A Simplified, GIS-Based Method of Estimating River Flood Inundation Extent

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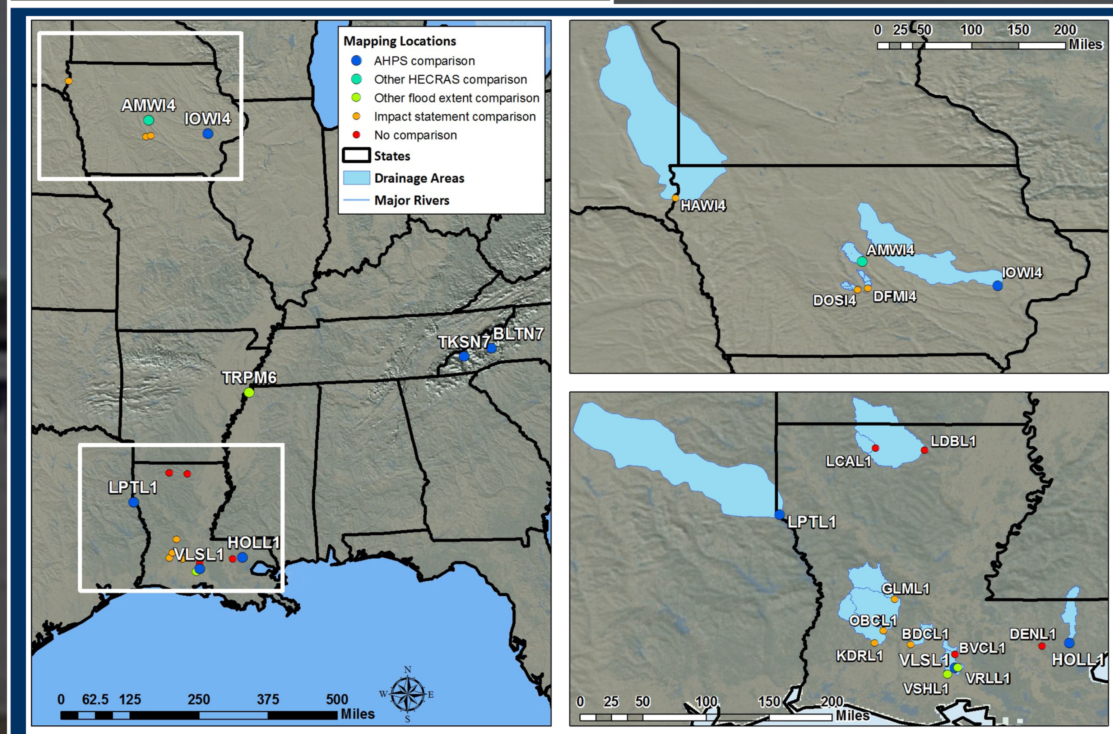
INTRODUCTION

National Weather Service (NWS) customers and partners have identified inundation mapping as a high-priority service, as flooding is the 3rd most deadly weather-related phenomena since 1980. Current procedures within the NWS to create maps of flood inundation extent require a hydraulic study and LiDAR-derived elevation data, both of which involve substantial time and financial resources to produce. Because only a few locations in the U.S. meet both of these requirements, maps can be developed at only a small number of sites and only over a small geographic area around them. A simpler and less time-consuming method of mapping flood inundation has the potential to save significant cost and map many more areas.

A GIS method to estimate water surface profiles was created at the NWS Weather Forecast Office (WFO) Des Moines, IA, and further developed at the NWS Lower Mississippi River Forecast Center (LMRFC) in Slidell, LA. This method, referred to as the LMRFC Flood Inundation Toolset, has been preliminarily tested at WFO Des Moines, IA, WFO Lake Charles, LA, and at the LMRFC. Results from the LMRFC Flood Inundation Toolset were evaluated against locations where current NWS procedures have already generated inundation map libraries and also for a few locations where other flood inundation extent information was available in GIS format. The LMRFC Flood Inundation Toolset, the objective evaluation method, and the conclusions drawn from this evaluation will be presented.

STUDY LOCATIONS



Locations where flood inundation extent maps were created using the LMRFC Flood Inundation Toolset. Locations have been verified using different techniques, as indicated by the color of each point. Existing AHPS maps or other HEC-RAS produced maps are assumed to be the most accurate representation of "observed" flooding for this study.

Compared to an AHPS Location

NWS ID	Site Description
BLTN7	Swannanoa River at Biltmore, NC
HOLL1	Tickfaw River at Holden, LA
IOWI4	Iowa River at Iowa City, IA
LPTL1	Sabine River at Logansport, LA
TKSN7	Tuckasegee River at Bryson City, LA
VLSL1	Vermillion River at Lafayette, LA (Surrey St.)

