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INUNDATION MAPPING EMPLOYING HYDRAULIC MODELING AND GIS: CASE STUDY TAR RIVER DURING HURRICANE FLOYD

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1. INTRODUCTION

Storm induced flooding event is a major concern in many regions of the world (M.R. Knebl et al. 2005). Annually in the United States, this natural hazard causes $6 billion in losses, 160 deaths, damage to infrastructure and economic disruption (USGS, 2006). In order to reduce the effects of this natural hazard, emergency responders, policy makers and general public need accessible, simple and clear information. Previous studies have shown that hydraulic models and GIS are efficient tools to develop inundation maps (D.Z. Sui, 1999; Aschwanden, 2008). As part of an effort to help mitigate the effects of these kinds of events, the National Weather Service (NWS) recently began to provide static inundation maps developed at selected river forecast points through the Advanced Hydrologic Prediction Service (AHPS) web pages (http://www.weather.gov/oh/ahps/). Additionally, NWS is in the process of integrating the US Army Corps of Engineers (USACE) Hydrologic Engineering Center-River Analysis System (HEC-RAS) software into the NWS Community Hydrologic Prediction System (CHPS). HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels (Brunner, G. W. 2006).

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HEC-RAS has the capability of performing the analysis in steady state (simplistic approach; flow does not change through time) and unsteady state (More complex and realistic approach). Use of HEC-RAS should enable more rapid implementation of new dynamic hydraulic routing models at forecast points. We hypothesize that flood forecast maps produced from real-time, dynamic models will be more accurate than maps produced using the static mapping approach. Here we describe a case study designed to test this hypothesis as well as examine how the HEC-RAS models perform between calibration points, since the observations along the river that aid the model calibration are scarce. We need to understand the uncertainties adhered to the model and its resultant flood extent maps in order to deliver clear information.

In this study, we used Geographic Information System (GIS) through an ArcMAP 9.2 extension, HEC-GeoRAS. The HEC-GeoRAS provide the tools to develop and modify HEC-RAS model geometries as well as to perform flood extent mapping analysis. We employed this GIS tool to geo-reference a HEC-RAS model and to facilitate the mapping processes results analysis. The objective of this project is to evaluate two HEC-RAS models from a section of the Tar River basin at Greenville, North Carolina, during the Hurricane Floyd. One model was run in steady state mode and another in unsteady state mode. Then the model results were analyzed with the HEC-GeoRAS to produce the flood extent polygons. In terms of how well the model perform between calibration points we compared in situ observations with the results obtained from the steady state HEC-RAS model and found that the accuracy decreases with distance from the lower boundary calibration point. Although the comparison of steady and unsteady modeling results is still in progress, the preliminary results reinforce our confidence that this model and the application of GIS can produce valuable information that can be easily used and understood by watershed managers, emergency responders, and land use planners.

2. SPATIAL AND TEMPORAL ATTRIBUTES

2.1 Study Area:

The Tar River is 346 km long and drains an area of 5,571 km². The Tar River below Tarboro was modeled with HEC-RAS and flood maps were created for a small segment of the Tar River Basin at Greenville, North Carolina (Figure 1). The city of Greenville in Pitt County is susceptible to flooding from the Tar River. Greenville is located in the north central coastal plain region of Eastern North Carolina, approximately 136.7 km east of Raleigh, North Carolina's capital. Greenville is approximately 140.0 km west of the Atlantic Ocean and approximately 426.5 km south of our nation's capital, Washington, DC. Pitt County has a population of 133,798, and the City of Greenville has a population of 76,058. Pitt County has a relatively mild climate and experiences all four seasons each year. The average summer temperature is 84^{o}F while the average winter temperature is 44^{o}F. The average yearly rainfall for Pitt County is approximately 121.9 cm (Greenville web)

2.2 Rainfall Event:

Hurricane Floyd, which made landfall near Cape Fear, NC on September 16, 1999, passed near Greenville and the flood stage was recorded. Floyd made landfall at Cape Fear, NC dumping another 25.4–50.8 cm of rain east of Interstate 95. In the space of only two weeks, parts of eastern North Carolina received up to 76.2 cm of rainfall, or a full 60% of the 121.9 cm yearly average (Colby, 2000). The flood extent was larger than the 100 year flood plain and in some sites even exceeded the 500 year flood plain.

