Modeling of the Mississippi and Atchafalaya Rivers below Old River to Develop Flood Loading Curves

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Introduction

Flood loadings for the Mississippi and Atchafalaya Rivers downstream of the Old River Control Complex (ORCC) were developed using a procedure involving a flow frequency analysis, two-dimensional (2D) hydraulic modeling, and post-processing results for hundreds of locations. Stage-frequency relationships from a calibrated and validated hydraulic model were used to develop site-specific estimates of loadings and overtopping probabilities for locations of interest. The US Army Corps of Engineers New Orleans District (MVN) used a 2D HEC-RAS hydraulics model to develop water levels for flood flows of varying magnitudes, an updated flood flow frequency analysis to inform the annual exceedance probabilities of those flood flows, and a MATLAB-based code to extract water surface elevation results at hundreds of locations where stage-frequency data were needed. This effort simplified the estimation of flood risk at numerous locations for use in ranking and categorizing the highest risk segments in the systems.

Methodology

Flow frequency analysis

A flood flow frequency analysis was completed using combined discharges for the Atchafalaya and Mississippi Rivers just downstream of the ORCC for the period 1962-2021 (60 years). A Bulletin 17C analysis in HEC-SSP was used to develop the flow frequency curve, with the resulting curve shown in Figure 1. Flows for annual exceedance probabilities (AEP) of 0.5, 0.1, 0.02, 0.01, 0.005, 0.002, and 0.001 were computed. The AEP for the project design flood flow was also estimated. Once the combined Atchafalaya and Mississippi flows were determined, they were allocated 30%/70% respectively, consistent with the intent of the ORCC, to be used as inputs for hydraulic modeling.

