FINAL REPORT TO USGS OHIO WATER RESOURCES CENTER

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Grant Title: A Hydraulic Modeling Framework for Producing Urban Flooding Maps in Zanesville, Ohio

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PROBLEM AND RESEARCH OBJECTIVES

This project examines the flooding dynamics along the Muskingum River near the city of Zanesville, Ohio. Simulating various peak flood events using a hydrodynamic model will provide Muskingum County engineers with valuable information regarding inundated areas, extent, and effect on local communities for different flood events. The impact of various Muskingum River flood events, including the 100 year flood, on the urban environment in Zanesville, Ohio was studied. The project provides a useful hydraulic modeling framework that produces urban flooding maps for the city of Zanesville. These maps show how water surface elevations and water depths vary spatially and temporally, and will provide a more detailed picture of how flood waves move in urban environments. A hydrodynamic model called LISFLOOD-FP is used to simulate river flow and flooding. LISFLOOD-FP is a finite-difference flood inundation model that can accurately model 1D channel flow along with 2D floodplain flow. LISFLOOD-FP is a well-established hydrodynamic model that has been proven to properly simulate flood inundation for fluvial, coastal, and urban events.

The Federal Emergency Management Agency, FEMA, conducts flood insurance studies to identify a community's flood risk. The flood risk study is based upon statistical data for river flow, storm tides, hydrologic and hydraulic analyses, and rainfall and topographic surveys. The FEMA maps only provide a one-time snapshot of a flood, and do not describe the full extent of the flood event including the spatial and temporal variability of various flood events. Questions, such as the changes in flood inundation extent with time for the city of Zanesville, cannot be fully explored using the FEMA maps. It has been shown that accurate mapping of urban flooding events must take hydraulic connectivity and mass conservation into account. In other words, extending potential flood elevations along lines of equal elevation given a river elevation, the so-called "Planar GIS method," may be inadequate for characterizing urban flooding. An alternative approach involves the simulation of hydraulic processes, which would control flooding and inundation patterns in downtown Zanesville given the FEMA 100 year Muskingum River main stem water surface elevation. Such an approach provides the framework, not only for producing dynamic maps of different frequency flood events for the city of Zanesville, but also evaluating the impacts of adding and/or removing structures or changing land use on urban flooding.

PERSONNEL

This work was done by Mr. Jeremiah Lant, and makes up his Master of Science thesis under Prof. Doug Alsdorf in the Geodetic Science division of the School of Earth Sciences. Mr. Lant defended his M.S. thesis on 24 May, 2011, and is currently finalizing the thesis document to be filed with the University.

METHODOLOGY

The objective of this research project was to create an urban flood study using a 2D hydrodynamic model, LISFLOOD-FP, for the city of Zanesville, Ohio. Flood inundation on a floodplain is controlled by the overlying topography and friction. Such flow is spatially complex, especially in the urban environment, with varying patterns of water velocity and depth that are two dimensional in space and dynamic in time. The creation of flood maps of water surface elevation and depth that provide a dynamic picture of flood inundation in the urban environment require a two dimensional hydrodynamic model. The LISFLOOD-FP hydrodynamic model is a two dimensional storage cell hydrodynamic model based on a finite difference scheme that can accurately simulate floodplain inundation in urban environments. The purpose of the LISFLOOD-FP code is to help improve understanding of flood hydraulics, flood inundation prediction, and flood risk assessment.

A 5 meter DEM derived from a 2.5 foot LIDAR dataset from the Ohio Geographically Referenced Information Program, OGRIP, was used. For an urban flooding scenario, building heights for the city of Zanesville, acquired from the Muskingum County engineers' office, were added onto the high resolution bare earth DEM using the same techniques to change the channel cell values. Muskingum River cross-sections are from 1934 Army Corps of Engineer maps. These maps were acquired from the Ohio Department of Natural Resources. Average bed elevations at each data cross-section were computed within the river channels. From the Federal Insurance Study (FIS) conducted for the city of Zanesville, FEMA defined the 100 year flood discharge along the Muskingum River near the city of Zanesville, Ohio to be 68,000 cubic feet per second, and the 100 year flood discharge along the Licking River below the Dillon Dam to be 7,200 cubic feet per second. To show the spatial and temporal evolution of a possible 100 year flood for Zanesville, hydrographs from the USGS for the Muskingum River and Licking River with peaks nearest the FEMA defined 100 year flood discharge were found and used. These hydrographs consisted of a twelve day flood event. Each hydrograph was linearly scaled to match the respective FEMA peak.