3. METHODS

A United States Geological Survey calibrated HEC-RAS model of the Tar River at Greenville, NC, were modified employing ArcMap 9.2 and HEC-GeoRAS in order to produce flood extent maps for the hurricane Floyd event (Figure 2). The main modification that was done on this model was to define the Spatial Reference (NAD 1983 StatePlane NC FIPS 3200Feet). Several steps were needed to complete this process. The first step was to manually digitize the Tar River center line, as a shapefile format, utilizing the HEC-GeoRAS geometry pre-processor tools and background Aerial Pictures and Digital Topographic Maps as guidance to indentify the river location. These images and other data were retrieved from the NC Department of Transportation GIS website (http://www.ncdot.org/IT/gis/). The rest of the shapefiles required by HEC-GeoRAS; river banks, flow path lines and cross sections, were also created although the only imported into the HEC-RAS model was the river centerline. Then some cross-sections were modified to avoid intersection among other cross-sections. Subsequently we compared the hydraulic model geometries with aerial images to verify the spatial reference accuracy. Since both images matched well, we proceed to declare the hydraulic model as geo-referenced (Figure 3). Then we ran the model and exported the calculated surface water elevation into the GIS as Xml format and processed the results with the HEC-GeoRAS mapping tools. The initial step for the HEC-GeoRAS mapping process is to transform the HEC-RAS results into GIS format. Then the bounding polygon was determined, followed by the water depth calculation, and finally the flood extent delineation for each water surface elevation (WSE). We focus this study on the maximum WSE and the resultant flood extent polygon, which is when the river stage reached 8.4 m (Figure 4).

4. RESULTS

Inundation maps were produce showing the calculated flood extent at peak flow during the Hurricane Floyd event. This flood extent map compared reasonably well with the maps available at the AHPS webpage. In terms of how the model results (steady-state only) compare with the field observations (High water marks), we have found that the model is underestimating in average by a foot (Table 1) and the percentage of error decreases with distance from the lower river calibration point. Unfortunately, there are not sufficient High water marks to produce a reliable statistical analysis (Figure 5).

5. DISCCUSION AND CONCLUSION

After processing and editing the two models we have found that the HEC-RAS models are valuable tools for inundation mapping, if:

- The cross-sections cover the entire floodplain. Although the comparison between the calculated flood extent maps and the AHPS maps matched reasonable well some areas that were flooded did not showed on the HEC-RAS maps since the river cross-sections were not long enough. It is key that the geometries of a HEC-RAS model designed to produce flood mapping analysis cover the areas vulnerable during extraordinary events like Hurricane Floyd.
- The HEC-RAS models need to be geo-referenced. Considering that the final product will be a map, it is crucial that the hydraulic model is georeferenced from the beginning in order to reduce the uncertainty added through the geo-referencing processes.
- High resolution elevation data is used for the flood extent calculations. The high resolution elevation models produce maps with more details. This improvement could help on the evacuation planning and possibly will be the difference in evacuating whole cities or just areas more vulnerable to get flooded.
- It is crucial to understand how the uncertainties in the model and the flood analysis affect the final map in order to identify the possible error along the map and its flood probabilities. The results of the comparison between the in situ observations and the calculated WSE by the steady-state model suggest that the error decreases toward the lower calibration point. This could be related to the type of data that the models require for the lower boundary which is the river stage instead of river discharge. However, more studies are needed in order to identify the reason of this trend.

Further analysis is needed to complete our comparison of the steady and unsteady models. We plan to compare the inundated area from the steady flow model generated with the flood peak flow to the maximum inundated area at each cross-section produced by the unsteady flow model.

With the possibility of increasing frequency and intensity of rainfall events with climate changes, increasing populations and the associated land use changes in coastal areas, it is becoming more important to develop accurate models that will predict the effects of rain events for both emergency management and development planning. Although there is still research needed in order to accurately take into account the different uncertainties and how they affect the flood extent maps, this approach employing hydraulic model and GIS has proved to be a great tool which can produced simple and clear data for the public.

6. AKNOWLEDGEMENTS

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7. REFERENCES

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Greenville, NC (2009) website http://www.greenvillenc.gov

8. ILUSTRATIONS AND TABLES

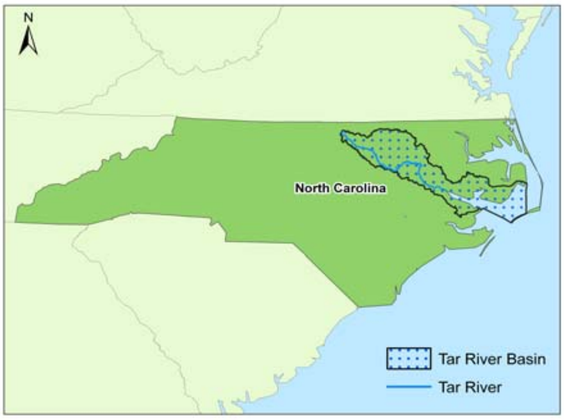

Figure 1: Tar River Basin, NC.

