q_{100} = 141 \cdot A^{0.669}$ (12.5)	$Q_{100} = 1,800 \cdot A^{0.415}$ (25.9)	$Q_{100} = 3,300 \cdot A^{0.357}$ (26.2)
$Q_{200} = 159 \cdot A^{0.672}$ (13.2)	$Q_{200} = 2,200 \cdot A^{0.403}$ (26.5)	$Q_{200} = 4,160 \cdot A^{0.340}$ (29.0)
$Q_{500} = 183 \cdot A^{0.676}$ (13.7)	$Q_{500} = 2,790 \cdot A^{0.389}$ (26.0)	$Q_{500} = 5,490 \cdot A^{0.321}$ (31.0)
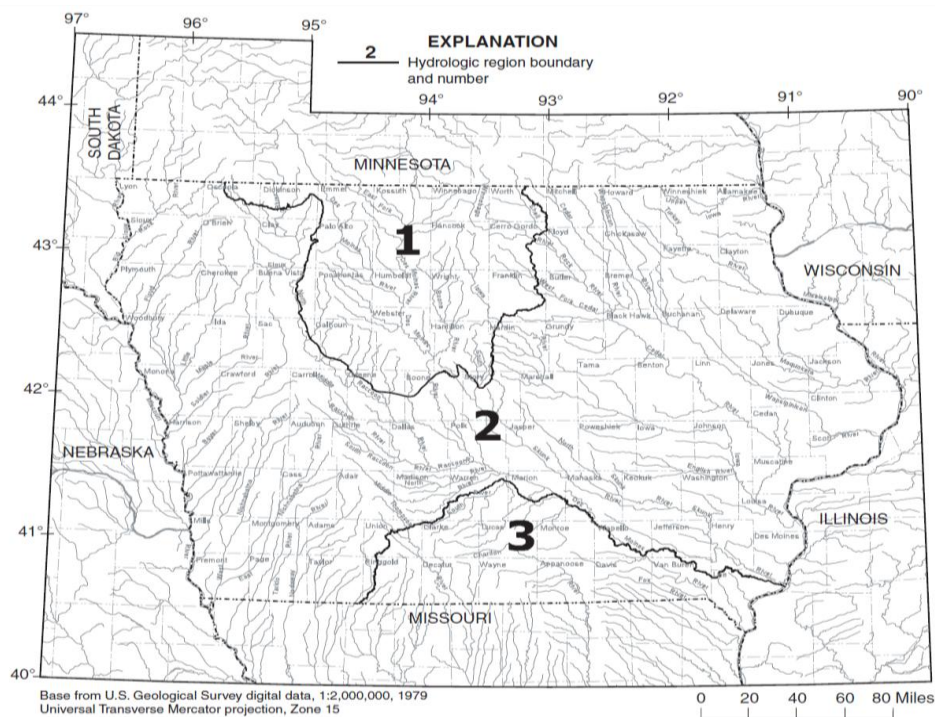
Figure 3.19: Hydrologic regions identified by the 2001 regional regression analysis for Iowa (Eash, 2001)

Annual exceedance discharges for sites draining between 20 and 50 square miles are calculated as the arithmetic mean of estimates made using regression equations developed by both Lara (1987) and Eash (2001).

It should be noted that Eash (2001) also identifies two- and three-parameter regression equations for some areas. While these equations have lower standard errors than the single-parameter equations listed in Table 3.5, the complexity of the calculations prevents broad implementation at numerous sites throughout the state. Therefore, the single-parameter equations are used in this study.

Discontinuities in the streamwise direction exist caused by variations in regional regression flow calculations and hydrologic region change as seen in Figure 3.20. In some instances, the irregularities cause discharge to decrease with an increasing drainage area. Most commonly locations of hydrologic region change exemplify this behavior. To account for these situations, a smoothing and stepping routine is created, see Section 4.3 for more detail.
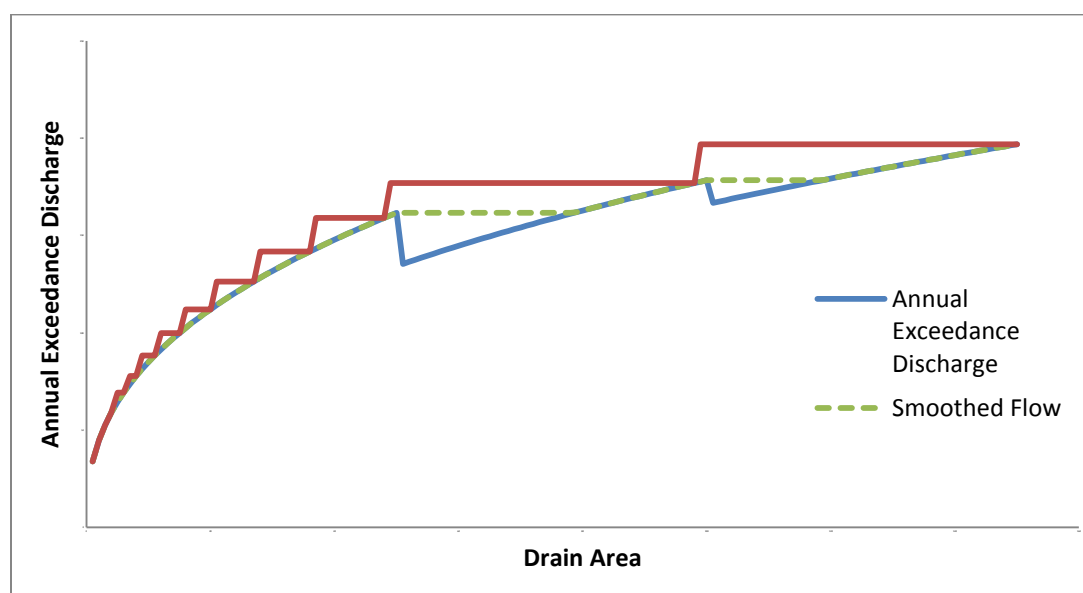
Figure 3.20: Flow smoothing and stepping functions, a solution to the abrupt flow changes when a stream crosses hydrologic regions

3.3.2 Process Automation

Hydrologic modeling using regional regression equations is a process that is automated using a scripting method similar to Section 3.2.3. Scripts are created for both determining the drainage area and applying the regional regression equations. The drainage area is found by the process applied in Section 3.2.1, which inputs a 1-meter DEM and stream centerline data, and outputs the DA.shp dataset. A tool called "Model Builder" within ArcGIS allows a user to set up a series of ArcGIS functions and exports them to a Python code to complete the routine. Annual exceedance flows are determined by another python script which assumes all locations are ungaged locations on an ungaged stream. This assumption covers most of the reaches. Gaged locations and locations within the gage influence area are calculated manually, the HEC-SSP analysis has too many complications to include in the "Model Builder".

3.3.3 Section Summary

The DEM is altered to force flow into the streams by decreasing elevation at the stream centerline locations. The ArcHydro raster processing suite is utilized to manipulate the DEM and produce data points every three meters along the streamline identifying the drainage area at that stream location. The points are divided into three categories of flow calculation based on proximity to a stream gages. The three categories are gaged locations, locations within gage influence, and ungaged location. Each utilizes a varying combination of gage weight and regional regression analysis to determine the annual exceedance flow at each location. Fifty, 20, 10, 4, 2, 1, 0.5, and 0.2 percent annual exceedance discharges are calculated at each point in preparation for use in the hydraulic analysis. For summary of tools and methods used to compute the annual exceedance flows in Iowa streams see Figure 3.21.
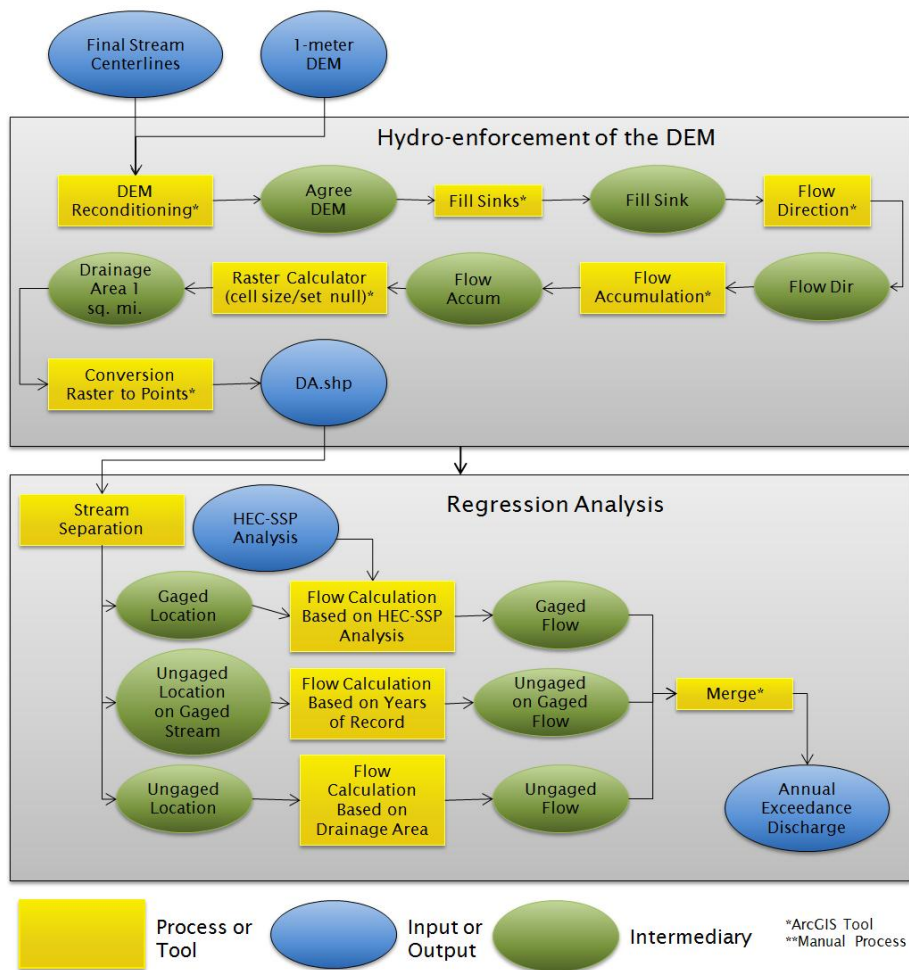
Figure 3.21: Hydrologic modeling work flow

3.4 Hydraulic Analysis

As part of the Iowa statewide floodplain mapping program, water surface elevations are being calculated to establish flood levels associated with Fifty, 20, 10, 4, 2, 1, 0.5, and 0.2 percent annual exceedance discharges. Hydraulic analysis is performed using the United States Army Corps of Engineers Hydrologic Engineering Center River Analysis System (HEC-RAS). HEC-RAS predicts water surface profiles based on the standard step backwater method. HEC-RAS requires geometric data describing the

stream network, and boundary conditions describing stream discharges and downstream water surface elevations. The procedure is discussed in greater detail in the following sections.

3.4.1 Reach Separation

River systems are broken down into smaller stream reaches to simplify the modeling procedures and minimize errors. Each stream is labeled based on the DFIRM naming convention. If the DFIRM's don't provide a name, the NHD naming convention is utilized. Named streams are identified by the NHD naming convention and are modeled from start to finish as one model. If the NHD doesn't provide a name then the USGS 7.5 minute map names are utilized. If a name is not found in the USGS maps the NHD reach numbers system called "RCH_CODE" is used as a naming tool. Each segment or a piece of a river running from one junction to the next is assigned a different number. The longest combination of the stream segments are modeled as one stream. This process continues until all segments are modeled.   Only streams within the one square mile drainage area threshold are modeled. Each reach or selection of segments modeled together must be at least half of a mile in stream centerline length, otherwise it is of insufficient length, and is considered irrelevant based on FEMA mandated standards. Stream reaches are modeled and mapped separately then combined in production of Flood Insurance Rate Maps.

3.4.2 Geometry Definition

In a one dimensional model, defining geometry which accurately describes a river reach is essential. HEC-GeoRAS based in ArcGIS is used to accurately represent the river reach geometries. Furthermore HEC-GeoRAS is applied as a suite of hydraulic preprocessing tools allowing for ease of geometric data definition and transfer between ArcGIS and HEC-RAS. These programs allow for the extraction of spatial data from the DEM for use by HEC-RAS. Stream centerlines, cross sections, banks lines, and flow

paths are capable of describing channel geometry. Each is defined in ArcGIS by applying differing techniques described within this section.

The final digitized stream centerlines described in Section 3.2.2 are used to establish the river reach network of the HEC-RAS model. The river centerline is digitized from upstream to downstream. Each reach contains only one river centerline without breaks. A Data Management Tools extension "Dissolve" is applied to the centerline to aggregate multiple features into one. This tool also generalizes the centerline attributes and disregards the classification. The classifications are not used in the remainder of the modeling process. The output is a single defined centerline digitized from upstream to downstream accurately representing the river flow.

River valley cross-sections are used in HEC-RAS and other standard step backwater models to define the channel and floodplain geometry. Cross sections are used to extract elevation information from a digital terrain model to create profiles of the ground surface. HEC-GeoRAS extracts cross sectional geometry from the 1-meter DEM. Cross sections must be cut from left descending bank to right descending bank (i.e. left to right, looking downstream). Maintain a consistent spacing between cross sections; IDNR mandated spacing of approximately 500 meters, see Figure 3.22.

HEC-RAS assumes that the energy head is constant across the cross section and that the stream flow is perpendicular to the cross section. So, cross-sections should be oriented perpendicular to the anticipated flow direction. As flow direction may vary along a cross-section's length, cross-sections may take on an irregular shape. Variation in flow direction with discharge should also be considered. When simulating more frequent flow events, the segment of a cross-section in the immediate vicinity of the main channel should be oriented perpendicular to the channel's path, while segments further from the channel should be oriented perpendicular to the river valley. To assist in cross section delineation, the cross section profile tool shows a profile of a digitized cross section.

This tool allows a user to determine if the cross section adequately describes the flood plain and profile depths prior to final extraction of elevation information.

Following the execution of the HEC-RAS model, HEC-GeoRAS is used to delineate floodplain boundaries. The boundary is defined by the cross section extents. Areas outside of the boundary are not inundated by the automated HEC-GeoRAS process and must be manually edited. Therefore, it is important to extend the cross sections as far up the valley walls as necessary.

Stream bank locations are identified at each model cross section on each side of the river centerline. The bank lines are short line segments which identify where the terrain shifts from the main channel to the floodplain. The banks need only be described at each cross section location, see Figure 3.22. Bank lines are also used to identify a change in Manning's n value for over land flows.

HEC-RAS requires information describing flow paths in the overbank areas to calculate flow energy losses over the distance between model cross-sections. HEC-GeoRAS compiles this information by recording the overbank distance between two consecutive cross-sections. The lines must remain outside the channel banks and cannot cross one another. Ideally, the lines should identify the path which the bulk of the active overland flow takes as it travels downstream, see Figure 3.22.

The HEC-RAS model has only four necessary geometric inputs previously described, in order for the one dimensional model to operate. Cross sections in a one dimensional model are not capable of creating a full description of the land surface. Gross misrepresentations of the system are often created through extension of cross sections or other cross section location related issues. Ineffective flow areas and obstruction areas can aide in the model description in these areas.
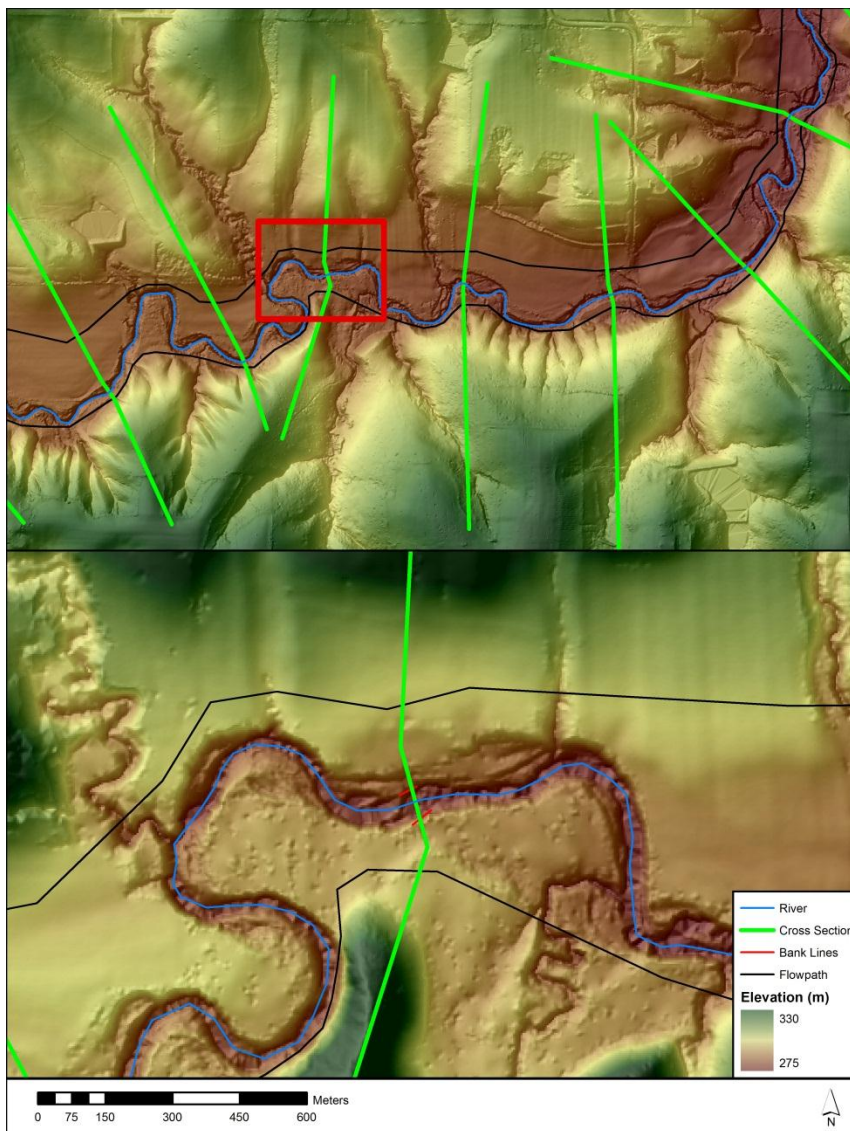
Figure 3.22: Hydraulic geometry required to model a typical channel. (Cross sections, Flowpaths, Bank Lines, and a Stream Centerline) *Scale bar represents the bottom figure

Ineffective flow areas typically refer to locations of standing water, caused by high levels of inundation. Identifying an ineffective flow area in a cross section indicates that the area is not to be used for conveyance but can still hold water. Typical locations with areas of ineffective flow are elevated roadways running parallel to the stream centerline, elevated "islands" within a large floodplain, expansion and contraction areas

around bridge abutments, or uncertified levees along the stream banks. Ineffective flow area polygons should completely contain the areas deemed unsuitable for flow conveyance.

Identifying obstruction areas is a final step in defining the geometric constraints of the modeled area. Obstructions represent blocked flow areas or areas that contain no water and no flow. Typically, they are in locations of buildings in the floodplain. In this study they are also applied to low lying areas in a cross section caused by tributaries, or other forms of lateral inflow which have created significant gullies. To accurately describe the channel geometry, creating a cross section which traverses another stream is sometimes necessary. To ensure the flow is not altered due to a low area an obstruction is added to the alternate channel. Obstructed flow area polygons should completely contain the areas deemed unsuitable for inundation.

In order to establish model connectivity, cross-sections must cross both overland flow path lines, both bank lines, and the stream centerline. The hill shade grid and overlain 1-meter DEM were used as backgrounds to located cross sections and visualize flow paths and bank lines during digitization. This combination offers the most vivid depiction of the required features, see Figure 3.22.

Spatial variation in flow resistance due to land cover is characterized in HEC-RAS using Manning's roughness coefficients. Manning's coefficients are assigned to cross sections segments according to the types of natural or man-made surfaces and obstructions present. HEC-RAS allows assignment of up to 20 different roughness values in segments along each cross-section.

Using HEC-GeoRAS, roughness coefficients are assigned to cross-sections based upon geospatial land cover data. The USGS 2001 NLCD was used to generate statewide roughness coefficients. NLCD 2001 data includes satellite-derived 30-meter-resolution classifications of land cover, available in ArcGIS polygon shapefile format. A direct conversion of land cover to roughness coefficients was created based on Table 3.6.

Table 3.6: Roughness conversion from land use, combination of Chow (1959) and
Mattocks and Forbes (2008).

Channel roughness coefficients

Contributing Drainage Area	Manning's roughness coefficient
Less than 10 square miles	0.045
Greater than 10 square miles	0.035

Overbank roughness coefficients

NCLD 2001 Classification	Manning's roughness coefficient
11 - Open water	0.02
21 - Developed, Open Space	0.03
22 - Developed, Low Intensity	0.05
23 - Developed, Medium Intensity	0.1
24 - Developed, High Intensity	0.15
31 - Barren Land	0.05
41 - Deciduous Forest	0.12
42 - Evergreen Forest	0.12
43 - Mixed Forest	0.12
52 - Scrub/Shrub	0.08
71 - Grassland/Herbaceous	0.035
81 - Pasture/Hay	0.035
82 - Cultivated Crops	0.07
90 - Woody Wetlands	0.1
95 - Emergent Herbaceous Wetland	0.045

Roughness coefficients vary greatly in overland flow areas but within the channel they remain relatively constant. Manning's n values within the banks are altered to adjust for variability in flow resistance. Depending on the drainage area at the location of the cross section, a discrete representation is chosen to represent the channel resistance. For drainages lower than 10 square miles, a roughness coefficient of 0.45 is appled, while

locations with drainages greater than 10 square miles, a roughness coefficient of 0.35 are applied. Typically in smaller drainages the channel bed is comprised of sizable rocks and gravel, while larger drainages contain bed particles of a smaller size. The large particles lead to a greater flow resistance. The two discrete roughness values chosen more accurately describe the main channel than a single value. The alterations take place in HEC-RAS and are changed only between the previously identified bank lines.

HEC-RAS takes a number of input parameters for the hydraulic analysis of a river system. The parameters are used to describe the river channel and the flows associated with it by creating a series of cross sections along a known stream path (Tate, 1999). Within each cross section the banks are determined which delineate the main channel from the left and right floodplain. Furthermore, roughness coefficients are assigned to locations along each cross section based on land use. Along the stream lines, flow paths are defined to better delineate the flood flow areas. The geometric descriptors are created using ArcGIS software and imported into HEC-RAS. Longer reaches often contain datasets too large to be exported from ArcGIS as one model. Further discussion of reach separation is completed in Section 4.4. With a complete description of the channel, only boundary constraints are required to complete the hydraulic model.

3.4.1.3 Boundary Conditions

Model boundary conditions provide HEC-RAS with information necessary to perform standard step backwater calculations. They include stream discharges at each model cross-section and water surface elevations at downstream model boundaries, calculated with the assumption of uniform flow.

Fifty, 20, 10, 4, 2, 1, 0.5, and 0.2 percent annual exceedance discharges were calculated at each stream cross-section in the hydraulic model using the USGS regional regression equations, see Section 3.3. The product of the hydrologic analysis is a point file describing the flow in each channel every three meters. Flow points closest to the

cross sections cut are selected, paired with the corresponding cross section, and utilized in a steady flow analysis processed in HEC-RAS to compute water surface elevations.

