A SIMPLIFIED GIS-BASED METHOD OF ESTIMATING RIVER FLOOD INUNDATION EXTENT

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1. 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 2001 and possibly the most deadly since 1981 (OCWSS, 2011). Current procedures within the NWS to create maps of flood inundation extent require a hydraulic study and LiDAR-derived elevation data (NOAA NWS, 2011), both of which involve substantial time and financial resources to produce.

Inundation maps made public by the NWS are displayed on the Advanced Hydrologic Prediction Service (AHPS) site after quality-control efforts have been completed at the local, regional, and national levels. In most cases, the estimates of inundation extent are produced from the Hydrologic Engineering Center River Analysis System (HEC-RAS) model developed by the U.S. Army Corps of Engineers (USACE). HEC-RAS is a sophisticated hydraulic model that is consistent with the NWS guidelines on inundation mapping, but model and time requirements preclude many places from being mapped. Because only a few locations in the U.S. meet the current guidelines, maps can be developed at only a small number of sites and only over a small geographic area around them. A simpler method of mapping flood inundation has the potential to save significant cost and map many more areas in a shorter period of time.

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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.

2. STUDY LOCATIONS

The LMRFC Flood Inundation Toolset has been used to estimate flood inundation extent for a number of locations across the country (Figure 1). When possible, the method was used where it could be validated against actual flood extent estimated from a post-flood survey or from HEC-RAS model output. For the purposes of this analysis, the HEC-RAS output or 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. When neither were available, results from the tool were compared to impact statements compiled by local NWS offices. Because impact statements provide little or no spatial information, they were not included in this analysis.

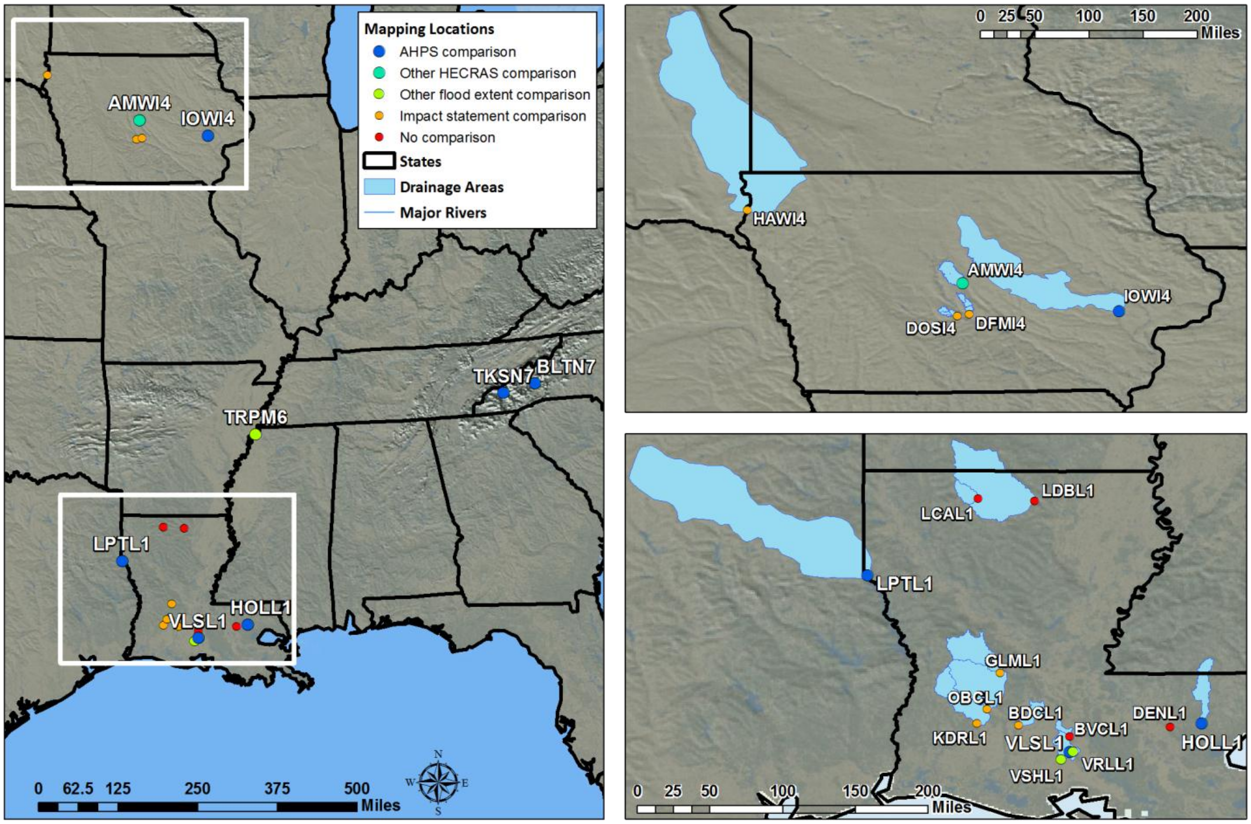

Figure 1. Locations where flood inundation extent maps were created using the LMRFC Flood Inundation Toolset. Locations have been verified using different techniques, as indicated by the color of each point. Existing AHPS maps or other HEC-RAS produced maps are assumed to be the most accurate representation 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.)

Table 1. Locations where the LMRFC Flood Inundation Toolset has been used to estimate flood inundation extent.

3. 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 surface 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.

3.2 Water Surface Profile From Points Tool

The Water Surface Profile From Points Tool is the simplest method of calculating a water surface profile from LiDAR data in the LMRFC Flood Inundation Toolset. The tool requires the user to place a series of points in the LiDAR-derived river channel; then the tool extracts the water elevation at each point and interpolates the values to a raster grid. Un-intended results can occur that may increase error/uncertainty because the interpolation tools of ArcGIS are more geared toward 2-dimensional interpolation. The best interpolation for water surface profiles would be 1-dimensional (in the sense that the slope follows the river channel and the flow gradient is parallel to that gradient in both perpendicular directions).