PRINCIPAL FINDINGS AND SIGNIFICANCE

The study produced a model framework that yields dynamic urban flood maps of Zanesville. The framework was built around simulating a FEMA-defined 100 year flood. Modeling efforts demonstrate similar flood profiles and water surface elevations when compared to FEMA (Figure 1). The flood maps show how a 100 year flood wave evolves over time.

A comparison study was made between 1D HEC-RAS and 2D LISFLOOD-FP models. Results have shown that both models produce comparable water surface elevations within the river channel and on the floodplain (Figure 2). With the model framework built, simulations of other flood events can be completed. Since the heart of Zanesville is fairly protected from the 100 year flood, an investigation into the amount of discharge needed to reach downtown Zanesville was conducted. It was found that a massive flood wave, over 100,000 cfs, might be needed to inundate the entire downtown area of Zanesville (Figure 3). A flowrate of this magnitude is approximately 50% greater than the 100 year flood utilized in the FEMA study. Although highly improbable, the dynamic mapping of this flood event provides a deeper understanding of how flood waters could move in the urban environment. A flood event case with data from USGS Streamstats was completed to analyze how a flood might impact Zanesville without the influence of any flood control structures. Without such flood control structures, Zanesville would be seriously inundated if a 100 year flood occurred.

The model framework built in this study allows the sensitivity of climate change and urbanization on the FEMA 100 year water surface elevations and extent to be analyzed. A follow-on study could, ideally, use this framework to further explore changing flooding patterns in an urban environment due to dam sedimentation, land use and land cover change, climate change, and urbanization. This study of urban flooding on the Muskingum River also represents an opportunity to more fully understand the performance of the upcoming Surface Water Ocean Topography Mission, SWOT (http://swot.jpl.nasa.gov), over modest sized rivers in an urban environment. The SWOT satellite will have the capability of measuring temporal and spatial changes in water surface elevations and inundated areas for fresh water bodies around the world. From these measurements, depth and discharge along much of the Muskingum River can be extracted and used in hydrodynamic models like LISFLOOD-FP. Better knowledge of discharge on the Muskingum River will provide a valuable insight into how floods travel through the floodplain and affect the urban environment.

CONCLUSION

Mr. Lant has completed the construction of the hydraulic framework for testing flooding scenarios in Zanesville. Several example scenarios were presented here. The work formed the bulk of Mr. Lant's M.S. thesis, and was presented at four conferences, including ASCE and AWRA. We plan to submit a full-length journal manuscript on this work in the upcoming months.

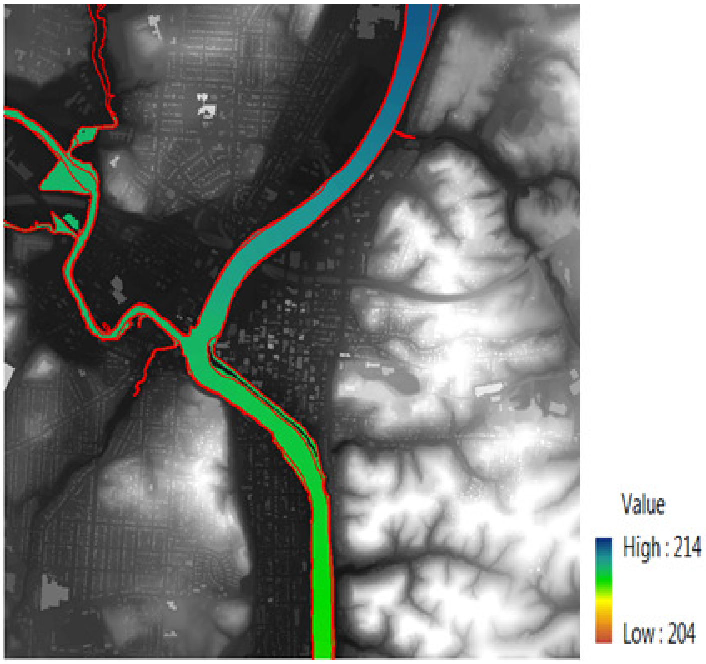

Figure 1. LISFLOOD-FP flood extent shows good agreement with FEMA 100 year flood extent (red). Water surface elevation values are in meters.