Typical rivers and streams in Iowa are of the subcritical flow regime, to solve a subcritical flow regime a downstream boundary condition is required. Water surface elevations at the downstream model boundaries are calculated by HEC-RAS using Manning's equation with a user input of the channel bed slope. Given a channel discharge, roughness, and slope, HEC-RAS uses Manning's equation to predict the uniform flow depth at the model outlet. In general application of Manning's equation the slope is that of the energy gradient line. The slope of the energy grade line is equal to the slope of the bed in normal depth calculations. Channel slopes at the downstream model boundaries were calculated by sampling LiDAR elevations at the furthest downstream cross section and at another cross section approximately one kilometer upstream. Employing this set of boundary conditions assumes that there is no backwater effect from the downstream reach. Manning's equation assumes a state of uniform flow, where gravitational and friction forces are balanced. HEC-RAS computes the downstream water surface depth by applying Manning's equation to the final cross section where the channel geometry, roughness, flow, and slope are known.

Detailed studies previously performed are incorporated into the Hydraulic model. A detailed study is typically performed over a small river reach including a more complex hydrologic model and HEC-RAS hydraulic calculations. The output is a water surface elevation at each cross section cut for the HEC-RAS model. Cross section locations from the detailed studies are replicated in the approximate study. The only difference in incorporating the detailed information is in the boundary conditions. Known water surface elevations are input into the steady flow analysis at each of the detailed cross sections, along with the standard downstream slope and flow conditions previously applied. The output includes the water surface elevations at each cross section with the incorporated detailed study.

3.4.3 Section Summary

A geometric description, flow rate, and downstream boundary conditions are the major parameters input into the HEC-RAS hydraulic model. ArcGIS is used to create model geometry and couple previously calculated flow values from the hydrologic analysis to the geometries. HEC-GeoRAS creates an interface between GIS software and HEC-RAS modeling tool, enabling extraction of geometry information from the DEM for use in HEC-RAS. HEC-RAS computes the water surface profile using a one dimensional steady flow model. The resulting data includes water surface elevations at every cross section within a given reach. Water surface profiles for the Fifty, 20, 10, 4, 2, 1, 0.5, and 0.2 percent annual exceedance discharges are created in preparation for use in the floodplain mapping process. For a summary of tools and processes, see Figure 3.23.
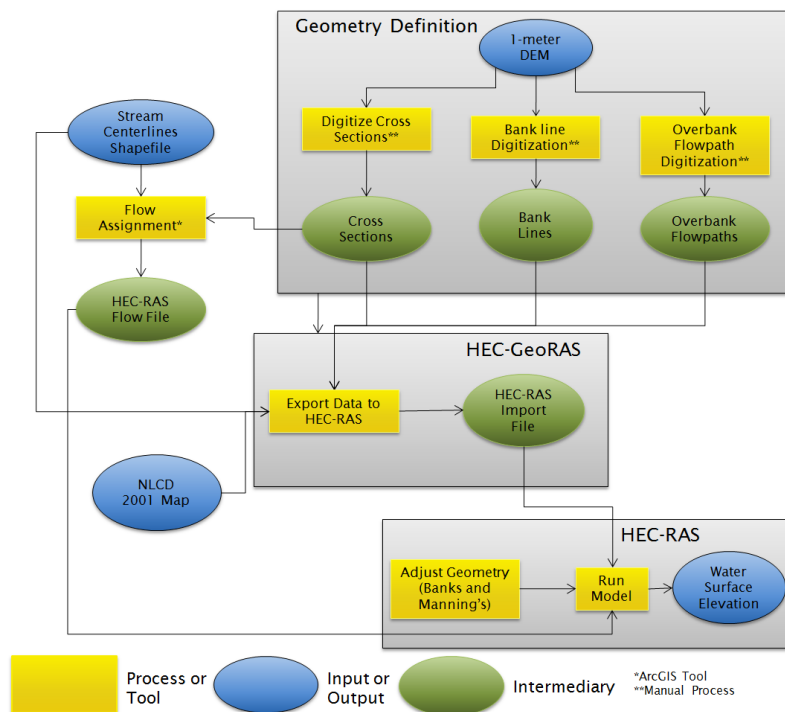
Figure 3.23: Hydraulics modeling work flow

<u>3.5 Floodplain Mapping</u>

Flood inundation maps offer a spatially descriptive view of the floodplain and its extents for a given flow event. This makes it an attractive alternative to water surface elevations described by HEC-RAS. The following section describes the procedure in greater detail.

3.5.1 Implementation

Creating a flood inundation map begins with the results of the hydraulic model, consisting of water surface elevations at each cross section for the eight different input flows. Through the suite of HEC-GeoRAS tools, the data is assimilated into a GIS environment for spatial representation of flood inundation. The procedure involves three major steps: defining the mapping extents, creating a water surface triangulated irregular network (TIN) from the HEC-RAS results, and mapping the flood inundation.

Definition of the mapping extents is a preliminary process in producing flood inundation areas. The extents are defined by connecting the ends of each cross section. A tool called "Read RAS GIS Export File" within the HEC-GeoRAS tool suite creates the bounding polygon. The tool also imports and aligns the water surface and bank points with the associated cross section for use in TIN creation, see Figure 3.24.

A TIN is a representation of a surface based on elevation data, similar to a DEM. It takes a set of data points each having x, y, and z components, and forms triangles by connecting the points, creating angled planes due to variations in elevation. An algorithm adjusts the size of the triangle based on the amount of elevation change. Areas of large elevation change require more detail thus smaller triangles, areas of little elevation change require less detail thus larger more expansive triangles. A DEM uses evenly distributed points to describe a surface where a TIN employs an algorithm to determine where added detail is needed to accurately represent the terrain (Tate, 1999). A HEC-GeoRAS tool "Water Surface Generation" creates a TIN to represent the water surface of

the reach by interpolating the water surface elevations between each cross section see Figure 3.24. The water surface TIN is created without reference to the land surface DEM. A TIN is created for each of the annual exceedance flow frequencies.
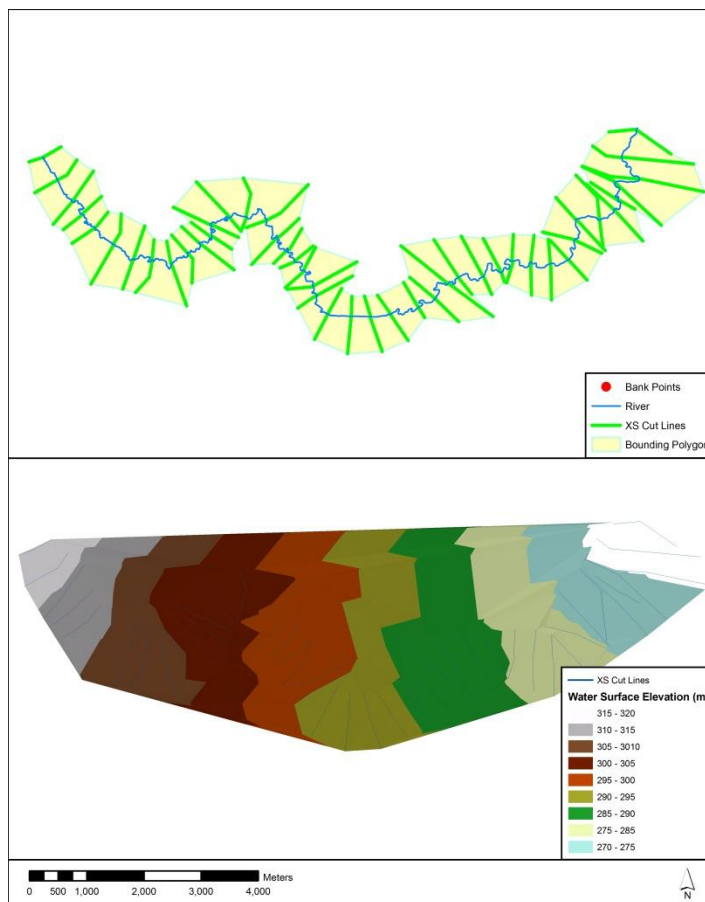
Figure 3.24: Flood mapping with HEC-GeoRAS, flood extents and water surface TIN

Note: Top, Maximum flood extents defined by connecting the end points of each cross section. Bottom, Water Surface Elevation TIN

The floodplain is delineated through the use of the water surface TIN and the 1-meter DEM of the terrain. The HEC-GeoRAS tool "Floodplain Delineation" is employed

to find the difference between the water surface TIN and the 1-meter DEM. Positive values represent areas of low elevation inundated with flood waters, while negative values represent higher dry terrain. The location of intersection between the flood TIN and the terrain DEM identifies the flood extent. If the water surface and the terrain do not intersect, the edge of the bounding polygon is implemented as the inundation extent. It is important to extend cross sections to create a larger, more descriptive floodplain without truncated inundation areas. In conjunction with the creation of a raster depicting water depth from the ground elevation, a shape file of the floodplain area is also a product of the procedure, see Figure 3.25.
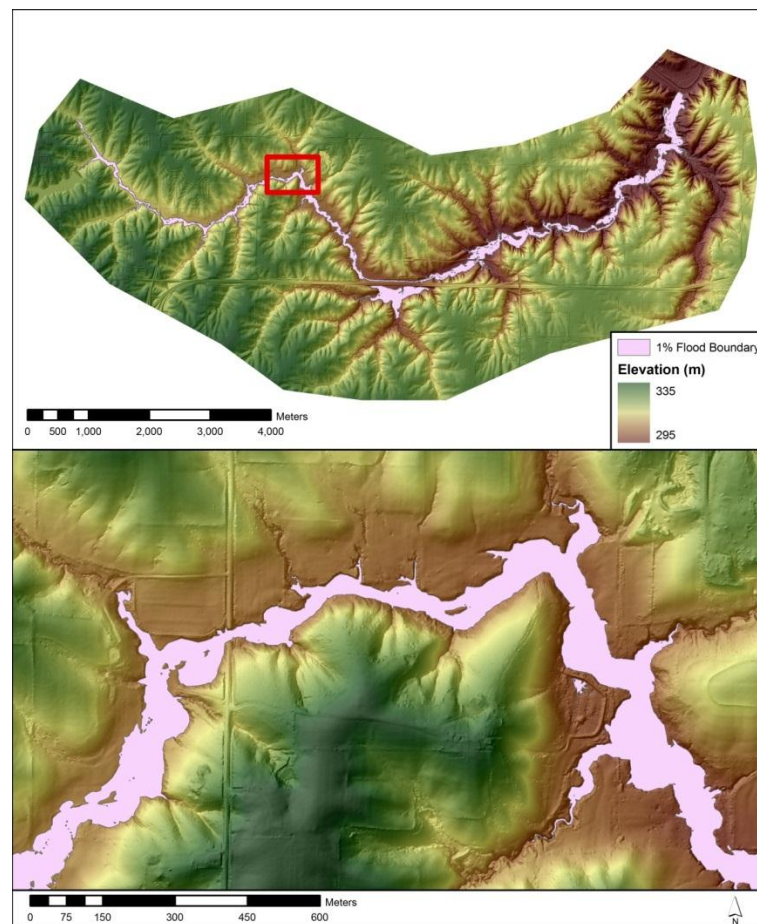
Figure 3.25: Flood extents final product of the HEC-GeoRAS process. *Scale bar represents the bottom figure

Completion of these methodologies creates a product containing flaws. The maps must be checked for quality. Viewing the inundation map and the underlying terrain together can reveal errors in the inundation map or artifacts in the DEM. Alterations in the geometric data to more accurately describe the channel and floodplain area may be necessary, creating an iterative process. With experience, proper maps can be created in a timely and accurate fashion.

3.5.2 Section Summary

Producing an inundation map is the final product of the mapping procedure. The maps allow visualization of flooding extents and flooding depths. The process to map the flooding begins with the cross sectional water surface elevation information from the hydraulic analysis. A water surface TIN is created from the water surface elevation which is compared to the ground surface DEM to produce a flood inundation map. The datasets identified through the FEMA Methodology procedure are to be submitted to FEMA for quality assurance and data distribution, discussed in the proceeding section. Figure 3.26 summarizes the procedures and tools to create inundation extents.
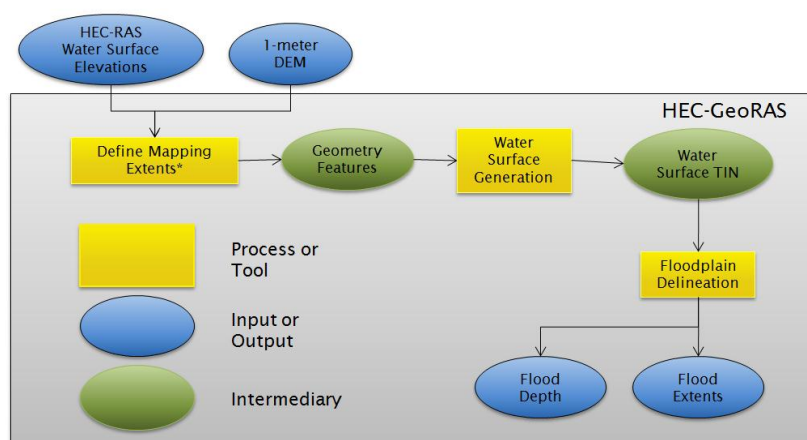
Figure 3.26: Flood boundary delineation work flow

3.6 Data Management

Floodplain coverage and associated risks must be conveyed to the federal, state, county, and local communities for use in prevention and planning. FEMA acts as the governing body which distributes this information to the necessary locations. The following section discusses in further detail the process of data submission, data capture standards, and final flood hazard maps. Flood Insurance Rate Maps are one form of emergency management data allowing users to visualize accepted areas of inundation in a local community. The following section describes the submission process and products of FEMA flood inundation maps.

3.6.1 FEMA Submittal Process

Submission of data and analysis to FEMA is a serial process with three submission sections, Hydrology, Hydraulics, and Digital Flood Insurance Rate Maps (DFIRM). The method of submission is through a File Transfer Protocol (FTP) server, a standard way to transfer files from one host to another through internet connection. The first leg of the three tiered submission process is the hydrologic analysis, see Section 3.6.2 for content oriented information. FEMA or a contracted engineering firm performs a quality assurance analysis on the hydrology. Recommendations for error correction are conveyed to the original modeling partner. The hydrologic analysis is rectified and resubmitted. This process is iterated until the hydrologic analysis is accepted. The hydraulic analysis, see Section 3.6.2 for content oriented information, is submitted, inspected, and corrected following the same procedure as the hydrologic analysis submittal process. DFIRM see Section 3.6.3, is the final set of information to be submitted, analyzed, and accepted.

The Hydraulics and Hydrology portions are submitted by large watershed or HUC8 boundary, each reach is accounted for within the analysis folder. DFIRM maps are completed by political boundaries, information from many reaches can be viewed in

the same map. Each analysis portion is furnished to the FEMA database and checked for quality in a similar fashion. To expedite the process standards are put in place for the data pertaining to folder structure, shape file specifications, and data table requirements. The set of requirements are referred to as Data Capture Standards (DCS) and DFRIM standards.

3.6.2 Data Capture Standards

Data Capture Standards (DCS) provide a consistent framework for submittal, storage, and retrieval of technical and administrative data needed for a Flood Insurance Study (FIS) or to revise a Flood Insurance Rate Map (FIRM) (FEMA, 2009). The intention is to improve the quality of study, efficiency of data transfer between organizations, provide ease of retrieval and protect the investment made in the dataset.

Hydraulic and hydrologic analyses are the two major areas of study having to conform to the DCS, each having its own specifications of submission. Typically dataset formats useful in producing inundation maps do not align completely with the DCS specifications. Alterations to the datasets are made to conform to FEMA's guidelines. The following sections will cover the folder structure, data organization, and data conversion.

3.6.2.1 Hydrologic Analysis

This section describes the hydrologic data that must be submitted to FEMA for a FIS. Hydrologic data in this study is determined by a combination of regional regression analyses, a bulletin 17B frequency analysis, and gage influence. Flow data determined with either a regional regression analysis or Bulletin 17B analysis technique is considered an approximate study, and is accompanied by specific data standard requirements. Four datasets are required for each reach to describe the results of the hydrologic analysis, S_Submittal_Info, S_Nodes, S_Hydro_Reach, and L_Summary_Discharges. Each is described in detail in the following section.

S_Submittal_Info is a polygon shape file showing the area completely encompassing reach. This dataset contains essential information about each study area giving a brief overview of how the data was obtained and from whom. Attribute tables within the dataset describe the level of study performed, the research team submitting the data, when it was submitted, the hydrologic model used in the engineering analysis, and the source of analysis information, see Table 3.7 and Table 3.8.

S_Nodes is a point type shape file plotting the location of flow changes. The dataset contains points on the stream centerline at locations where cross sections intersect the centerline. The nodes are used to represent hydrologic connectivity. Attribute tables within the dataset describe the location of the point, identification of each point, and a reference to a table showing the discharge L_Summary_Dsicharges, see Table 3.9 and Table 3.10.

S_Hydro_Reach is a line type shape file showing the connectivity between S_Node points. The dataset is a collection of lines coupling the S_Nodes points, it describes the flow direction and reach length. The attribute table accompanying the shape file identifies the line segments and defines the upstream and downstream node locations, see Table 3.11 and Table 3.12.

L_Summary_Discharge is a table referenced by the S_Nodes shape file. The table stores hydrologic information including drainage area, and annual exceedance discharges associated with each S_Nodes point. When conducting an approximate study, the 1% annual exceedance discharge representing the 100 year flow is necessary for submission. The table includes a reference to the S_Nodes point file, drain area, units of measure, and the 1 percent annual exceedance discharge, see Table 3.13 and Table 3.14.

The Hydrologic data describing each reach conveyed in the previous section is sufficient for FEMA investigation. The four datasets describing the area, flow, and model connectivity concisely show the results of the data, see Figure 3.27. FEMA also requires a description of methodologies to acquire the 1 percent discharge, and

documentation of correspondence between the mapping partner and FEMA. Other
requirements exist for studies see FEMA appendix M. Each study is described in detail
in the following section.

Table 3.7: S_Submittal_Info table description

Attribute Name	Required/Applicable/Optional	Description
SUBINFO_ID	R	Key for table lookup
CASE_NO	R	FEMA case number
CASE_DESC	R	General description of study area
SUBMIT_BY	R	Mapping partner submitting data
COMP_DATE	R	Work completion date
TASK_TYP	R	Data development task type
HYDRO_MDL	A	Name hydrologic model used for analysis
HYDRA_MDL	A	Name hydraulic model used for analysis
CST_MDL_ID	A	Name of coastal model used for analysis
SOURCE_CIT	R	Citation describing model

Table 3.8: S_Submittal_Info table example inputs

FID	Shape *	SUBINFO_ID	CASE_NO	CASE_DESC	SUBMIT_BY	COMP_DATE	TASK_TYP	HYDRO_MDL	HYDRA_MDL	CST_MDL_ID	SOURCE_CIT
0	Polygon	1		Approximate Study	Iowa Flood Center	4/20/2011	HYDROLOGI	REGRESSION EQUATIONS			Lara1987

Table 3.9: S_Nodes table description

Attribute Name	Required/Applicable/Optional	Description
NODE_ID	R	Key for table lookup
NODE_TYP	A	Node type description
WTR_NM	R	Name of water body
SUMDSCH_ID	A	Hydrologic model info. associated with node
FUTDSCH_ID	A	Future conditions associated with node
SUMELEV_ID	A	Water body elevation info.
MODEL_ID	R	Identification of the specific model
SOURCE_CIT	R	Citation describing model

Table 3.10: S_Nodes table example inputs

FID	Shape *	NODE_ID	NODE_TYP	WTR_NM	SUMDSCH_ID	FUTDSCH_ID	SUMELEV_ID	MODEL_ID	SOURCE_CIT
0	Point	07080209000907_000638.99		07080209000907	07080209000907_000638.99			000638.99	

Table 3.11: S_Hydro_Reach table description

Attribute Name	Required/Applicable/Optional	Description
REACH_ID	R	Key for table lookup
UP_NODE	A	Upstream node identification
DN_NODE	A	Downstream node identification
ROUTE_METH	A	Hydrologic routing method
SOURCE_CIT	R	Citation describing model

Table 3.12: S_Hydro_Reach table example inputs

FID	Shape *	REACH_ID	UP_NODE	DN_NODE	ROUTE_METH	SOURCE_CIT
0	Polyline	07080209000907_022	07080209000907_000831.24	07080209000907_000638.99		

Table 3.13: L_Summary_Discharge table description

Attribute Name	Required/Applicable/Optional	Description
SUMDSCH_ID	R	Key for table lookup
NODE_DESC	A	Node location description
WTR_NM	R	Name of water body
DRAIN_AREA	R	Drainage area
AREA_UNIT	R	Unit of measure for DRAIN_AREA
DSCH_10PCT	A	10-percent-annual-chance flood at the node
DSCH_2PCT	A	2-percent-annual-chance flood at the node
DSCH_1PCT	R	1-percent-annual-chance flood at the node
DSCH_02PCT	A	0.2-percent-annual-chance flood at the node
DISCH_UNIT	R	Unit of measure for DSCH_XXPCT
WSEL_10PCT	A	10-percent-annual-chance surface elevation
WSEL_2PCT	A	2-percent-annual-chance surface elevation
WSEL_1PCT	A	1-percent-annual-chance surface elevation
WSEL_02PCT	A	0.2-percent-annual-chance surface elevation
LEN_UNIT	A	Unit of measure for WSEL_XXPCT
V_DATUM	A	Vertical reference datum

Table 3.14: L_Summary_Discharge table example inputs

OID	SUMDSCH_ID	NODE_DES	WTR_NM	DRAIN_ARE	AREA_UNIT	DSCH_10PCT	DSCH_2PCT	DSCH_1PCT	DSCH_02PCT	DISCH_UNIT	WSEL_10PC	WSEL_2PC	WSEL_1PCT	WSEL_02PCT	L
0	07080209000907_000638.99		0708020900090	2.3466	SQUARE KILOMETERS	-9999	-9999	38.75	-9999	CMS	-9999	-9999	-9999	-9999	
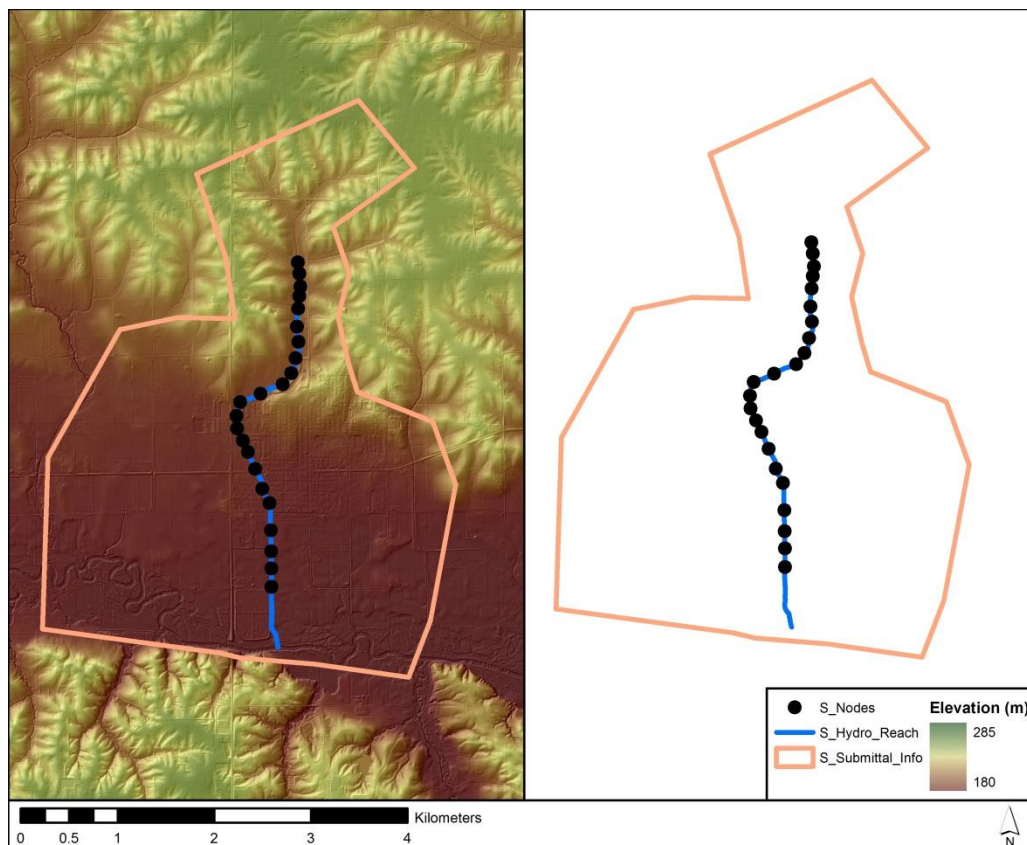
Figure 3.27: Spatial view of hydrologic analysis submission

3.6.2.2 Hydraulic Analysis

Submission of a Hydraulic analysis follows the completion of the Hydrologic analysis. This section describes the hydraulic data that must be submitted to FEMA for a FIS. Hydraulic data in this study is determined by a combination of the HEC-RAS and HEC-GeoRAS programs, through application of the standard backwater method. An approximate study classification is placed on this Hydraulic analysis as flow data determined from a regression analysis is considered an approximate hydrologic study. For hydraulic submittal five data sets are required for each reach to describe the results of the hydraulic analysis: S_Submittal_Info, S_Profile_Basin, S_Stn_Start, S_XS, and S_Fld_Haz_Ar.