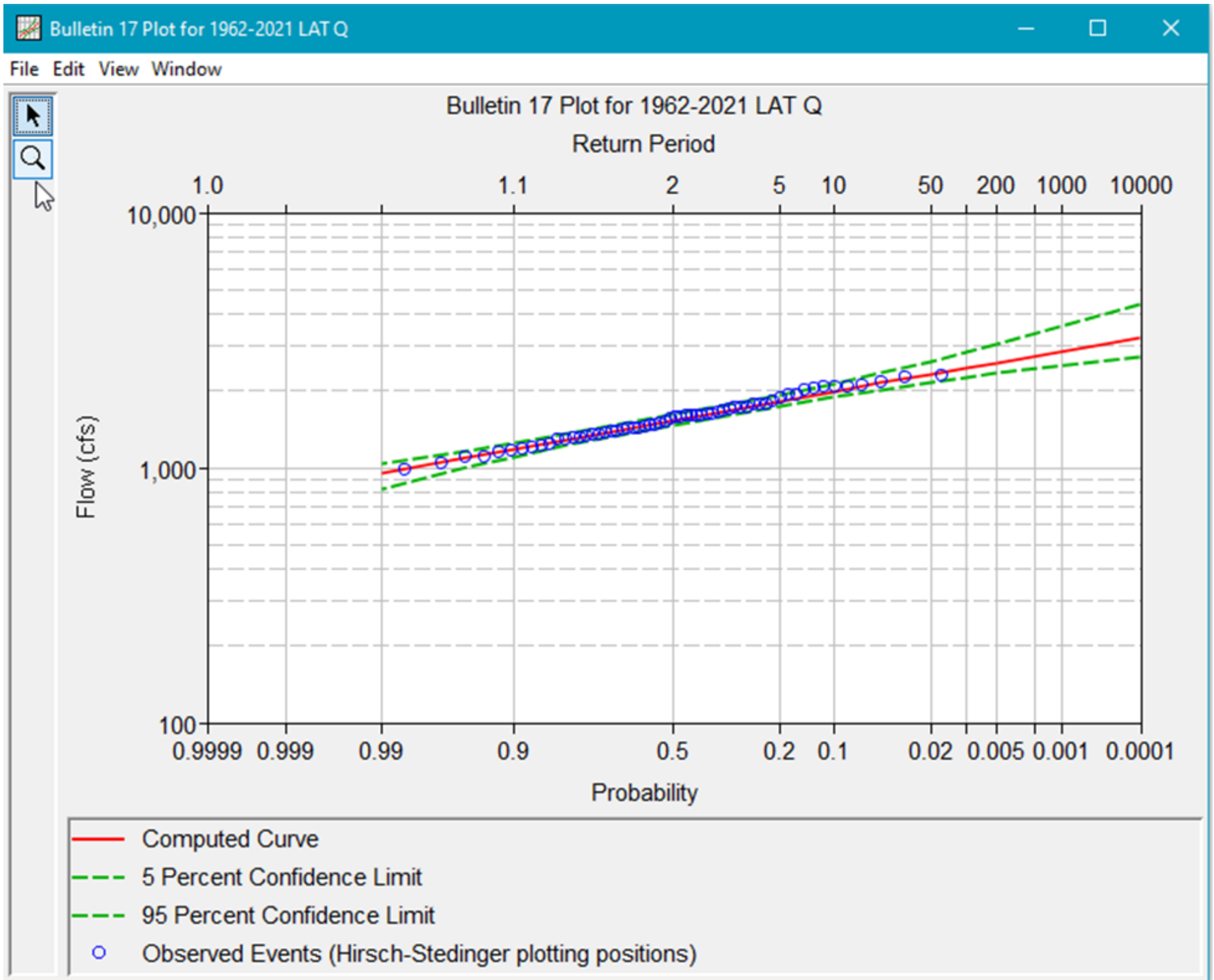

Figure 1. Flow Frequency Analysis Results using HEC-SSP

HEC-RAS calibration, validation, event modeling

An HEC-RAS geometry with a single 2D Area covering nearly all the MVN area of responsibility was used for the hydraulic modeling, as shown in Figure 2. The United States Geological Survey (USGS) Northern Gulf of Mexico (NGOM) “topobathy” (topography and bathymetry) dataset was the base terrain layer, upon which some refinements and modifications were made. Levee, floodwall, and structure elevations for Mississippi River and Tributaries (MR&T) systems were burned into the HEC-RAS terrain and those elevations were enforced in the 2D Area mesh using break lines. While the upper half of the Atchafalaya Basin is contained by the Atchafalaya River levees, the lower half is marked by wide floodplains, bifurcations, and small distributaries and tributaries. Where detailed bathymetric data were not available for the smaller but significant channels, cross section dimensions were estimated and burned into the terrain using Terrain Modification features in RAS Mapper.