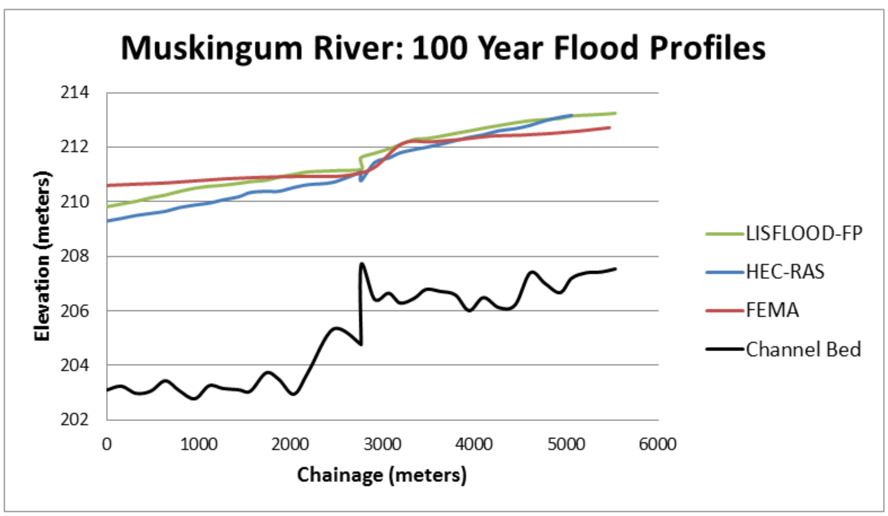

Figure 2. Comparison of water surface profiles.

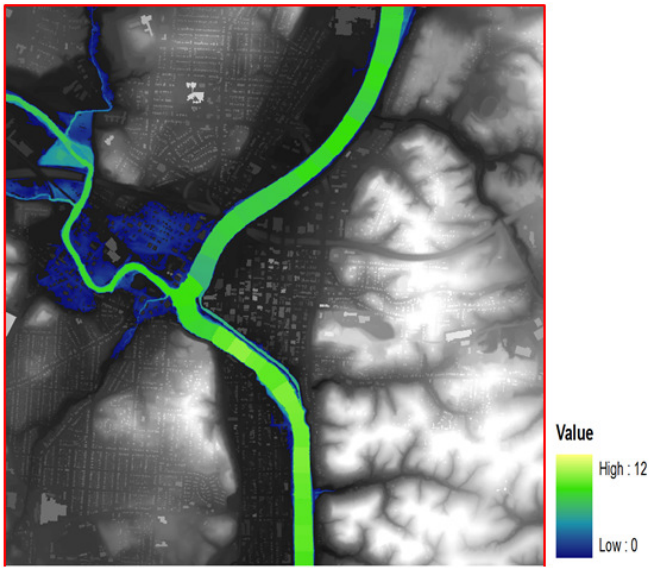

Figure 3. Water depth map of increasing FEMA flood peak by 50%. Water depths are in meters. The city of Zanesville is inundated with water depths ranging from 0.1 meters to 1.5 meters.

Master of Science Thesis

Lant, Jeremiah, 2011, A Hydraulic Modeling Framework for Producing Urban Flood Maps for Zanesville, Ohio, MS Thesis, Division of Geodetic Science, School of Earth Science, The Ohio State University, Columbus, Ohio, 50 pp.

Conference Presentations

Lant, Jeremiah, Michael Durand, and Doug Alsdorf, 2009, Hydrodynamic modeling of the Muskingum River near Zanesville, Ohio, paper presented at the Water Management Association of Ohio 2009 meeting, 4-5 November, Columbus, Ohio.

Lant, Jeremiah, Michael Durand, and Konstantinos Andreadis, Doug Alsdorf, 2010, Hydrodynamic Modeling of the Muskingum River near Zanesville, Ohio, paper presented at the American Society of Civil Engineers Environment and Water Resources Institute Watershed Management Conference meeting, 23-27 August, Madison, Wisconsin.

Lant, Jeremiah, Michael Durand, and Konstantinos Andreadis, Doug Alsdorf, 2010, A hydraulic modeling framework for producing urban flooding maps in Zanesville, Ohio, paper presented at the American Water Resources Association meeting, 1-4 November, Philadelphia, Pennsylvania.

Lant, Jeremiah, Michael Durand, and Konstantinos Andreadis, Doug Alsdorf, 2010, A hydraulic modeling framework for producing urban flooding maps in Zanesville, Ohio, paper presented at the Water Management Association of Ohio 2009 meeting, 17-18 November, Columbus, Ohio.