S_Submittal_Info is a polygon shape file showing the area completely encompassing reach. This dataset contains essential information about each study area

giving a brief overview of how the data was obtained and from whom. In the Hydraulic model submission each of the cross section ends are connected to form the outer extents. The attribute table accompanying this shape file uses the same data as the Hydrologic model and is described further in Section 3.6.2.1. The only variation in the two is the study type.

S_Profile_Basln is a polyline type shape file describing the reach flow path between modeled cross sections. It is the horizontal distance along the flood profile, derived from the stream centerline. The attribute table accompanying the shape file labels the polyline by reach code, describes the type of study to be performed, and how the file is utilized in the model, see Table 3.15 and Table 3.16.

S_Stn_Start is a point type shape file identifying the furthest downstream location within the reach. The data described the beginning of the hydraulic model and serves as a reference point for the S_XS layer. The attribute table for the data set includes an identification number and a description of application, see Table 3.17 and Table 3.18.

S_XS is a polyline shapefile of the cross sections utilized in the hydraulic modeling procedure. The cross sections define the geometry of the channel and floodplain as an input into a HEC-RAS model which calculates the flood elevations. The accompanying attribute table contains reference information based on the S_Stn_Start point, water surface elevations, and a reference datum, see Table 3.19 and Table 3.20.

S_Fld_Haz_Ar is a polygon shape file outlining the flood hazards within the study area. The polygon describes the 1 percent exceedance flood extent and is considered draft flood hazard area as it has not yet been accepted by FEMA. The draft flood hazard zones are used to designate varying insurance parameters. The table associated with the flood hazard area contains information designating the type of study and identifying a reference datum, see Table 3.21 and Table 3.22.

The Hydraulic data describing each reach and its corresponding flood hazard areas have been conveyed in the previous section and are sufficient for FEMA

processing. The five datasets describing the area, channel geometry, model connectivity, and flood inundation areas concisely show the results of the data. FEMA also requires a description of methodologies to acquire the 1 percent flood inundation. Other requirements exist for these studies which are not applicable to this project as each process is completed by a single entity as an approximate study.

Table 3.15: S_Profile_Basin table description

Attribute Name	Required/Applicable/Optional	Description
BASELN_ID	R	Key for table lookup
WTR_NM	A	Name of water body
SEGMT_NAME	O	Unique segment name
STUDY_TYP	R	Study performed for flood hazard identification
WATER_TYP	R	Type of watercourse represented
SOURCE_CIT	R	Citation describing model

Table 3.16: S_Profile_Basin table example inputs

FID	Shape *	BASELN_ID	WTR_NM	SEGMT_NAME	STUDY_TYP	WATER_TYP	SOURCE_CIT
0	Polyline	1	07080209000907		APPROXIMAT	PROFILE BASELINE	

Table 3.17: S_Stn_Start table description

Attribute Name	Required/Applicable/Optional	Description
START_ID	R	Key for table lookup
START_DESC	R	Description of station start location
SOURCE_CIT	R	Citation describing model

Table 3.18: S_Stn_Start table example inputs

FID	Shape *	START_ID	START_DESC	SOURCE_CIT
0	Point	07080209000907_01	Distances are measured in meters upstream	

Table 3.19: S_XS table description

Attribute Name	Required/Applicable/Optional	Description
XS_LN_ID	R	Key for table lookup
XS_LTR	A	Identification of each XS for use on FIRM
WTR_NM	R	Name of water body
WSEL_1PCT	R	1-percent-annual-chance surface elevation
LEN_UNIT	R	Unit of measure for WSEL_XXPCT
V_DATUM	R	Vertical reference datum
XS_ELEV_ID	A	Cross section identification for FIS
XS_FUTR_ID	A	Cross section identification for FIS future conditions
XS_LV_ID	A	Cross section levee identification for FIS
MODEL_ID	R	Identification of model output
SOURCE_CIT	R	Citation describing model

Table 3.20: S_XS table example inputs

FID	Shape *	XS_LN_ID	XS_LTR	WTR_NM	WSEL_1PCT	LEN_UNIT	V_DATUM	XS_ELEV_ID	XS_FUTR_ID	XS_LV_ID	MODEL_ID	SOURCE_CIT
0	Polyline	07080209000907_000638.99		07080209000907	198.9129	METERS	NAVD88				000638.99	

Table 3.21: S_Fld_Haz_Ar table description

Attribute Name	Required/Applicable/Optional	Description
FLD_AR_ID	R	Key for table lookup
STUDY_TYP	R	Study performed for flood hazard identification
FLD_ZONE	R	Flood zone designation
FLOODWAY	A	Designated floodway, area to remain free of development
SFHA_TF	R	Special flood hazard area, True for A or V, false otherwise
STATIC_BFE	A	Static base flood elevation, typically in coastal areas
V_DATUM	A	Vertical reference datum
DEPTH	A	Depth for zone OA areas
LEN_UNIT	A	Units of measure for STATIC_BFE
VELOCITY	A	Velocity measurement of the flow in area
VEL_UNIT	A	Unit of measure for VELOCITY
SOURCE_CIT	R	Citation describing model

Table 3.22: S_Fld_Haz_Ar table example inputs

FID	Shape *	FLD_AR_ID	STYDY_TYP	FLD_ZONE	FLOODWAY	SFHA_TF	STATIC_BFE	V_DATUM	DEPTH	LEN_UNIT	VELOCITY	VEL_UNIT
0	Polygon	1	APPROXIMAT	A		T	-9999	NAVD88	-9999	FEET	-9999	FEET/SECOND

3.6.2.3 Data Conversion

FEMA requires specific naming conventions and file structure for each submission. A conversion of working files to submittal files is necessary for transfer to a FEMA database. Currently reach specific working files utilized in the modeling procedure are identified by reach codes.   Each reach model is contained within a simple folder structure which varies from the FEMA mandated structure. A python based process creates the correct folder structure described in the following section. The script also extracts the necessary shape files from each reach working file directory, renames

the shape file, and populates the attribute tables. Completion of this process results in complete hydraulic and hydrologic modeling folders for release to FEMA.

The state of Iowa is broken down and submitted to FEMA by HUC8 delineation. Each HUC8 is further divided into either a hydraulic of hydrologic model and then by river reaches as discussed in Section 3.4.1.1. Each reach contains shape files described in Section 3.6.2.1 and Section 3.6.2.2, created by the python script. The folder structure is shown in Figure 3.28.
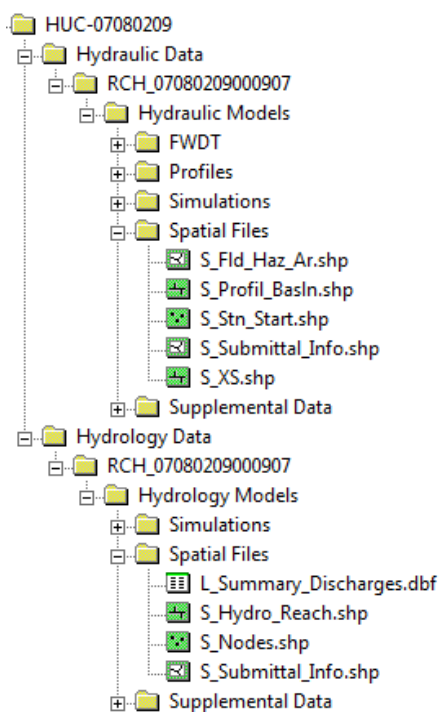
Figure 3.28: DCS submission basic folder structure identifying the correct locations of each of the spatial datasets created in this study

Completion of the data conversion to DCS yields data to be submitted to FEMA by a process described in Section 3.6.1. Information given to FEMA is delegated to a

third party to complete a quality check on the information. Through FEMA's acceptance of the mapping partner's serial DCS submissions, regulatory maps may be generated.

3.6.3 Digital Flood Insurance Rate Map (DFIRM)

Digital Flood Insurance Rate Map (DFIRM) is a product of political base information, topography, Hydrologic, and Hydraulic analyses, performed to FEMA specifications, submitted to a FEMA review process, and accepted by FEMA representatives. DFIRM's are the official maps published by FEMA which spatially delineate the 1-percent annual exceedance floodplain in reference to political boundaries and manmade infrastructure. Generating maps in this format allows for ease of use by administrators, insurance agencies, and the general public. As Defined in the FEMA DFIRM requirements (FEMA, 2010):

> *"The Digital Flood Insurance Rate Map (DFIRM) Database depicts flood risk information and supporting data used to develop the risk data. The primary risk classifications used are the 1-percent-annual-chance flood event, the 0.2-percent-annual-chance flood event, and areas of minimal flood risk. The DFIRM Database is derived from Flood Insurance Studies (FISs), previously published Flood Insurance Rate Maps (FIRMs), flood hazard analyses performed in support of the FISs and FIRMs, and new mapping data, where available. The FISs and FIRMs are published by the Federal Emergency Management Agency (FEMA). The file is georeferenced to earth's surface using the State Plane projection and coordinate system UTM NAD83 in meters. The specifications for the horizontal control of DFIRM data files are consistent with those required for mapping at a scale of 1:12,000."*

Information submitted to the FEMA DFIRM Database includes the spatial information necessary to produce a DFIRM, in conjunction with the tabular information to develop a (FIS). The objective of obtaining data in this format described by FEMA is to provide a standardized and systematic scheme to distribute details of flood studies to the general public and other stakeholders (FEMA, 2010). Revised DCS Hydraulic and Hydrologic spatial and tabular files are included along with datasets describing the transportation, political bounds, and other pertinent information. Datasets necessary for

FEMA submission are spilt in to spatial and tabular formats and described in greater detail.

3.6.2.1 Spatial Datasets

The spatial datasets submitted to FEMA DFIRM Database include S_Fld_Haz_Ar, S_Fld_Haz_Ln, S_Gage, S_Gen_Struct, S_Nodes, S_Pol_Ar, S_Profil_Basin, S_Submittal_Info, S_Transport_Ln, and S_XS. The following information describes each dataset.

S_Fld_Haz_Ar, S_Nodes, S_Profil_Basin, S_Submittal_Info, and S_XS datsets have been completed for each reach, required information within the file can be found in Sections 3.6.2.1, and 3.6.2.2.

S_Fld_Haz_Ln is polyline type feature which aides in the description of the flood hazard area boundaries. The flood hazard area describes the 1-percent annual exceedance flood extent while the line feature bounds the area. Tabular data associated with this spatial feature includes look-up identification keys, and a line type designating either a flood zone boundary or a limit of study extent, see Table 3.23.

S_Gage is a point file detailing the location of gages within the mapped area. Gages are applied in the hydrologic analysis thus making it useful to spatially describe the locations. The information contained within this file includes identification, type of gage, recording intervals, period of record, and area drained to that point, Table 3.24.

S_Gen_Struct is a polyline type feature outlining locations of hydraulic structures or other structures impacted by the flood extent. The lines must represent the general characteristics of the structure. Bridge decks, dams, and culverts are contained within this shape file. The table associated with the data set contains information on the type of structure, location description, and station within the reach, see Table 3.25.

S_Pol_Ar is a polygon type feature describing the local political areas. This feature describes the varying political jurisdictions. Participation in the National Flood

Insurance Program (NFIP) is decided by political jurisdiction. Availability of insurance, floodplain regulations, and floodplain management may differ for each political area. The accompanying table includes information about state, county, and community location and label, see Table 3.26.

S_Transport_Ln is a polyline type feature representing the transportation features such as roads and railroads. Typically the transportation features are retrieved from the U.S Census Bureau MAF/TIGER transportation data. The information associated with this dataset includes a name and description of each feature, see Table 3.27.

The spatial datasets adequately describe the hydraulic, hydrologic, and mapping outputs of the project allowing for the production of Flood Insurance Rate Maps. Although every dataset is not incorporated into the DFIRM, each is still submitted to the database for use in quality control and producing a more robust and comprehensive description of the flood risk areas.

Table 3.23: S_Fld_Haz_Ln table description

Attribute Name	Required/Applicable/Optional	Description
DFIRM_ID	R	Study identifier
VERSION_ID	R	Product version identifier
FLD_LN_ID	R	Key for table lookup
LN_TYP	R	Describes the flood boundary
SOURCE_CIT	R	Citation describing model

Table 3.24: S_Gage table description

Attribute Name	Required/Applicable/Optional	Description
DFIRM_ID	R	Study identifier
VERSION_ID	R	Product version identifier
GAGE_ID	R	Key for table lookup
WTR_NM	R	Surface water feature name associated with gage
AGENCY	R	Agency responsible for gage maintenance
DTA_ACCESS	R	URL for finding gage data
GAGE_DESC	R	Gage description
GAGE_TYP	R	Gage type or what it measures
REC_INTRVL	A	Fixed interval recording information
TIME_UNIT	A	Unit of measure for REC_INTRVL
START_PD	R	Start of gage recording period
END_PD	R	End of gage recording period
DRAIN_AREA	R	Area drained to the gage location
AREA_UNIT	R	Unit of measure for DRAIN_AREA
SOURCE_CIT	R	Citation describing model

Table 3.25: S_Gen_Struct table description

Attribute Name	Required/Applicable/Optional	Description
DFIRM_ID	R	Study identifier
VERSION_ID	R	Product version identifier
STRUCT_ID	R	Key for table lookup
STRUCT_TYP	R	Hydraulic structures located within the flood risk project area
CST_STRUCT	A	Costal structure classification
STRUCT_NM	R	Proper name of structure
WTR_NM	R	Surface water feature name associated with structure
LOC_DESC	R	Description of the structure location
STRUC_DESC	R	Description of the structure
SHOWN_FIRM	R	Captures if the structure is shown on the FIRM
DS_STR_STN	R	Downstream station of structure
US_STR_STN	R	Upstream station of structure
LO_CHRD_EL	R	Low-chord elevation of bottom of deck or beam
HI_CHRD_EL	R	High-chord elevation of top of deck or beam
LEN_UNIT	R	Unit of measure for structure stationing
V_DATUM	A	Vertical Datum
SOURCE_CIT	R	Citation describing model

Table 3.26: S_Pol_Ar table description

Attribute Name	Required/Applicable/Optional	Description
DFIRM_ID	R	Study identifier
VERSION_I	R	Product version identifier
POL_AR_ID	R	Key for table lookup
POL_NAME1	R	Primary/Official name of area
POL_NAME2	A	Secondary/Common name of area
CO_FIPS	R	County Federal Information Processing Standard Code
ST_FIPS	R	State Federal Information Processing Standard Code
COMM_NO	R	Community number assigned by FEMA
CID	R	Community identification number assigned by FEMA
ANI_TF	R	Area not included
ANI_DFIRM	A	Area not included DIRM identification
COM_NFO_ID	A	Community information identification
SOURCE_CIT	R	Citation describing model

Table 3.27: S_Transport_Ln table description

Attribute Name	Required/Applicable/Optional	Description
DFIRM_ID	R	Study identifier
VERSION_ID	R	Product version identifier
MTFCC	R	MAF/TIGER feature class code describing transportation type
FULLNAME	R	Full name of feature
ALTNAME1	A	First alternative name of feature
ALTNAME2	A	Second alternative name of feature
ROUTENUM	A	Route number used to place route shields on FIRM
SOURCE_CIT	R	Citation describing model

3.6.2.2 Tabular Datasets

The tabular datasets submitted to the FEMA DFIRM database include
Study_Info, L_Bibliography, L_CBRS_Plan, L_Comm_Fld_Src, L_Comm_Info,
L_Comm_Pan, L_Comm_Revis, L_Comm_Zone, L_Meetings, L_Mtg_POC,
L_Pan_Comm, L_Pan_Revis, L_Pol_FHBM, L_Source_Cit, L_Stn_Start,
L_Summry_Discharges, and L_Summary_Elevations. Each table is briefly described in
the following section.

The corresponding tabular datasets are submitted to FEMA better describe the
higher level details and overall DFIRM texts applied to the mapping process. Each of the
tables included are listed in Table 3.28 along with a brief description. General planning,
jurisdiction delineation, references obtained, and community identification are among the
major concerns. Complete descriptions of each of the spatial or tabular datasets along
mapping specifications are made available in FEMA's Guidelines and Specifications
document (FEMA, 2010).

Descriptions of the spatial and tabular datasets are given within this document.
Production of FEMA DIRM's is not completed by this mapping partner. The exact

details of use and production of the completed maps are outside of the projects domain.

The Datasets necessary to complete each DFIRM are transferred to a third party for map

creation.

Table 3.28: Description of tabular datasets for submission to FEMA for DFIRM

Table Name	Table Description	Example Entry
Study_Info	general information about flood risk project	Project Name, Datum, Projection
L_Bibliography	all bibliography entries	Title, Author, Publisher
L_Comm_Fld_Src	flooding sources for each community	Water (Source) Name
L_Comm_Info	map history information	Revisions, Multi-community, Flood Prone
L_Comm_Pan	panels per community	FIRM Panel Number
L_Comm_Revis	revision dates per community	Revision Date
L_Comm_Zone	flood prone zones per community	Flood Zone (linked to A_Fld_Haz_Ar)
L_Levee_Info	panels per accredited levee	Water (Source) Name, Levee ID
L_Meetings	information regarding meetings regarding FIS	Type, Date, Purpose
L_Mtg_POC	points of contact	Name, Position, Agency
L_Pan_Comm	communities per panel	Panel Number, Community Identification
L_Pan_Revis	revision records	Revision Date, Panel Number
L_Pol_FHBM	information of Flood Hazard Boundary Map Revisions	Community Identification, Revision Date
L_Source_Cit	doccument sources of data	Source Citation, Originator, Publish Date
L_Stn_Start	information on starting locations	Start Description
L_Summry_Discharges	hydrologic information	Discharge, Drain Area
L_Summary_Elevations	elevation information for water bodies	Flood Event type, Water Surface Elevation, Datum

3.6.4 Section Summary

FEMA's DFIRM Database offers a comprehensive view over an entire Floodplain Mapping project, effectively encompassing every consideration necessary to produce flood inundation extents. Conforming to FEMA standards and specifications produces consistent and easily reproducible and revisable information. Ultimately, submission of hydrologic, hydraulic, and mapping information through the FEMA progression allows Federal, State, county, and local community leaders to better prepare for and prevent major flood damages.

3.7 Chapter Summary

Production of floodplain maps for the Iowa statewide floodplain mapping effort begins with reliable source datasets. A one meter LiDAR derived DEM covering the state of Iowa represents the ground surface used to identify stream centerlines, drainage areas, hydraulic geometric inputs, and the final flood extents. NDH, NLCD, USGS stream gage location, and hydrologic region shape file datasets encompass published datasets required to complete the mapping procedures.

Stream centerlines are identified directly from the one meter LiDAR derived DEM. Centerline digitization is split into large and small streams based on the width of the channel. Small streams are located from a series of ArcHydro raster manipulation tools by identifying locations of large flow accumulation. Large streams require that the edge of water on each side of the river is first identified, and then collapsed into a centerline. Large and small streams are classified by NHD standards and combined together in preparation for use in hydrologic modeling.

Eight statistically significant annual exeedance discharges are calculated for each stream location based on a gage weighted regional regression analysis. Drainage areas are first calculated for each stream location by reconditioning the DEM with the digitized stream centerline. The DEM is then input into a series of raster manipulation tools to

produce a set of data points along the stream centerline attributed with the drainage area at each location. Drainage area points are separated into three categories based stream gage influence. In each category the flow calculation techniques differ to produce the most realistic representation of flow through the stream location.

Water surface elevations at input cross section locations are calculated with a one dimensional HEC-RAS steady flow model. Four geometric inputs are identified to represent the river and the associated floodplain. NLCD land usage information is used to represent the overland flow resistance. Information is extracted from ArcGIS with HEC-GeoRAS and input into HEC-RAS. Flows are identified at each cross section location, a downstream uniform flow boundary condition is implemented, and the model is run.

Flooding extents are calculated for each river reach for eight annual exceedance discharges using HEC-GeoRAS. A water surface TIN is created from the water surface elevations at each cross section location. The water surface TIN is compared to the one meter LiDAR derived DEM. Locations where the water surface intersects the ground surface are identified as the flooding extents.

Information is submitted to FEMA for quality assurance and distribution purposes. FEMA requires submission using DCS which identifies specific spatial and tabular datasets which must be submit for each the hydrology, hydraulics, mapping, and DFIRM submissions.

Inundation maps are employed as a flooding estimation tool. Combinations of hydrologic and hydraulic modeling with stream gage history, stream geometry data, and a comprehensive LiDAR based elevation dataset aid in the completion of statewide floodplain maps. The previous chapter describes the methodologies to produce floodplain maps while the proceeding chapter highlights a specific watershed as a case study.

CHAPTER 4: CASE STUDY

Applications of the principles discussed in Chapter 3 FEMA Methodology are used to further understand the procedures and their subtleties. Images, example calculations, and detailed strategies are employed to offer another description of the routines necessary to delineate flooding extents. References to Chapter 3, texts and figures, allow for a concise representation.   This chapter follows a parallel topic structure to Chapter 3, completing each of described modeling procedures. The section begins with discussing stream centerline digitization, hydrologic analyses, hydraulic modeling, and is finalized in floodplain boundary delineation.

4.1 Case Study Location

The South Raccoon watershed (HUC-8 designation 07100007) is approximately 1137 square miles and is located in the west central portion of Iowa. The three major rivers traversing the watershed are the Brushy Creek, South Raccoon River, and Middle Raccoon River that merge into the South Raccoon River, totaling 217 miles in total length. This watershed is shown in Figure 4.1 is identified to be a suitable location to complete the case study.

