Effects of Land-Use Change (1938–2018) on Surface Runoff and Flooding in the Amite River Basin, Louisiana, USA Using Coupled 1D/2D HEC-RAS–HEC-HMS Hydrological Modeling

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Abstract

Formed by Mississippi River sediments, south Louisiana is a flat, low-lying coastal region with high-clay content soils and heavy annual precipitation that is particularly susceptible to damage caused by extreme storms and flooding. In August 2016, a stationary storm system caused over 50 cm of rain to fall across much of southeast Louisiana. Largely rural, the major trends in the hard-hit Amite River Basin have been conversion of agricultural land to forest beginning in the mid-20th century and rapid urbanization and development spurred by economic and population growth in the Baton Rouge area following the oil boom of the 1970s, as well as later waves of migration following Hurricane Katrina and the 2016 floods. This analysis examines the effects of spatially and temporally changing land use on runoff and flooding within the watershed and is part of a larger research project which seeks to also quantify the relative impacts of changes in precipitation and planform geometry. To quantify the effects of land-use change on flooding, runoff curve number (CN) maps were created using NRCS soil type data and USGS land cover data. Areas with a higher CN experience less interception and infiltration of surface water and the flood risk is consequently greater. While CN for the Basin overall dropped from 86 to 79 between 1938 and 2018, CN dropped from 82 to 70 in rural areas due to reforestation and increased from 86 to 90 in the southern portion of the Basin due to urbanization. These data were then input into the HEC-HMS and coupled 1D/2D HEC-RAS components of a numerical model of the Amite River Basin. Flooding behavior under different design storms and land cover conditions was then observed and quantified. In examining the major contributing factors to flooding in south Louisiana, this research project aims to create a more comprehensive understanding of flooding and propose potential mitigation strategies and design interventions for alleviating the worst effects.

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Abstract: Formed by Mississippi River sediments, south Louisiana is a flat, low-lying coastal region with high-clay content soils and heavy annual precipitation that is particularly susceptible to damage caused by extreme storms and flooding. In August 2016, a stationary storm system caused over 50 cm of rain to fall across much of southeast Louisiana. Largely rural, the major trends in the hard-hit Amite River Basin have been conversion of agricultural land to forest beginning in the mid-20th century and rapid urbanization and development spurred by economic and population growth in the Baton Rouge area following the oil boom of the 1970s, as well as later waves of migration following Hurricane Katrina and the 2016 floods. This analysis examines the effects of spatially and temporally changing land use on runoff and flooding within the watershed and is part of a larger research project which seeks to also quantify the relative impacts of changes in precipitation and planform geometry. To quantify the effects of land-use change on flooding, runoff curve number (CN) maps were created using NRCS soil type data and USGS land cover data. Areas with a higher CN experience less interception and infiltration of surface water and the flood risk is consequently greater. While CN for the Basin overall dropped from 86 to 79 between 1938 and 2018, CN dropped from 82 to 70 in rural areas due to reforestation and increased from 86 to 90 in the southern portion of the Basin due to urbanization. These data were then input into the HEC-HMS and coupled 1D/2D HEC-RAS components of a numerical model of the Amite River Basin. Flooding behavior under different design storms and land cover conditions was then observed and quantified. In examining the major contributing factors to flooding in south Louisiana, this research project aims to create a more comprehensive understanding of flooding and propose potential mitigation strategies and design interventions for alleviating the worst effects.

Background and Study Area

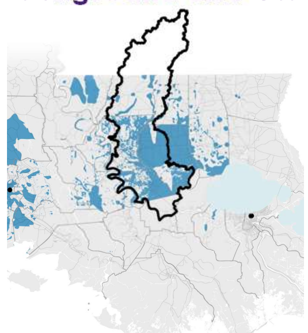

Fig. 1: Extents of the August 2016 floods, with Amite basin overlaid. (Modified from https://www.nytimes.com/interactive/2016/08/22/us/louisiana-flooding-maps.html)

- The Baton Rouge region has a high flood risk due to the Amite River Basin's flat topography, high precipitation, and clayey soils
- The August 2016 storm caused record levels of flooding in many areas
- A total of 13 deaths and $10-15 billion in property damage were attributed to the floods
- Pulses of rapid urban growth during the 1970s and early 21st century drew focus away from city development plans that incorporated networks of connected parks and waterways

Methods

- NRCS Curve Number (CN) method was used as preliminary tool to identify overall changes in the watershed (CN is a direct function of soil properties and land use)
- Two major trends were identified: 1) reforestation in the north which decreased CN and potential for runoff, and 2) urban growth in the southern part of the basin which led to increased runoff potential and CN