Compared to Other HEC-RAS Output

NWS ID	Site Description
AMWI4	Squaw Creek at Ames , IA

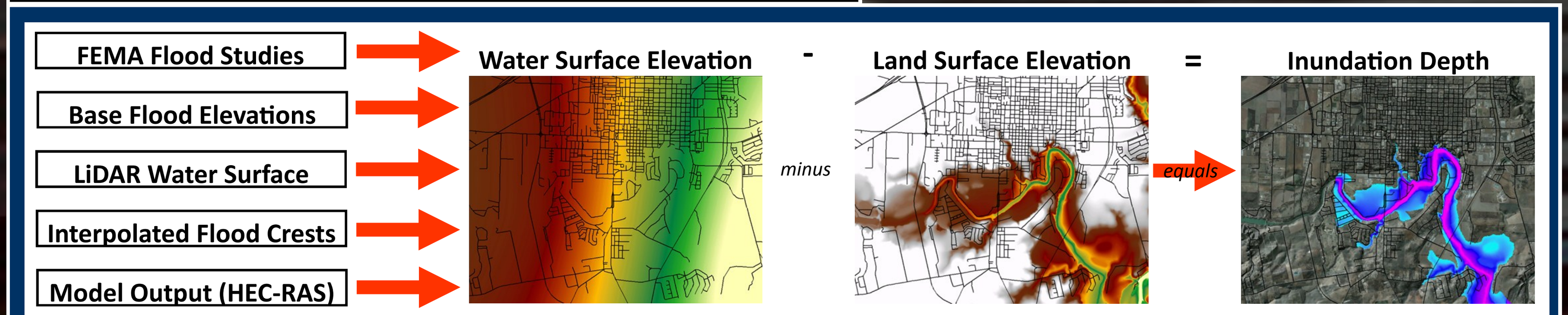
Compared to Actual Flood Extent

NWS ID	Site Description
TRPM6	Mississippi River at Tunica Riverpark, MS

Other Locations Not in Analysis

NWS ID	Site Description
BDCL1	Bayou D'Cannes at Eunice, LA
DFMI4	Fourmile Creek at Des Moines, IA
DOSI4	Walnut Creek at Des Moines, IA
GLML1	Calcasieu River at Glenmora, LA
HAWI4	Big Sioux River at Hawarden, IA
KDRL1	Calcasieu River at Kinder, LA
OBCL1	Calcasieu River at Oberlin, LA
VRLL1	Vermillion River at Lafayette, LA (Lake Martin)
VSHL1	Vermillion River at Lafayette, LA (Broussard Rd.)

INUNDATION MAPPING STEPS



Water Surface Elevation

- Current NWS guidelines require hydraulic model output, typically from HEC-RAS software developed by US Army Corps of Engineers
- Can also be based upon the elevations in a water elevation profile in a river's FEMA flood study, base flood elevations, flood crests interpolated between observation gauges, or extracted directly from a LiDAR survey.
- Tools in the LMRFC Flood Inundation Toolset create a water surface elevation grid from LiDAR surveys, or from manual estimates.

Land Surface Elevation

- Elevation grid from LiDAR survey generally required for adequate mapping; 30m elevation derived from USGS topographic maps not suitable in most cases
- Higher vertical accuracy of elevation grid generally correlates with lower uncertainty in inundation

Inundation Depth

- Estimated depth of water at a given grid location based upon a given water surface elevation

GENERATING A WATER SURFACE PROFILE

Estimating the water surface elevation profile is usually the most important step in the creation inundation maps because in most cases it has the highest uncertainty. Regardless of the source of the water surface profile, the resulting inundation is just an estimate of a hypothetical flood. Every flood is different both temporally and spatially, even if the maximum stage is the same.

The LMRFC Flood Inundation Toolset contains two methods of estimating the water surface profile. The simplest and quickest method is the Water Surface Profile From Points Tool, although it requires a high-resolution land elevation dataset that includes the elevation of the stream/river being evaluated. The other method, the Water Surface Profile From Cross Sections Tool, is likely to produce better results in most cases and should be used when the water surface profile is based upon information from other sources. The cross section method requires more time because of non-automated steps, but seems to produce the best results and thus was used for all the locations in this evaluation.