4.2 Hydrography

Both large and small stream centerlines are used as inputs for multiple processes within the floodplain delineation procedure. Accurate stream centerline digitization enables higher modeling accuracies. The centerlines are also used to update the outdated NHD streamlines. The procedure is split into two portions, large stream digitization and small stream digitization, differentiated by the channel width.
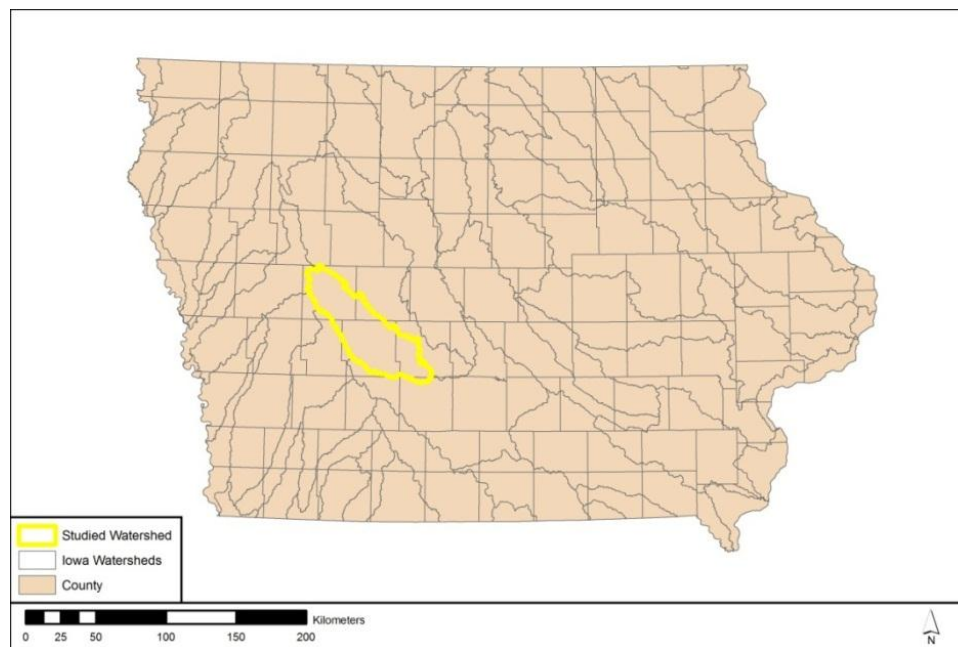
Figure 4.1: South Raccoon watershed location map

4.2.1 Small Stream Digitization

Small stream digitization employs an ArcHydro analysis tool suite which analyzes the DEM and creates a most likely flow path. To reiterate Section 3.2, the fill sinks tool is applied to the DEM, which alters the elevations allowing continuous flow to the downstream outlet. The flow direction tool is applied to the fill sinks grid, determining the direction of flow in each grid space by comparing relative elevations of neighboring cells. From the flow direction grid, the peaks and valleys are located through application of the flow accumulation tool, which measures the area drained to each grid space. The ArcHydro streamline uses the stream definition tool to create a flow path from the flow accumulation grid, see Figure 3.11. This process documented in Section 3.2.2.1.

The ArcHydro streamline is used as a reference for small stream digitization. The tools required to complete the manual digitization process are the ArcHydro streamline, fill difference DEM, aerial photography, DEM, and hillshade. This section includes

general guidance into the use of raster datasets and common pitfalls in manual digitization.

Streams are digitized from the furthest upstream ends of the river network to the downstream areas. Determining an accurate beginning location of a final stream centerline is the most tedious portion of this task. Two items are needed to start the stream centerline, an ArcHydro line, and a well-defined channel. Start at the farthest upstream segment of the watershed defined by the ArcHydro line which shows the initiation of 24 acres of land being drained in the DEM. A drainage threshold for the ArcHydro line is set to 24 acres for stream classification purposes. Typically well-defined channels drain more than 24 acres, so the ArcHydro line will often run further upstream than a well-defined channel location, see Figure 4.2. Never digitize upstream of an ArHydro line. The hillshade and DEM are scrutinized in areas with an ArcHydro line to identify the location of a constant well defined stream channel.

The stream centerlines created in ArcHydro are usually the best guides for stream digitization. However, these are not always reality based as artifacts in the DEM, or alterations in the DEM from the fill sinks process change DEM, and thus the ArcHydro flow path. Locations where fill occurs due to water running under roads, bridges, culverts, or areas of dense vegetation cause the ArcHydro lines to diverge from the actual stream course see Figure 4.3.

In densely wooded areas where vegetation overhangs the stream, the DEM and hillshade can be useless in identifying a stream channel. In these locations the fill difference and aerial photography become useful, see Figure 4.4. At locations where the stream is not visible due to overhanging vegetation, most of the LiDAR information reflects off the vegetation at a higher elevation. Some of the signal also reflects from the water surface, the difference in elevation between the low water surface elevations and the higher vegetation elevations create pools which are filled through the fill sinks process. The fill difference DEM is the difference between the original DEM and the

filled DEM, illustrating the amount of fill. Overlaying the fill difference DEM on the
hillshade depicts a vivid image of the stream centerline in locations with fill, see Figure
4.4c. In some locations, none of the raster based datasets are enough to determine a
centerline location, therefore aerial photography is supplemented.
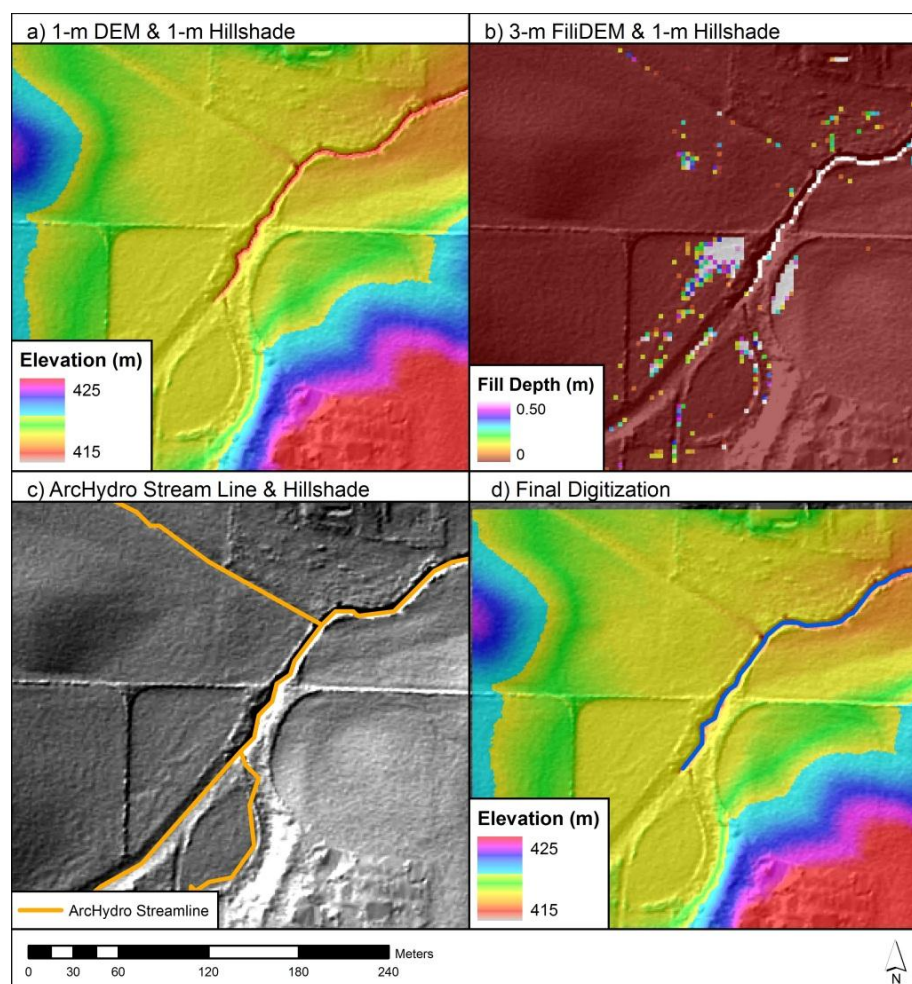
Figure 4.2: Small stream digitization beginning

Note: a) 1 meter DEM grid overlaid onto the 1 meter hillshade, a channel is clearly
identifiable. b) 3 meter Fill Difference DEM grid showing locations where the Fill Sinks
tool altered elevations. c) ArcHydro estimated streamline is identified in lesser defined
channels. d) Final digitized stream line with a 1 meter DEM and hillshade
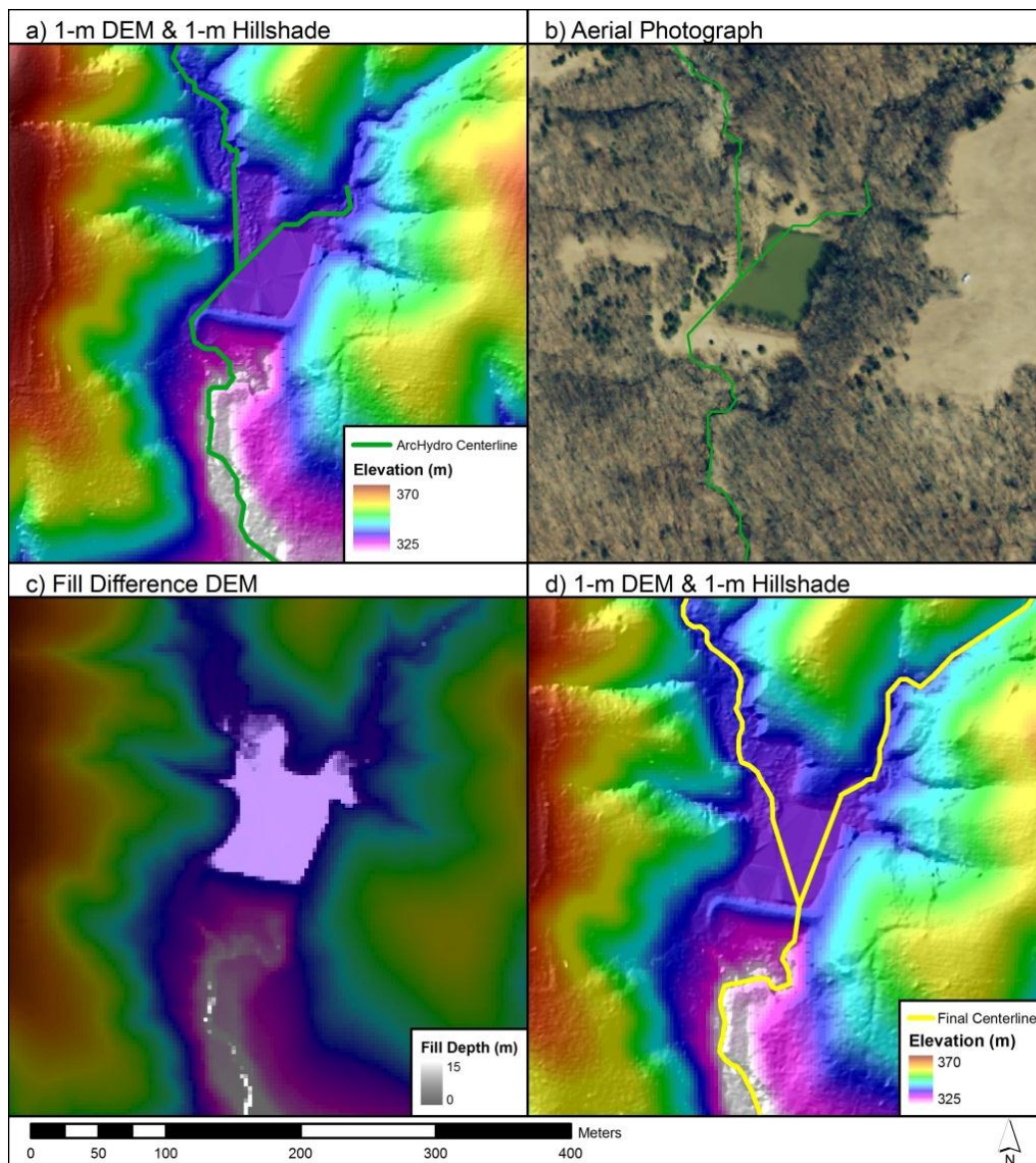
Figure 4.3: ArcHydro streamline diversion due to fill

Note: a) ArcHydro Centerline with a 1 meter grid DEM and hillshade showing the estimated streamline identified incorrectly. b) Aerial photography of the area identifying the estimated streamline is incorrect. c) Fill Difference DEM identifies a stream line though the heavily vegetated area. d) Final centerline digitization over a 1 meter DEM and hillshade
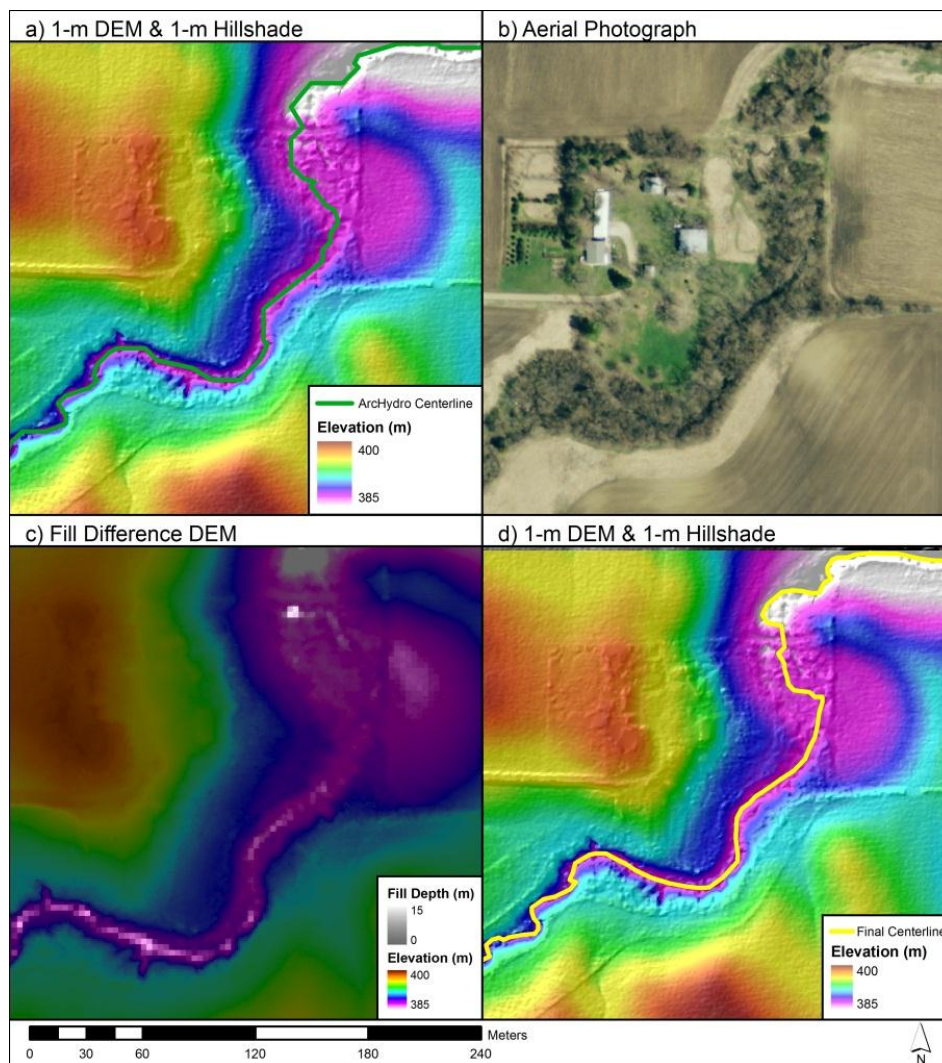
Figure 4.4: Centerline digitization in vegetated areas

Note: a) 1 meter grid DEM and hillshade identifying an area where an exact centerline is not easily defined. b) Aerial Photography showing vegetation and a stream clearing c) Fill Difference DEM, filled locations illuminate a centerline location. d) Final centerline digitization

Urban areas cause ArcHydro streamlines to run askew due to the large amount of elevated roadways, drainage ditches, culverts, and artificially flattened areas, see Figure 4.5a. These locations rely on the DEM and hillshade to aide in describing the open channel flows. Culverts and other underground flows are more difficult to delineate as

the channel cannot be viewed from the land covers. To digitize these areas engineering judgment must be employed. Locations of culverts and roadway overpasses can be identified through aerial photography and DEM. The FiliDEM can be used upstream of these locations as the Fill Sinks process typically fills these areas. Downstream of these locations the ArcHydro path can identify centerline locations, see Figure 4.5.
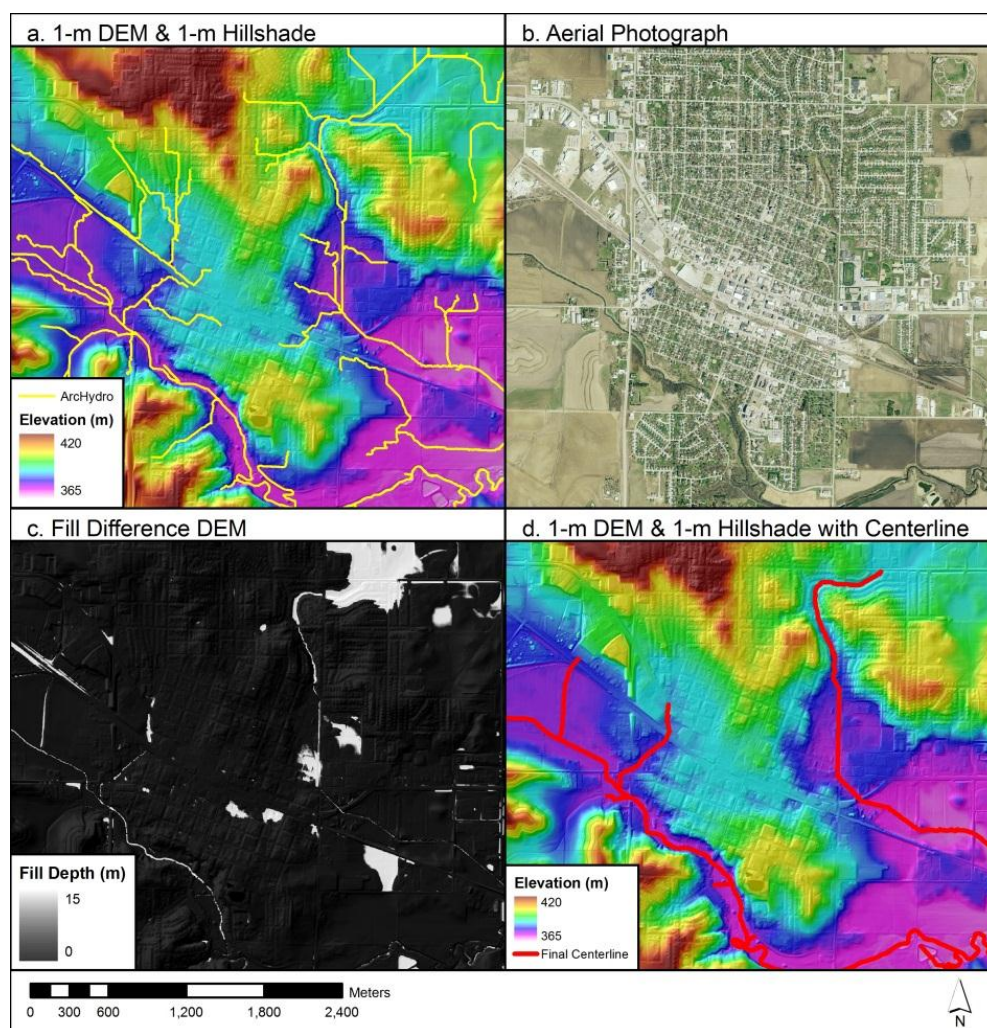
Figure 4.5: Centerline digitization in urban areas

Note: a) 1 meter grid DEM, hillshade and ArcHydro centerline identify congested urban area. b) Aerial Photography aiding in stream flow visualization. c) Fill Difference DEM, show filled areas highlight flowpaths. d) Final centerline digitization.

In addition to mapping an accurate stream centerline, NHD classification is required. As stated in Section 3.3.1, Table 3.1, each stream segment is categorized as one of four classifications based on its interaction with water flow, see Figure 4.6. A break in continuous centerline digitization is placed at each location where two reaches join or a digitized stream centerline segment changes classification. Placing each centerline in a category enables the governing agency to better inventory the waterways for cartographic and hydrologic analyses.
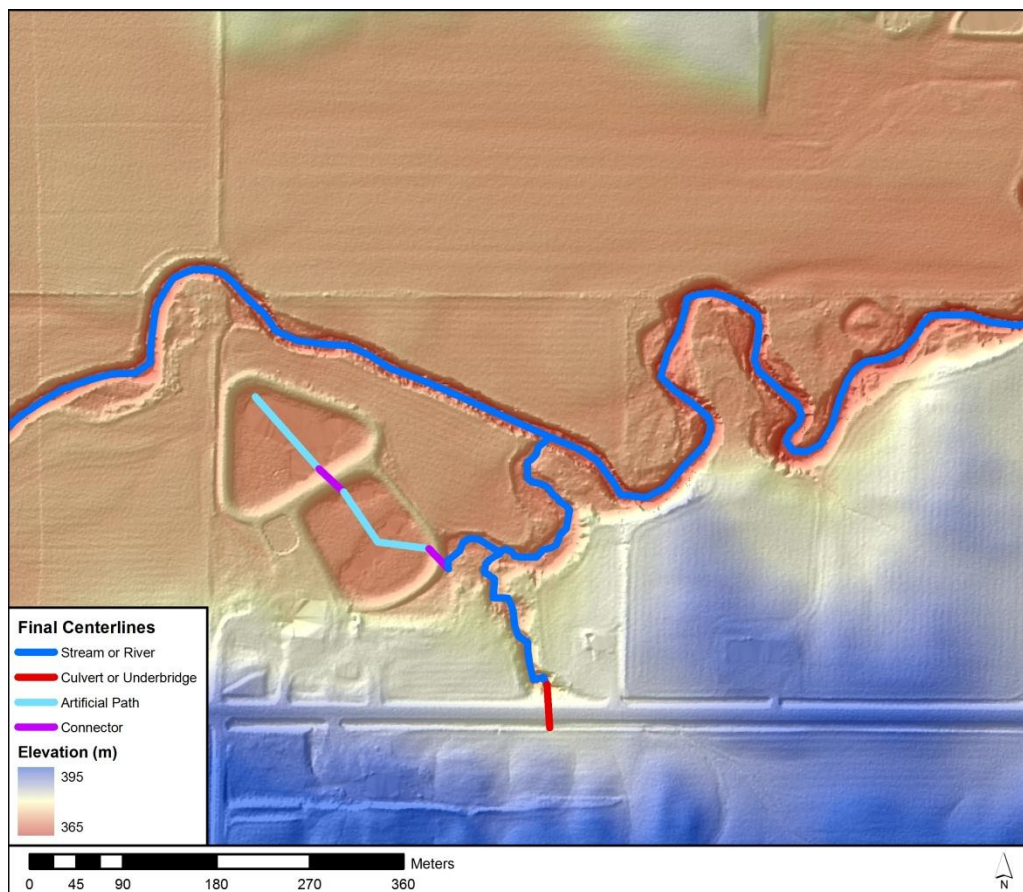
Figure 4.6: Small stream classification by NHD conventions. Streams, culverts, connectors, and artificial paths are identified.

In summary, to create a small stream centerline, an ArcHydro stream is derived from the LiDAR based DEM. The ArcHydro streamline is used as a guide only. Digitization begins at the furthest upstream location that a channel is well defined and there is a reference streamline. A stream is typically never digitized upstream of the ArcHydro streamline. A watershed is always digitized from upstream to downstream. A combination of a DEM and hillshade offers the most consistently descriptive digitization tool. If this combination is not sufficient, aerial photography or a fill difference DEM can be used. Each stream segment is given a classification based on NHD standards. This process is completed for all streams less than seven meters wide.

4.2.2 Large Stream

Streams consistently larger than seven meters wide become increasingly difficult to manually digitize a centerline accurately. A digitization method using a LP360 is used to delineate the bank lines and compile them into a centerline. This section discusses the bank digitization process, centerline identification, and common issues with bank digitization such as loss of data, islands, sandbars, bridge decks, and narrow channels.

LAS elevation data viewed in point cloud form is the source of information from which LP360 operates. Bank lines are digitized through a combination of plan and cross sectional views enabling the user to pin point the location where the water surface becomes the bank, see Figure 3.9.

Before beginning the digitization process, adjustments are made within LP360 to ease bank line identification. LiDAR remote sensing collects information from every surface under the sensor. This includes not only the water and ground surface, but also includes vegetation, buildings, wildlife, etc. Adjustments within the display properties filter out the unnecessary point data, minimizing the amount of clutter around the banks of the stream. After placing the first bank point, a cross section bar replaces the cursor.