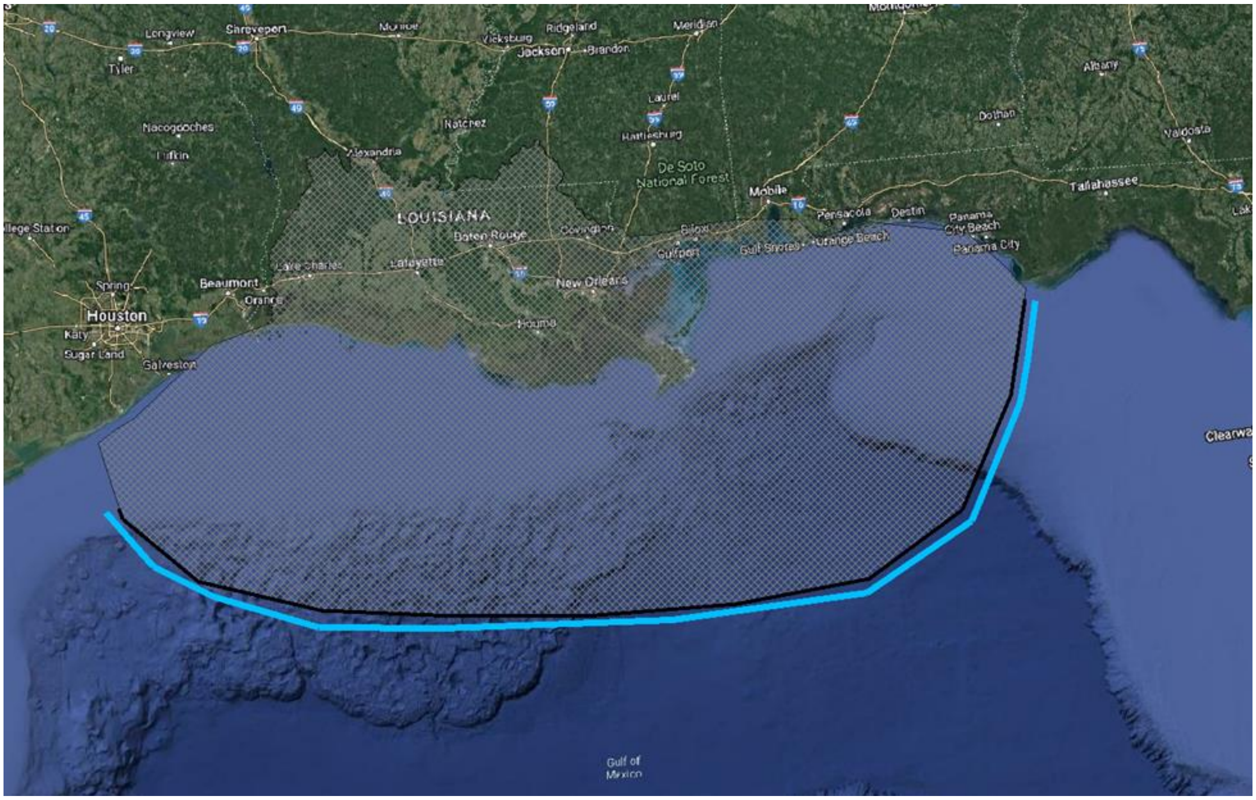

Figure 2. HEC-RAS geometry domain

The model was calibrated to the 2019 flood, primarily by varying the Manning's n values for the land use types in the model domain. An example calibration hydrograph is shown in Figure 3. In some instances, the estimated dimensions of smaller channels that had been burned into the terrain were refined to improve the model's fit to observed data. Daily computed flows on the Atchafalaya River at Simmesport, LA, Mississippi River at Red River Landing, LA, and Morganza Floodway Control Structure were used as upstream boundary conditions. The model was validated to the 2011 flood, the modern flood of record which required operation of the Morganza Floodway.

