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A GIS-Based Data Model and Tools for Analysis and Visualization of Levee Breaching Using the GSSHA Model

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of Levee Breaching Using the GSSHA Model

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ABSTRACT

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of Levee Breaching Using the GSSHA Model

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Levee breaching is the most frequent and dangerous form of levee failure. A levee breach occurs when floodwater breaks through part of the levee creating an opening for water to flood the protected area. According to National Committee on Levee Safety (NCLS), a reasonable upper limit for damage resulting from levee breaching is around $10 billion per year during 1998 and 2007. This number excludes hurricanes Katrina and Rita in 2005 which resulted in economic damages estimated to be more than $200 billion dollar and a loss of more than 1800 lives.

In response to these catastrophic failures, the U.S. Army Corps of Engineers (USACE) started to develop the National Levee Database (NLD) on May 2006. The NLD has a critical role in evaluating the safety of the national levee system. It contains information regarding the attributes of the national levee system.

The Levee Analyst Data Model was developed by Dr Norm Jones, Jeff Handy and Thomas Griffiths to supplement the NLD. Levee Analyst is a data model and suite of tools for managing levee information in ArcGIS and exporting the information to Google Earth for enhanced visualization. The current Levee Analyst has a concise and expandable structure for managing, archiving and analyzing large amounts of levee seepage and slope stability data. (Thomas 2009).

The new set of tools developed in this research extends the ability of the Levee Analyst Data Model to analyze and mange levee breach simulations and store them in the NLD geodatabase. The capabilities and compatibilities with the NLD of the new geoprocessing tools are demonstrated in the case study. The feasibility of using GSSHA model to simulate flooding is also demonstrated in this research.

Keywords: GSSHA, levee breach, flood, inundation, National Levee Database, NLD, levee analyst, WMS, Google Earth.

ACKNOWLEDGEMENTS

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1 INTRODUCTION

Levees are earth embankments constructed along rivers or coastlines to protect the adjacent area from flooding. Figure 1-1 shows a typical cross section of a levee. During the early days of levee building in the United States, construction was irregular and simplistic. The construction typically did not take advantage of any engineering principles of safe and sustainable design. The great floods on the Mississippi and Ohio Rivers, which led to significant loss of life, resulted in national attention on Levee safety. The Flood Control Acts of 1928 and 1936 were established in response. Thousands of miles of levees were constructed during this time to provide protection against events ranging from the standard flood to the largest reasonable flood. Many of the constructed levees can protect against 500-year floods and in some cases even the 1000-year flood (Safety, 2009).

The National Flood Insurance Program (NFIP) was established by the National Flood Insurance Act of 1968. NFIP requires regulation of floodplain activity and mandatory purchase of flood insurance for those who live behind levees that cannot withstand the 100-year flood. This became the new target design level for many areas because it would provide relief for the resident from the mandatory flood insurance. Not many people are aware that a 100-year flood corresponds to a 26% probability of flooding during a 30-year span. This is a very high

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probability. For comparison, the chance of a 500-year flood during a 30-year span is approximately 5.8% (Safety, 2009).

Hurricanes Katrina and Rita caused more than $200 billion dollars in damage and killed more than 1800 people. This catastrophe was the wakeup call for National Levee Safety Program. One of the recommendations from The National Committee on Levee Safety to Congress was to extend the National Levee Database so that "the critical safety issue, true costs of good levee stewardship, and the state of individual levees can inform priorities and provide data for needed risk-informed assessments and decision-making" (Safety, 2009).
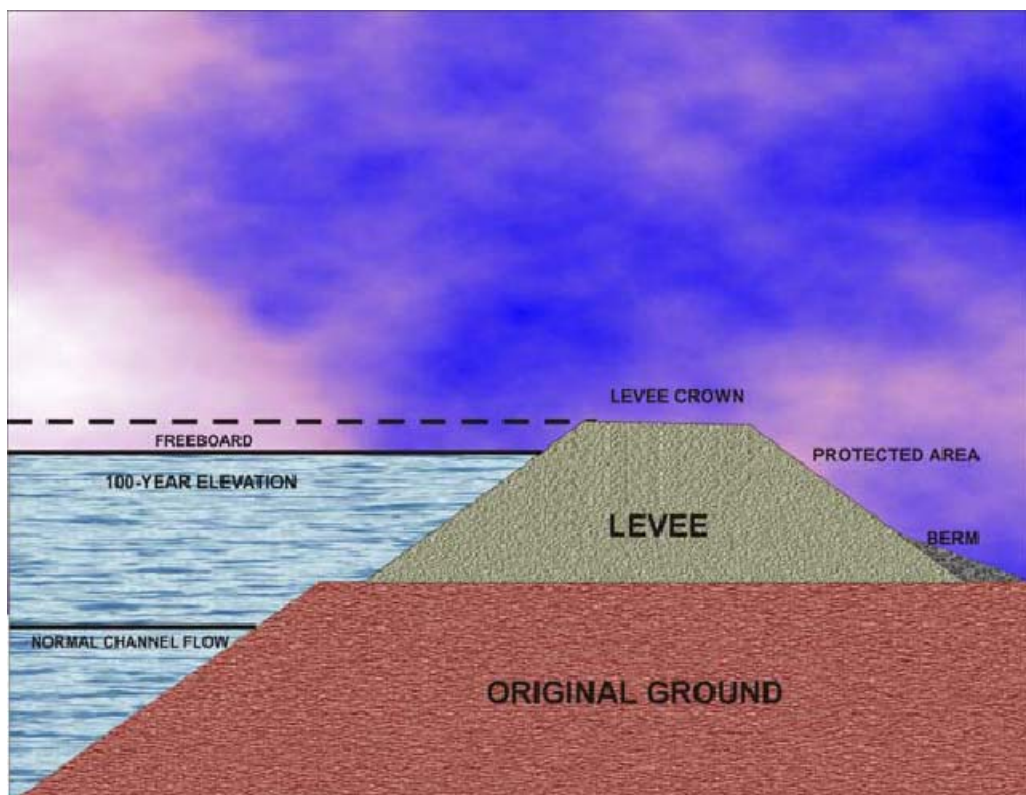
Figure 1-1: Typical cross section of a Levee (Miller, 2006).

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1.1   National Levee Database

Many levees have been built across the country. The Department of Homeland Security's Federal Emergency Management Agency (FEMA) estimates that levees are built in approximately 22 percent of 3147 counties in the United States. The National Levee Database was established as a central location for storing levee information on May 2006 by the United States Army Corps of Engineers. Understanding the impact of flooding has a critical role in emergency evacuation planning because of time constraints. Total evacuation time in rural and urban areas is 135 and 80 minutes, respectively (Cheng, Qian, Zhang, Wang, & Sheng, 2010). Flood analysis provides an estimation of the flood arrival time and flood path on the floodplain, shown in Figures 6-12 and 6-13. This information can assist the people living in the flooded area to evacuate to a safe area.

1.2   Levee Analyst

Although the NLD contains features and tables storing most types of data typically associated with levees, it does not have a structure for storing information on seepage, slope analysis, and flood analysis information. The Levee Analyst is a Geographic Information System (GIS) data model and set of geoprocessing tools. The Levee Analysis Data Model (LADM) provides a structure for storing levee centerlines, levee cross section lines, and model data associated with seepage and slope stability analyses. The data model schema includes feature classes, relationship classes, coded value domains, and tables. This schema established a standard methodology for storing large amounts of levee simulation data and created a standard set of field names necessary for using the geoprocessing tools in the Levee Analyst. The data

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model was created in a manner to allow future expansion (Jones, Handy, & Wallace, 2008). The LADM is an extension of and is fully compatible with the NLD.

The first iteration of Levee Analyst involved developing a suite of tools for archiving and managing seepage (SEEP2D) and slope stability analyses (UTEXAS) in a spatial database. In the second iteration, support was added for SEEP/W and SLOPE/W simulations and a set of tools was developed for exporting the Levee Analyst data to Google Earth. This research represents a third iteration of tools and our main objective was to prototype a system for doing automated levee breach analysis using the GSSHA model.

1.3   GSSHA

GSSHA (Gridded Surface Subsurface Hydrologic Analysis) is a physically-based, distributed-parameter, structured grid, hydrologic model that simulates 2D overland flow, 1D stream flow, 1D infiltration, 2D groundwater, and full coupling between groundwater and surface water (Downer, 2010). The GSSHA model is derived from the CASC2D model with significant reformulation and enhancement. CASC2D is a two-dimensional, physically-based model. This model only works when Hortonian flow is dominant. This assumption is not appropriate for most of the cases because it neglects the contribution from the infiltration to the stream system, shown in Figure 1-2.

On the other hand, GSSHA is capable of calculating flows, stream depths, and soil moistures in variety of hydrologic regimes and conditions including non-Hortonian watersheds. Compared with more sophisticated implicit finite difference and finite element schemes, the algorithm used in *GSSHA* is simple. The friction slope between one grid cell and its neighbors is calculated as the difference in water-surface elevations divided by the grid size. Compared with

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the kinematic wave approach, this diffusive wave approach allows *GSSHA* to route water through pits or depressions, and regions of adverse slope. The Manning formula is used to relate flow depth to discharge. Use of the Manning formula implies that the flow is both turbulent and that the roughness is not dependent on flow depth. Neither of these assumptions may be valid on the overland flow plane. While being simple, the method is powerful because it allows calculations to proceed when only portions of the stream network or watershed are flowing (Ogden, 2006).
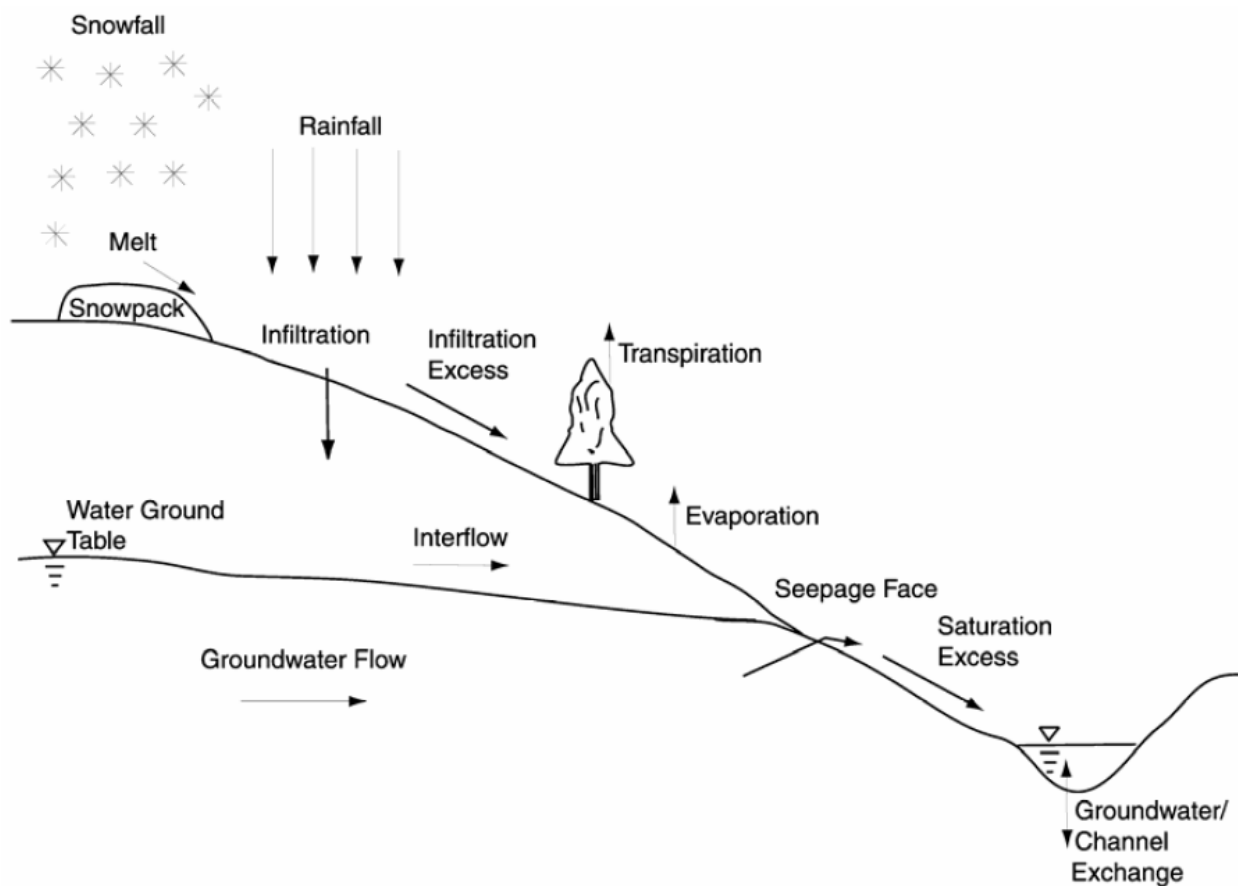
Figure 1-2: Infiltration contributes to the stream system (Ogden, 2006).

The input hydrograph can be integrated into the GSSHA model in two ways. The first way is to assign the input hydrograph at an appropriate grid cell. The second way is to assign the input hydrograph at a stream node. These two ways lead to two different approaches to simulate levee breach in GSSHA model. The first approach is to assign the variable stage (water surface elevation) at grid cells where the levee breach occurs. The second approach is to assign the input hydrograph upstream and lower the grid cells associated with the levee breach. The second approach is not only a better way but also a more efficient way to simulate flooding for several reasons. First, the estimated hydrograph upstream can be estimated using WMS from dimensionless hydrograph derived from the National Streamflow Statistics (NSS) program, as shown in Figure 1-3. The NSS program replacing the National Flood Frequency (NFF) program is a computer program used to estimate the stream flow statistics for different flood frequencies for sites in urbanized area (USGS).

Second, instead of having to manually calculate the hydrodynamics to estimate the appropriate hydrograph at each grid cell as in the first method, the GSSHA model will calculate the hydrodynamics of the flood at the levee breach in the second method. However, the user needs to turn on the overbank flow option because GSSHA model doesn't allow water to leave streams unless the overbank option is used.

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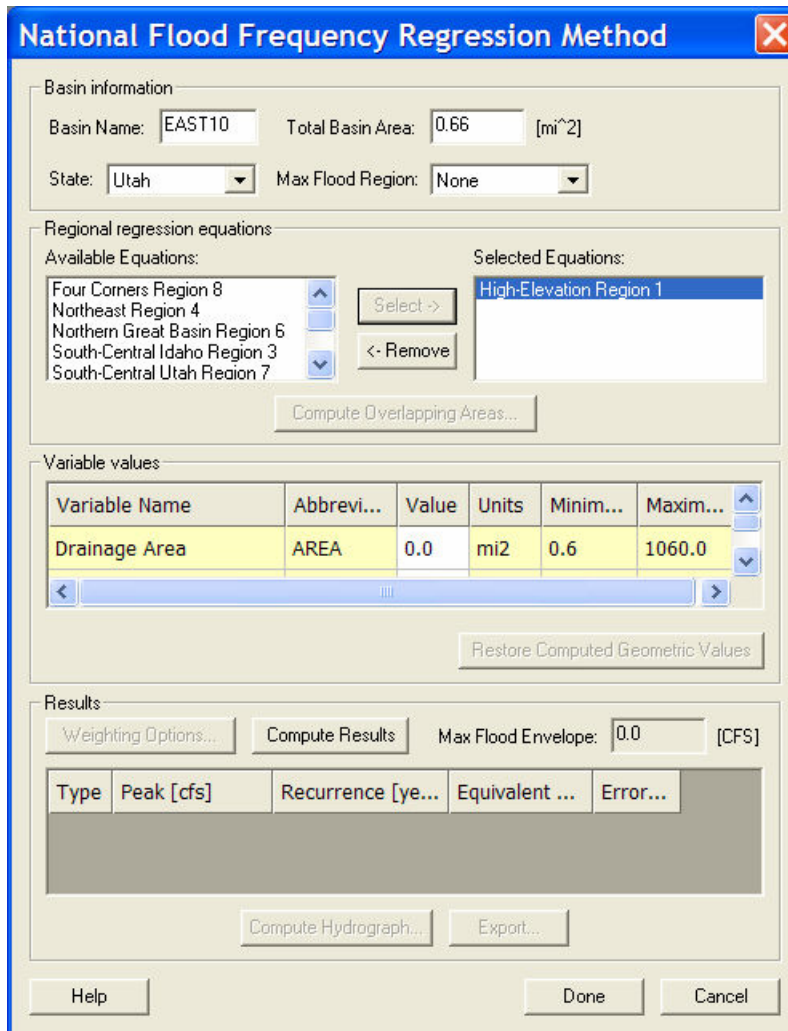
Figure 1-3: NSS program interface in WMS (WMSwikipage, 2007).

1.3.1 Overbank Flow in GSSHA

The overbank flow option in GSSHA allows the water to flow from the stream to the overland region if the water level in the stream is greater than the flood plain elevation and vice versa. The top of the bank, shown in Figure 1-4, is defined by the thalweg elevation of the stream and the depth of the channel. If the top of the bank is higher than the water elevation at the land

surface/cell elevation, the flow is computed as weir flow. Otherwise, the flow is computed as overland flow.