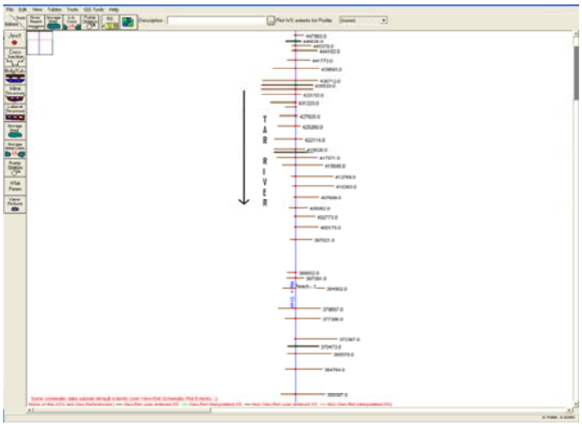

Figure 2: Screen preview of the USGS calibrated HEC-RAS model geometries for the Tar River at Greenville, NC (before geo-referenced).

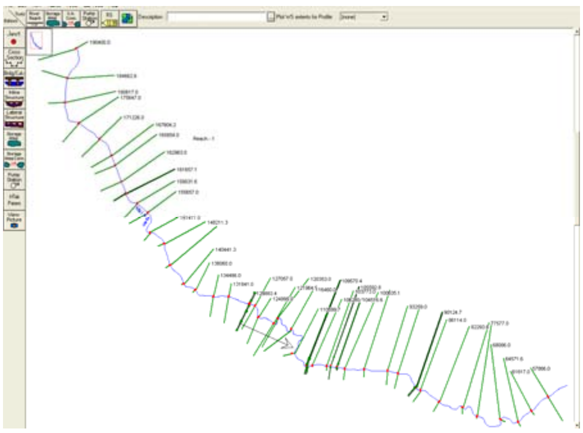

Figure 3: Screen preview of the USGS calibrated HEC-RAS model geometries for the Tar River at Greenville, NC (after geo-referenced).

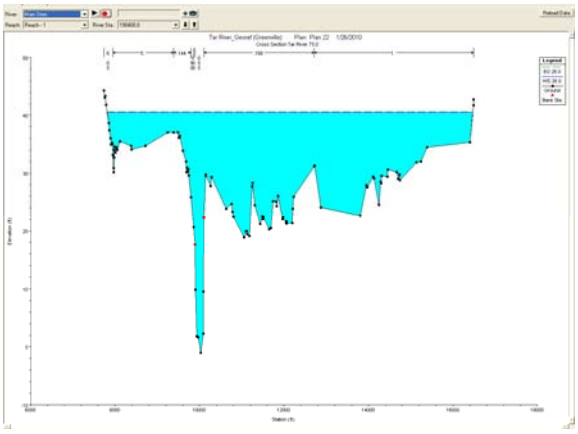

Figure 4: Cross-section view for Tar River HEC-RAS model at peak flow (8.2 m) during Hurricane Floyd.

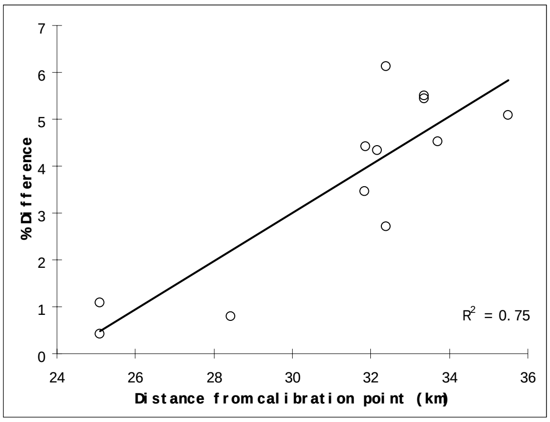

Figure 5: This line is showing how the Percentage of Error Increases with distance from the Lower Boundary Calibration Point in the Tar River Steady-state HEC-RAS model.

Table 1: This table illustrates the summary of the high water marks (HWM) and the HEC-RAS Water Surface Elevation (WSE) comparison. According to this data the average error presented by the model is 0.3 m.

Distance	HWM (m)	HEC-RAS WSE (m)	Error	% Error
25.08	7.0	7.1	0.1	1.1
25.08	7.4	7.4	0.0	0.4
28.43	7.6	7.6	0.1	-0.8
31.84	8.2	7.9	0.3	-3.5
31.86	8.4	8.0	0.4	-4.4
32.17	8.4	8.0	0.4	-4.3
32.39	8.6	8.1	0.5	-6.1
32.39	8.3	8.1	0.2	-2.7
33.36	8.7	8.2	0.5	-5.5
33.36	8.7	8.2	0.5	-5.4
33.71	8.7	8.4	0.4	-4.5
35.50	8.9	8.4	0.5	-5.1