The bar represents a pseudo-cross section showing a swath width and length which indicates which LAS points are able to be viewed from the profile window. The width and length can be adjusted to more readily view the elevation information. Variables such as the width of the stream, and amount of LAS data available in the area govern the swath width and length adjustments.

Digitization of each bank line is completed from upstream to downstream. Common issues which arise in application of LP360 include insufficient data points, bridges, and islands. To solve these issues the banks can be located from aerial photography or hillshade information.

Loss of data between the two banks is a typical problem. The location between the two banks where data is missing is most often due to issues collecting data off the water surface. In the case of missing data, the endpoint of each bank foot is digitized as the edge of water, see Figure 4.7.
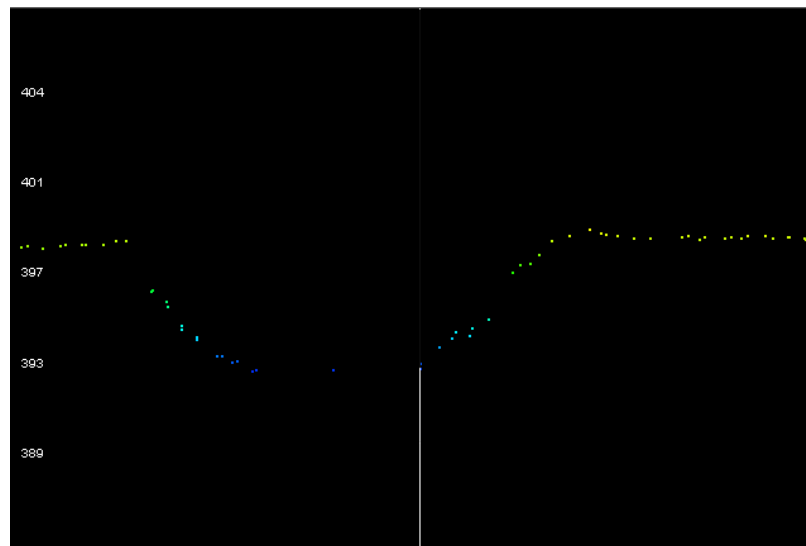
Figure 4.7: Large stream digitization with data missing from the banks in a cross
        sectional view

At bridge locations the aerial based LiDAR system is unable to capture ground elevation data. In these situations the closest point before and after the bridge deck are digitized while the bank is assumed to be straight for this small length.

Islands formed from deposition of river sediment load are often located in streams. As part of this project, the islands are digitized, see Figure 4.8. Each side of the island is completed separately, sharing a point at the upstream and downstream end.
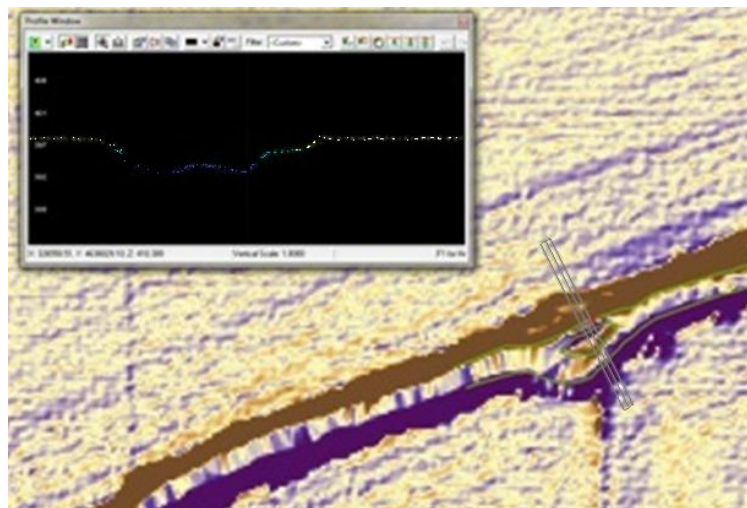
Figure 4.8: Large stream digitization of islands

Note: Left, pseudo-cross sectional view of an island in a river. Right, LiDAR point data of stream section containing an island in the stream.

A location where the bank slope is unidentifiable can be caused by vegetation. In these locations the 1-meter hillshade and aerial photography are viewed to identify the best bank location without using the cross section information.

Sandbars are similar to islands in their formation due to deposition of sediment in the stream and in their occurrence interval. The foot of the sandbar is digitized in these

areas, not the foot of the bank as the water is only conveyed over these areas in times of high flows, sees Figure 4.9.
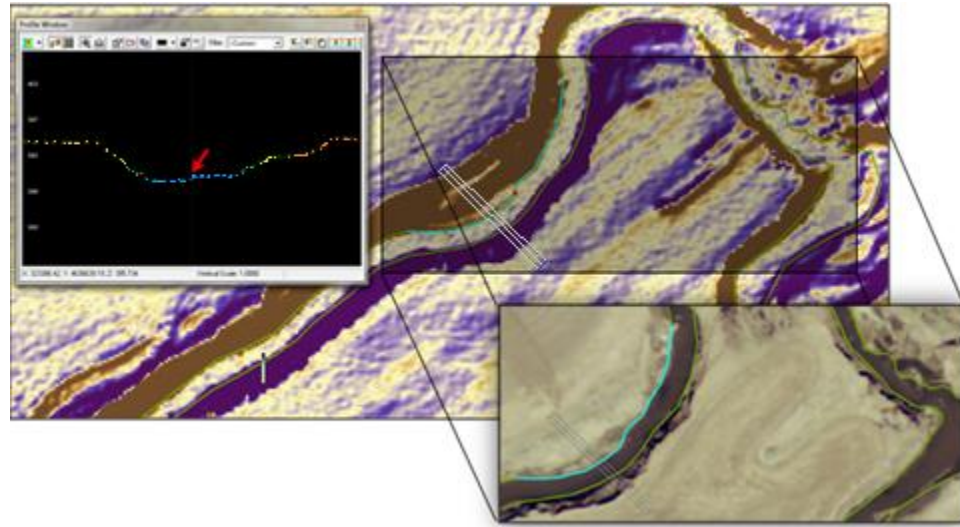
Figure 4.9: Large stream digitization of sandbars

Note: Left , pseudo-cross sectional view of a sand bar in a river. Right, LiDAR point data of stream section containing a sandbar in the stream. Bottom, Aerial Photograph of the sandbar in the stream.

In narrow channels the edge of the water surface can be difficult to identify. In these locations, digitize where the elevation data becomes constant, see Figure 4.10.

After digitization of both right and left banks, the features can be collapsed into a centerline. The process applies the "Collapse Dual Lines to Centerline" tool described in Section 3.2.2.2. This tool determines the average distance between dual feature datasets and outputs a centerline see Figure 4.11. The collapsed centerline must be edited as errors occur at junctions of streams, at islands, and in the general flow direction. The centerline is checked for errors and combined with the small stream centerlines to complete the network of streams throughout a watershed, see Figure 4.11.
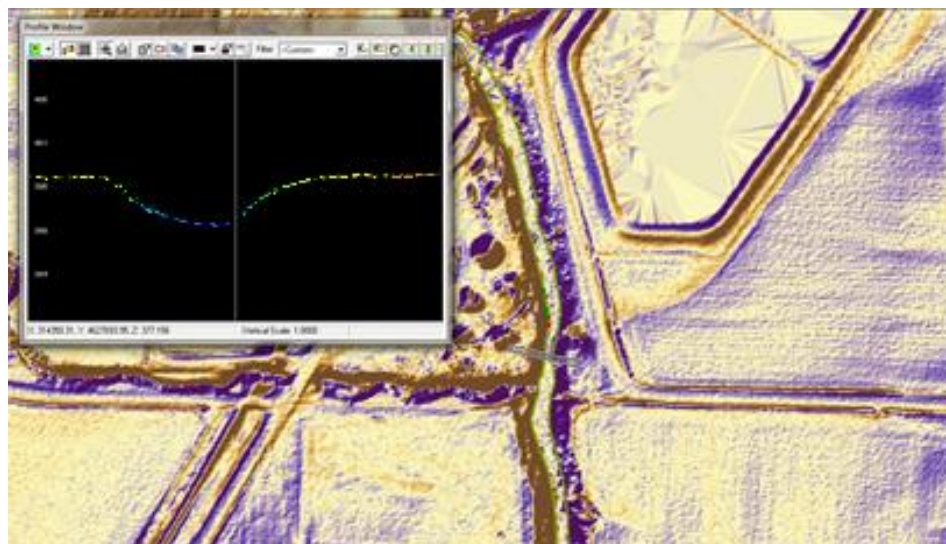
Figure 4.10: Large stream digitization with an undefined edge of water

Note: Left, pseudo-cross sectional view of a narrow channel. Right, LiDAR point data of a narrow stream section.
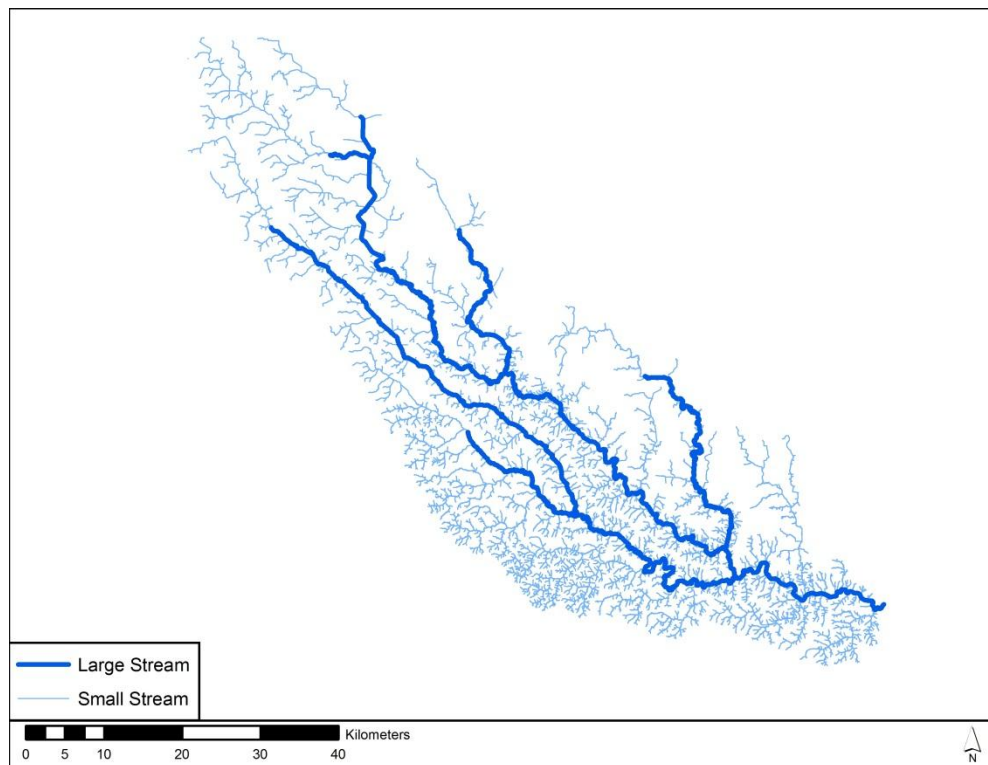
Figure 4.11: Combining digitized large and small streams in South Raccoon watershed

4.2.3 Section Summary

Stream centerlines are identified by utilizing the one meter LiDAR derived DEM. Streams are split into large and small regimes by the width of the channel. Small streams are identified through a raster manipulation tools suite. In instances when the raster manipulation technique cannot fully describe the centerline alternatives are offer in the form of a fill difference DEM and aerial photography. Large streams employ software which uses LAS data to identify edge of water locations and collapse them into a centerline. Large and small streams are classified by NHD standards, combined into one dataset, and prepared for use in hydrologic analysis. Specific methods, troubleshooting, tools, and datasets offer another description of stream centerline identification.

4.3 Hydrologic Analysis

Fifty, 20, 10, 4, 2, 1, 0.5, and 0.2 percent annual exceedance discharges are to be determined through a regional regression hydrologic modeling scheme. Per IDOT and DNR standards a gage weighted regional regression analysis is applied to calculate discharge estimations. Detailed discussions of these methods are described in Section 3.3 and Section 4.3.

Regression analyses rely on the drainage areas determined at each stream point to calculate stream flow. The three meter DEM contains obstructions to flow within the channel such as roadways and vegetation which does not offer a true image of the water flow through the DEM. Reconditioning the DEM to a user defined threshold with the final digitized streamlines, forces the water to flow through the streams. Before reconditioning the DEM the stream centerlines at the outlets of the watershed must be extended past the edge of the DEM to ensure flow out of the watershed. Following the procedure in Section 3.3.2.1, the DEM is reconditioned with the stream centerlines, sinks are filled, flow direction is determined, and flow is accumulated. The flow accumulation given in number of cells is converted into square miles. Cells draining less than one

square mile are set to a null value. The one square mile accumulation is converted to points, see Figure 3.11.

Applying combinations of Lara and Eash based regression analyses to the drainage areas outputs a flow discharge value. Both analyses are dependent on drainage area and hydrologic region. Hydrologic regions are based on soil types and topographic information. South Raccoon watershed in completely contained within Eash 2001 Region 2 and is split between Lara 1987 Regions 3 and 4, see Figure 4.12.

Site Number	Drainage	Gage Start	Gage End	Gage Count
5483318	45	6/12/1966	6/27/2010	43
5483343	9.22	6/15/1991	3/3/1994	4
5483349	6.58	6/12/1966	6/27/2010	45
5483450	375	7/3/1973	6/28/2010	33
5483600	440	6/10/1953	6/27/2010	54
5484000	994	7/31/1940	6/27/2010	71
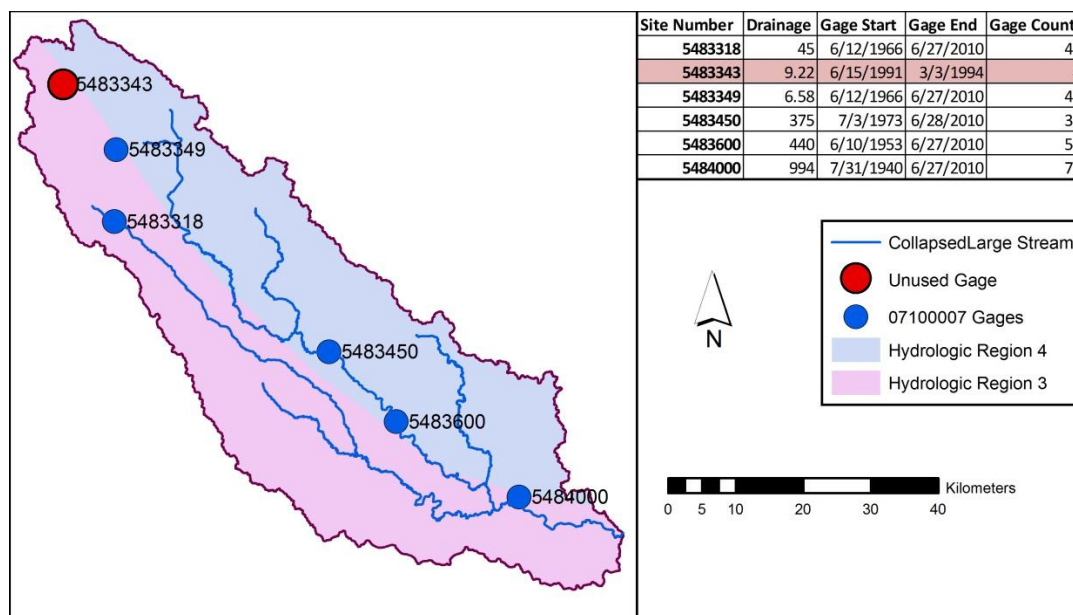
Figure 4.12: Gage locations in South Raccoon watershed, and gage information identifying gage 5483343 as unusable.

In the South Raccoon watershed there are six gaged locations, see Figure 4.12. By viewing the attributes of the selected gages, gage number 5483343 is deemed unusable as the stream flow data provided isn't current enough or contain a long enough time span to represent the current situation. The criteria for inclusion of a gage into the study are reviewed here. Consider gages within the past 10 years from the current year.

The record length must be 10 years or greater. If a gage is not missing greater than 10% of events within that record length, the gage should be used in the hydrologic analysis. Each of the other five gage locations comply with these regulations.

A gage influence can only alter the flows for the stream that the gage is monitoring. To determine the influence area, identify the drainage area ratio (DAR) at drainage area point using Equation 3.5. To be considered within the gages influence the DAR must be less than 0.5, identifying stream locations within 50% of the gage drainage area. Separate the points which are influenced by each gage, see Figure 4.13.
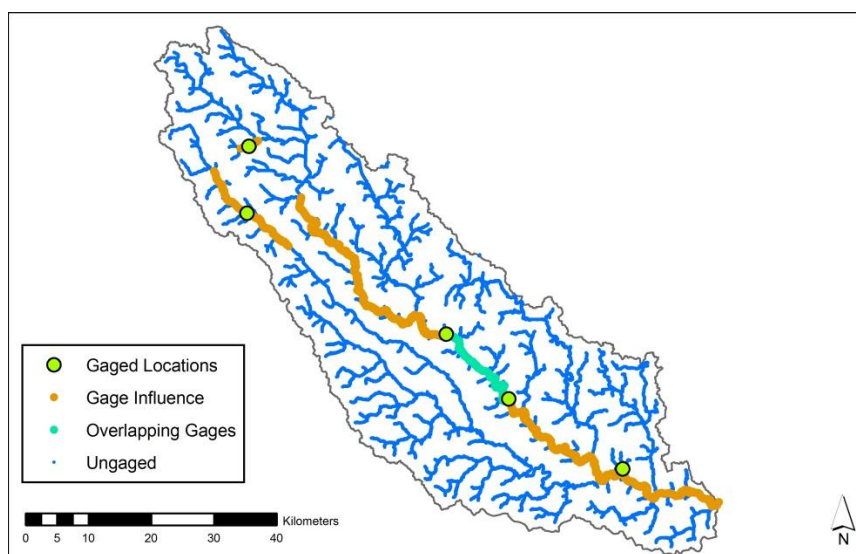
Figure 4.13: Gages and areas of gage influence in South Raccoon watershed

Performing the hydrological calculations in order to determine the flow is divided into four categories: gaged locations, ungaged locations on gaged streams, ungaged locations on ungaged streams, and locations of overlapping gage influence. Locations from each of the four categories have been chosen as examples, see Figure 4.14
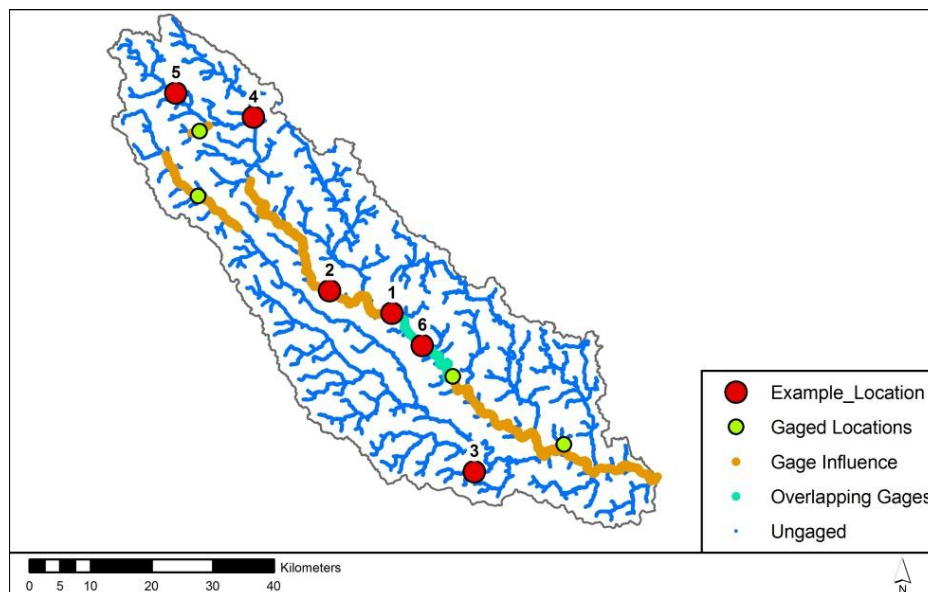
Figure 4.14: Locations used as examples for the case study in South Raccoon watershed

4.3.1 Gaged Location

At each gaged location it is important to determine whether the data is deemed relevant. A gaged location on the Middle Raccoon River near Bayard Iowa has been chosen to represent the gaged points, example Location 1, Figure 4.14. The drainage area at this location determined by this study is 373.7 square miles as compared to 375 square miles record by the USGS. The difference is within reason and evaluation of the flow can continue. To calculate the discharge at this point a weighted scheme is applied, see Equation 3.4 repeated below.

$$Q_{t(wg)} = \frac{Q_{t(pg)}(ERL) + Q_{t(rg)}(EYR)}{(ERL + EYR)} \tag{3.4}$$

Where $Q_{t(wg)}$ is the weighted discharge estimate for a gaged site for recurrence interval t, $Q_{t(pg)}$ is the flood-discharge estimate (log-Pearson Type III) for a gaged site for recurrence interval t (listed (Eash D. A., 2001), table 2), ERL is the effective record length for a gaged site, in years (equivalent to the systematic record length if historical

data are not considered; calculated according to Equations 3.1, 3.2 and 3.3 when historical data are used), $Q_{t(rg)}$ is the regional-regression discharge estimate for a gaged site for recurrence interval t (listed in the flood-frequency discharges (Eash D. A., 2001), table 2, or calculated using the 2001 single parameter regression equations in tables 3-5), and EYR is the equivalent years of record for the regional regression equation used to determine Qt(rg) (Eash 2001, tables 3-5).

A HEC-SSP analysis is the first step of calculating the weighted discharge estimate. The process begins by importing the annual peak data from USGS into the HEC-SSP software and beginning a Bulletin 17B Flow Frequency Analysis. To complete this analysis, both the Regional Skew and Reg. Skew MSE need be determined and incorporated into the analysis. The Regional Skew varies based on the gage location and is the same as the "Generalized Skew" in table 2 of (Eash D. A., 2001). If the gage is not listed in table 2 (Eash D. A., 2001), then it must be visually interpreted from the "Generlaized Skew Isolines" graph, see Figure 3.17. For this location the Regional Skew is listed in table 2 of (Eash D. A., 2001). It identifies a skew of -0.359, see Figure 4.15. The Reg. Skew MSE is 0.156 for the whole state of Iowa.

Map no. (figs. 1 and 6)	Station number	Station name	DA (mi²)	Station skew	Gener- alized skew	Hydrologic region (fig. 7)	Discharge (cubic feet per second) for indicated recurrence interval (years)							
							2	5	10	25	50	100	200	500
164	05483450	Middle Raccoon River near Bayard, IA	375	NA	-0.359	2	3,590	6,690	9,250	13,100	16,400	20,000	24,000	30,000
							4,470	8,460	11,400	15,200	18,100	21,000	24,000	28,000
							3,190	6,310	8,650	11,600	13,800	16,000	18,200	21,200

Figure 4.15: Selection from Table 2 (Eash D. A., 2001) for determination of Regional Skew

Before running the analysis, the annual peak flow record is scrutinized for historic data. Historic flood data is defined as information that indicates that any flood peaks which occurred before, during, or after the systematic record are maximums in an

extended period of time. Data that fits these criteria should be used in the analysis. First check to see if any data is coded as historic in the USGS Quality Codes of Annual Peak Flow Data. At this location one event in July 1973 is considered a historic event, see Figure 4.16.