The reliability of the overbank flow option was tested as part of this research. The procedure and results are described in Chapter 4 of this research.
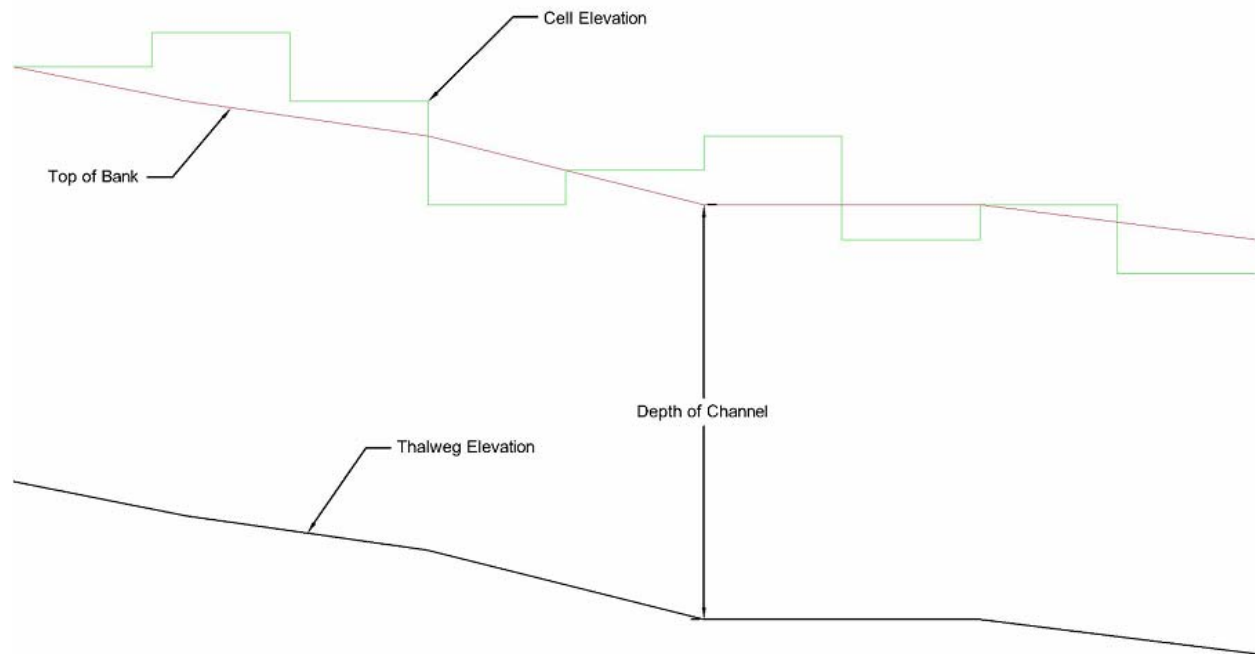
Figure 1-4: Top of bank defined in GSSHA.

1.4   Watershed Modeling System

The watershed modeling system (WMS) developed by Aquaveo is a comprehensive graphical environment for all phases of watershed hydrology and hydraulics. WMS is fully capable of dealing with all types of GIS data for hydrologic and hydraulic modeling. WMS provides a powerful set of tools which allow the users to import, create, and manipulate GIS

vector and raster data. Many hydrologic parameters such as area, slope, mean elevation, maximum flow distance and many more can be auto-computed using WMS. WMS also provides the ability to export the working model into Google Earth to enhance the visualization experience. Moreover, using WMS is the most efficient way to build a GSSHA model. GSSHA developers have strongly recommended users to use WMS for pre and post processing (GSSHA Wiki, 2010).

1.5   Research Objectives

The objective of this research is to develop a data model and a set of tools that allow users to generate and archive flood simulation in a GIS-based environment to the NLD geodatabase. The flood simulation is generated using the Gridded Surface/Subsurface Hydrologic Analysis (GSSHA) numeric model and includes custom scripts involving ArcGIS and WMS. Information related to the simulation is archived to the NLD geodatabase. This information is helpful for risk management. They are breach depth, breach location, inundation area, maximum depth, hydrograph upstream, and file path to the flood animation. The flood animation can be viewed in Google Earth to see how fast the flood is moving and what area is inundated.

2   LITERATURE REVIEW

Besides GSSHA, many more existing numerical models are available for simulating flood events. This section will describe some of the most popular model and review how this research differs from previous efforts.

2.1   HAZUS – MH Flood Model

HAZUS-MH is a GIS-based software developed by the Federal Emergency Management Agency (FEMA). HAZUS is used to estimate the potential losses from hurricane winds, earthquake and floods. The Flood Model in HAZUS is a popular model for comprehensive loss estimation due to flood. The Flood model provides three levels of analysis depending on the skill of the user. Level one requires minimum user interaction. Level two requires more data for more detailed analyses using the Flood Information Tool. Level three is for expert users.

2.1.1   Flood Model – Level 1

With limited information on the area, the Hazus flood model uses a rating curve to estimate the area of inundation. For example, the water stage for a triangular cross section is estimated using the following equation (FEMA, 2010):

$$d_i = \sqrt[5]{\frac{4s_L^2 s_R^2}{g(s_L + s_R)^2} Q_i^{(\frac{2}{5})}} \tag{2-1}$$

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where: d_i = the critical depth

S_L = approximate side slope on the left side of the reference point based on 100-year flood plain, shown in Figure 2-1

S_R = approximate side slope on the right side of the reference point based on 100-year flood plain, shown in Figure 2-1

Q_i = discharge
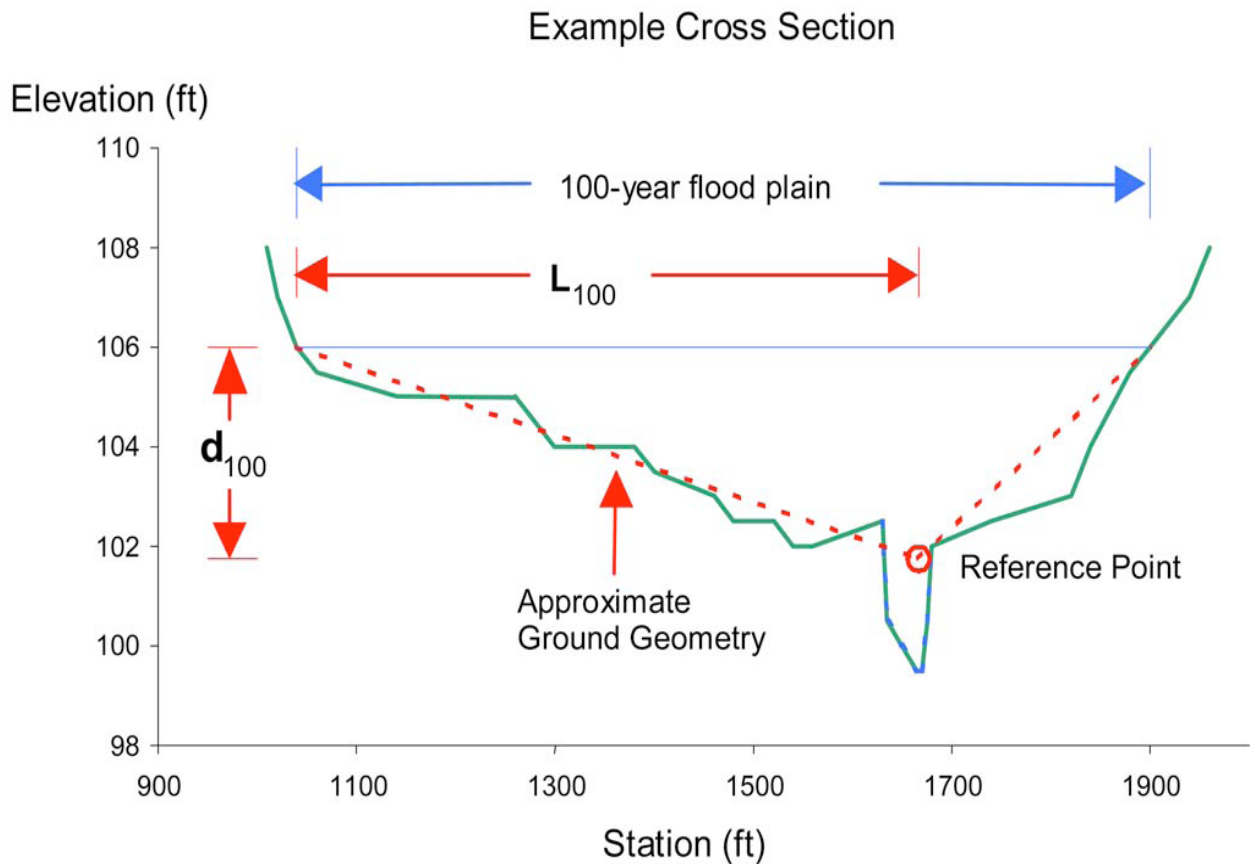
Figure 2-1: Floodplain geometry using to estimate the rating curve (FEMA, 2010).

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2.1.2 Flood Model – Level 2

The flood model level 2 uses the Flood Information Tool (FIT) to estimate the flood depth. The FIT requires more flood hazard data. The FIT contains algorithms that interpolate flood elevations and perform flood analysis by calculating grids of flood depth on the study area (FEMA, 2010).

2.1.3 Flood Model – Level 3

The flood model level 3 is integrated with the Advanced Engineering Building Module and Portable Water System Analysis Model (FEMA, 2010). The Advanced Engineering Building Module is an extension of the more general method of loss estimation methodology used in HAZUS for specific building damage. The Portable Water System Analysis Model module is used to analyze the damage to the water networks. Level 3 requires a high degree of expertise.

2.1.4 Levees

The Flood model has an option to integrate a levee into the area protected by the levee. The flood depths are zero if the levee can withstand the flood recurrence interval. Otherwise, the model will compute the flood depths as if there is no levee (Scawthorn, et al., 2006). This approach isn't designed to handle flooding due to levee breach for two reasons. First, flooding due to levee breach occurs mostly when failure happens to part of the levee. When the levee can't withstand the flood in this approach, the model will ignore the existence of the whole levee when calculating the flood depths. Second, by ignoring the existence of the levee, the model isn't capable of computing the hydrodynamics at the breach.

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2.2 Hydrologic Engineering Center - River Analysis System

The Hydrologic Engineering Center's River Analysis System (HEC-RAS) is developed by the U.S. Army Corps of Engineers. HEC-RAS can simulate one-dimensional unsteady flow including levee breaching analysis. HEC-RAS is compatible with GIS using HEC-GeoRAS. HEC-GeoRAS is a set of geoprocessing tools that assist the interaction between HEC-RAS and ArcGIS. HEC-GeoRAS allows the user to import the geometric data from GIS into HEC-RAS and to export the results such as the water surface profile data and velocity data from HEC-RAS into ArcGIS.

One-dimensional unsteady flow models such as HEC-RAS have some advantages compared to two-dimensional models such as faster computation time and less data preparation. However, they are not practical for use in many cases. First, one-dimensional unsteady flow models may face numerical difficulties when there are sudden changes in the cross section area of the channel. Second, one-dimensional models assume that the calculated water surface elevation for the channel would be extended to when the overland elevation is greater than or equal to the water elevation. This assumption can exaggerate the amount of flooding due to overtopping, as shown in Figure 2-2. Third, the inundated area computed by a one-dimensional model needs to be converted into 2D maps by interpolating between the one-dimensional results and the DEM data (Altinakar, Matheu, & McGrath, NEW GENERATION MODELING AND DECISION SUPPORT TOOLS, 2009). Interpolating the results with the DEM data does not account for the land use or soil type of the protected area. This approach has a negative effect not only on estimating the inundation area but also the arrival time of the flood.

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Flow in the channel ─── ────── exaggerated water level
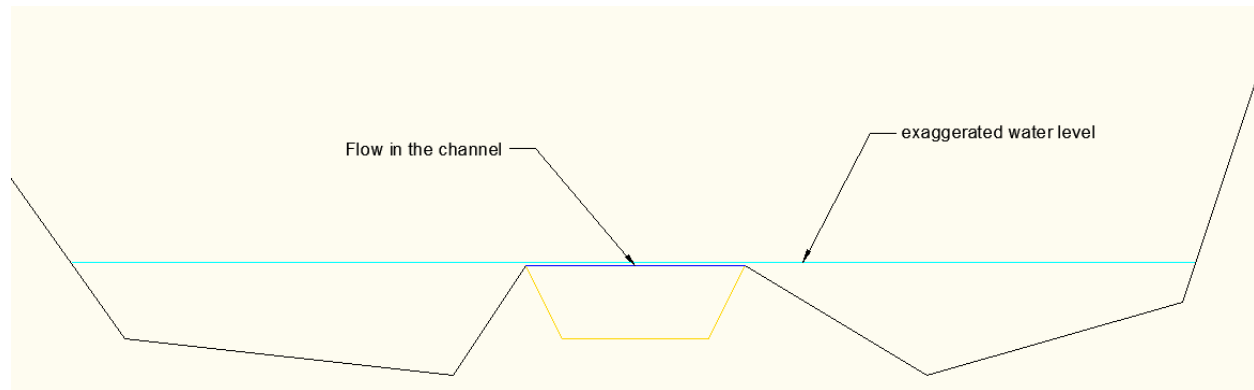
Figure 2-2: Exaggerated water level in one-dimensional model due to overtopping.

2.3   MIKE FLOOD

Developed by DHI in Denmark, MIKE FLOOD is a commercial flood model simulating

two-dimensional overland flow (MIKE 21) coupling with one-dimensional stream flow (MIKE

11). MIKE FLOOD has a sub-grid feature that allows the user to use smaller grid size to

represent the channels, culvert, etc. MIKE FLOOD also supports a flexible mesh system.

However, momentum is not allowed with lateral flows in a one-dimensional model

(Environment, 2007). Without the momentum, the flood model can't fully simulate the

hydrodynamics of the flood at the breach because the impact of flood velocities and mass are

completely ignored.

2.4   CCHE FLOOD

Developed by the University of Mississippi's National Center for Computational

Hydroscience and Engineering (NCCHE), CCHE FLOOD is a two-dimensional numerical model

solving full dynamic unsteady flow equations. CHHE FLOOD also use coupled one-dimensional

and two-dimensional modeling to simulate the interaction between river and the overland.

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Similarly MIKE FLOOD, only mass exchange is calculated when the model calculates the interaction between river and the overland. There is no momentum exchange involved (Altinakar, Matheu, & McGrath, 2009).

2.5   FLO-2D

Developed by FLO-2D Software, Inc., FLO-2D is a two-dimensional flood routing model. FLO-2D uses square grid-based system and full dynamic wave equations to simulate the progression of the flood in eight directions. FLO-2D breach mechanism is capable of simulate levee breach caused by overtopping or piping/seepage (O'Brien, 2010). The breach mechanism allows users to specify breach failure conditions. The breach starts to initiate when these conditions are met. For example, users can specify the elevation of prescribed failure. If the water elevation exceeds the specified elevation, the levee will start to breach. Integrating this mechanism into the automated levee breach system is beyond the scope of this research.

2.6   TUFLOW

Originally developed by WBM Ply Ltd and The University of Queensland, TUFLOW is one-dimensional and two-dimensional tidal flow simulation software solving full dynamic equations of unsteady flow. TUFLOW is widely used in the United Kingdom and Australia. TUFLOW allows the user to generate the stream using a two-dimensional approach. Thus, the momentum between the stream and the overland is accounted for in the model. However, this approach requires having sufficient cell resolution to represent the stream. Figure 2-3 shows an example of a narrow stream is poorly represented in the two-dimensional model (WBM, 2007).

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TUFLOW is probably the most suitable model for simulate levee breach because the momentum is conserved. However, this approach requires a lot of stream data which is very hard to obtain for this research. The simpler approach, described in chapter 1.3, is used.
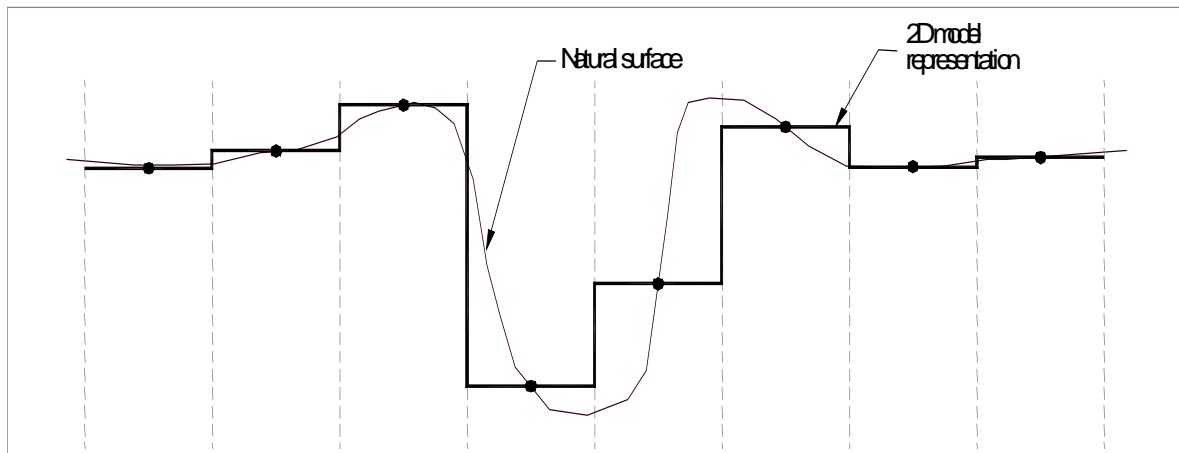
Figure 2-3: Poor representation of a narrow stream in 2D model (WBM, 2007).

2.7   Summary

A one-dimensional model can estimate very quickly the impact of flooding caused by levee breach to the associated area. However, it can't provide the accuracy as in two-dimensional model such as MIKE FLOOD, CCHE, FLO-2D and TUFLOW. The biggest disadvantage of two-dimensional models is that they are time consuming. This disadvantage will be much less significant with time because of the increasing in computer speed. GSSHA is programmed in C++ for Windows and Linux will support parallel computing in the near future. The parallel computing allows the user to run a single flood simulation using different machines or cores simultaneously. This approach in GSSHA can significantly decrease the running time of the model.