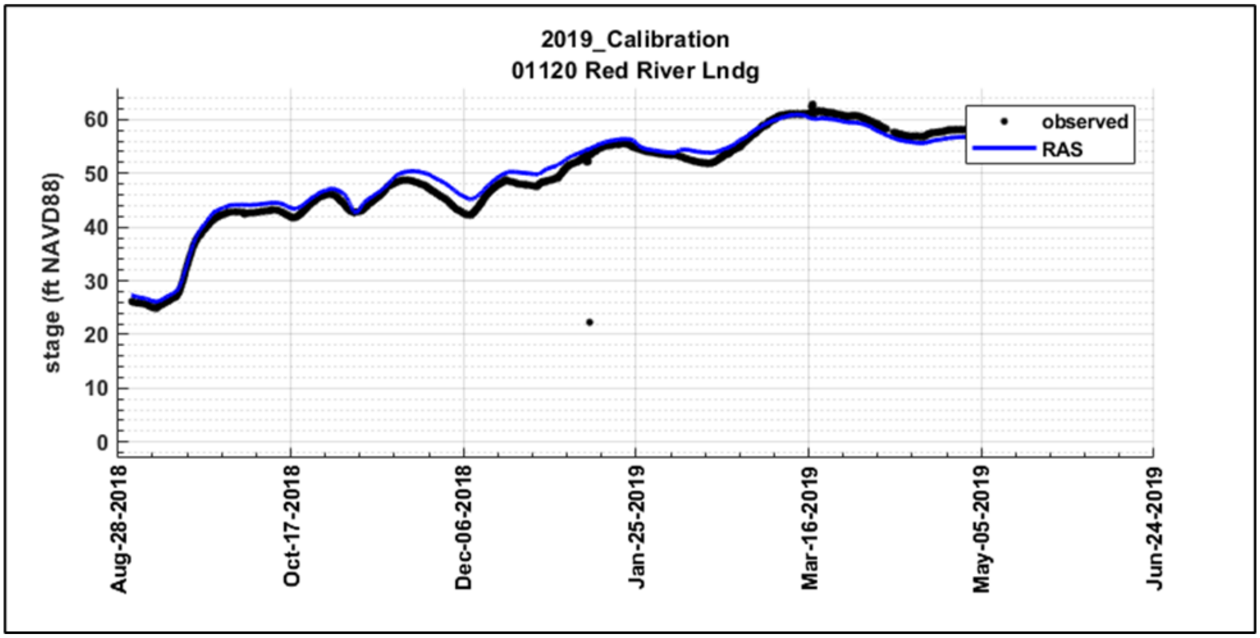

Figure 3. Mississippi River at Red River Landing calibration plot

Once calibrated and validated, flood flows for varying frequencies were simulated in the HEC-RAS model. Computed discharges were used as upstream boundary conditions at the appropriate location. The downstream boundary for each model run used a representative Gulf of Mexico water level. Simulations used a constant discharge and downstream water level for a long enough period to achieve a "steady state" condition. All simulations used the full momentum equation set in HEC-RAS version 6.1, the most recent release at the time this analysis was performed.

Results post-processing

A MATLAB script was developed to read the HEC-RAS hdf5 output file for any location desired. The maximum water surface elevation (WSE) for each point was reported in a spreadsheet that could be used for further analysis. This effort extracted partial and full loadings of levees and floodwalls throughout the Mississippi and Atchafalaya River systems. An example stage-frequency curve for a selected point on the east side of the lower Atchafalaya Basin is shown in Figure 4 and Figure 5. The loadings that were developed were used in geotechnical analyses, for estimates of overtopping AEP, and for developing the consequences associated with overtopping at certain frequencies.