3.3 Water Surface Profile From Cross Sections Tool

The Water Surface Profile From Cross Sections Tool is a more involved, but generally more accurate, method of calculating a water surface profile in the LMRFC Flood Inundation Toolset. Of particular note is that cross sections method can be used with data from existing flood inundation studies, such as those done by the FEMA to create Flood Insurance Rate Maps. The tool requires the user to place a series of cross sections across the LiDAR-derived river channel perpendicular to the floodplain direction; then the tool takes user-entered elevations for each cross section and interpolates the values to a raster grid. The interpolation of cross section values generally creates a more realistic water surface profile than using points because the gradient is forced to be parallel to the downward slope of the floodplain. For the purposes of this analysis, the Water Surface Profile From Cross Sections Tool will be used to estimate flood inundation.

4. ESTIMATING FLOOD INUNDATION DEPTH

Once a GIS raster of the estimated water surface 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 is the second and final step needed to create inundation rasters of hypothetical floods. The tool requires the user to supply an elevation dataset and estimated water surface profile; then the tool increments the height of the water surface profile grid upward in 1 foot increments, subtracting the landsurface elevation each time. The maximum height added to the estimated water surface profile is 40 ft.

Map confidence should be determined by comparing inundation tool results to other independent sources. These sources may include impact statements, flood reports from local emergency managers, FEMA flood insurance maps, AHPS inundation maps, as well as flood photos and anecdotes. When more independent sources are consistent with results from the tool, higher confidence can be given to the results. Distance from the reference gauge, especially if there are major changes to the river channel or floodplain and confluences with other streams, also should affect map confidence. For the purposes of this analysis, an objective validation method was used to test the accuracy of inundation maps developed with the LMRFC Flood Inundation Toolset; validation is discussed further in Section 5.

5. VALIDATION OF THE LMRFC FLOOD INUNDATION TOOLSET

Maps of estimated inundation can be validated by comparing results to independent sources. These sources may include impact statements from past flood events, anecdotes from local emergency managers, FEMA flood insurance maps, AHPS inundation maps, high water mark surveys, as well as flood photos and anecdotes. 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.

As discussed in Section 2, 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. The F-score is shown as Equation 1:

$$F_{score} = \frac{C}{A + B + C} \tag{1}$$

Where A is the area where only the LMRFC method indicates flooding, B is the area where flooding was observed but not indicated by the LMRFC method, and C is the area where the model and the observations both indicated flooding.

Results for both raw output from the LMRFC method and quality-controlled output from the LMRFC were compared against the observations using Equation 1. Quality control involved correction of only obvious errors, such as flooding of un-connected flow areas and flooding behind levees. F-scores for both the raw output and the quality-controlled output are shown in Table 2. Examples of F-scores are illustrated by Figure 2.

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*
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*

Table 2. 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.

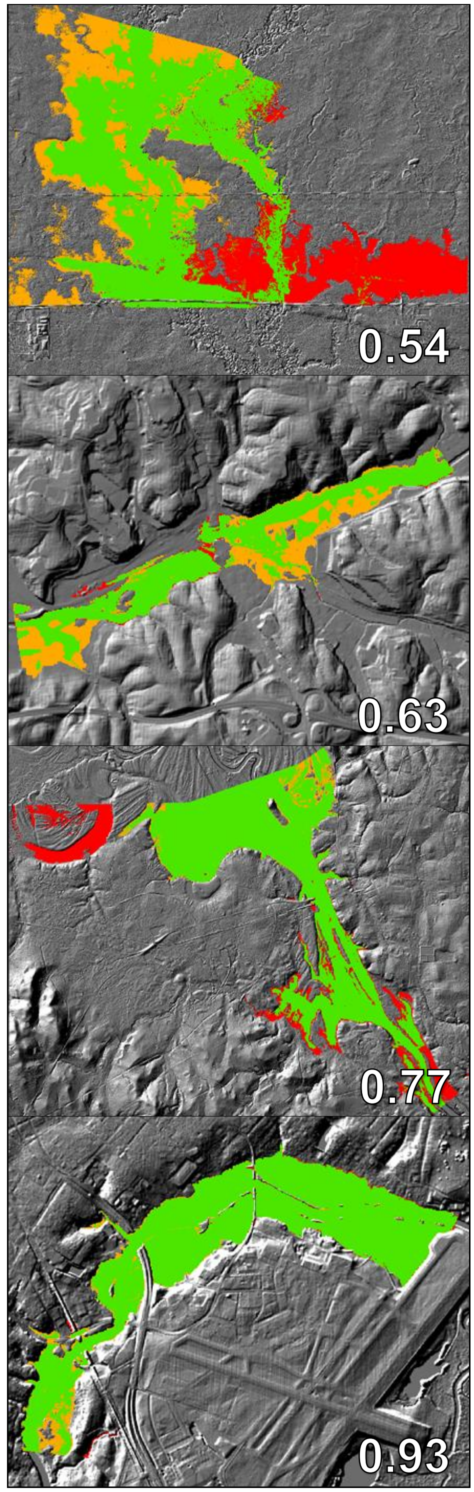

Figure 2. Examples of various F-scores as described by Kuiry et al (2010). Green represents areas where the model and the observations both indicate flooding. Orange represents areas where only the LMRFC method indicates flooding. Red represents areas where flooding was observed but not shown by the LMRFC method.

6. CONCLUSIONS AND 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.

7. REFERENCES

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