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None of the flood model above has been integrated with a GIS such that a user could quickly modify boundary conditions, run and archive a flood simulation for different levee breach scenarios into a geodatabase. The purpose of this research is to develop such a system.

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3   LEVEE BREACH ANALYSIS METHODOLOGY

The purpose of this section is to describe the overall approach of prototyping a system for doing automated levee breach analysis. Figure 3-1 shows the flow chart of the levee breach analysis system in GIS environment. The gray rectangles represent the data provided in the NLD. The olive green ovals represent the required input from the user. The yellow rounded rectangles represent the geoprocessing tool in Levee Analyst toolbox. Finally, the blue rectangles represent the results after running the geoprocessing tool. The flow chart can be divided into three main parts. The first part is data preparation. The second part is data processing. The last part is data post-processing.

3.1   Data Preparation

The NLD contains many protected area polygons organized in the *Protected_Area* feature class. Each of these protected areas has one or many corresponding *Levee_Centerline* features. The *Levee_Centerline* feature has information related to the levee such as height, length, etc.

The user needs to prepare a GSSHA model for each protected area of interest and at one or more possible breach location. First, the GSSHA model is created using WMS. The details on how to create this model can be found in Chapter 6. When the model is done, the user uses the *Archive GSSHA Simulation* geoprocessing tool to archive this model into the NLD. Second, the

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breach location can be quickly created using the *Create Breach* geoprocessing tool. The *Create Breach* geoprocessing tool is described more in Chapter 5.

3.2   Data Processing

Each flood scenarios has its own characteristics such as magnitude and breach details. The magnitude of the flood is represented by the upstream hydrograph specified by the user. The breach details are represented by the breach location created in the previous step, and the breach depth, specified by the user. The user also has options to control simulation time, time step, etc.

The objective of the *Simulate Flood and Archive* geoprocessing tool is to assist the user in quickly performing many flood scenarios and archiving these results into the NLD for further assessment. The results contain helpful information such as inundation area or maximum depth.

3.3   Data Post-Processing

The inundation area only tells how large the flood has spread. It does not tell the exact location. The purpose of this step is to translate the raw data, such as number of flooded grid cells, into images or animation which can be visualized using Google Earth. The last two geoprocessing tools, *Export Simulation to KML* and *Export Breach Location to KML,* are designed to provide this capability.

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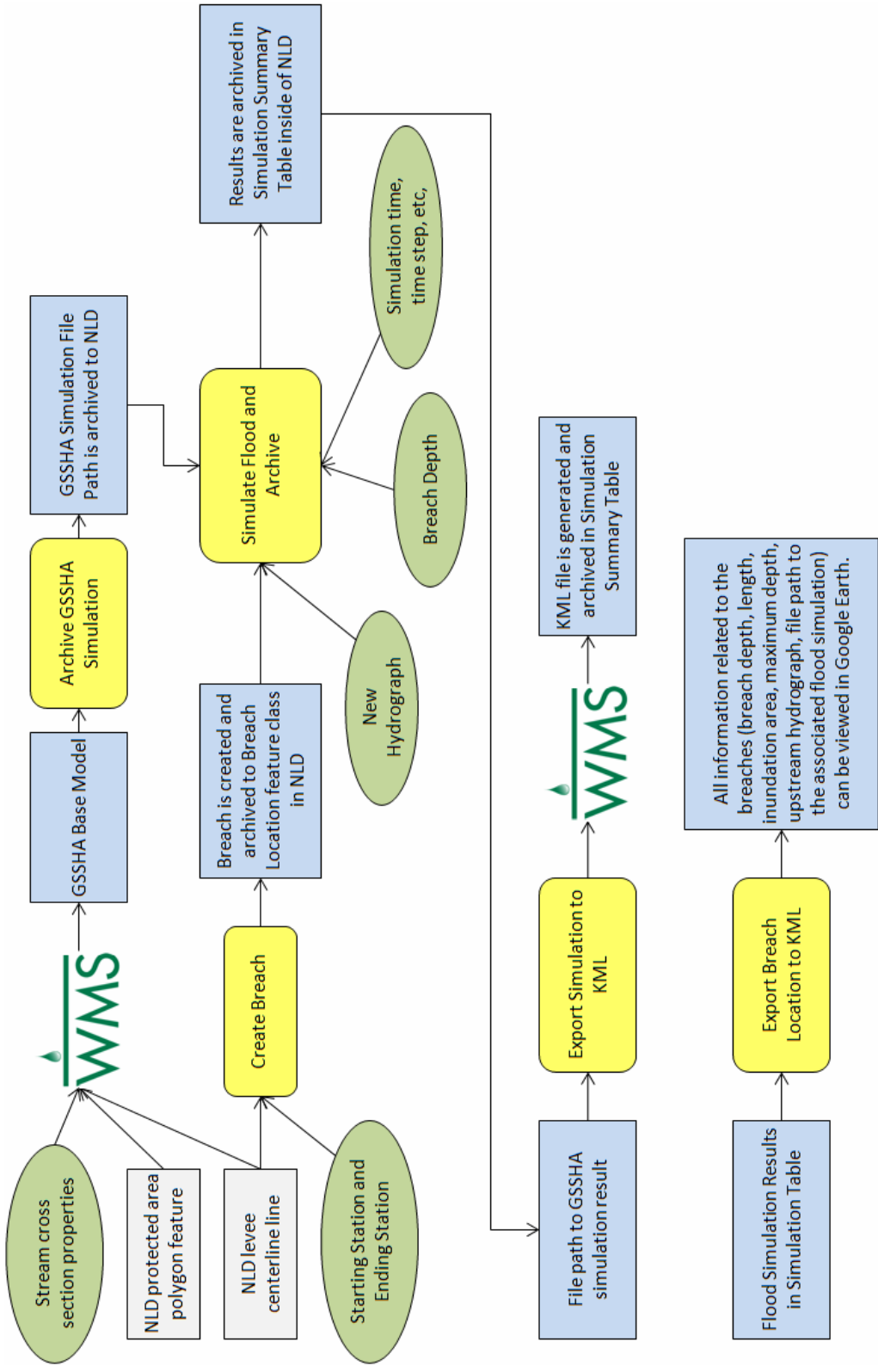
Figure 3-1: Flow chart of the levee breach analysis system.

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4 OVERBANK FLOW OPTION IN GSSHA

The objective of this research is to use GSSHA and Levee Analyst to simulate flooding resulting from a levee breach. GSSHA is used to simulate the flooding of the protected zone and it requires a boundary condition to represent the levee breach. One approach is to use a constant head boundary condition to represent the flood. However, the problem with this method is that it can generate an unrealistic amount of water because the head at the grid cells, where the levee is breached, is set to a constant value. This method only works if there is an infinite supply to the breach. In reality, the flow will stop when the head reaches an elevation that no flow occurs. Figure 4-1 shows one of the simulations we did in St Louis using the constant head boundary condition. The unrealistic inundation area is caused by the infinite water supply from the constant head boundary condition.

Another approach for the boundary condition is to supply a hydrograph upstream and use the overbank flow option in GSSHA to simulate water spilling onto the flooded area. In order to do this, we need to understand the best way to conceptualize this within GSSHA and we need to test the method to ensure that is reasonably simulates both the filling and draining of the protected area. Therefore, we have done a sensitivity analysis with respect to the node spacing on the stream and with respect to the number of cells lowered to represent the levee breach.

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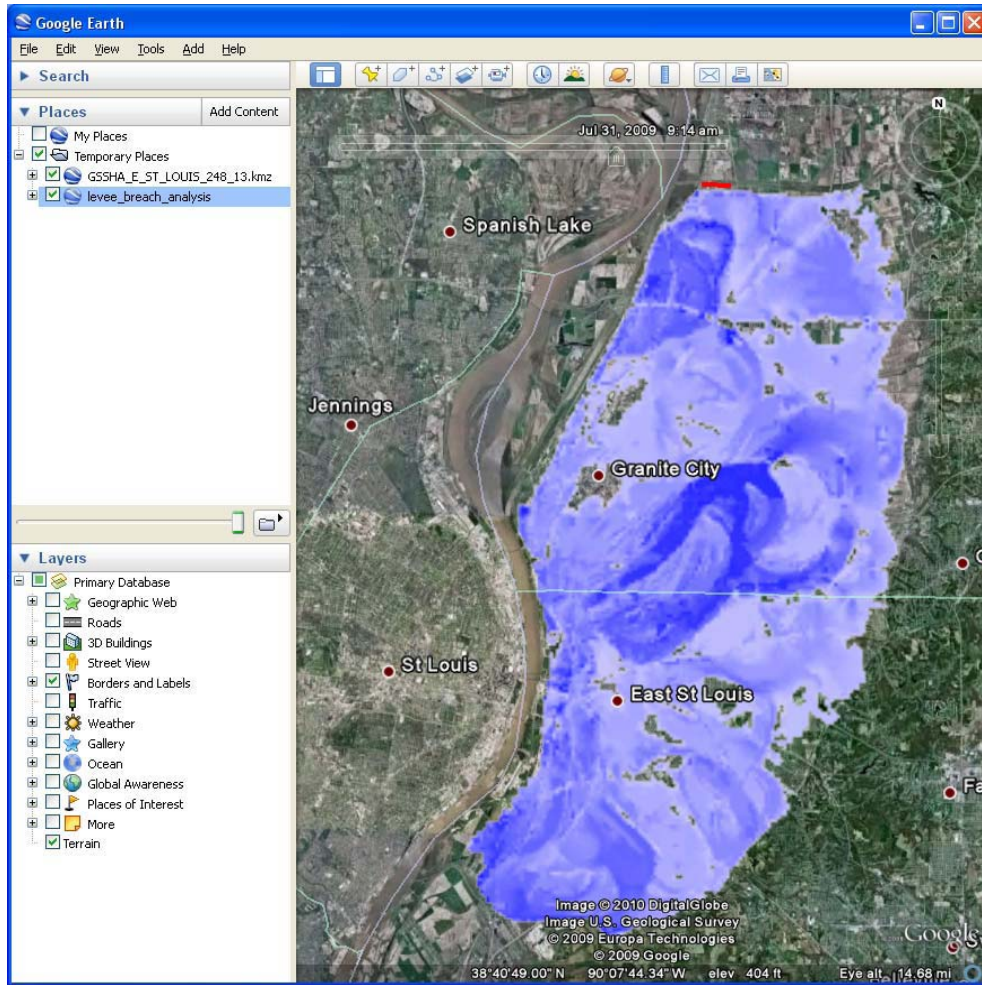
Figure 4-1: Flood simulation using a constant head boundary condition at the breach.

4.1   Description of the Sample Model

To test the boundary condition, we created a 10x10 GSSHA 2D grid sloping from West

to East. One stream channel was created on the West side running from North to South. The

roughness of 0.01 was assigned uniformly. We simulated the breach by lowering the elevation of

the grid cells coincident with the stream channel. The water is generated by using a hydrograph

input upstream. Figure 4-2 corresponds with one of the case studies.
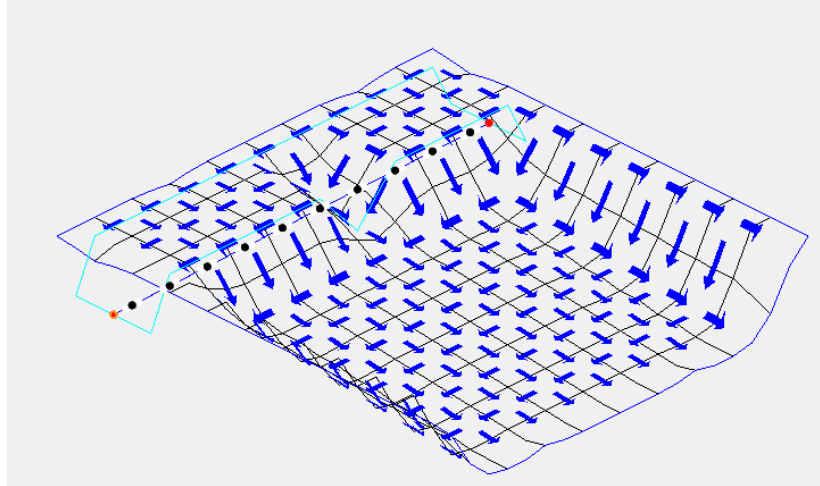
Figure 4-2: Sample model in WMS with one stream cell lowered.
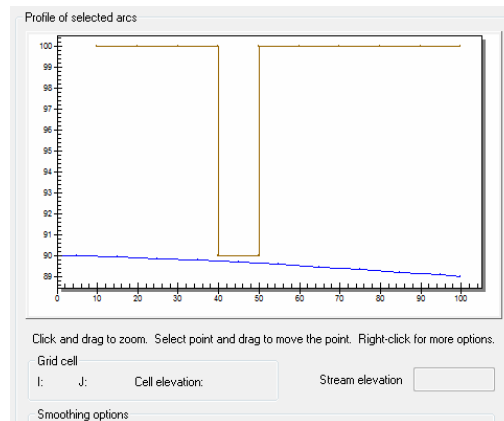
Figure 4-3: River elevation (blue) vs. grid cell (levee) elevation (brown).

The following case studies were performed:

1. Lower one cell at the middle of the stream

    a. 3 nodes per stream cell

    b. 4 nodes per stream cell

    c. 5 nodes per stream cell

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d.   6 nodes per stream cell

e.   7 nodes per stream cell

2.   Lower one cell downstream, as shown in Figure 4-4.

a.   3 nodes per stream cell

b.   4 nodes per stream cell

c.   5 nodes per stream cell

d.   6 nodes per stream cell

e.   7 nodes per stream cell

Similarly, we lowered 2, 3, and 5 cells at the middle of the stream and downstream. Again, the nodes were increased from 3 nodes to 7 nodes per stream cell, inclusively. All the nodes are distributed uniformly across the stream. The purpose of lowering cells downstream is that we want to test how the location of the breach might affect the results.
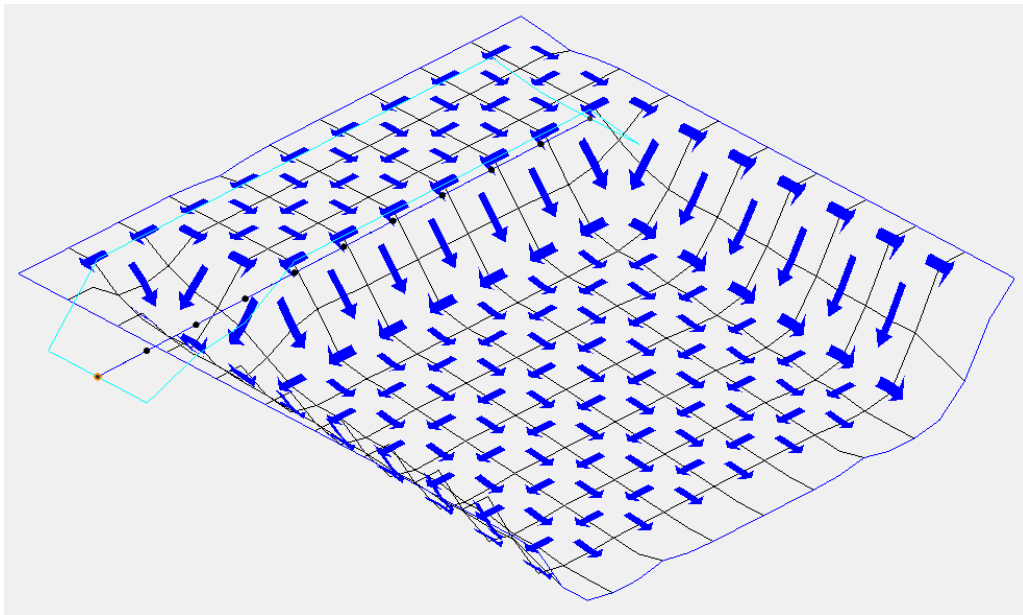
Figure 4-4: Lower one cell downstream in the sample model.

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4.2   Results

Here are some of our observations from the results from the above case studies.

1.   The mass conservation error and lateral flow increased significantly if the number
      of nodes on the stream cell is greater than 5 nodes, shown in Figure 4-5 and
      Figure 4-6.

2.   The results are very consistent if we have 5 or less nodes per stream cell. The
      location of the lowered cells doesn't seem to have effect on the result.