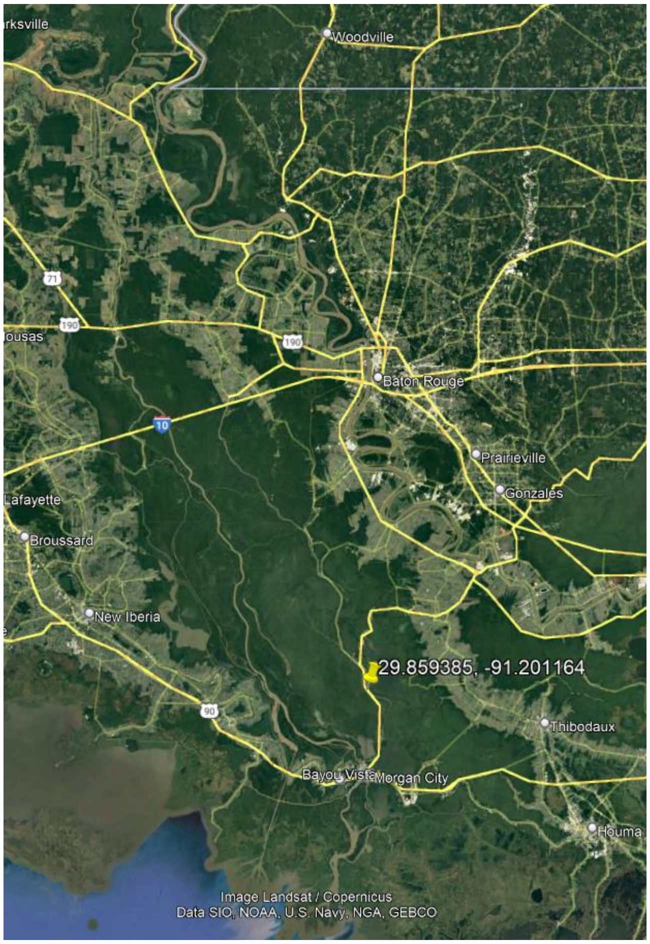

Figure 4. Location of point of example output

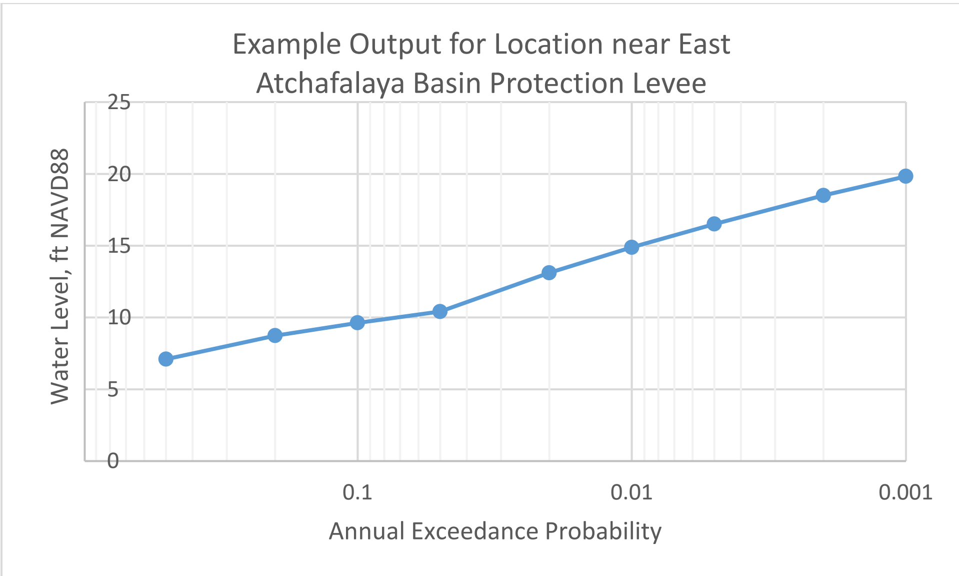

Figure 5. Example stage-frequency curve for the point shown in Figure 4

Conclusions

Output from a calibrated 2D hydraulic model can be used to provide estimates of the flood hazard for a spatially dense and high number of points of interest. This approach makes use of detailed topographic data as well as bathymetric data where available. It also utilizes spatially explicit land use datasets that define the land use within a large floodplain like the Atchafalaya Basin. This information provides benefits for parameterizing the roughness values used in the model.

This procedure represents a significant improvement over processes utilized previously – which may have used a 1-dimensional hydraulic model with inherent simplifications and estimates made to model a system with 2D flow patterns, or interpolations between locations where stage-flow rating curves could be developed.

However, this procedure is not without limitations. To separate the hypothetical river-only flood risk from the coastal flood risk, a single simulation with a set downstream boundary water level was used for each flood flow. In reality, river floods can occur with varying downstream water levels affecting stages in the portions of each river sensitive to compound flooding. A hypothetical flood could occur coincident with a low Gulf of Mexico water level, or an elevated water level caused by a frontal system, or a coincident tropical cyclone event causing even higher water levels than the flood alone would be affected by. River flood loadings developed by the procedure described in this paper were later supplemented with tropical cyclone driven loadings for further analysis.

The Project Design Flood – 3,030,000 cubic feet per second (cfs) across both rivers at the latitude of Red River Landing (Lewis, 2018) – is larger than the flood of record post-ORCC construction (2,304,000 cfs in 2011) by 726,000 cfs. Model calibration is limited to the extent of observed data.

Additional limitations of the hydraulic modeling include not modeling or accounting for groundwater interaction and not modeling infiltration in the floodplain for extreme high floods.

Operational uncertainty is not accounted for in the frequency estimates. While 70%/30% distribution is intended, data uncertainty and unknowns in extreme flood events could contribute to operation slightly different than exact 70%/30% distribution.

References

Lewis, James, et. al., "Mississippi River and Tributaries Flowline Assessment Main Report," MRG&P Report No. 24; Volume 1, December 2018.