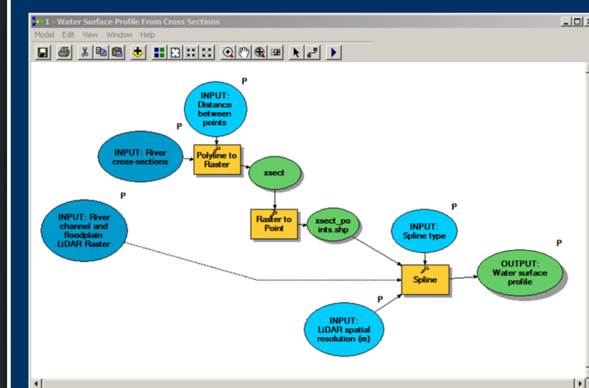
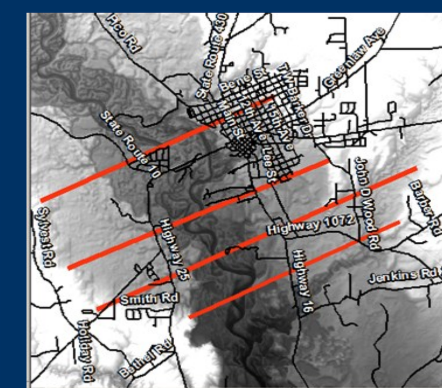
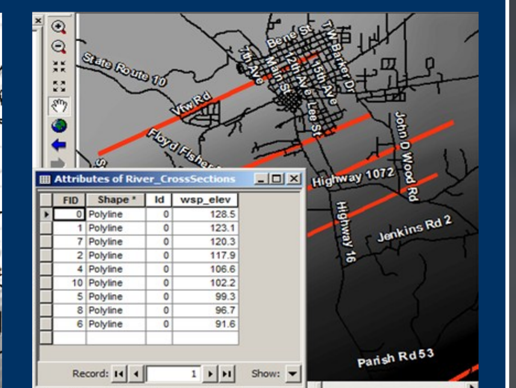


Diagram of the Water Surface Profile from Cross Sections Tool as seen in ArcGIS's ModelBuilder.



Cross sections created for the Water Surface Profile from Cross Sections Tool in a test study area.



Water surface elevations manually entered for each cross section and the resulting water surface elevation upon running the Water Surface Profile from Cross Sections Tool.

GENERATING INUNDATION EXTENTS

Once a water surface elevation profile is created, it can be used to estimate areas of inundation based upon a stage at a reference gauge. The tool used to estimate inundation depth from a water surface profile in the LMRFC River Inundation Toolset is the Inundation From Water Surface Profile Tool.

The Inundation From Water Surface Profile Tool takes the water surface profile and subtracts the land surface elevation. This process is repeated with the water surface profile increased by 1 foot increments. The resulting gridded datasets are estimated inundation depths based upon the indicated water surface profile. The inundation layers can be referenced to a nearby gauge location or can also be used to show relative inundation; thus showing what depth of flooding is expected at the same river/stream stage.

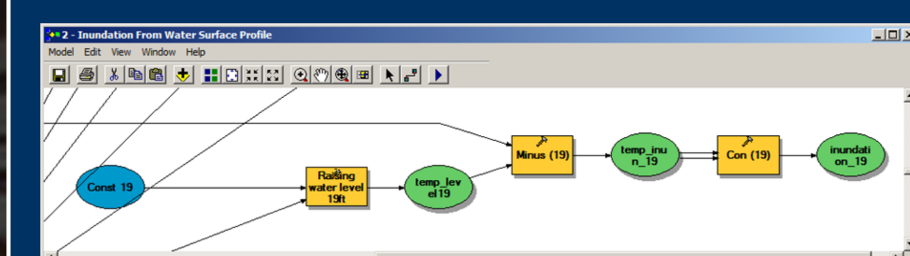
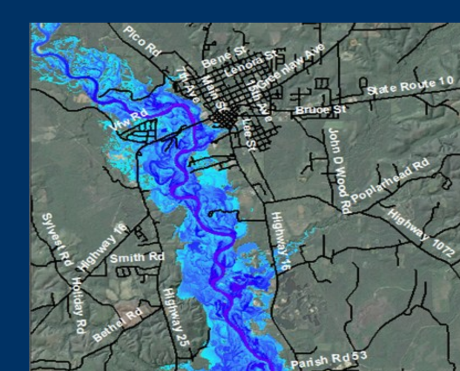


Diagram showing a portion of the Inundation From Water Surface Profile Tool as seen in ArcGIS's ModelBuilder.



An inundation estimate created by running the Inundation From Water Surface Profile Tool.

VERIFICATION & ANALYSIS

Maps of estimated inundation can be verified by comparing results to other modeling studies, aerial surveys and photography taken during a flood event, high water mark surveys, or impact statements from past flood events. Aerial surveys and high water marks are not available for most flood events unless particularly significant, while impact statements are available for more locations but are generalized in regards to flood magnitude and provide little spatial information.

The tool was used at six (6) locations where HEC-RAS was used to estimate flood extent for public use via the NWS AHPS, one (1) location where HEC-RAS modeling was used for a post-flood case study, and one (1) location where flood extent was estimated by aerial photographs and substantial quality control by both the NWS and the US Army Corps of Engineers. For each of these locations, the HEC-RAS output or the post-flood surveys were used as the "observed" flood extent, and the output from the LMRFC Flood Inundation Toolset was used as the "modeled" flood extent. To objectively compare the modeled flood extent to the observed flood extent, the F-score described in Kuiry et al (2010) was used.