3.   The system will eventually gain water if the stream is assigned too many nodes,
      such as 4 nodes per stream cell in the 5-cell-lowered case. For these cases, the
      water actually flows from the overland to the river.
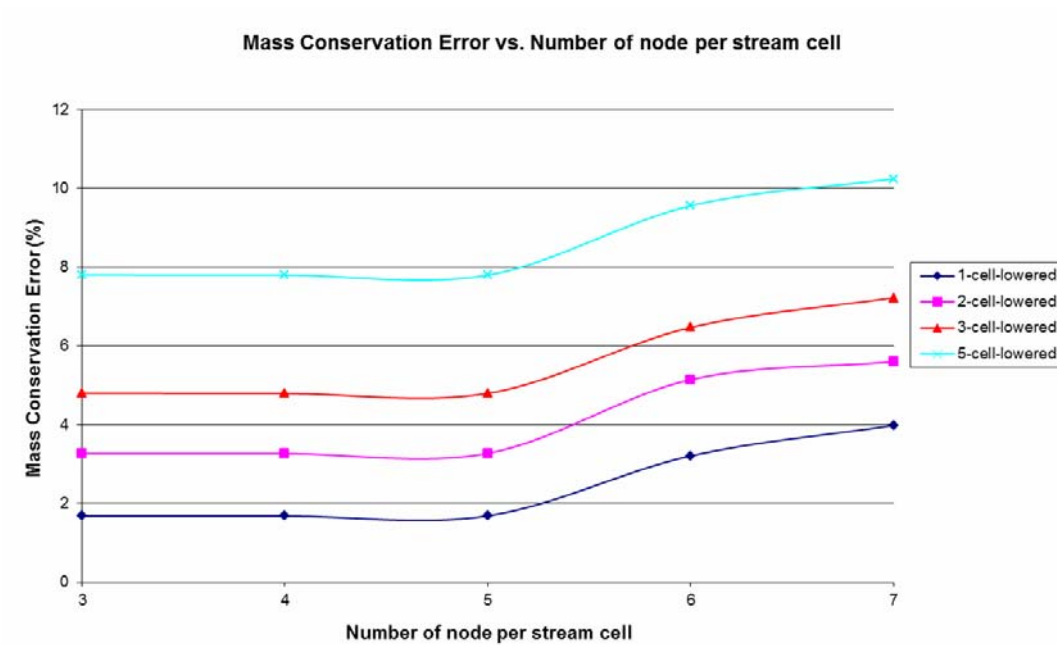
Figure 4-5: Mass conservation error vs. number of stream node.

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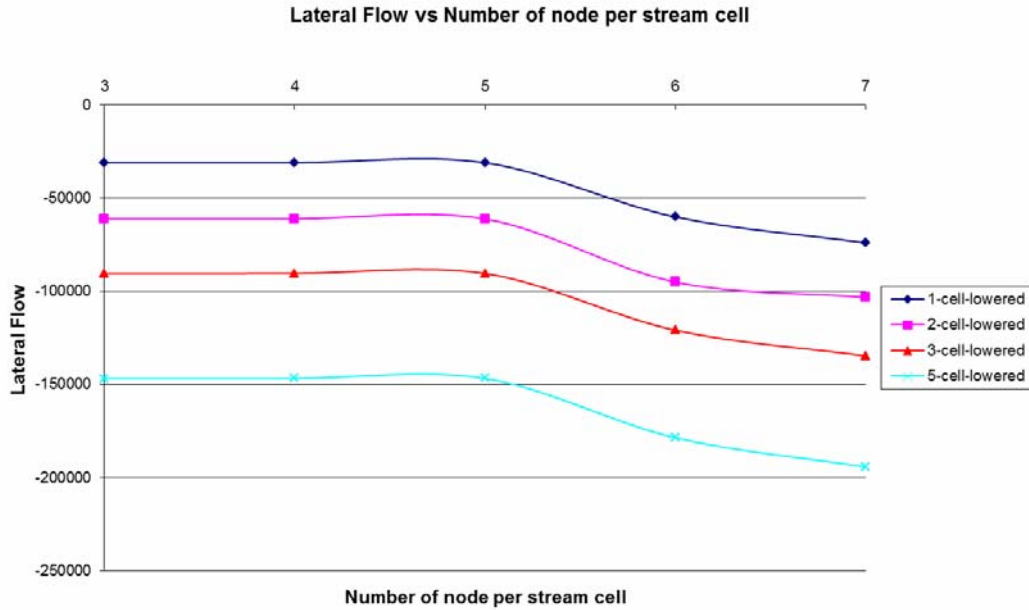
Figure 4-6: Lateral flow vs. number of stream nodes.

4.3 Conclusions

The results from the running the overbank option in GSSHA are very consistent if the numbers of stream nodes are limited. Even with some limitations, GSSHA model can simulate flooding due to levee breach with limited stream nodes for several reasons. First, the stream can be well-represented with only a few stream nodes, as shown in the case study in chapter 6. Second, fewer stream nodes can significantly improve the computation time and the stability for the flood simulation.

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5   EXPANDED LEVEE ANALYST TOOL

The current Levee Analyst Data Model allows the user to archive and manage seepage
(SEEP2D, SEEP/W) and slope stability analyses (UTEXAS, SLOPE/W) into the National Levee
Database. The expanded Levee Analyst will provide the capability of running pre- and post-
processing of GSSHA simulations in the ArcGIS environment for levee breach analysis. This
chapter contains a description of each of the geo-processing tools developed by this research to
perform this task.

5.1   Archive GSSHA Simulation

The first requirement to use the Levee Analyst tool is to prepare a GSSHA model for
each protected area. The protected area is the adjacent area of the constructed levees. It
represents the area of inundation if flooding due to levee breach occurs. Figure 5-1 shows the
input requirements for the *Archive GSSHA Simulation* geoprocessing tool.

The *Archive GSSHA Simulation* geoprocessing tool allows the user to archive the base
model into the NLD geodatabase. The tool archives the *Base Model* file path associated with the
Protect_ID to the *Protected_Area* feature class. Figure 5-2 shows the workflow of the *Archive
GSSHA Simulation* geoprocessing tool. The top image in Figure 5-2 is the *Archive GSSHA
Simulation* geoprocessing tool. The bottom image is the *Protected_Area* feature class in the NLD
showing the new record in the feature class resulting from running the Archive GSSHA
Simulation tool.

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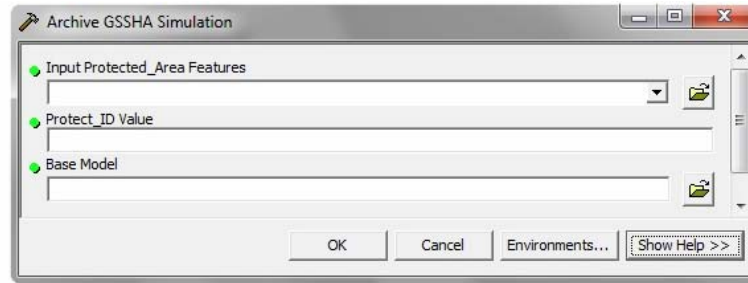
Purpose: Archives the GSSHA base model into the *Protected_Area* feature class.

Field name	Description
Input Protected_Area Features	The *Protected_Area* feature class in the NLD
Protect_ID Value	The *Protect_ID* value associated with the GSSHA base model
Base Model	The path to the GSSHA base model files

Figure 5-1: *Archive GSSHA Simulation* **geoprocessing tool.**
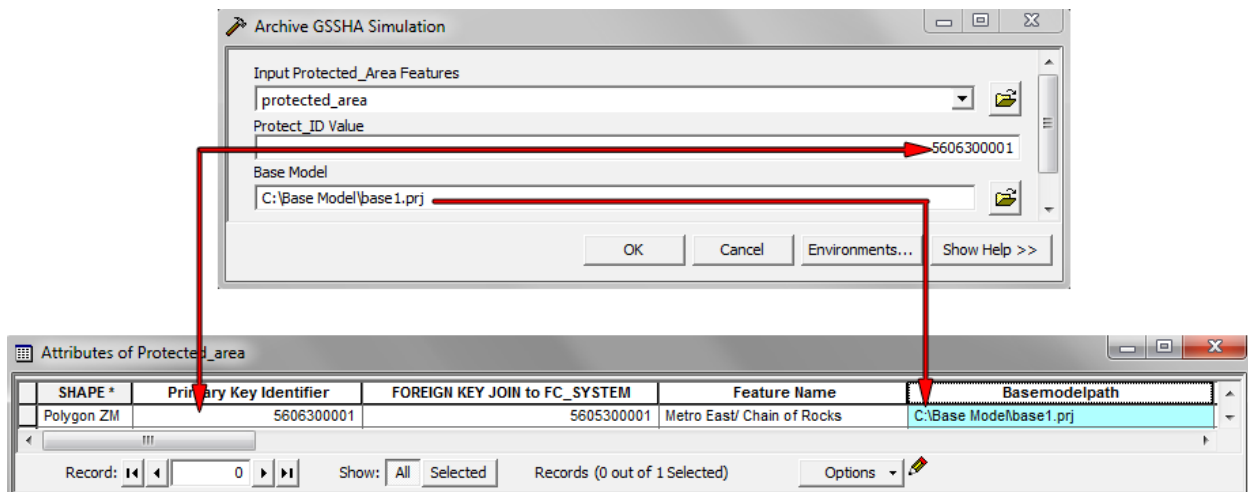
Figure 5-2: Workflow for *Archive GSSHA Simulation* **geoprocessing tool.**

5.2   Create Breach

A breach location line feature is created from a segment of an associated levee centerline. This process can be done using the linear referencing tools in ArcGIS as shown in Figure 5-3. However, the procedure to generate a segment from a line is quite complex. First, the user needs

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to run the *Create Routes* tool. Second, the user needs create a temporary table listing the levee centerline ID (Levee_ID), the starting station, and the ending station. Finally, the user runs the *Make Route Event Layer* geoprocessing tool to create a segment from the *Levee Centerline* feature class. The *Create Breach Location* geoprocessing tool is designed to simplify all of these steps into a single tool. It creates a segment from a levee centerline where the user thinks a levee breach may occur, and archives this feature into *Breach Location* feature class for future analysis.
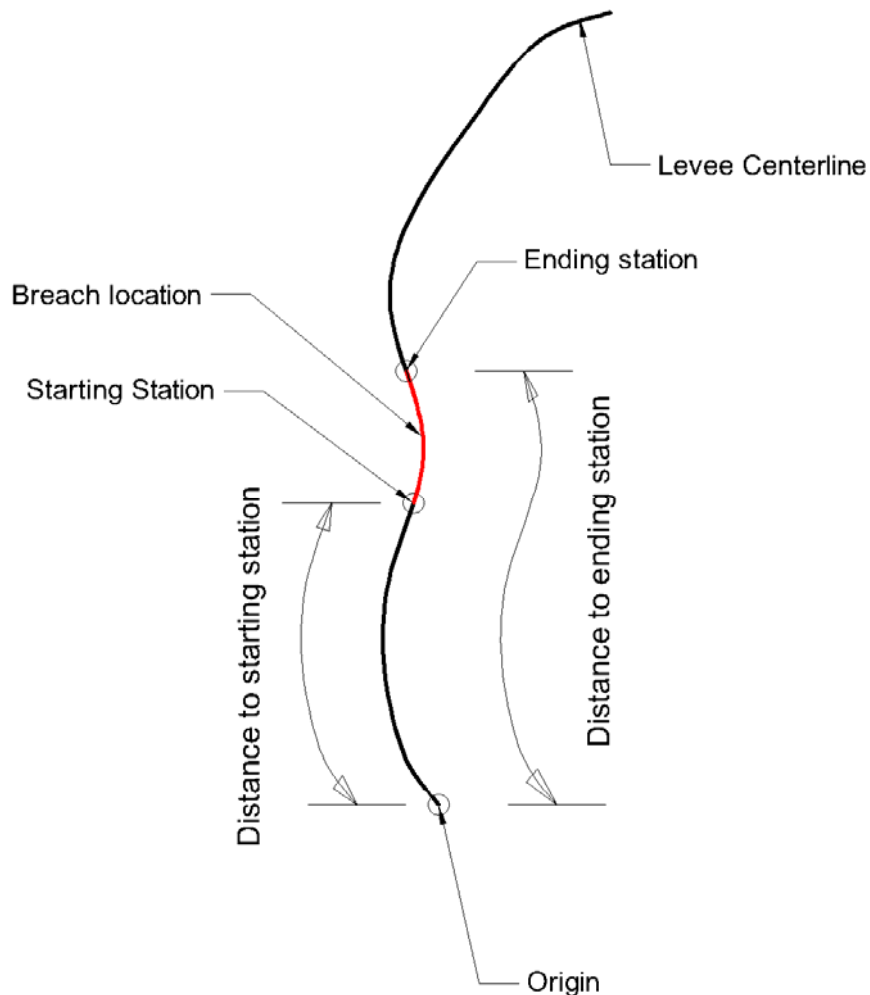
Figure 5-3: Starting and ending station concept.

The *Create Breach* geoprocessing tool is shown in Figure 5-4. Besides creating a new levee breach line feature, the tool also archives all the important information related to the newly created breach in the *Breach Location* feature class. They are associated levee ID, protect ID, Levee names, starting station (From-Measure Value) and ending station (To-Measure Value), as shown in Figure 5-6.
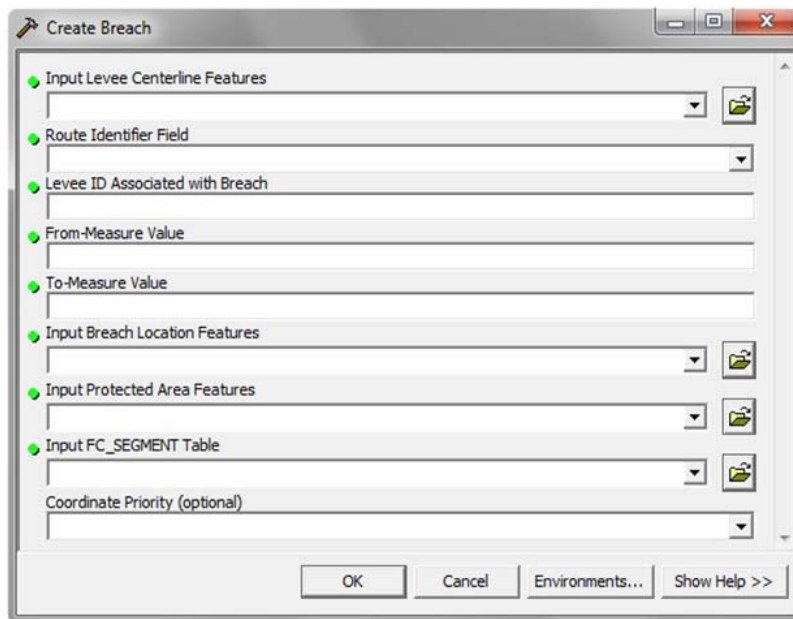
Purpose: Create levee breach location along the associated *Levee_Centerline* feature class

Field name	Description
Input Levee Centerline Features	The *Levee_Centerline* feature class in NLD
Route Identifier Field	The field corresponding to the Levee ID in the *Levee_Centerline* feature class
Levee ID associated with breach	The Levee_ID associated with the levee breach
From-Measure Value	The distance from the origin point to the starting station to the levee breach
To-Measure Value	The distance from the origin point to the ending station to the levee breach
Input Breach Location Features	The *Breach_Location* feature class - this is where the levee breach location is archived
Input Protected Area Features	The *Protected_Area* feature class
Input FC_SEGMENT Table	The *FC_SEGMENT* table – this is required to trace down the associated *Protect_ID*
Coordinate Priority (Optional)	Defines the location of the origin point

Figure 5-4: *Create breach* **geoprocessing tool.**

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The Protect_ID can be traced down from the Levee_ID in the NLD geodatabase. Each levee ID has an associated FC_Segment value stored in the *Levee_Centerline* feature class. This FC_Segment value has a corresponding FC_System value stored in the FC_Segment Table. Each FC_System has a unique Protect_ID value stored in the *Protected_Area* feature class. This relationship is demonstrated in Figure 5-6.

OBJECTID_1 *	Shape *	Levee_ID	From_	To_	Breach_ID	Protect_ID	Levee_Name	Shape_Length
11	Polyline ZM	5601040001	0.01	0.06	1	5606300001	Chain of Rocks Levee	0.053063
12	Polyline ZM	5601040001	0.05	0.06	2	5606300001	Chain of Rocks Levee	0.054979
13	Polyline ZM	5601040001	0.05	0.065	3	5606300001	Chain of Rocks Levee	0.020048
14	Polyline ZM	5601040001	0.065	0.072	4	5606300001	Chain of Rocks Levee	0.010836
15	Polyline ZM	5601040001	0.07	0.079	5	5606300001	Chain of Rocks Levee	0.011981
16	Polyline ZM	5601040001	0.073	0.086	6	5606300001	Chain of Rocks Levee	0.017936
17	Polyline ZM	5601040001	0.0745	0.0855	7	5606300001	Chain of Rocks Levee	0.015068
18	Polyline ZM	5601040001	0.0745	0.086	8	5606300001	Chain of Rocks Levee	0.016055
19	Polyline ZM	5601040001	0.1	0.12	9	5606300001	Chain of Rocks Levee	0.0239
20	Polyline ZM	5601040001	0.118	0.123	10	5606300001	Chain of Rocks Levee	0.009146
21	Polyline ZM	5601040001	0.119	0.1239	11	5606300001	Chain of Rocks Levee	0.008851
22	Polyline ZM	5601040001	0.1205	0.1239	12	5606300001	Chain of Rocks Levee	0.006879
23	Polyline ZM	5601040001	0.1215	0.1239	13	5606300001	Chain of Rocks Levee	0.005892
24	Polyline ZM	5601040001	0.122	0.124	14	5606300001	Chain of Rocks Levee	0.004948

Figure 5-5: Breach Location feature class.
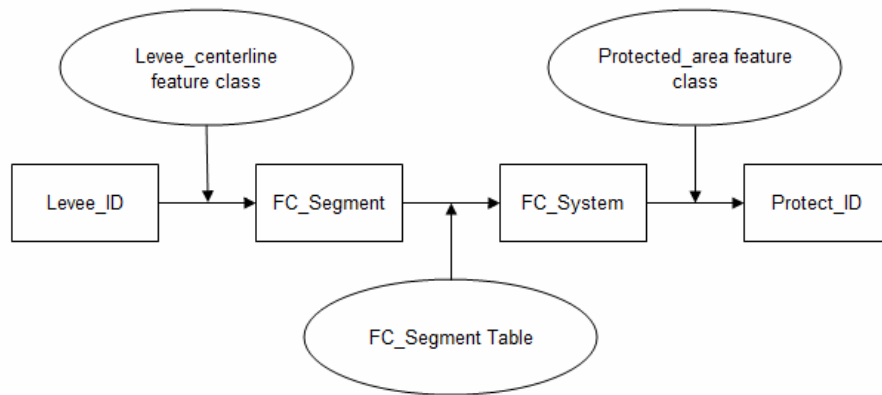
Figure 5-6: Levee_ID and Protect_ID relationship in NLD geodatabase.