Ordinate	Date / Time	BAYARD, IA CODE-PEAK ... USGS
Units		CFS
Type		INST-VAL
1	03 Jul 73, 24:00	7.0000
2	19 Mar 79, 24:00	
3	16 Mar 80, 24:00	
4	30 Jun 81, 24:00	
5	22 Feb 82, 24:00	2.0000
6	02 Jul 83, 24:00	
7	30 Apr 84, 24:00	
8	22 Feb 85, 24:00	2.0000
9	30 Jun 86, 24:00	
10	12 Oct 86, 24:00	
11	08 Jun 88, 24:00	
12	08 Sep 89, 24:00	
13	17 Jun 90, 24:00	
14	16 Jun 91, 24:00	
15	25 Jul 92, 24:00	
16	09 Jul 93, 24:00	
17	19 Feb 94, 24:00	2.0000

Figure 4.16: Codes for peak flow on Middle Raccoon River at Bayard Iowa. A code 7 indicates a historical data point

A plot of data is scrutinized in order to determine if other recorded data should be deemed historic, see Figure 4.17. Check to see if there are extreme high values in the systematic record or if there are points that are recorded several years before the systematic record begins. Generally, using historic data reduces flow values, because it adjusts for high outliers in the data. When a gap of unrecorded years occurs between an early data point and the systematic record, the historic value is typically the highest recorded in that time period. At this location two historical events are taken into account the event in 1973 and in 1993 Figure 4.17. To include these points a high threshold of 14,500 CFS is applied to the data. Unless there is strong evidence to use historic data, it is recommended that all the recorded data be treated as systematic (Bradley, 2011). It is

helpful to run the analysis in HEC-SSP with and without historic data to compare differences and determine if historic data should be used, see Table 4.1. If the historical data does have a significant effect on the flow frequency analysis it should be deemed historic.
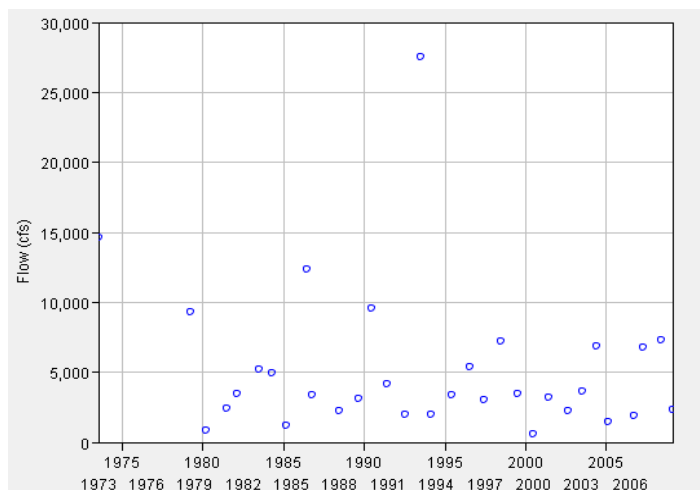
Figure 4.17: Annual peak flow data on Middle Raccoon River at Bayard Iowa, two points are identified as historic in 1973 and 1993

Table 4.1: Comparison of HEC-SSP analysis with and without historical events to compute flood discharge estimates

	w/ Historic Values	w/o Historic Values
%	Qt(pg) (CFS)	Qt(pg) (CFS)
50	3,707	3,887
20	7,254	7,502
10	10,205	10,298
4	14,580	14,154
2	18,288	17,200
1	22,363	20,353
0.5	26,827	23,608
0.2	33,355	28,058

Historical data is used in calculation of the flood discharge estimation, so the estimated record length (ERL) must be determined, by Equations 3.1, 3.2, and 3.3 repeated below. If data is not considered historical the ERL from HEC-SSP can be used without alterations.

$$\text{ERL} = \text{LS} + (\text{HST} - \text{LS})a \qquad (3.1)$$
$$a = 0.55 - 0.1\left[\log_e\left(\frac{\text{ph}}{1-\text{ph}}\right)\right] \qquad (3.2)$$
$$\text{ph} = 1.0 - \frac{\text{np}}{\text{HST}} \qquad (3.3)$$

Where np is number of historic and extremely large discharge (high-outlier) peaks, LS is the systematic record length of a gaging station in years (the number of water years during which the gaging station was operating), and HST is the historic record length of a gaging station, in years, as used in a Pearson Type-III historical flood frequency analysis, if a systematic flood frequency analysis was performed, HST = LS, and if (HST-LS) > 200, set (HST-LS) = 200.

Example 1: Determine the ERL on Middle Raccoon River at Bayard Iowa, Location 1, Figure 4.14. From the information listed in the GIS attributes, the systematic record length is 32 years, the historical record length is 37 years, and the number of historic events used for the Bulletin 17B Flow Frequency Analysis in HEC-SSP is 2.

$$\text{ph} = 1.0 - \frac{\text{np}}{\text{HST}} = 1.0 - \frac{2 \text{ events}}{37 \text{ total events}} = 0.946$$

$$a = 0.55 - 0.1\left[\log_e\left(\frac{\text{ph}}{1 - \text{ph}}\right)\right] = 0.55 - 0.1\left[\log_e\left(\frac{0.946}{1 - 0.946}\right)\right] = 0.264$$

$$\text{ERL} = \text{LS} + (\text{HST} - \text{LS})a = 32 + (37 - 32)\,0.264 = 33.32$$

Example 2: Determine gaged annual exceedance discharge on Middle Raccoon River at Bayard, Location 1, Figure 4.14. The flood discharge estimate from HEC-SSP is listed in Table 4.1, the effective record length determined from Example 1 is 33.32, the regional regression discharge estimates are listed in Table 4.2, and the equivalent years of

record are given in Table 3.5 and are repeated in Table 4.2 for 2001 hydrologic region 2. See example 7 to determine the regression based discharges. The weighted estimate is completed for the 50 percent annual exceedance discharge and each of the other seven discharges is shown in Table 4.2. These calculations are completed for each gaged location.

$$Q_{t(wg)} = \frac{Q_{t(pg)}(ERL) + Q_{t(rg)}(EYR)}{(ERL + EYR)} = \frac{3707cfs(33.32) + 4470cfs(3.6)}{(33.32 + 3.6)} = 3781.40cfs$$

Table 4.2: Completed weighted gage discharges for Middle Raccoon River Bayard Iowa, table includes gage flow estimate, ERL, EYR, and regression discharge

%	$Q_{t(pg)}$ (cfs)	ERL	EYR	$Q_{t(rg)}$ (cfs)	$Q_{t(wg)}$ (cfs)
50	3,707	33.32	3.6	4,470	3,781
20	7,254	33.32	7.9	8,460	7,485
10	10,205	33.32	13.5	11,400	10,550
4	14,580	33.32	20.5	15,200	14,816
2	18,288	33.32	24	18,100	18,209
1	22,363	33.32	25.9	21,000	21,767
0.5	26,827	33.32	26.5	24,000	25,575
0.2	33,355	33.32	26	28,000	31,008

4.3.2 Ungaged Locations on Gaged Streams

Stream gage influence is based on the drainage area at a stream location compared to the gage drainage area influencing the particular stream location. Example Location 2, Figure 4.14, has been chosen to demonstrate the area-weighted discharge estimate, this estimation technique is applied to gage influence areas when a gage has a period of record greater than 25 years, see Equation 3.8 repeated below.

$$Q_{t(aw)} = Q_{t(wg)} \left(\frac{DA_u}{DA_g} \right)^x \tag{3.8}$$

Where $Q_{t(aw)}$ is the area-weighted discharge estimate for an ungaged site on a gaged stream for recurrence interval t, $Q_{t(wg)}$ is the weighted discharge estimate for a gaged site for recurrence interval t (from Equation 3.4), DA_u is the drainage area of the ungaged site, DA_g is the drainage area of the gaged site, and x is the mean exponent for a hydrologic region defined in (Eash D. A., 2001); for Region 1, the mean exponent is 0.665; Region 2, 0.446; and Region 3, 0.403.

Example 3: Determine if Location 2, Figure 4.14 is within the gage influenced zone. The drainage area at Location 2 is calculated to be 237.1 square miles, and the gaged drainage area is 373.7 square miles. Apply Equation 3.5 repeated below to the chosen stream location. The value is determined to be less than 0.5 so it is within this gages influence.

$$DAR = \frac{|DA_g - DA_u|}{DA_g} \tag{3.5}$$

Where DAR is the drainage area ratio, DA_g is the drainage area of the gaged location, and DA_u is the drainage area of the ungaged location.

$$DAR = \frac{|DA_g - DA_u|}{DA_g} = \frac{|373.7 - 237.1|}{373.7} = 0.366$$

Example 4: Calculate the annual exceedance discharge for Location 2, Figure 4.14, ungagged location on a gaged stream with a period of record less than 25 years. The weighted discharge for a gaged site was determined in Example 2 and repeated in Table 4.3, the drainage area at the gaged location is 373.7 square miles, the drainage area at the ungaged site is 237.1 square miles, and the mean exponent is 0.446 for hydrologic Region 2. The calculation below is completed for the 50 percent annual exceedance discharge, while the other seven discharges are listed in Table 4.3.

$$Q_{t(aw)} = Q_{t(wg)} \left(\frac{DA_u}{DA_g}\right)^x = 3781.4cfs \left(\frac{237.1 \text{ sq. mi.}}{373.7 \text{ sq. mi.}}\right)^{.446} = 3{,}087cfs$$

Table 4.3: Annual exceedance discharges for Location 2 calculated by the area weighted method

%	$Q_{t(wg)}$(cfs)	$Q_{t(aw)}$(cfs)
50	3,781	3,087
20	7,485	6,110
10	10,550	8,611
4	14,816	12,094
2	18,209	14,863
1	21,767	17,767
0.5	25,575	20,875
0.2	31,008	25,310

Since none of the gage locations in this watershed have less than 25 years of recorded data an example from another watershed must be used. If a location has less than 25 years of record then the annual exceedance discharges are determined by a regression-weighted method, see repeated Equation 3.6 below.

$$Q_{t(rw)} = Q_{t(ru)}[AF - (2DAR)(AF - 1)] \tag{3.6}$$

Where $Q_{t(rw)}$ is the regression-weighted discharge estimate for an ungaged site on a gaged stream for recurrence interval t, $Q_{t(ru)}$ is the regional regression discharge estimate for an ungaged site for recurrence interval t, determined using the technique described in (Eash D. A., 2001), and AF is the adjustment factor for the gaged site and is calculated as

$$AF = \frac{Q_{t(wg)}}{Q_{t(rg)}} \tag{3.7}$$

Where $Q_{t(wg)}$ is the weighted discharge estimate for a gaged site for recurrence interval t (from Equation 3.4), and $Q_{t(rg)}$ is the regional-regression discharge estimate for a gaged site for recurrence interval t (listed in the flood-frequency discharges in (Eash D. A., 2001), table 3).

Example 5: Calculate the annual exceedance discharge for an ungaged location on a gaged stream, with less than 25 years of record. The drainage area at this location is 923.5 square miles, and at the nearby gaged location is 977.3 square miles. The regional regression discharges for both the gaged and ungaged locations are given in Table 4.4, and the weighted discharge estimate for the gaged location is also given in Table 4.4. See Example 7 to determine the regression based discharges. The calculation below is completed for the 50 percent annual exceedance discharge, while the other seven are listed in Table 4.4.

$$DAR = \frac{|DA_g - DA_u|}{DA_g} = \frac{|977.3 \text{ sq. mi.} - 923.5 \text{ sq. mi.}|}{977.3 \text{ sq. mi.}} = 0.055$$

$$AF = \frac{Q_{t(wg)}}{Q_{t(rg)}} = \frac{10685.3 \text{ cfs}}{7493.4 \text{ cfs}} = 1.43$$

$$Q_{t(rw)} = Q_{t(ru)}[AF - (2DAR)(AF - 1)] = 7267.9 \text{ cfs}[1.43 - (2(.055))(1.43 - 1)] = 10023.0 \text{ cfs}$$

4.3.3 Ungaged Locations on Ungaged Streams

Areas where the gages do not influence the annual exceedance flows, the Eash (2001), the Lara (1987), or combinations of the two regional regression analyses are applied to the drain areas to determine an annual exceedance discharge. Three locations were chosen, one to describe each calculation technique. Location 3, Figure 4.14, has a drainage area of less than 20 square miles, therefore the exceedance discharge is

calculated by applying only the 1987 equations. Location 4, Figure 4.14, has a drain area

of more than 50 square miles, so the exceedance discharge is calculated with only the

2001 equations. Location 5, Figure 4.14, has a drain area between 20 and 50 square

miles; the exceedance discharge is calculated by taking the arithmetic mean of both the

Lara and Eash based discharge estimates.

Table 4.4: Weighted discharge estimate for an ungagged location on a gaged stream.
         Included, gage weighted discharge, regional regression discharges for the
         gaged and ungagged sites and the adjustment factor.

%	$Q_{t(wg)}$ (cfs)	$Q_{t(ru)}$ (cfs)	$Q_{t(rg)}$ (cfs)	AF	$Q_{t(ru)}$ (cfs)
50	10,685	7,268	7,493	1.43	10,023
20	17,955	13,170	13,540	1.33	16,991
10	22,913	17,421	17,885	1.28	21,779
4	29,223	22,750	23,325	1.25	27,869
2	34,013	26,583	27,233	1.25	32,472
1	38,917	30,615	31,342	1.24	37,199
0.5	43,899	34,474	35,270	1.24	41,981
0.2	50,699	39,734	40,618	1.25	48,510

At locations of less than 20 square miles the 1987 Lara regression analysis is

applied to the location to determine the annual exceedance discharges for the two-, 5-,

10-, 25-, 50-, 100- year return periods, but it does not include the 200- and 500- year

analysis. To compute the final two return period flows, an extrapolation technique is

applied. The 1987 regression relations were developed using a log Pearson Type II (LP3)

technique. Three peaks value points are required to describe the entire curve and

extrapolate to the 200 and 500 year peak discharges, see Figure 4.18 and Table 3.4.
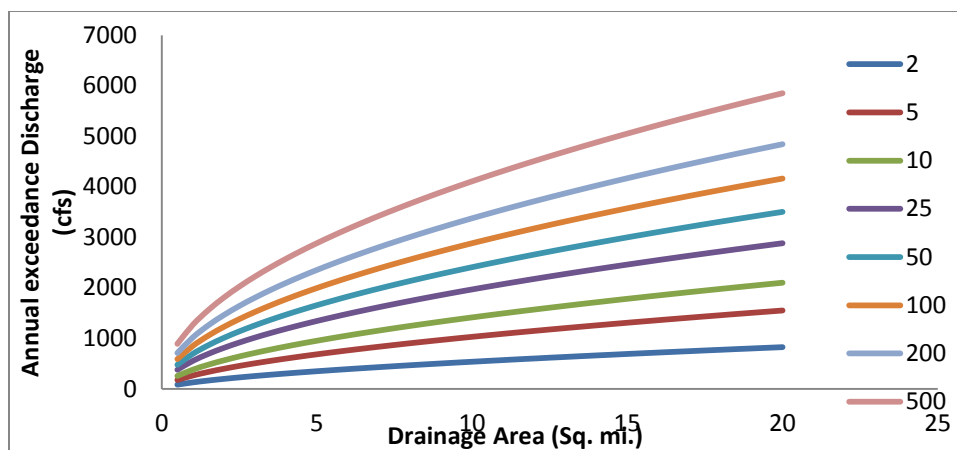
Figure 4.18: Extrapolated 200 and 500 return period flows for 1987 Lara regression
analysis

Example 6: Determine the annual exceedance discharge at Location 3, Figure
4.14, with a drainage area of less than 20 square miles. Location 3 has a drainage area of
10.8 square miles, and is in 1987 hydrological Region 3, therefore it uses the Lara 1987
regression equations in Table 3.3 and Table 3.4. The 50 percent annual exceedance
discharge is calculated and the other seven discharges are shown in Table 4.5.

$$Q_2 = 129A^{0.62} = 129(10.8)^{0.62} = 564.6 \text{ cfs}$$

Table 4.5: Annual exceedance discharges for Location 3, Figure 4.14, draining less than
20 square miles

%	Q (cfs)
50	564.6
20	1,079.8
10	1,480.3
4	2,056.0
2	2,514.1
1	3,006.0
0.5	3,518.2
0.2	4,277.4

Example 7: Determine the annual exceedance discharge at Location 4, Figure 4.14, with a drainage area greater than 50 square miles. Location 4 has a drainage area of 54.2 square miles, and is in 2001 hydrological Region 2. This location uses the Eash 2001 regression equations in Table 3.5. The exceedance discharge can be estimated. The 50 percent annual exceedance discharge is calculated and the other seven discharges are shown in Table 4.6.

$$Q_2 = 182A^{0.540} = 182(54.2)^{0.540} = 1582.4 \text{ cfs}$$

Table 4.6: Annual exceedance discharges for Location 4, Figure 4.14, draining greater than 50 square miles

%	Q (cfs)
50	1,571.4
20	3,281.3
10	4,659.2
4	6,513.1
2	7,918.9
1	9,435.6
0.5	10,992.9
0.2	13,183.3

Example 8: Determine the annual exceedance discharge at Location 5, drainage area between 20 and 50 square miles. Location 5 has a drain area of 37.7 square miles, and is in the 2001 hydrological Region 2 and the 1987 hydrologic Region 3. Using the Eash 2001 regression equations in Table 3.5 and the Lara 1987 regression equations in Table 3.3 and Table 3.4, the exceedance discharge can be estimated by taking the arithmetic mean of the two values. The 50 percent annual exceedance discharge is

calculated for each regression analysis and averaged while the other seven averaged

discharges are shown in Table 4.7.

2001 regression analysis $\quad Q_{2, \ 2001} = 182A^{0.540} = 182(37.7)^{0.540} = 1292.1 \ \text{cfs}$

1987 regression analysis $\quad Q_{2, \ 1987} = 129A^{0.62} = 129(37.7)^{0.62} = 1224.4 \ \text{cfs}$

Average $\quad Q_2 = \dfrac{Q_{2, \ 2001} + Q_{2, \ 1987}}{2} = \dfrac{1292.1 \text{cfs} + 1224.4 \text{cfs}}{2} = 1258.2 \ \text{cfs}$

Table 4.7: Annual exceedance discharges for Location 5, Figure 4.14, draining between 20 and 50 square miles

%	Q (cfs)
50	1258.2
20	2501.5
10	3476.3
4	4818.4
2	5858.7
1	6972.0
0.5	8116.6
0.2	9767.7

4.3.4 Locations with Influence From Two Gages

In some situations, a location's DAR is 0.5 or less for two stream gages. In this

case, regression- or area-weighted discharges are calculated using each gage; then the

two calculated discharges are averaged using the logarithmic averaging scheme described

by (Sando, 1998).

$$Q_{t(wa)} = \log^{-1}\left[\frac{\log Q_{t(w1)} + \log Q_{t(w2)}}{2}\right] \tag{3.9}$$

Where $Q_{t(wa)}$ is the logarithmically averaged discharge for an ungaged location on a gaged stream for which two gages satisfy the drainage area ratio criterion described by Equation 3.5, $Q_{t(w1)}$ and $Q_{t(w2)}$ are regression- or area-weighted discharges calculated using Equations 3.6 and/or 3.8.

Example 9: Determine the annual exceedance discharge at Location 6, Figure 4.14 influenced by two stream gages. Location 6 has a drainage area of 394.1 square miles and is within the influence area of two gaged locations, see Figure 4.14. A gaged analysis has been completed for each of the gaged locations the flow values are listed in Table 4.8. $Q_{t(w1)}$ and $Q_{t(w2)}$ are determined by applying Equation 3.4. The drain area of the upstream gage is 373.7 square miles and the downstream gage, is 422.1 square miles, and the mean exponent is 0.446 for 2001 hydrologic region 2. Equation 3.9 is applied to $Q_{t(w1)}$ and $Q_{t(w2)}$ to determine the flow at this location. The 50 percent annual exceedance discharge is calculated for each gage analysis, the other seven discharges are shown in Table 4.9.

Table 4.8: Flow estimates at Location 6, Figure 4.14, within the influence area of two
        gages

%	$Q_{t1(wg)}$ (cfs)	$Q_{t2(wg)}$ (cfs)
50	3,781	4,956
20	7,485	8,536
10	10,550	11,365
4	14,816	15,310
2	18,209	18,411
1	21,767	21,699
0.5	25,575	25,116
0.2	31,008	29,959

$$Q_{t(w1)} = Q_{t(wg)} \left(\frac{DA_u}{DA_g}\right)^x = 3781.4 \text{cfs} \left(\frac{394.1 \text{ sq. mi.}}{373.7 \text{ sq. mi.}}\right)^{.446} = 3987.8 \text{ cfs}$$

$$Q_{t(w2)} = Q_{t(wg)} \left(\frac{DA_u}{DA_g}\right)^x = 4955.8 \text{cfs} \left(\frac{394.1 \text{ sq. mi.}}{422.1 \text{ sq. mi.}}\right)^{.446} = 4806.4 \text{ cfs}$$

$$Q_{t(wa)} = \log^{-1}\left[\frac{\log Q_{t(w1)} + \log Q_{t(w2)}}{2}\right] = \log^{-1}\left[\frac{\log(1858.3 \text{ cfs}) + \log(2156.2 \text{ cfs})}{2}\right] = 4313.6 \text{ cfs}$$

Table 4.9: Annual exceedance discharges for Location 6, Figure 4.14, between two gaged locations

%	Q (cfs)
50	4,314
20	7,964
10	10,912
4	15,009
2	18,247
1	21,658
0.5	25,257
0.2	30,374

4.3.5 Section Summary

Hydrologic analysis begins by determining the drainage area at each point along the digitized stream centerline through a "Terrain Preprocessing" tool suite. Gages are located and scrutinized to determine which contain acceptable datasets. The drainage points are separated based on gage influence, and annual exceedance discharges are calculated for each drainage point. The datasets are then merged together to form a complete network of flow values through a watershed.

<u>4.4 Hydraulic Analysis</u>

HEC-RAS is the software employed to complete the hydraulic analysis. Cross sections, stream centerlines, flow paths, bank lines, and boundary conditions are the input parameters for the HEC-RAS one dimensional flow model. The outputs are water surface elevations corresponding to the different annual chance floods at each cross section delineated along the reach.

The streams are broken up into reaches to simplify the modeling procedure. As a review, the order which the naming conventions are applied to split the reaches is DFIRM, NHD "NAMES", USGS 7.5 minutes maps, and then the NHD "RCH_CODE for all others, see Section 3.4.1.

4.4.1 Model Geometry

One dimensional hydraulic models rely on cross sectional information to describe the topography and to route water. Geometric information which accurately represents the landscape is required. A reach from South Raccoon watershed called Bay Branch was chosen to discuss the modeling procedure.

Before beginning to define geometric information, spatial data pertinent to the reach is copied from the larger watershed features to simplify the input parameters, increase ArcGIS responsiveness, and reduce load times. A shape file called "Model_Polygon" is digitized to boarder the catchment of the modeled stream and to contain all of the flood extents. This feature is used to export the flow, DEM, land roughness, and hillshade data, see Figure 4.19.