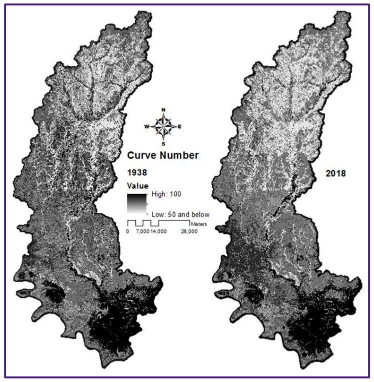

Fig. 2: Change in runoff potential (as indicated by CN values). Darker areas have higher CNs and runoff potential, while lighter areas have lower CNs and more absorptive potential

HEC-HMS

- The USACE's HEC-HMS hydrology modeling software was used to calculate the effects of impervious surfaces on hydrologic routing
- Two main methods were used and three main parameters changed
- In Green and Ampt loss method, % impervious value determines the area for which losses will not be calculated
- The ModClark transform method converts gridded precipitation data into point outflows in a subbasin; the two parameters used are time of concentration (TC) and storage coefficient (R)
- Runs for existing conditions and for a "no urban" condition in which all % impervious was set to 0 and TC and R adjusted accordingly

Results

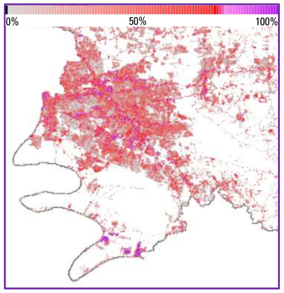

Fig. 3: Closeup showing percent impervious cover by pixel for the Baton Rouge region of the Amite River Basin (NLCD 2011)

- Much of the Amite River Basin is still largely rural, with only11% of its total area urbanized and only 3.6% covered by impervious surfaces
- However, most of the basin's population is concentrated within the Baton Rouge metropolitan area
- Any increase in flood hazard due to urbanization will thus impact a significant set of the population

- Supporting the CN findings, results from HEC-HMS runs of the Aug. 2016 rainfall event indicate significant increases in discharge from runoff in the southern part of the basin
- Subbasins which had a minimum of 5% impervious cover in 2011 experienced an average increase in peak discharge of 19.3% relative to the non-urbanized condition
- Additionally, the decreased time of concentration (TC) and storage coefficient (R) of surface runoff led to peak discharge being reached 49.3 minutes earlier on average across all subbasins under urbanized conditions

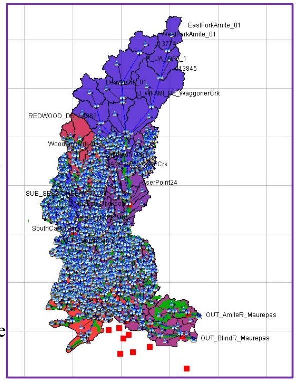

Fig. 4: Overview of the Amite River Basin Numerical Model (ARBNM)'s HEC-HMS component (Dewberry 2019)

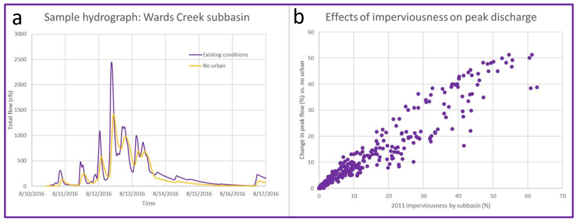

Fig. 5a shows results from HEC-HMS runs of the August 2016 storm event for a heavily urbanized subbasin in Baton Rouge. Fig. 5b shows the effect on peak discharge of surface imperviousness. Together, the results suggest that an increase in imperviousness leads to faster flow of water and less infiltration, resulting in higher and earlier flood peaks.

Discussion

Fig. 6: Aerial shot of flooding in Baton Rouge, LA in Aug. 2016 (staff photo by Bill Feig, theadvocate.com)

- Extreme flooding is a natural feature of low lying and flat coastal regions like southeastern Louisiana; there are upper limits to what engineering interventions can accomplish
- The proliferation of impervious surfaces can exacerbate flood risk, especially if residential neighborhoods are built in existing floodplains without adequate precautions being taken
- Flood hazard mitigation is possible, especially for lower-return period storms; restoring meanders, vegetation, and natural stream flow can help attenuate flood peaks and reduce damage

Future Work

- The HEC-HMS component of the ARBNM links directly to the coupled 1D/2D HEC-RAS component via DSS files; future work will include running the RAS model with the various scenario outputs from HMS
- For more accurate and detailed results, ponding factors and channel bank Manning's n values can also be adjusted

Acknowledgements

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