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5.3   Archive Breach Discretization

A discretization file contains the position of the GSSHA grid cells associated with the breach location feature created using the Create Breach geoprocessing tool. Figure 5-7 shows an example of the discretization file.

```
69 71 20.0668
70 71 107.593
71 71 17.733
71 70 89.8667
72 70 107.836
73 70 3.72072
73 69 104.041
74 69 97.9279
74 68 9.62742
75 68 107.744
76 68 83.2093
76 67 24.8237
77 67 107.132
78 67 73.1728
78 66 34.2186
79 66 107.468
```

Figure 5-7: Sample discretization file.

The first two columns are the row and column indices of each of the cells associated with the breach. The third column is the length of the breach arc in the cell. The purpose of the discretization file is to locate the breach in the GSSHA grid. This method allows the *Simulate Flood and Archive* geoprocessing tool to locate the "breached" cell grid and modify its elevation based on the breach depth specified by the user. The discretization file is then archived to the *Breach Location* feature class inside of the NLD geodatabase using the A*rchive Breach Discretization* geoprocessing tool shown in Figure 5-8. This tool works in a similar way with the *Archive GSSHA Simulation* geoprocessing tool.

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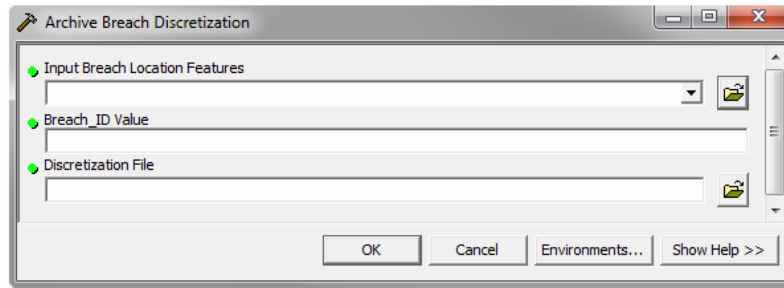
Purpose: Archive the discretization file into the Breach_Location feature class. This allows the *Simulate Flood and Archive* geoprocessing tool to locate the starting and ending station.

Field name	Description
Input Breach_Location Features	The *Breach_Location* feature class in the NLD
Breach_ID Value	The *Breach_ID* value associated with the Discretization file
Discretization file	The path to the Discretization file

Figure 5-8: *Archive Breach Discretization* **geoprocessing tool.**

WMS 8.4 has a feature called "Raise grid to elevation" which allows the user to create the discretization file very easily. This will be described in the case study on the next section.

5.4   **Simulate Flood and Archive**

The *Simulate Flood and Archive* geoprocessing tool is the most complex tool in the suite. This tool does several things. First, the tool modifies the GSSHA base model boundary conditions based on the input provided by the user. It takes the starting and ending elevation of the levee breach and applies these changes to the elevation file which contains the elevation of each cell in the GSSHA model. The tool then assigns the new hydrograph defined by the user to the upstream hydrograph in the GSSHA input. Second, the *Simulate Flood and Archive* geoprocessing tool runs GSSHA to simulate the flood corresponding to the modified model. Finally, the tool archives the result into the NLD geodatabase. The *Simulate Flood and Archive* tool is shown in the Figure 5-9.
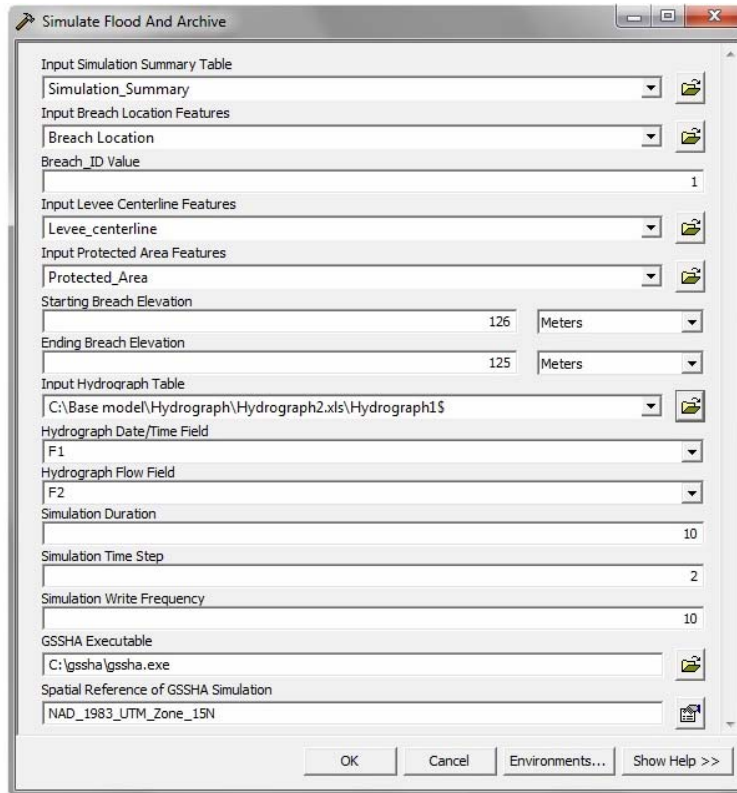
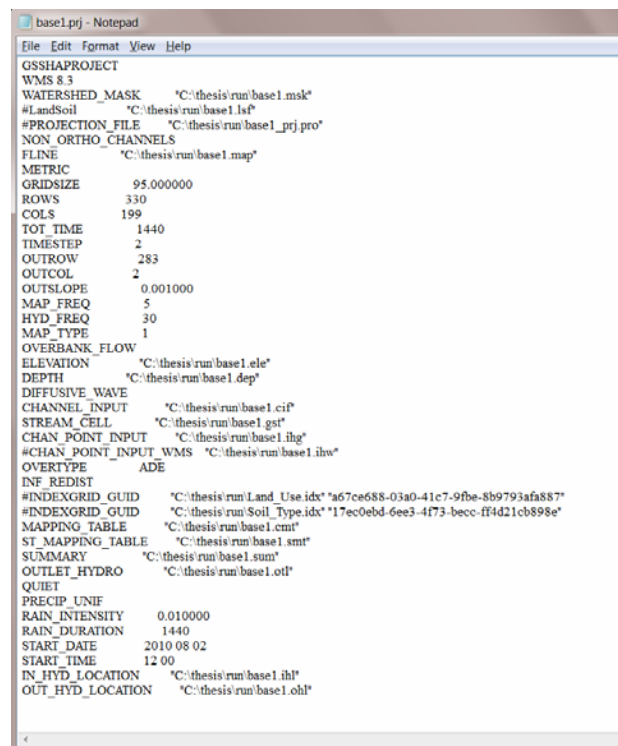| Purpose: Update boundary conditions and archive the results	
Field name	**Description**
Input Simulation Summary Table	The *Simulation Summary* Table
Input Breach Location Features	The *Breach_Location* feature class - this is where the levee breach location is archived
Breach_ID Value	The *Breach_ID* value
Input Levee Centerline Features	The *Levee_Centerline* Features - use to trace down the associated Levee_ID value
Input Protected Area Features	The *Protected_Area* features - use to trace down the associated Protect_ID value
Starting Breach Elevation	The elevation at the Starting Station
Ending Breach Elevation	The elevation at the Ending Station
Input Hydrograph Table	The new Hydrograph Table which is used in this simulation
Hydrograph Data/Time Field	Specifies which column is date/time
Hydrograph Flow Field	Specifies which column is Flow
Simulation Duration	Specifies how long the simulation will run
Simulation Time Step	Specifies how often (in time step) GSSHA needs to solve for the solution
Simulation Write Frequency	Specifies how often GSSHA will write out the solution
GSSHA Executable	The Path to GSSHA executable
Spatial Reference of GSSHA Simulation	The coordinate of the GSSHA base model.

Figure 5-9: *Simulate Flood and Archive* **geoprocessing tool.**

The simulation table, Figure 5-12, contains all important information for each flood

simulation. For each simulation, the *Simulate Flood and Archive* geoprocessing tool will

generate a new simulation ID. Each simulation ID has its unique characteristic defined by breach depth, breach length and the upstream hydrograph. The tool first takes the breach ID specified by the user and find the ID of the protected area (Protect_ID) archived in the *Breach Location* feature class. With the protected ID, it then looks up the base model file path archived in the *Protected Area* feature class. The tool then creates a new subfolder inside of the folder identified with the base model path and names it after the simulation ID (ex 00001). The tool also copies the following files into the subfolder: elevation file (.ele), project file (.prj) and hydrograph files (.ihg and .ihw). The elevation file contains all the elevation of each grid cells. The hydrograph files contain the hydrograph for the upstream node. Finally, the project file contains the path of all the input/output files used by GSSHA. Figure 5-10 shows an example of a project file.

Figure 5-10: Sample of a GSSHA project file (.prj)

Each simulation is unique by breach length/location and upstream hydrograph. Therefore, the tool only copies the elevation files and the upstream hydrograph into the subfolder. This approach also requires the tool to modify the path to these files in the project file. Figure 5-11 shows a sample of a modified GSSHA project file. This approach can save a lot of storage space because it avoids duplicating the unnecessary files.

Figure 5-11: Sample of a modified GSSHA project file.

The path of the solution (.file) file is also edited so that each subfolder, which is associated with one unique simulation value, has its own unique solution. With everything in place, the *Simulate Flood and Archive* geoprocessing tool modifies the elevation file in the subfolder using the discretization file and the starting/ending breach elevation specified from the

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input. The tool also gets the new hydrograph from the input table and modifies the hydrograph files inside of the subfolder to match the new one.

The *Simulate Flood and Archive* tool asks the user to specify the projection of the GSHSA base model. This input is necessary for calculating the inundation area because the model boundary is always bigger than the protected area boundary. The GSSHA solution contains all the water elevation at all the grid cells bounded by the model boundary. This method makes sure that we only calculate the cells in the protected area. The tool uses this information to line up the base model polygon with the associated protected area. Once these two polygons are lined up, the tool will look for all the cells in the base model that belong to the protected area. The maximum depth in meters and inundation area in square meters is calculated based on the water depth at these cells only.

The tool also allows the user to specify the simulation duration, simulation time step, and simulation write frequency. Finally, the tool runs GSSHA inside of ArcGIS and archives the results into the simulation summary table, shown in Figure 5-12.

Attributes of Simulation_Summary

Sim_ID	Breach_ID	BreachDepth	InputHydrograph	Maximum_Depth	Inundation_Area	Path_to_KMZ	Levee_ID	Protect_ID	Levee_Name	StartElevation	EndElevation
1	1	12.978853	Hydrograph1$	7.797216	1068180	C:\Base Mode\00	5601040001	5606300001	<Null>	123	123
2	3	8.978853	Hydrograph2$	3.15894	92500	C:\Base Mode\00	5601040001	5606300001	<Null>	127	127
3	14	10.978853	Hydrograph2$	10.025682	1469985	C:\Base Mode\00	5601040001	5606300001	<Null>	125	125
4	6	10.315998	Hydrograph4$	9.407703	1024845	C:\Base Mode\00	5601040001	5606300001	<Null>	122	122
5	14	10.232588	Hydrograph3$	9.105465	722520	C:\Base Mode\00	5601040001	5606300001	<Null>	126	125
6	8	10.232588	Hydrograph6$	9.32418	747650	C:\Base Mode\00	5601040001	5606300001	<Null>	126	125

Record: I◄ ◄   0 ► ►I   Show: All Selected   Records (1 out of 6 Selected)   Options ▼

Figure 5-12: Simulation Summary Table.

5.5   Export GSSHA Simulation to KML

The Levee Analyst is designed to enhance the visualization of flooding simulations. The *Export GSSHA Simulation to KML* geoprocessing tool, shown in Figure 5-13, allows the user to export the simulation into a KML file that contains images of the flood simulation at each time step, specified by write frequency parameter when running GSSHA. This KML can be loaded into Google Earth to create an animation for the flood simulation. From the animation, the user can see how fast the flood goes and what the inundation area is.
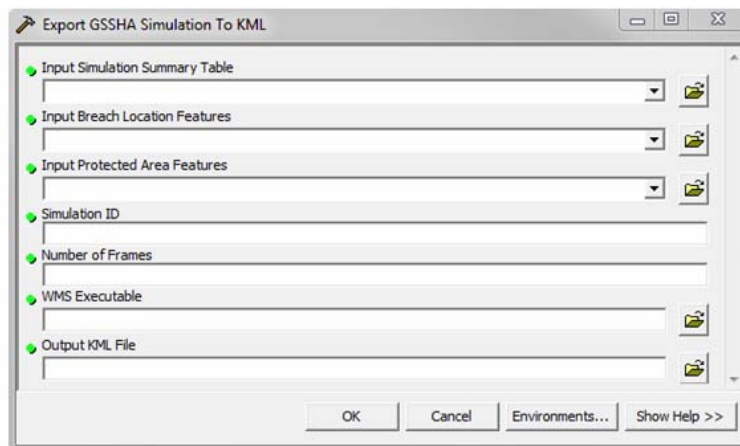
Purpose: Convert GSSHA solution into images or animation which can be viewed in Google Earth	
Field name	Description
Input Simulation Summary Table	The *Simulation Summary* Table
Input Breach Location Features	The *Breach_Location* feature class
Input Protected Area Features	The *Protected_Area* features
Simulation_ID	Specifies which GSSHA Simulation needs to be convert to KML
Number of Frame	Number of frames in the animation
WMS Executable	Path to the WMS executable
Output KML File	Location where the KML is saved

Figure 5-13: *Export GSSHA simulation to KML* **geoprocessing tool.**

The *export GSSHA simulation* geoprocessing tool takes the Simulation ID input and looks for the associated protect_ID. With the protect_ID, the tool determines the base model file

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path. From the base model file path and the simulation ID, the tool locates the path to the

GSSHA solution file (.dep) in the subfolder. The tool then will launch WMS and use the existing

tool in WMS to generate a KMZ[1] file. Finally, the file path of this KMZ file is archived into the

simulation summary table. Figure 5-14 shows WMS generating the KML file with the provided

GSSHA solution.
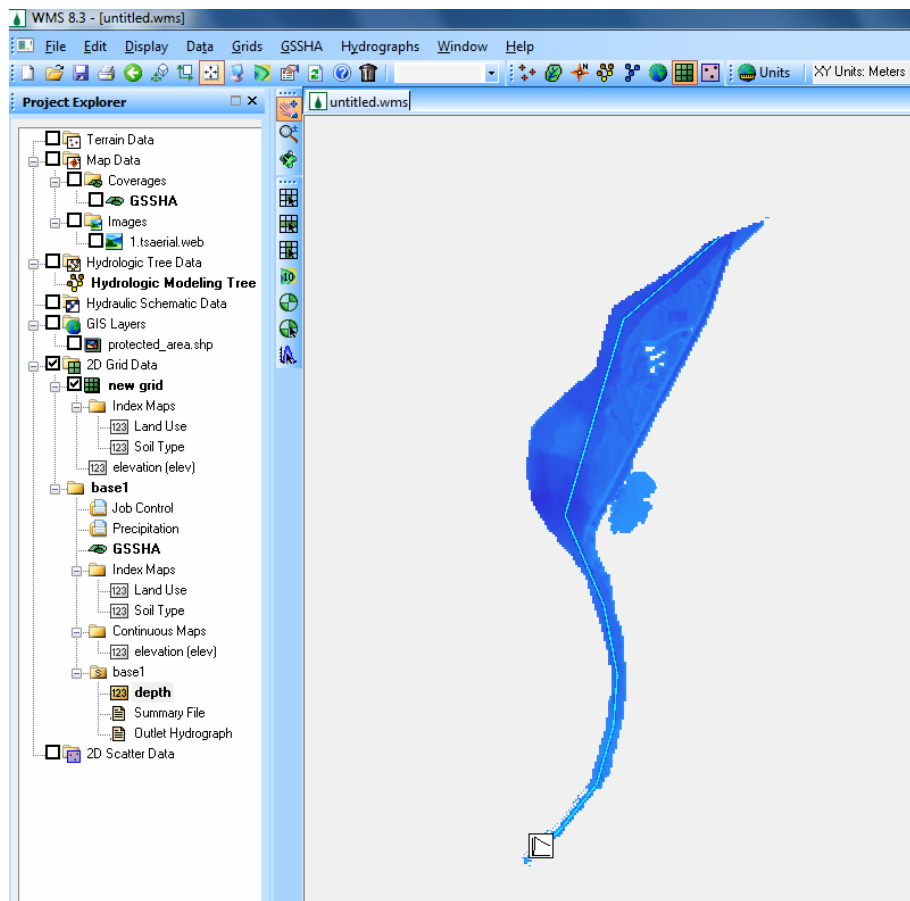
Figure 5-14: WMS generating KML file from a GSSHA solution.

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[1] KMZ is the compressed form of KML.