Geometry definition requires HEC-GeoRAS to aide in building, exporting to, and importing from HEC-RAS. Modeling the geometric features begins with the stream centerline feature class which HEC-GeoRAS calls "River" see Figure 4.20. The feature class "River" needs to be one continuous feature. A tool called "Dissolve" in the

Generalization tool box is applied to the final digitized stream centerline data to create a single continuous feature.
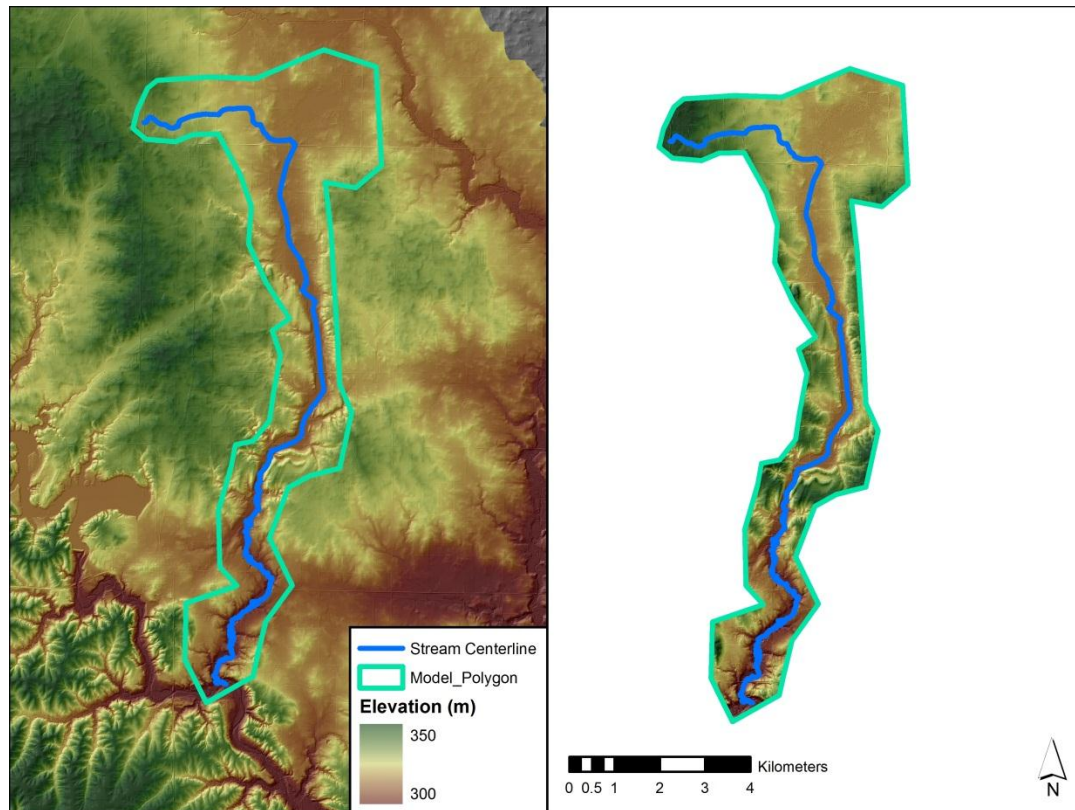

Figure 4.19: Extraction of information from the watershed data through Model_Polygon.

Note: Left, identifies the Model_Polygon based on the watershed characteristics. Right, is the extracted information ready for modeling.

HEC-GeoRAS names the cross sections "XSCutlines". Overlaying the DEM raster file to the hillshade highlights the topographic features easing the cross section definition process. The distance between two cross sections is recommended not to be longer than 500 meters according to IDNR mandate. An ArcGIS tool called ET Geo Wizards creates station points along the centerline. Station points are created at 500

meter intervals for ease of cross section location implementation. The cross sections must be drawn from left bank to right bank looking downstream. Cross sections are created perpendicular to topographic contours. Cross section should not have end points located in valleys. Instead cross section end points should be located at local high points. Backwater effects on tributaries are included by extending the cross sections immediately upstream and downstream of tributaries. If there is truncation of backwater effects, the geometry must be altered and the reach remodeled. Common cross section shapes and locations can be seen in Figure 4.20.

HEC-GeoRAS calls the bank geometry features "Bank Lines". Draw banklines at each "XS Cutline" on both sides of the "River", making sure the "Bank Lines" cross the "XS Cutlines", at the point where the river channel becomes the floodplain, see Figure 4.20.

Flow paths are the final required digitized geometric input. The lines must remain outside the channel banks and cannot cross one another. "The Flow Path Centerlines theme is used to identify the hydraulic flow path in the left overbank, main channel, and right over bank by identifying the center of mass flow" (Ackerman, 2002). The stream centerline can be used as the centerline flow path while the left and right over bank flow paths run between the "River" centerline and the feet of the hills, see Figure 4.20.

In locations where the cross section inaccurately contains a low lying area, ineffective flow areas can be used. Identifying an ineffective flow area in a cross section indicates the area is not to be used for conveyance, but can still hold water. Ineffective flow typically refers to low lying areas in the cross section which will take on standing water and adds to the conveyance, when in reality water will not flow through these areas. Typical locations with ineffective flow areas include, uncertified levees or natural levee systems, and valleys running parallel to the flow, see Figure 4.21

The NLCD database offers land use information at a 30 meter resolution. This spatial information is converted into Manning's n values. HEC-GeoRAS couples the

cross section information with the land roughness values by extracting the roughness at the cross section location, see Figure 4.22. All of the geometric datasets are attributed by HEC-GeoRAS and exported for use in HEC-RAS.
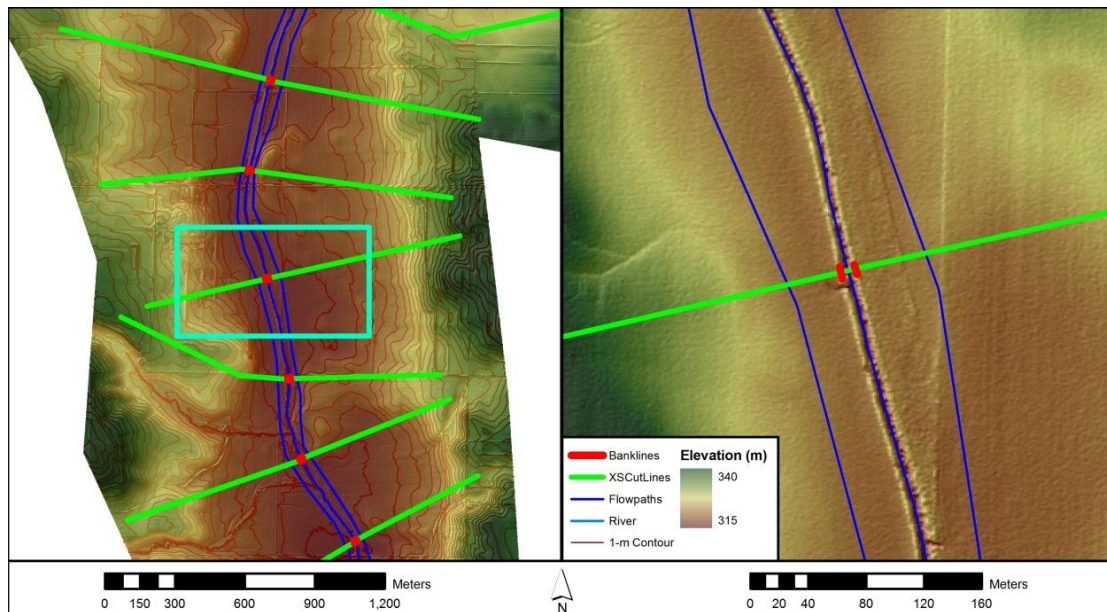

Figure 4.20: HEC-RAS required geometric inputs, Cross section, Bank Lines, Flow paths, and a River
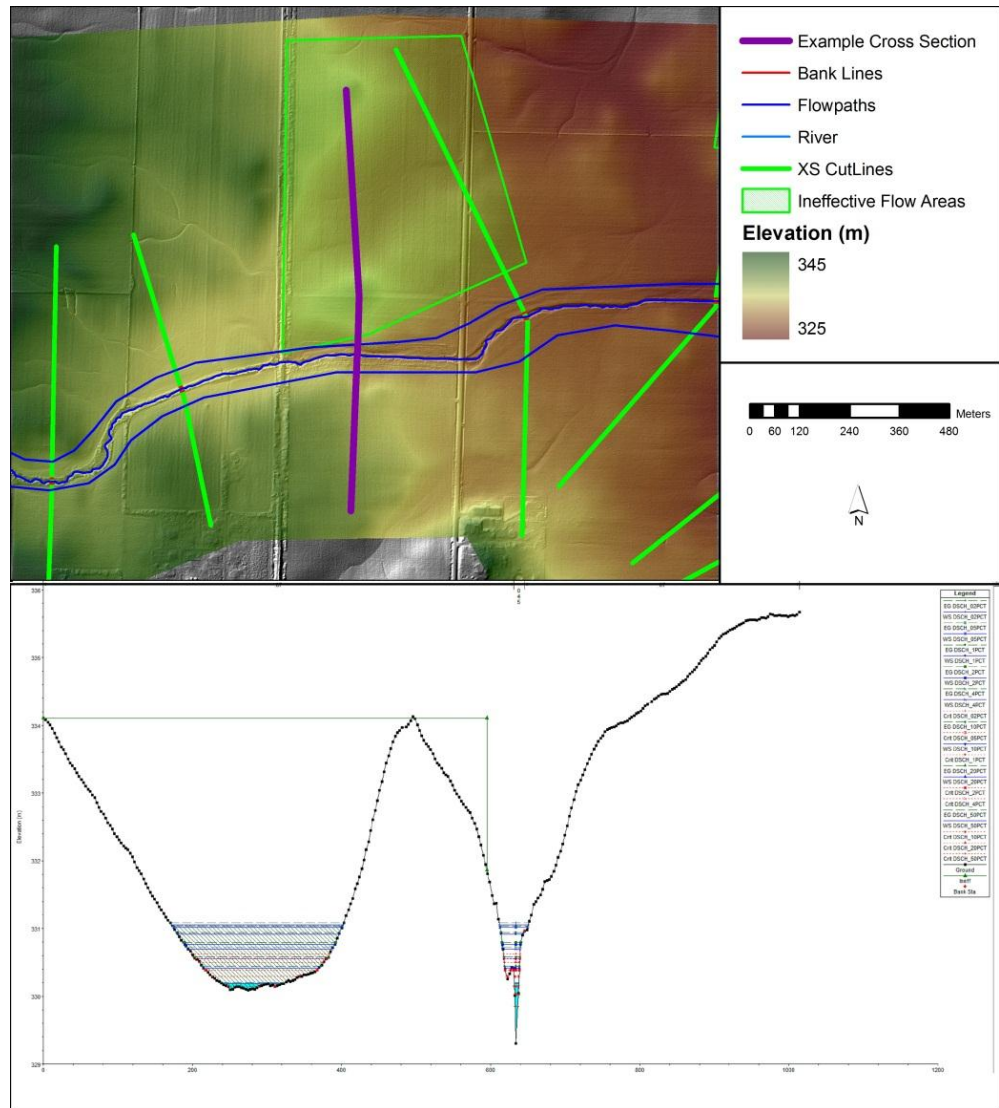
Figure 4.21: Example of ineffective flow area

Note: Top, ArcGIS plan view of an example ineffective flow area. Bottom, HEC-RAS cross sectional view of the example cross section
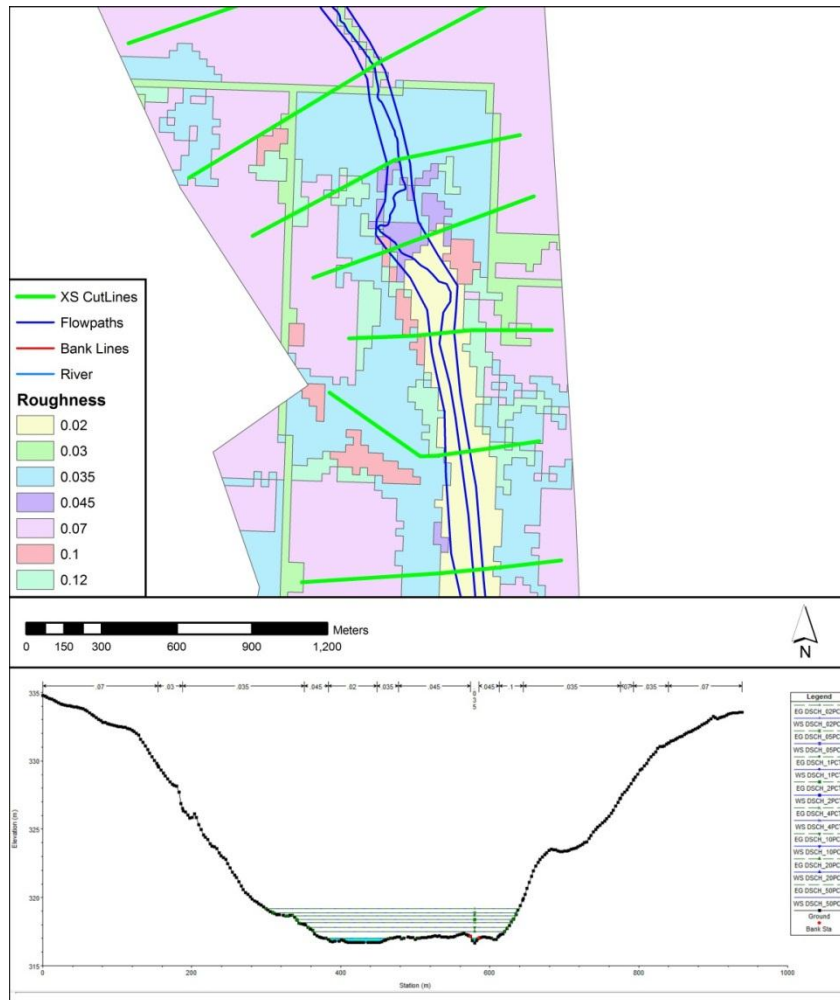
Figure 4.22: Manning's roughness values from NLCD conversion

Note: Top, is an ArcGIS plan view of the varying roughness. Bottom, is a HEC-RAS
cross section view demonstrating the roughness values.

In large model reaches typically longer than 20 miles, the export file can contain
too much information and lose data during the export process. The number of cross
sections and the length from left to right affects the amount of information stored, so the
actual stream length to reach the threshold is variable. In this situation, the model is
broken into two or more parts. This requires duplicates of each geometric file splitting
them into upstream and downstream geometry files. The river and flow path files must

be cut and separated. The upstream and downstream geometry files are exported separately, and added into HEC-RAS separately. In HEC-RAS an addition to the reach is added to reconnect the upstream to downstream ends. The upstream stations are renamed to align with the original geometry stationing. The left and right overbank flows at the junction cross section must be manually adjusted to the original lengths, and the HEC-RAS addition to the reach can be deleted.

4.4.2 HEC-RAS Modeling

HEC-RAS requires two sets of information to run a model, geometry and flow data. Each is discussed in Section 3.4 and in greater depth in this section.

The geometric information that HEC-RAS requires was created in ArcGIS with the aid of HEC-GeoRAS to attribute and export the datasets. Further manipulation of the data within HEC-RAS is needed to accurately describe the flow through the river valley. Geometric information is imported into HEC-RAS and can be viewed in the geometry edit window. The geometry can be checked for errors, (i.e. if the cross section are defined from left bank to right, if the flow is in the wrong direction, if there is a break in the centerline, and if Manning's roughness values were imported appropriately). In the graphical cross section editor the banks at each cross section can be checked for accuracy and adjusted to the correct locations. The roughness between the river banks must be changed to accurately represent the resistance to flow in the reach. This can be done by viewing the main channel Manning's n table in HEC-RAS and setting the area between the banks of each cross sections which drain more than 10 square miles to 0.35 and those which drain less to 0.45. The drainage areas can be seen in ArcGIS by viewing the attribute table of the flow values. After completing the alterations to the geometry, scrutinize each of the cross sections in the cross section editor to see if flow will take the correct routes. If not, either create additional ineffective flow areas when the areas should not convey water or add obstructions to negate flow all together, see Figure 4.23.

Obstructions can be used in situations where tributaries flow into the main channel or other topographic misrepresentations. Cross section extracted from a one meter grid DEM often contain a large number of data points, HEC-RAS can only accept 500 points per section, so the filter cross section tool is applied to discard data points to a user set threshold.
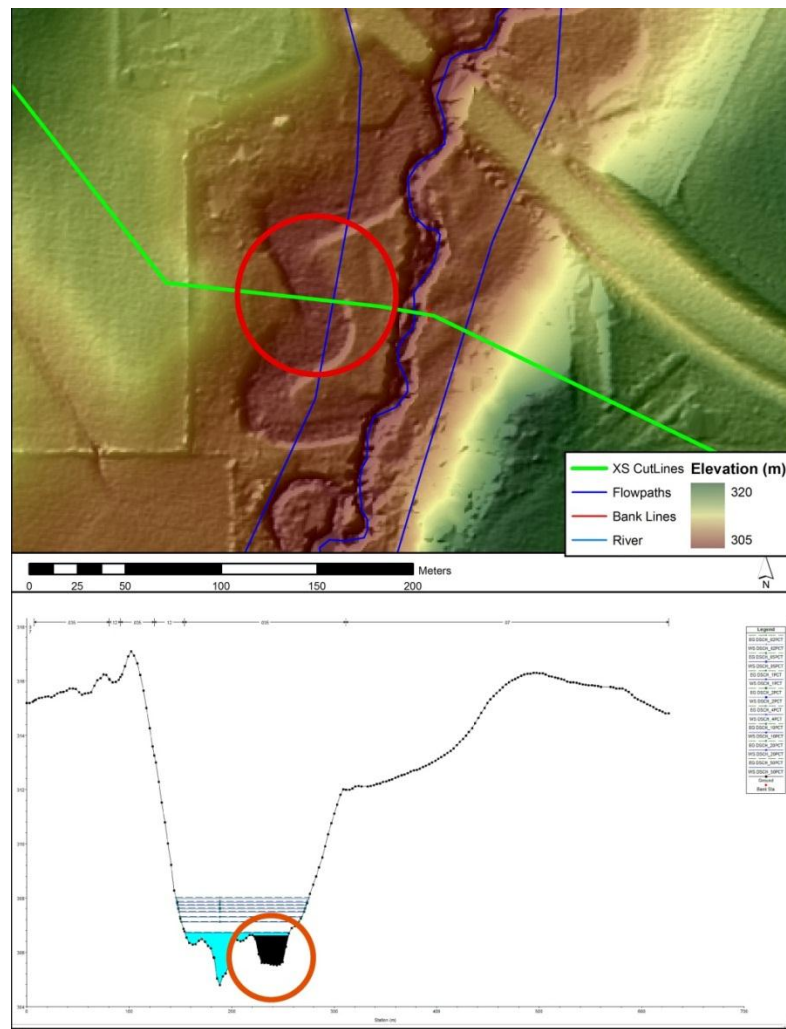

Figure 4.23: Blocked obstruction example

Note: Top, ArcGIS plan view of an example obstructed flow area. Bottom, HEC-RAS cross sectional view of the example cross section identifying obstructed area.

HEC-RAS requires boundary conditions to complete the standard step backwater analysis of the model. Flow information at each cross section, and a downstream normal depth are required for the analysis. The channel bed slope is assumed to be the slope of the energy grade line at the outlet in steady state conditions. To determine the bed slope at the outlet, a profile plot of the reach is viewed in HEC-RAS, see Figure 4.24. An elevation location approximately 1000 meters upstream from the outlet and the final cross section are used to calculate a slope see Table 4.10. A slope of 0.0022 is input into the HEC-RAS model for Bay Branch.
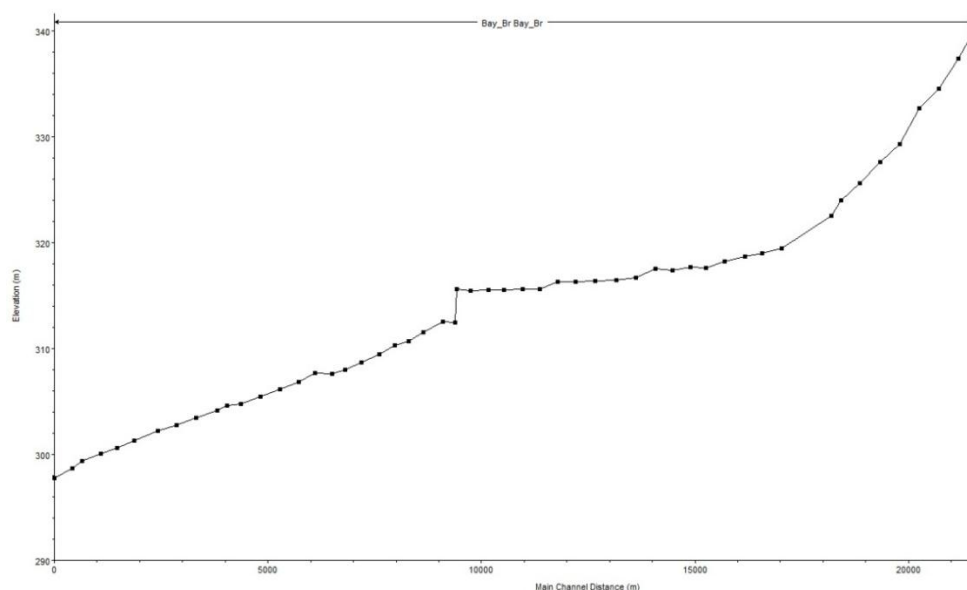

Figure 4.24: HEC-RAS Profile plot of Bay Branch for downstream slope determination

Table 4.10: Slope calculation for Bay Branch

Elevation (ft)	Station (ft)
300.10	1083.63
297.77	0.00
Slope	**0.0022**

Flow values at each cross section are a requirement for the HEC-RAS model. Through the ArcGIS tool "Spatial Join", the flow data is coupled with the corresponding cross section. Prior to stepping the flow values a smoothing function ensures that flow values increase with an increase in drainage area, see Figure 3.20. The flows are adjusted from an almost continuous flow curve into a discrete value function. Ten percent steps are created proceeding from the downstream end of the reach. The basic formulation is described by Equation 4.1 and alterations in the flow are seen in Figure 4.25 and in Table 4.11. Flow values are added into the HEC_RAS model for each cross section.

$$\text{IF } \left(\frac{|Q_1 - Q_2|}{Q_2}\right) \geq 0.1 \text{ Then } Q_1 \qquad (4.1)$$

$$\left(\frac{|Q_1 - Q_2|}{Q_2}\right) < 0.1 \text{ Then } Q_2$$

Where Q_1 is the calculated downstream flow and Q_2 is the upstream flow based on regression analysis.

Example 10: Determine the stepped flow values at station 12227 and 12699 for the 50% annual exceedance discharge. To determine the stepped flow values apply Equation 4.1 to the regional regression discharge values beginning from the furthest downstream locations and calculating in the upstream direction until the one square mile drainage threshold is reached. Both the 50% annual exceedance discharges and the stepped flow discharges are shown for a section of Bay Branch in Table 4.11.