Results for both raw output from the LMRFC method and quality-controlled output from the LMRFC method are shown below. Quality control involved correction of only obvious errors, such as flooding of un-connected flow areas and behind levees.

$$F_{score} = \frac{C}{A + B + C}$$

A = Indicated as flooded by the model only

B = Indicated as flooded by observations only

C = Indicated as flooded by both the model and

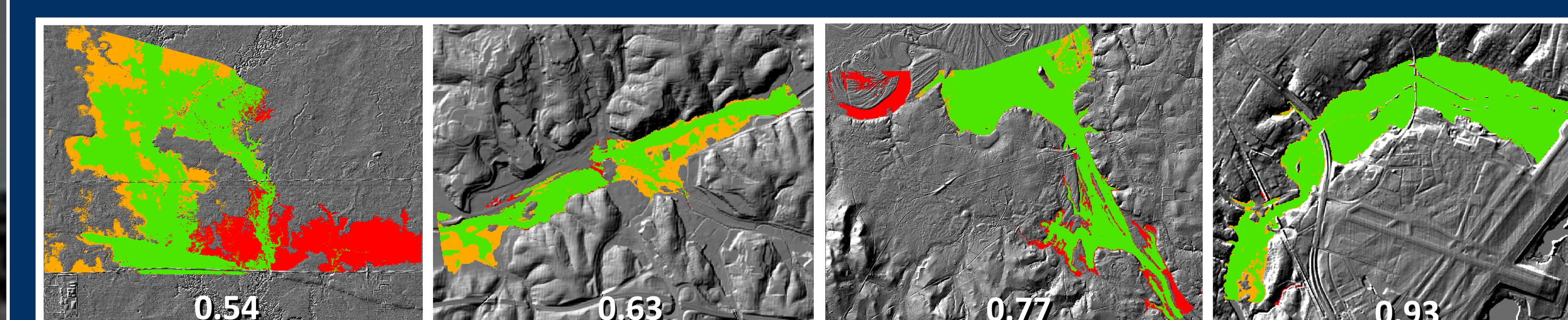
F-scores: Raw Output from LMRFC Flood Inundation Toolset

NWS ID	Minor	Moderate	Major	Record
BLTN7	0.71	0.67	0.63	
HOLL1	0.54	0.68	0.78	
IOWI4	0.64	0.64	0.65	
LPTL1	0.78	0.77	0.77	0.93
TKSN7	0.87	0.85	0.85	0.85
VLSL1	0.68	0.77	0.93	0.96
AMWI4	0.59	0.52	0.74	
TRPM6	0.70	0.65	0.76	0.77
AVG	0.69	0.69	0.76	0.88

F-scores: Output With Manual Quality-Control from LMRFC Flood Inundation Toolset

NWS ID	Minor	Moderate	Major	Record
BLTN7	0.75	0.68	0.63	
HOLL1	0.55	0.68	0.78	
IOWI4	0.74	0.80	0.74	
LPTL1	0.84	0.86	0.85	0.94
TKSN7	0.85	0.86	0.84	0.83
VLSL1	0.84	0.92	0.93	0.96
AMWI4	0.66	0.70	0.80	
TRPM6	0.75	0.79	0.95	0.98
AVG	0.75	0.79	0.82	0.93

F-scores for the evaluated locations at the minor, moderate, and major flood stages as defined by the NWS. Record stages were evaluated where available.



Examples of various F-scores as described by Kuiry et al (2010). Green represents areas where the model and the observations both indicate flooding. Orange represents areas where only the LMRFC method indicates flooding. Red represents areas where flooding was observed but not shown by the LMRFC method.

CONCLUSIONS & FUTURE WORK

Based upon the F-score values for the analyzed study areas, it is shown that the LMRFC Flood Inundation Toolset can vary widely in its ability to adequately estimate flood extent. Common characteristics between locations where the LMRFC method performed best include a well-established floodplain, and a lack of features that can significantly alter the river/stream hydraulics across differing stages. Quality control of obvious issues substantially improved flood inundation estimation by the LMRFC method. Based on this analysis, the LMRFC Flood Inundation Toolset might be a feasible method of estimating flood inundation extent for certain areas.

Future work on the LMRFC Flood Inundation Toolset should include the analysis of more sites to improve confidence in the tool. Sharing the tool with more NWS hydrologists will increase our feedback and may help with improving our techniques used to estimate flood extent where the current strict NWS requirements make traditional modeling unfeasible.

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Kuiry, S.N., D. Sen, and P.D. Bates, 2010: Coupled 1D-Quasi-2D Flood Inundation Model with Unstructured Grids. *J. Hydraul. Eng.*, **136**, 493-506.

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