5.6 Export Breach Location to KML

The final tool added to the Levee Analyst tools is called *Export Breach Location to KML.*
The purpose of this tool is to export data for needed risk-informed assessments and decision-
making into Google Earth. The *Export Breach Location to KML* geoprocessing tool is shown in
Figure 5-15.
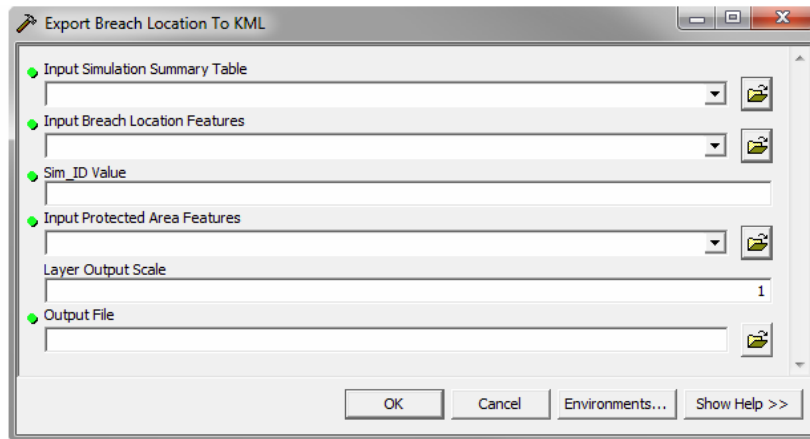
Purpose: Export the images to Google Earth; the sequence of images can be viewed as animation in Google Earth	
Field name	**Description**
Input Simulation Summary Table	The *Simulation Summary* Table
Input Breach Location Features	The *Breach_Location* feature class
Sim_ID Value	Specifies which breach location is exported based on the associated Simulation ID
Input Protected Area Features	The *Protected_Area* feature class
Layer Output Scale	Output scale
Output file	Location to save the KML file

Figure 5-15: Export Breach Location to KML geoprocessing tool.

First, the *Export Breach Location to KML* geoprocessing tool will find the ID of the
breach associated with the specified simulation ID (Sim_ID). Second, the tool uses a query to
find the IDs of all the simulations generated using this breach. Third, the tool exports the breach
line feature to Google Earth and puts all critical information associated with that breach into the
breach line feature in the KML file. The user is then able to see two tables for each breach line

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feature selected in Google Earth. The first table lists all the information for the breach obtained

from the *Breach Location* feature class. The second table lists all the fields and values in the

simulation summary table of this breach. These two tables can be seen in Figure 5-16.
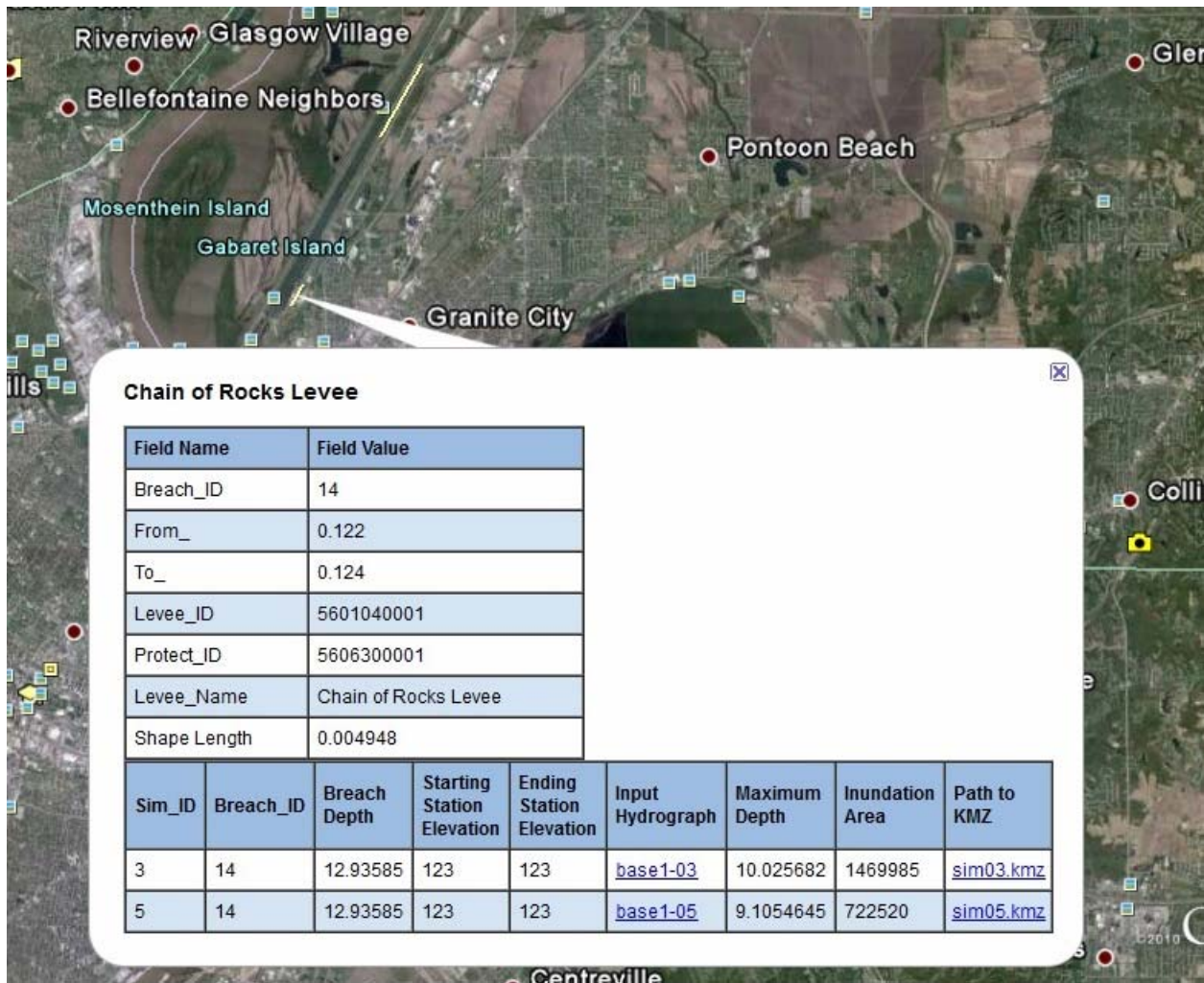
Figure 5-16: Exported breach into Google Earth.

In the second table, the tool not only exports all of the information from the simulation

summary table but it also creates a hyperlink to the input hydrograph and the KMZ file. The

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hyperlink of input hydrograph leads to the file path of the hydrograph file (.ihg) stored in the

subfolder which is created when running GSSHA. When the user clicks on the hyperlink for the

input hydrograph, the default program, such as notepad, will open this hydrograph file. However,

the user needs to turn on the placemark balloons option in Google Earth to get this to work

because Google Earth can't access to local files and personal data by default. If the user wants to

see the impact of the flood simulation, he/she can simply click on the *Path to KMZ* hyperlink.

Google Earth then generates an animation of the flood. Some screenshots for this type of

animation will be demonstrated in the case study.

6   CASE STUDY: ST. LOUIS NATIONAL LEVEE DATABASE

In this chapter, we demonstrate the compatibility of the new suite of tools in Levee

Analyst Data Model and NLD using a case study from St. Louis. The St Louis National Levee

Database was provided by the United States Army Corps of Engineers (USACE) and is

populated with the data along the Mississippi, Missouri and Illinois rivers.

The NLD geodatabase is not structured to store river elevations and cross section data. In

order to test the new suite of tools, fictitious river elevations and cross sections were used for the

GSSHA base model.

6.1   Create GSSHA Base Model

Each protected area (Protect_ID) must have its own GSSSHA base model. The GSSHA

base model in this example was built for the Granite City region using Watershed Modeling

System (WMS) developed by Aquaveo.

6.1.1   Import Protected Area Polygon to WMS

The protected area polygon was exported as a shape file using the *Export Data*

geoprocessing tool in ArcGIS. This shape file was imported into WMS and converted into a

polygon feature. We then imported an aerial image to assist us in creating the model boundary.

The aerial image can be imported into WMS quickly and easily using the *Get Data* tool .

Using the image background as a guide, we modified the protected area polygon to extend the

model boundary to the west in order to incorporate the river in addition to the protected area. Figure 6-1 shows the protected area polygon in aqua, the aerial photo, and the model boundary in red.

6.1.2 Create Stream Arcs and Define Hydrograph Upstream.

Next, we used the conceptual approach in WMS to create stream arcs. Using the *Create Arc* tool, we simply drew the stream arcs on top of the aerial photo. The conceptual approach allows us to define the properties of the stream directly on the stream arc. In this case, we specified the stream as a trapezoidal channel with the following properties:

- Manning's n: 0.01
- Depth: 11 meters
- Bottom width: 400 m
- Side slope: 1

The width of the river was measured from the aerial photo using the *Measure Tool* in WMS. These values above are fictitious because they are not provided in the NLD. The hydrograph was assigned at the top of the stream. Figure 6-2 shows the stream arc in blue.
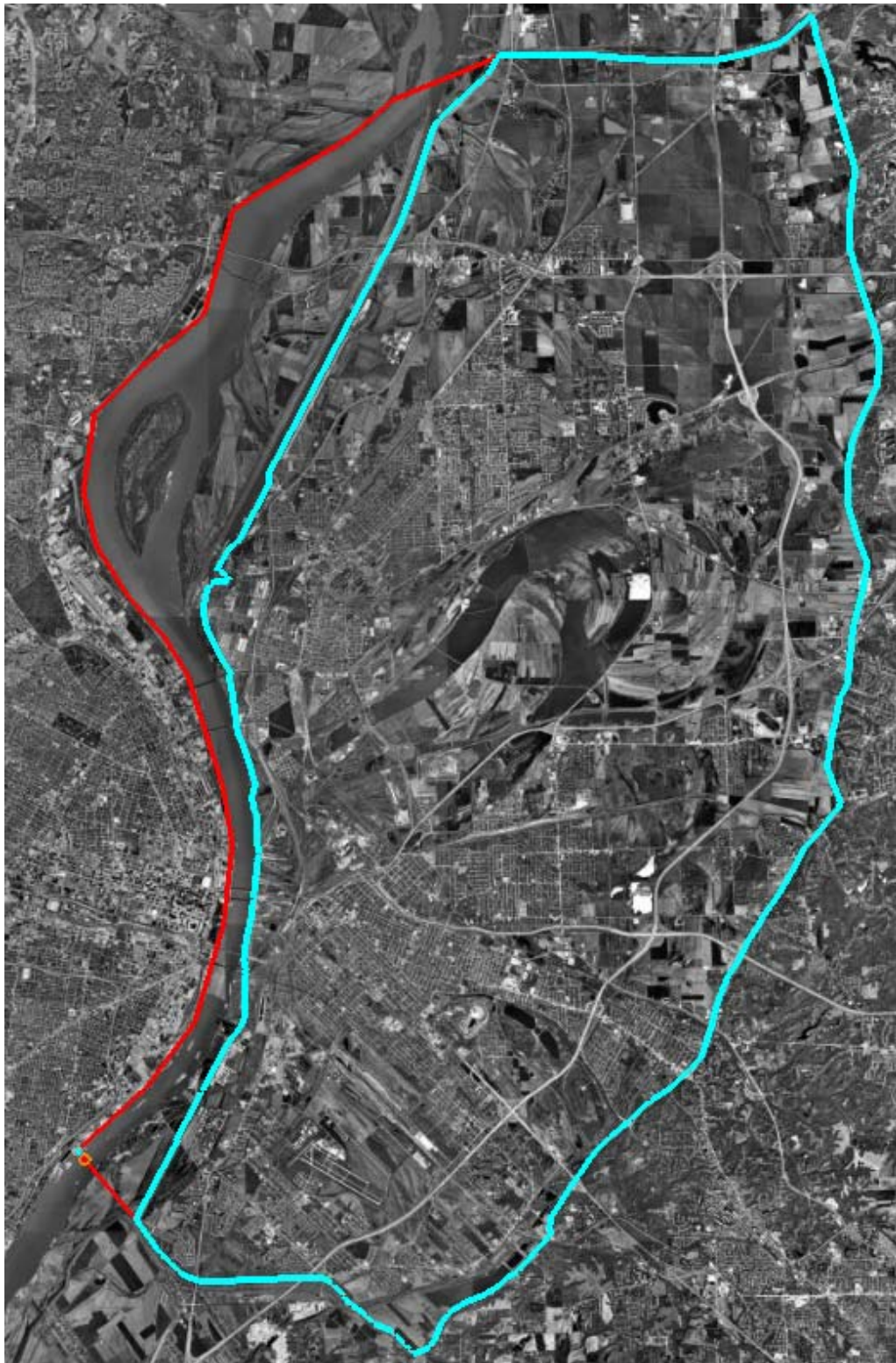
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Figure 6-1: Protected area and model boundary.
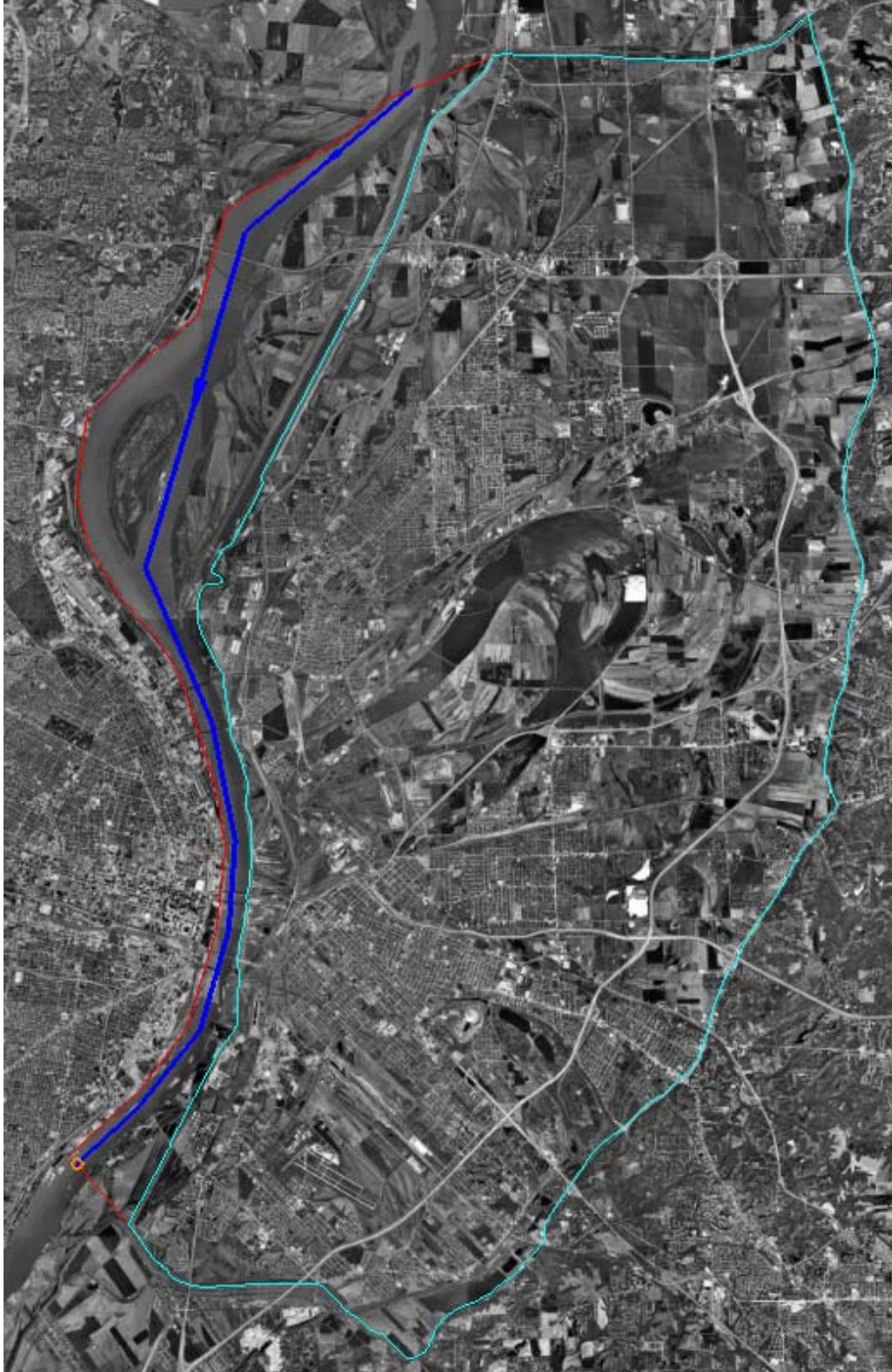
Figure 6-2: Basic model conceptual model with the river in blue.

6.1.3   Build GSSHA Grids

The GSSHA grids can be generated in WMS using the *Create Grid* tool. This tool allows the user to specify the number of cells in the x and y direction or the base cell size. The base cell size option allows the user to specify the uniform cell size for the area. For example, if the base cell size is 90 meters, WMS will generate a uniform cell size of 90 meters for the area. WMS automatically downloads the DEM data from a server and maps the elevations from the DEM data to the GSSHA grids. WMS also interpolates the elevation to the stream and lowers the grid elevation to the specified stream depth defined in the previous step.

In this case, we created a 90-meter cell size for the GSSHA model. It would make more sense to have more cells at the levee location and the river. However, GSSHA only support uniformly-distributed cell sizes. If there is a concern about grid resolution on solution accuracy, the user can increase number of cells in the model until the difference in results is insignificant.