Station 12227 $\quad \left(\frac{|Q_1 - Q_2|}{Q_2}\right) = \left(\frac{|202.00 - 220.01|}{220.01}\right) = 0.082 < 0.1 \text{ so } Q = 220.01$

Station 12699 $\quad \left(\frac{|Q_1 - Q_2|}{Q_2}\right) = \left(\frac{|195.64 - 220.01|}{220.01}\right) = 0.111 > 0.1 \text{ so } Q = 195.64$
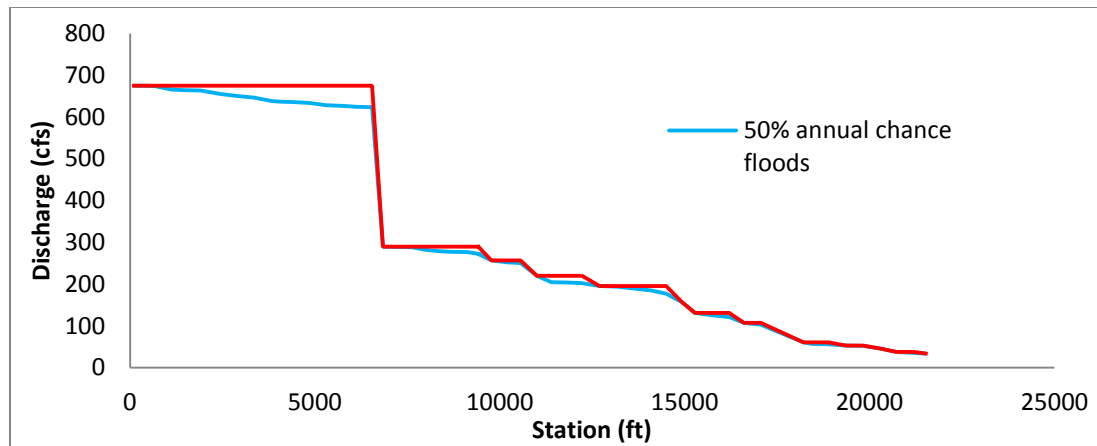
Figure 4.25: Bay Branch stepped flow function and continuous flow function

Table 4.11: Section of Bay Branch stepped flow calculation using Equation 4.1

Station (ft)	50 % Discharge (cfs)	Stepped Flow (cfs)
11,814	203.77	220.01
12,227	202.00	220.01
12,699	195.64	195.64
13,183	193.52	195.64
13,644	189.29	195.64
14,100	184.70	195.64
14,496	177.28	195.64
14,923	157.50	157.50
15,280	131.02	131.02
15,722	125.72	131.02
16,205	121.48	131.02
16,603	107.00	107.00
17,061	103.12	107.00
18,215	60.74	60.74
18,457	56.50	60.74
18,891	56.15	60.74
19,364	52.97	52.97
19,825	51.91	52.97
20,276	46.26	46.26
20,733	37.79	37.79
21,207	34.96	37.79
21,521	33.55	33.55

4.4.3 Section Summary

Hydrographic and hydrologic information are input into a one dimensional steady flow HEC-RAS model to produce water surface elevations at each cross section location. Four geometric inputs are required to describe the floodplain area including, stream centerlines, cross sections, bank identification, and overland flow paths. Each input is identified in ArcGIS and extracted for use in HEC-RAS by HEC-GeoRAS. Ineffective flow areas and obstructions can aide in describing the floodplain area more accurately. Overland flow resistance is identified by NLCD converted into Manning's roughness values and extracted at each cross section location by HEC-GeoRAS. Flow values are smoothed and stepped to removing unrealistic discontinuities in the streamwise direction and coupled with the cross section locations. A uniform boundary condition is identified at the downstream cross section and the model is run. The model outputs water surface elevations at each of the cross section locations for each of the eight annual exceedance discharges for use in floodplain delineation.

4.5 Floodplain Delineation

HEC-RAS outputs water surface elevations at each cross section within a reach. From these cross sections HEC-GeoRAS enables a user to create a water surface TIN, and compare the TIN to the DEM to determine flooded areas. The process outputs floodplains for each of the eight annual chance floods applied to each reach.

Water surfaces which were exported from HEC-RAS are imported back into ArcGIS via HEC-GeoRAS. The imported file is converted from a HEC-RAS type SDF file into an ArcGIS type XML file. The analysis is setup to use both the XML import file and the one meter DEM for use in delineating floodplain boundaries.

Three HEC-GeoRAS processes complete the floodplain delineation. The "Read RASGIS Export File" tool defines the mapping extents, imports, and aligns the water surfaces, see Figure 4.26. The "Water Surface Generation" tool creates a continuous

water surface TIN by interpolating between each water surface elevation, see Figure 4.26. The "Floodplain Delineation" tool is used to determine the difference between the water surface TIN and the one meter DEM. The final products are a shapefile containing the flooding extents and a water depth grid for each of the eight annual exceedance discharges Figure 4.27, and Figure 4.28.
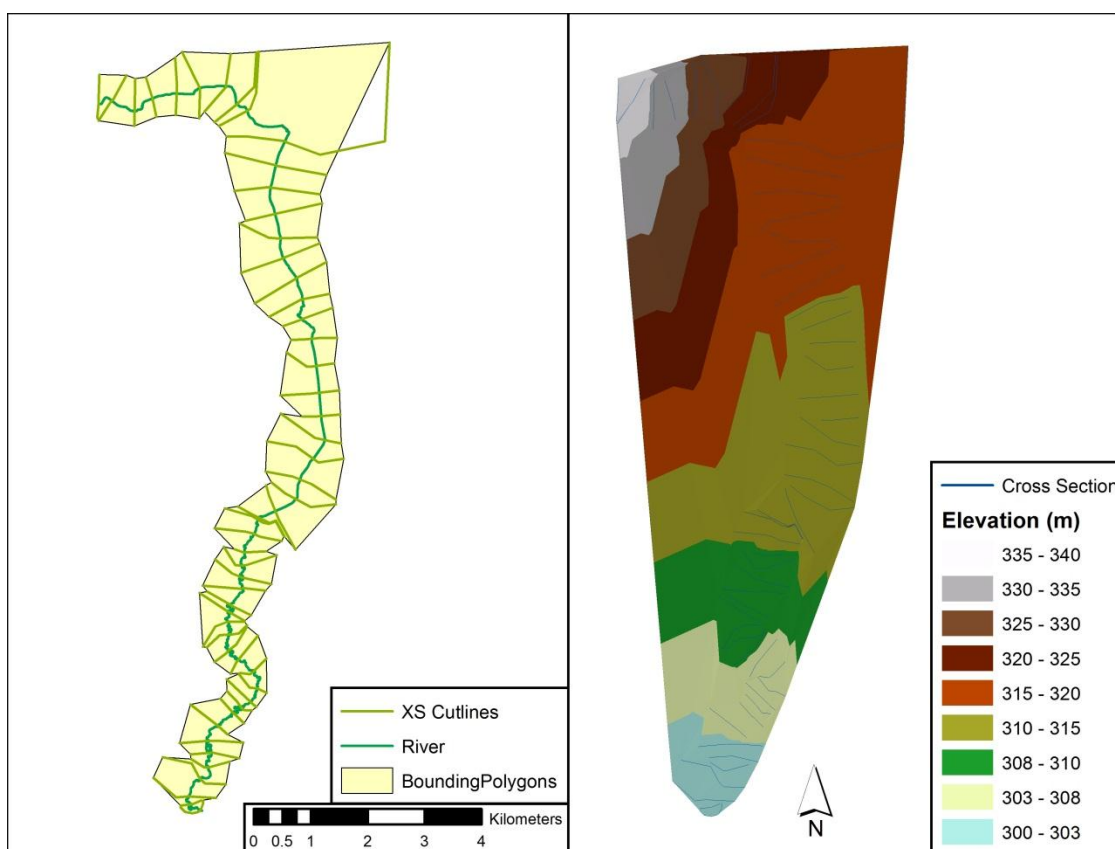

Figure 4.26: Bay Branch HEC-GeoRAS Read RASGIS Export File and Water Surface Generation

Note: Left, extents created from connecting cross section endpoints. Right, water surface TIN for a 50% annual exceedance discharge
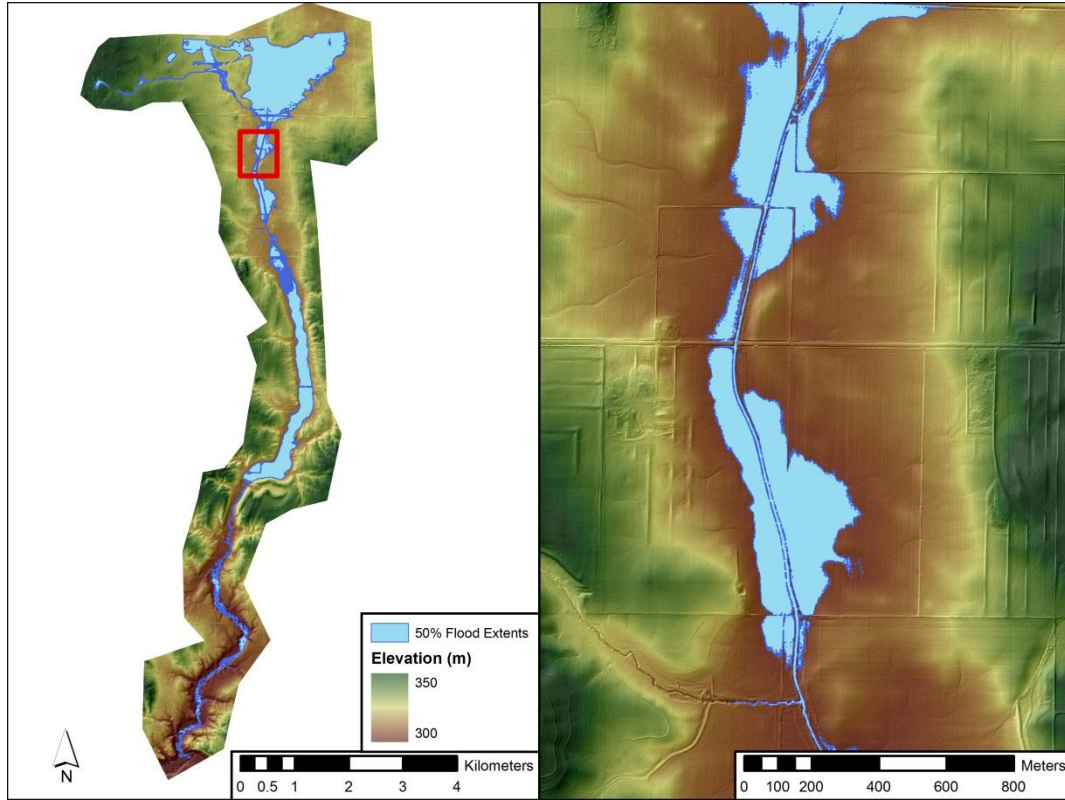
Figure 4.27: Bay Branch floodplain extents for a 50% annual exceedance discharge
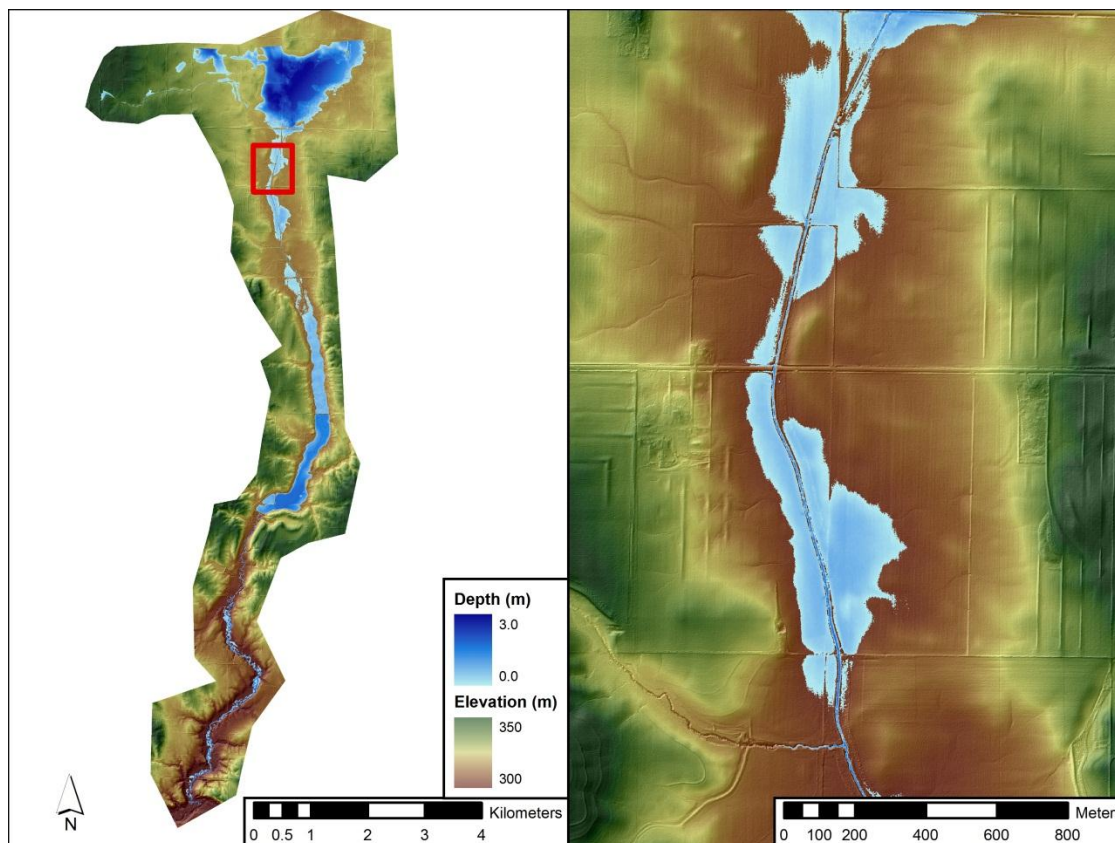
Figure 4.28: Bay Branch floodplain depth grid for a 1% annual exceedance discharge

Once the inundation maps are created, compare the flood inundation polygons to the DEM and hillshade rasters. Check if there are any major cutoffs in the inundation extents caused by short cross sections. If the flood polygons are cut off, the cross sections surrounding the area are extended and the model is rerun. A process similar to adding ponds upstream of a reach can also be used to delineate the truncated areas, the process is described in this section. Scrutinize the main channel to locate dry areas which should be flooded. Additional sections may be added to more accurately represent the terrain. Displaying the inundation maps over the landscape allows the user to understand the extent of a typical floodplain for use in future model building.

Occasionally the one square mile drainage threshold for hydraulic modeling starts at a reservoir, lake, or a pond. At these locations the downstream portion below the one

square mile drainage threshold is mapped by standard procedures. Cross sections are identified at furthest upstream end of the stream centerline, on the crest of the dam or berm holding the water in, and immediately after the crest or berm, at the location where the channel returns to normal, see Figure 4.29a. The calculated water surface elevation at the furthest upstream cross section is used to delineate the water boundaries for the rest of the upstream portions of the pond.

Begin by creating a "Pond_Boundary" polygon which will completely encompass the upstream lake, pond, or reservoir and the respective tributaries. The polygon should also contain the furthest upstream cross section, see Figure 4.29b. Add a field to the boundary polygon and input the water surface elevation at the final cross section as the first value. Using a Spatial Analyst tool called "Convert Features to Raster", convert the "Pond_Boundary" polygon into a raster with an output cell size of 1, with a height equal to the water surface elevation. Use the "Raster Calculator" and subtract the "Pond_Boundary" raster from the one meter DEM. Use the "Raster Calculator" again to set the values which are less than zero to null. Depths of less than zero are meaningless, as a value of zero indicates a location where the water surface meets the ground. The raster produced is equivalent to a water depth raster which the "Floodplain Delineation" tool creates, see Figure 4.29d. Using the Spatial analyst tool called "Reclassify" make the set null raster one single value. Using the Spatial Analyst tool called "Convert Raster to Features" the raster is converted back into a polygon shape file with the outline of the pond inundation. The polygon output is equivalent to the flood boundary extents produced by the "Floodplain Delineation" tool creates, see Figure 4.29c. The process is repeated for each of flow events with truncated inundation areas.

The output of the "Floodplain Delineation" tool is the flooding extents. In this process, small depressions or artifacts from the DEM creation hold water in areas outside of the main channel inundation. These extraneous polygons are removed from the inundation polygon at a threshold of 500 square meters. This same process is completed

for small islands inside of the flood extents at a 500 square meter threshold. This

produces a cleaner map identifying major flood inundation locations.
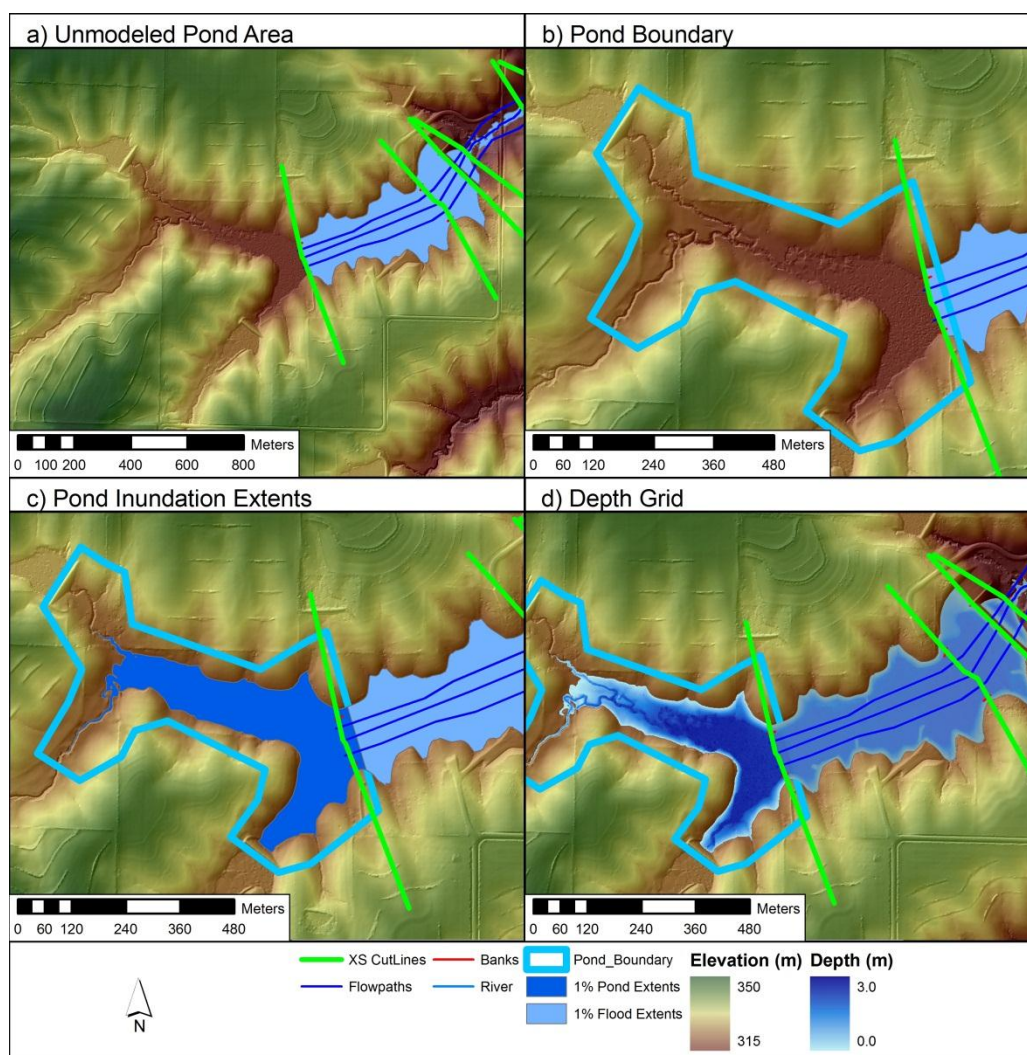

Figure 4.29: Ponds upstream of the one mile drain area threshold

Note: a) Pond area post downstream river model. b) Pond boundary delineation c) Pond
inundation extent d) Pond depth grid

4.5.1 Section Summary

Flood inundation areas and depths are identified from the water surface elevations. A water surface TIN is created from the water surface elevations at each cross section. The difference between the DEM and water surface TIN is used to determine the flooded areas and the associated depths. The bounding areas are smoothed and extraneous polygons and islands are removed. Finally, the inundations are merged together in preparation for DIRM mapping.

4.6 Chapter Summary

Chapter 4 Case Study applies the principles discussed in Chapter 3 FEMA Methodology to an Iowa watershed. Images, example calculations, and detailed strategies are employed to offer another description of the routines necessary to delineate flooding extents. Chapter 4 follows a parallel topic structure to the previous chapter discussing centerline digitization, regional regression hydrologic modeling, HEC-RAS based hydraulic modeling, and floodplain boundary delineation.

Identification of an accurate stream centerline requires a reliable representation of the ground surface found in the one meter DEM. Stream centerline digitization is split into small and large stream based on channel width. Small stream are located by inputting the DEM into a series of ArcGIS based raster manipulation tools. Large streams are located by first identifying the location where the water surface meets the land and averaging the distance across. Common trouble shooting techniques in identification of both the small and large streams are stated throughout the section including the use of alternate datasets.

Annual exceedance discharges are identified at each stream location through a gage weighted regional regression analysis, utilizing two USGS based regional regression analyses. Drainage areas in the streams are identified first through a series of raster manipulation tools. The flows are calculated based on the stream locations relation to a

stream gages. Examples, images, and detailed descriptions are utilized to better understand the hydrologic analysis.

Water surface elevations are identified at each stream location through a one dimensional HEC-RAS steady flow model. Geometries are identified for each reach within ArcGIS and extracted with HEC-GeoRAS. Overland flow resistance is computed with the NLCD. Flow values and overland roughness values are applied to each cross section location and the model is run producing water surface elevations.

Water surface elevations at each cross section are extrapolated in production of a water surface TIN. The ground surface DEM is subtracted from the TIN to identify the water depth grid and flood inundation area. Upstream ponded areas are manually modeled and abnormalities in the flooded areas are smooth and removed from the inundation. The final product of Chapter 4 Case Study is a flood boundary for a given reach.

CHAPTER 5: SUMMARY

This study identifies the procedures required to create flood boundaries based on FEMA mandated regulations for a study completed by approximate methods. The process uses semi-automated hydrologic and hydraulic modeling tools without the aid of bathymetric data or hydraulic structural data.

Mapping procedures begin with a comprehensive and consistent LiDAR dataset encompassing the entire state. The elevation dataset was collected through the IDNR and was identified as the highest point resolution of its time. Through the LiDAR data a one meter grid digital elevation model was created to be the foundation dataset for the Floodplain Mapping Program.

DEM raster manipulation and measurement tools contained in ArcGIS identify and estimate an ArHydro stream centerline. Estimated centerlines, DEM, hillshade, and secondary raster products enabled manual stream centerline digitization. Wider streams are identified more accurately through bank digitization and collapsing two lines into a centerline. USGS NHD centerline classifications were identified for each stream segment as the centerline produced in the floodplain mapping procedure is to replace the existing NHD information.

Streams are conditioned into the DEM, through raster manipulation tools the drainage area at each point on the stream centerline was determined. IDOT and IDNR standard practice hydrologic calculations were used in identifying stream flow. A gage weighted regional regression analysis combining Lara (1987) and Eash (2001) analyses are applied to Iowa streams to produce flows associated with the 50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent annual exceedance discharges.

Hydraulic modeling procedures utilize Army Corps of Engineers programs HEC-RAS and HEC-Geo RAS to produce a one dimensional steady flow analysis. Model geometries are identified in ArcGIS, and extracted by HEC-GeoRAS. HEC-RAS utilized

the HEC-GeoRAS geometries, flow values at each cross section, and an assumed downstream normal depth in a steady flow model. Which Produces water surface elevations at each of the geometric cross sections for each of the eight annual exceedance discharges.

HEC-GeoRAS imports the HEC-RAS water surface elevations into an ArcGIS environment. A water surface TIN is produced from the water surface elevations. The DEM is subtracted from the TIN to identify the flooding extents. Flood inundation boundaries are checked for quality, and extraneous polygons are removed. Hydrologic and hydraulic modeling information is delivered to FEMA for quality assurance. The data is produced to IDNR for use in DFIRM production.

GIS based tools alter DEMs enabling hydrologic and hydraulic modeling procedures to create FEMA acceptable floodplain maps. The state of Iowa is a unique case, as one partner is completing all of the modeling and mapping procedures from start to finish. The result is a consistent and reliable set of floodplain maps and secondary datasets for the entire state.

To date IFC Floodplain Mapping program has completed modeling and mapping procedures for 14 of the 55 major watersheds in Iowa. This Translates to approximately 9,500 stream miles of completed approximate study analysis.

Following the 2008 floods the U.S. HUD provided a $15 million grant to the state of Iowa for floodplain mapping. The Iowa Flood Center was contracted to perform a pilot study. From the pilot project the IDNR surmised that the IFC would be best suited to complete the mapping project for the state and appropriated $10 million in funding. Following FEMA mandated specifications for an approximate study the Iowa Flood Center will complete statewide maps able to be adopted by FEMA in four years.

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