6.1.4   Raise Grids to Levee Elevation

Since the levee width is very small compared with the resolution of the DEM. The DEM data can't accurately represent the ground surface elevation at the location of the levee. Fortunately, WMS has a tool that can help us overcome this problem called *Raise Grids to Elevation*. The *Levee_Centerline* line feature in the NLD has the centerline elevation stored with the line. We use the *Export Data* geoprocessing tool in ArcGIS to export the *Levee_Centerline* feature as a shape file containing the elevation of the levee. The shape file is then imported to WMS and it is converted to a feature object and integrated into GSSHA model. We then right-click on the newly-imported feature object and select the *Raise Grid to Elevation* command. This tool then raises all the grid cells that intersect the levee center line to the levee elevation.

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6.1.5   Import Land Use and Soil Type Data into the GSSHA Model

Land use data can be imported to WMS using the *Get Data* tool. Figure 6-4 shows the

land use data mapped into the GSSHA base model. Soil type data can be obtained through the

Natural Resources Conservation Services (NRCS) website as a shape file. The user can bring this

shape file into WMS and map these data into GSSHA base model. Figure 6-5 shows the soil type

data mapped into the GSSHA base model.

The land use and soil type data are used to define roughness and infiltration of the soil

respectively. The land use data contains curve numbers. Each curve number has a specified

roughness value. The soil type contains soil ID. Each soil ID has its own characteristic on

hydraulic conductivity, suction head, effective porosity, and porosity.

6.1.6   Define Precipitation

GSSHA always requires the user to specify precipitation in order to run the model. In this

case study, we focus only on the flood generated by the upstream hydrograph. Therefore, we set

the precipitation value to be very small (0.01 mm/day).

6.2   Import the Base Model File Path to Geodatabase

When the GSSHA base model was ready, we ran the A*rchive GSSHA Simulation*

geoprocessing tool. The tool archives the GSSHA base model file path into the *Protected_Area*

feature class, seen Figure 6-3.

SHAPE *	Primary Key Identifier	FOREIGN KEY JOIN to FC_SYSTEM	Feature Name	Basemodelpath
Polygon ZM	5606300001	5605300001	Metro East/ Chain of Rocks	C:\Base Model\base1.prj

Record: ◄◄ ◄ 0 ► ►◄   Show: All Selected   Records (0 out of 1 Selected)   Options ▼
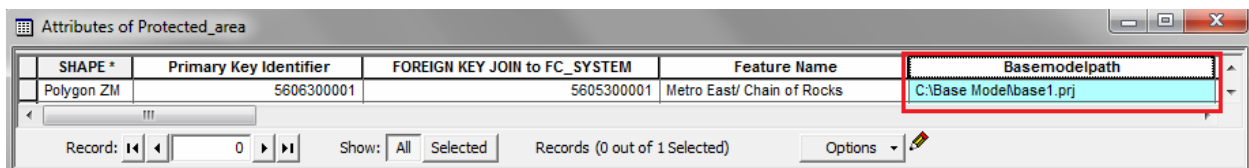
Figure 6-3: Modified Protected_Area feature class.

www.manaraa.com
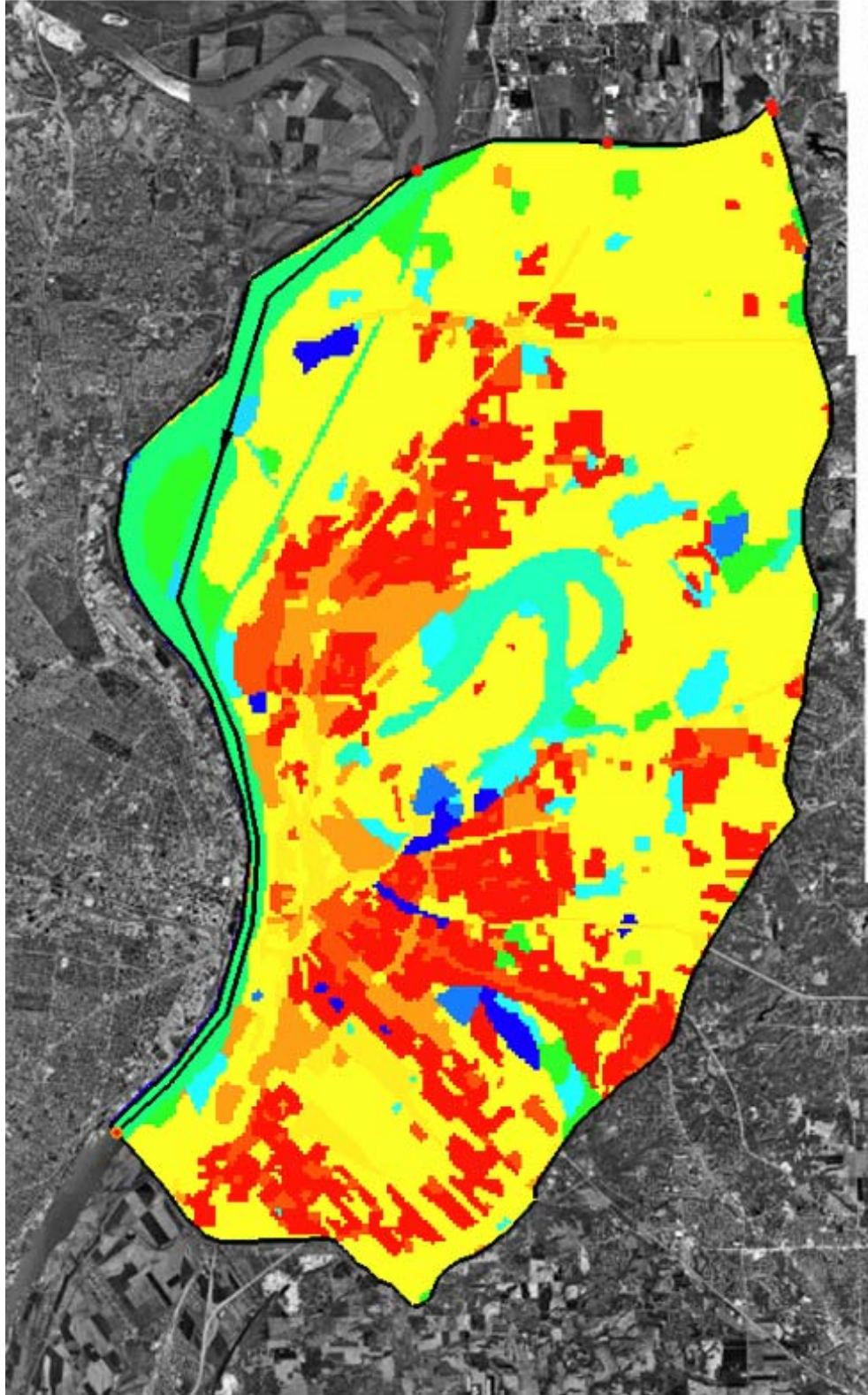
Figure 6-4: Mapped land use in GSSHA model.
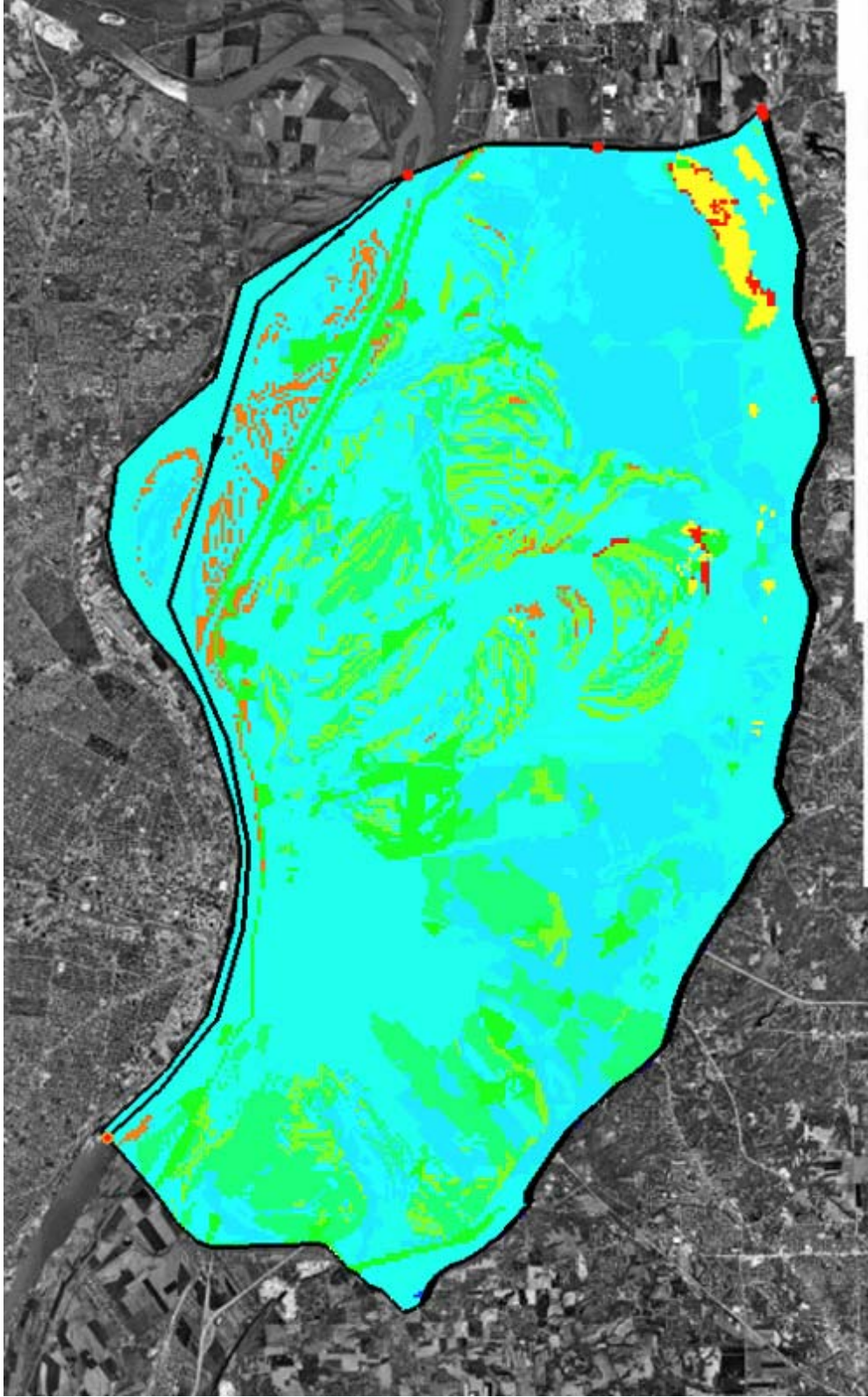
Figure 6-5: Mapped soil type in GSSHA model.

6.3   Create Breach Location from Levee Centerline

The next step is to create levee breach from the levee centerline. The breach was created

using the *Create Breach* geoprocessing tool, using the inputs shown in Figure 6-6.
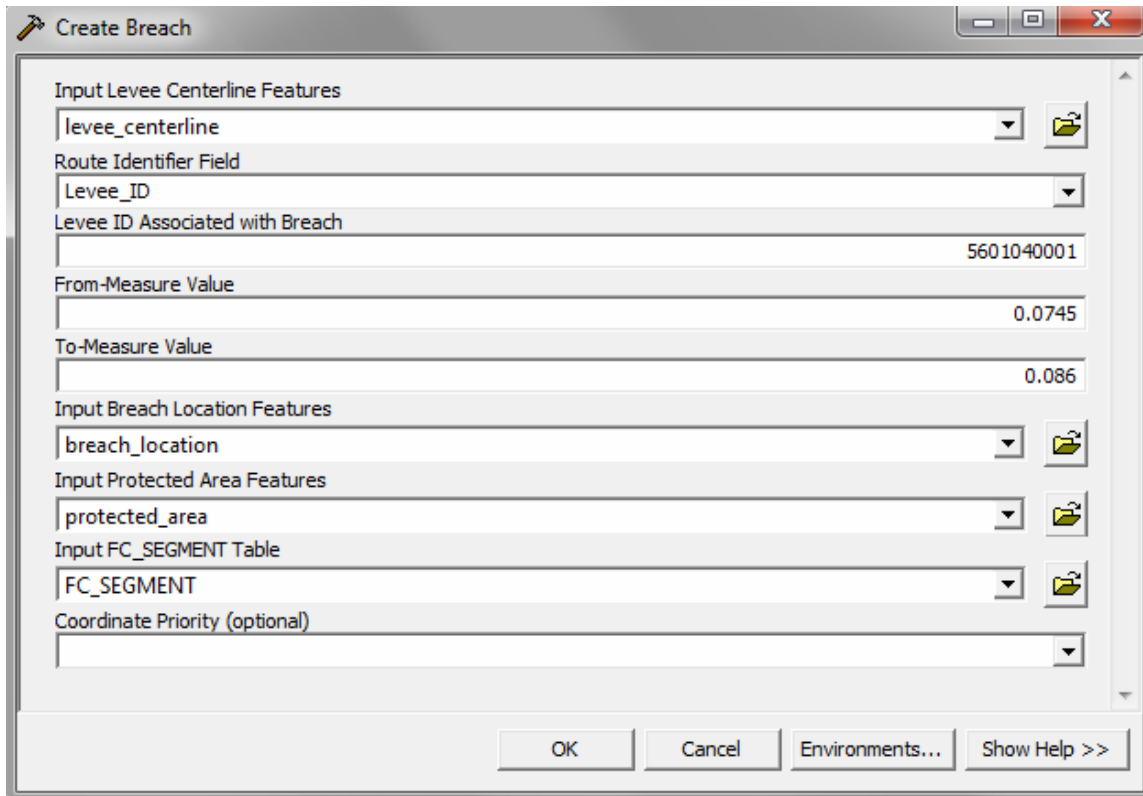
Figure 6-6: Inputs for create breach geoprocessing tool.

The current NLD geodatabase uses a geographic coordinate system. All the shape lengths

calculated in ArcGIS are calculated in decimal degrees units. The values in the *from_* and *to_*

fields imply that the breach will have a distance of 0.0745 to 0.086 decimal degrees from the

origin point of the levee. The location of the origin point can be specified using the coordinate

priority input. The default value for the coordinate priority is upper left corner. This implies the

origin point is the point closest to the minimum bounding rectangle's upper left corner. Figure

demonstrates how the location of the origin point is defined. The minimum bounding rectangle is in blue color. For example, if the coordinate priority is set to lower left corner, point B is the origin point because it's closest to the lower left corner. If the coordinate priority is set to the upper left corner which is by default, point A is the origin point.

Figure 6-7: Methodology to determine the origin point in GIS.

After we executed this tool, the new breach was generated (Figure 6-8) and archived (Figure 6-9) into the *Breach_Location* feature class.

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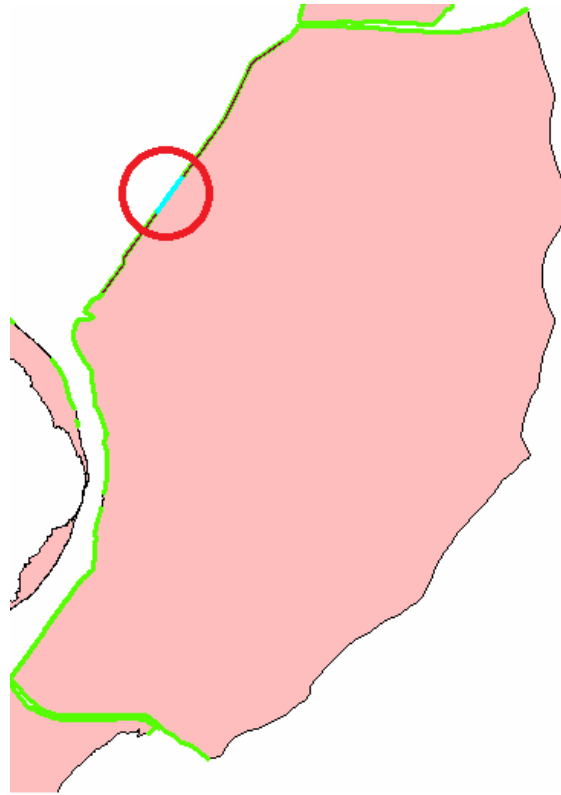
Figure 6-8: Breach generated using *Create Breach* geoprocessing tool.

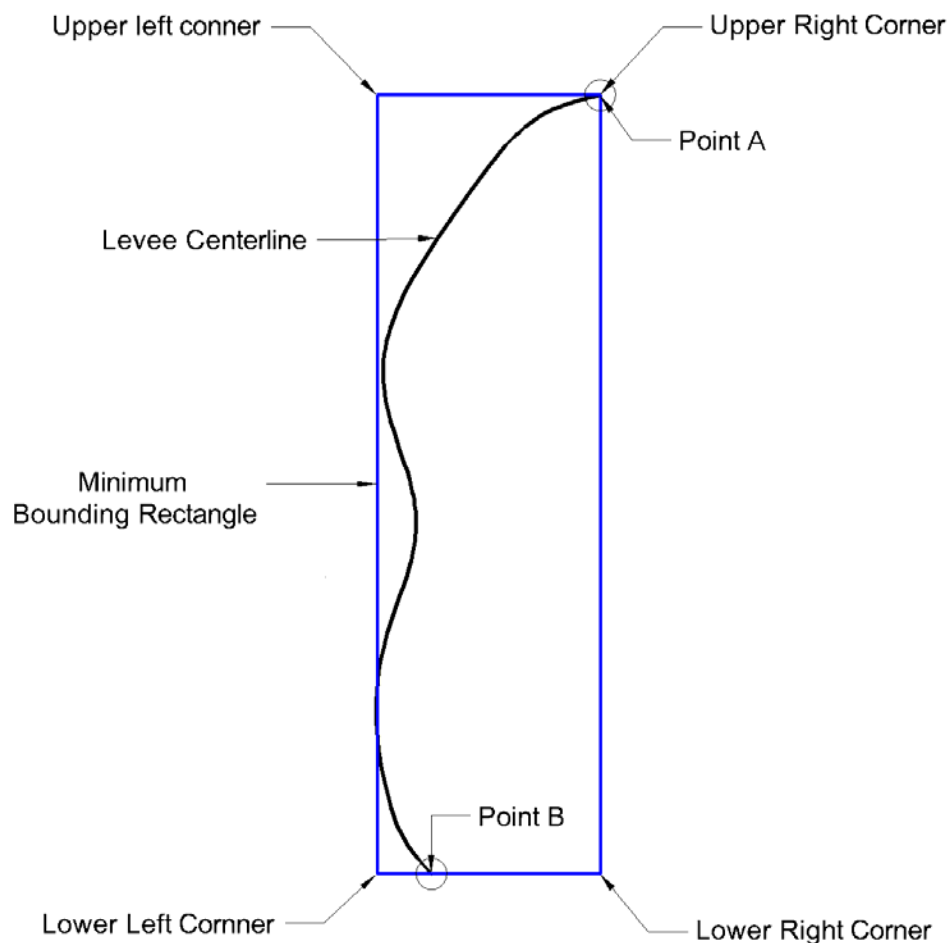| OBJECTID_1 *	Shape *	Levee_ID	From_	To_	Breach_ID	Protect_ID	Levee_Name	Shape_Length
11	Polyline ZM	5601040001	0.01	0.06	1	5606300001	Chain of Rocks Levee	0.053063
12	Polyline ZM	5601040001	0.05	0.06	2	5606300001	Chain of Rocks Levee	0.054979
13	Polyline ZM	5601040001	0.05	0.065	3	5606300001	Chain of Rocks Levee	0.020048
14	Polyline ZM	5601040001	0.065	0.072	4	5606300001	Chain of Rocks Levee	0.010836
15	Polyline ZM	5601040001	0.07	0.079	5	5606300001	Chain of Rocks Levee	0.011981
16	Polyline ZM	5601040001	0.073	0.086	6	5606300001	Chain of Rocks Levee	0.017936
17	Polyline ZM	5601040001	0.0745	0.0855	7	5606300001	Chain of Rocks Levee	0.015068
18	Polyline ZM	5601040001	0.0745	0.086	8	5606300001	Chain of Rocks Levee	0.016055
19	Polyline ZM	5601040001	0.1	0.12	9	5606300001	Chain of Rocks Levee	0.0239
20	Polyline ZM	5601040001	0.118	0.123	10	5606300001	Chain of Rocks Levee	0.009146
21	Polyline ZM	5601040001	0.119	0.1239	11	5606300001	Chain of Rocks Levee	0.008851
22	Polyline ZM	5601040001	0.1205	0.1239	12	5606300001	Chain of Rocks Levee	0.006879
23	Polyline ZM	5601040001	0.1215	0.1239	13	5606300001	Chain of Rocks Levee	0.005892
24	Polyline ZM	5601040001	0.122	0.124	14	5606300001	Chain of Rocks Levee	0.004948

Record: 1 Show: All Selected Records (1 out of 14 Selected) Options

Figure 6-9: Archiving breach into Breach Location feature class.

6.4 Generate Discretization File and Archive It into the Geodatabase

The final step before running the GSSHA model was to create a discretization file corresponding to the breach. First, we exported the breach into WMS and converted it from GIS data into a WMS feature object. Second, we selected the arc and select the *Raise Grid to Elevation* command from WMS. WMS generated the discretization file for the breach. Finally, we ran the *Archive Breach Discretization* geoprocessing tool to archive the discretization file into the *Breach Location* feature class, as seen in Figure 6-10.

	Breach_ID	Levee_ID	From_	To_	Protect_ID	Levee_Name	Shape_Length	Shape *	Discretizationpath
▶	1	5601040001	0.01	0.06	5606300001	Chain of Rocks Levee	0.053063	Polyline ZM	C:\Base Mode\discretization file\Breach1.txt
	2	5601040001	0.05	0.06	5606300001	Chain of Rocks Levee	0.054979	Polyline ZM	C:\Base Mode\discretization file\Breach2.txt
	3	5601040001	0.05	0.065	5606300001	Chain of Rocks Levee	0.020048	Polyline ZM	C:\Base Mode\discretization file\Breach3.txt
	4	5601040001	0.065	0.072	5606300001	Chain of Rocks Levee	0.010836	Polyline ZM	C:\Base Mode\discretization file\Breach4.txt
	5	5601040001	0.07	0.079	5606300001	Chain of Rocks Levee	0.011981	Polyline ZM	C:\Base Mode\discretization file\Breach5.txt
	6	5601040001	0.073	0.086	5606300001	Chain of Rocks Levee	0.017936	Polyline ZM	C:\Base Mode\discretization file\Breach6.txt
	7	5601040001	0.0745	0.0855	5606300001	Chain of Rocks Levee	0.015068	Polyline ZM	C:\Base Mode\discretization file\Breach7.txt
	8	5601040001	0.0745	0.086	5606300001	Chain of Rocks Levee	0.016055	Polyline ZM	C:\Base Mode\discretization file\Breach8.txt
	9	5601040001	0.1	0.12	5606300001	Chain of Rocks Levee	0.0239	Polyline ZM	C:\Base Mode\discretization file\breach9.txt
	10	5601040001	0.118	0.123	5606300001	Chain of Rocks Levee	0.009146	Polyline ZM	C:\Base Mode\discretization file\Breach10.txt
	11	5601040001	0.119	0.1239	5606300001	Chain of Rocks Levee	0.008851	Polyline ZM	C:\Base Mode\discretization file\Breach11.txt
	12	5601040001	0.1205	0.1239	5606300001	Chain of Rocks Levee	0.006879	Polyline ZM	C:\Base Mode\discretization file\Breach12.txt
	13	5601040001	0.1215	0.1239	5606300001	Chain of Rocks Levee	0.005892	Polyline ZM	C:\Base Mode\discretization file\Breach13.txt
	14	5601040001	0.122	0.124	5606300001	Chain of Rocks Levee	0.004948	Polyline ZM	C:\Base Mode\discretization file\Breach14.txt

Figure 6-10: Breach discretization file archived into Breach Location feature class.

6.5 Run GSSHA and Archive

With everything in place, we executed the *Simulate Flood and Archive* geoprocessing tool. As seen in Figure 6-10, we ran the flood simulation at breach_ID equal to14, with a starting breach elevation of 126 meters and an ending elevation of 125 meters. The upstream hydrograph was estimated based on the peak discharge of 1,080,000 cubic feet per second or roughly 31,000 cubic meter per second measured in St Louis on the Mississippi river on August 1993.

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When the simulation was complete GSSHA wrote out the solution file (.dep). The solution contains the water level of each cell at each time period. The tool analyzed the solution file and calculated the maximum depth and inundation area. Finally, it exported the results into the simulation summary table, seen in Figure 5-12.

6.6   Export Simulation to KML

Once the GSSHA simulation was finished, it was exported to a KMZ file using the *Export Simulation to KML* geoprocessing tool. The tool automatically traced down the file path to the solution and the project files and then ran WMS to generate the KMZ file. Finally the KMZ file was archived to the simulation summary table, seen in Figure 5-12.

6.7   Export to Google Earth

The final step was to export all the information into Google Earth using the *Export Breach Location to KML* geoprocessing tool, seen in Figure 5-15. In this case study, we only export the flood simulation associated with breach ID 14, seen in Figure 5-12.

To illustrate the capabilities of flood simulation using GSSHA, we include a series of flood simulation shown in Figure 6-11 and Figure 6-12. The simulation shows both flooding and draining of the protected area.
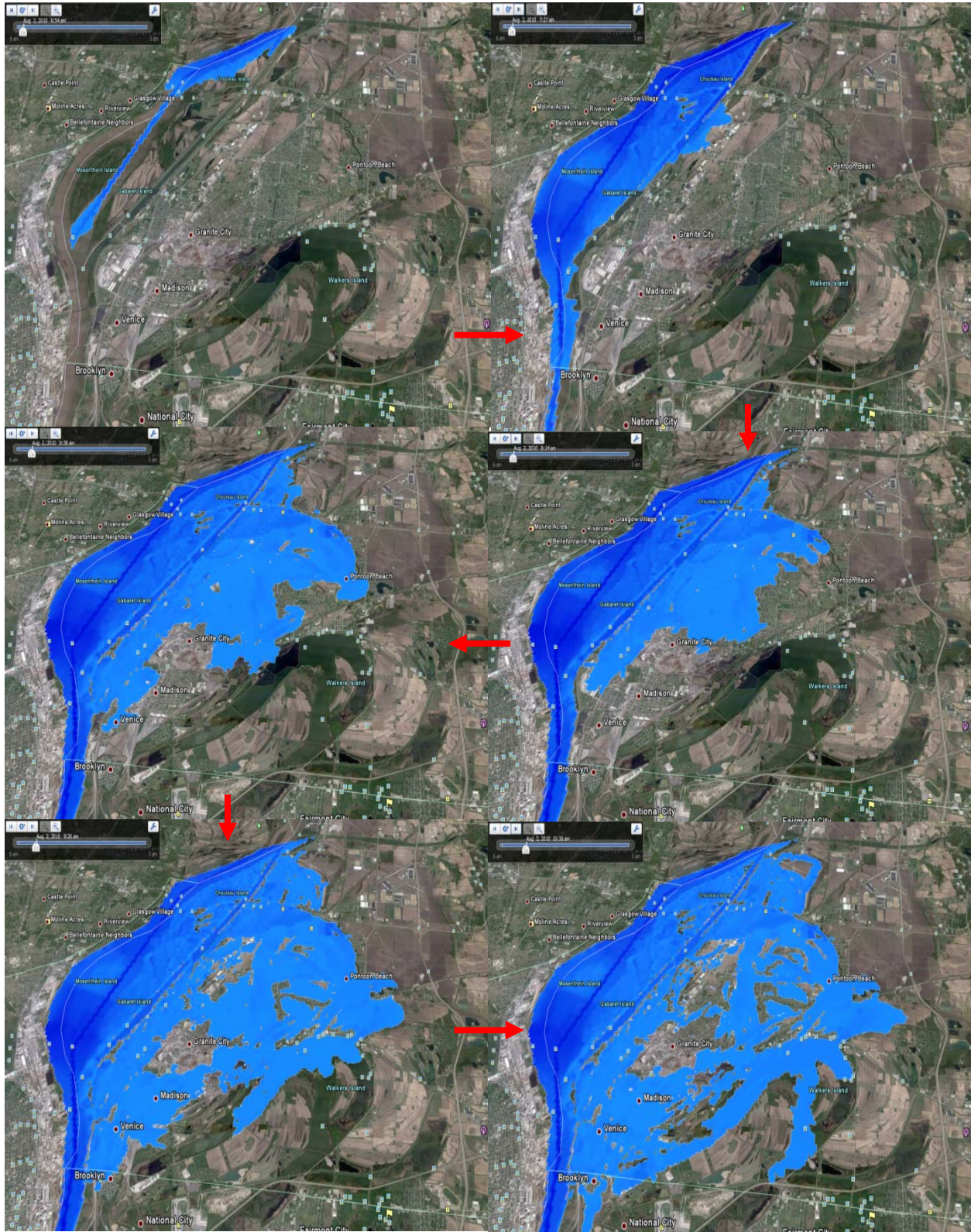
Figure 6-11: Flood simulation in Google Earth using GSSHA model- part 1.
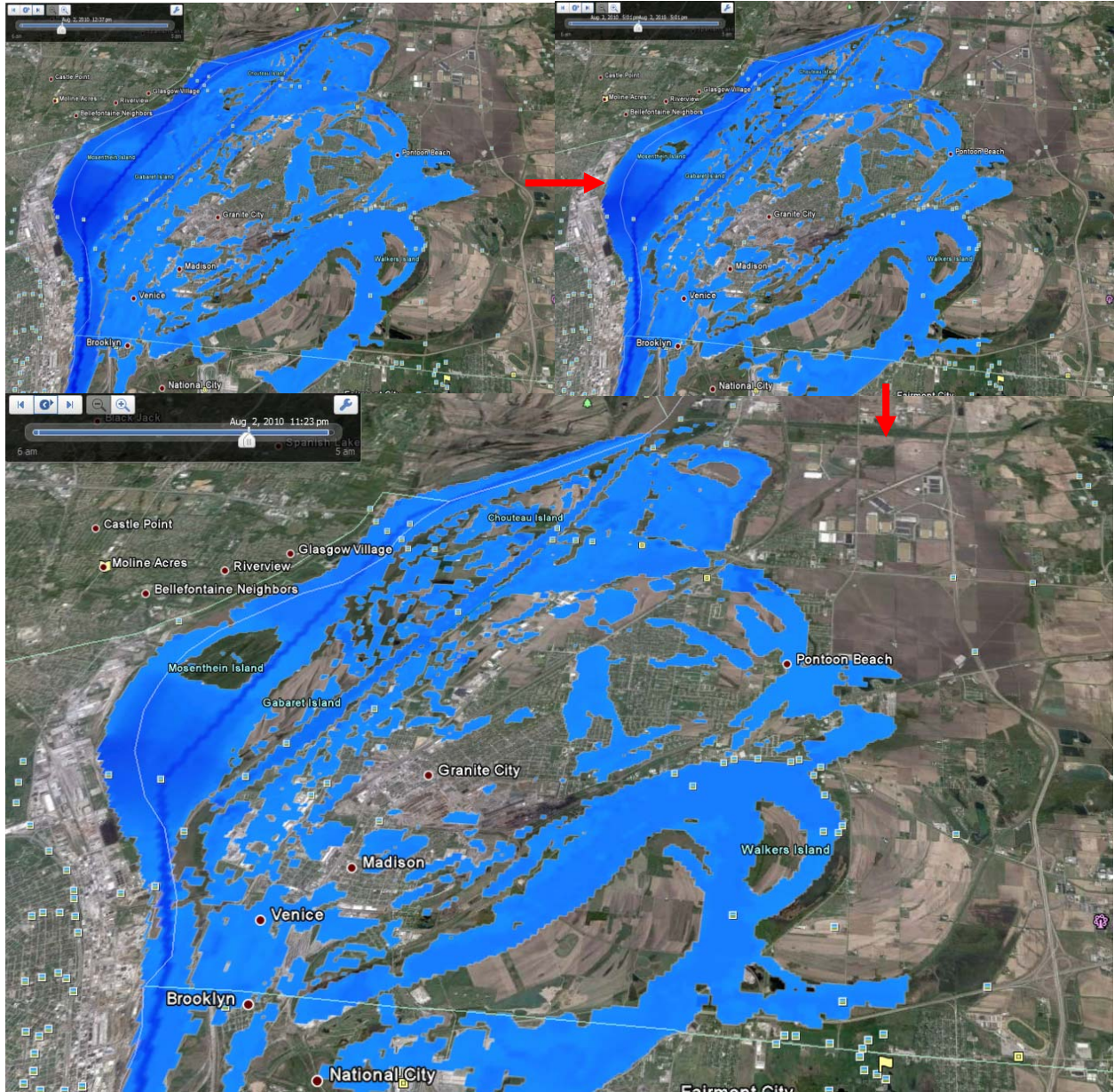
Figure 6-12: Flood simulation in Google Earth using GSSHA model - part 2.

The flood started at the first image as the water began to come out of the river. In the top right corner, we see the time and day of this even which is at 6:54 am on August 2, 2010. On the third image, we can see the first two cites had been flooded are Pontoon Beach and Venice around 8:38 am on the same day. It means the people living in Pontoon Beach and Venice have

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approximately 70 minutes to evacuate when the flood occurs. The sequence of images also shows the inundation area of Granite City. The flood had never reached the central and the close by area of the city. The flood did not reach Fairmont City and other southern cities.

These images can also be used for recovery planning. We can estimate the water would drain out of Granite City around 5:00 pm on the same day. This isn't the case for other cities. The water was still there after one and half days. Other solutions such as pumping might be considered.

7   CONCLUSIONS

The original Levee Analyst Data Model was designed to provide a central location, fully compatible with the NLD geodatabase, for storing large amount of levee seepage and slope stability. (Thomas 2009) This research sought to expand the capability of Levee Analyst Data Model for storing flood simulation to assist the National Levee Safety Program on critical decision-making.

7.1   Research Accomplishments

This research successfully implements the prototype system for doing automated levee breach analysis using GSSHA model. This research not only shows the capability and potential of using GSSHA for flood simulation but also the possibility of using other flood models beside GSSHA.

7.2   Future Developments and Research

The automated levee breach analysis requires the user to specify the breach location. The extended Levee Analyst toolbox might combine the levee seepage, slope analysis from the existing Levee Analysis data model and the river stage generated by GSSHA to decide where the breach might occur.

The first limitation of the current prototype system is that the system only allows one base model for each protected area. This means the flood can only effect on one side of the river.

This will not likely happen for a catastrophic flood. The second limitation of the current prototype system is that GSSHA model only is only capable of simulating levee breach with fixed length for each simulation. This doesn't represent how the breach occurs in real life. Research shows that the breach typically starts with a triangular shape until it reaches the embankment base. (O'Brien, 2010)

Even though, the GSSHA simulation shows great potential for flood analysis. The reliable and accuracy of GSSHA model needs to be tested more. Further research can also decide on which flood model, described in Chapter 2, is most suited for the automated levee breach analysis system.

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