Forecast Flood Inundation Mapping at Continental Scale from National Water Model River Discharges

Fernando Aristizabal[1], Fernando Salas[2], Brian Avant[1], Bradford Bates[1], Trevor Grout[1], Nick Chadwick[1], Ryan Spies[1], Gregory Petrochenkov[3], Roland Viger[3], and Zachary Wills[4]

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Abstract

The National Water Center (NWC), part of the National Weather Service's (NWS) Office of Water Prediction (OWP), seeks to provide forecast flood inundation maps (FIM) as services at the national scale along 2.7+ million river reaches. The National Water Model (NWM) forecasts stream discharges along these reaches at varying time horizons. Building on the methodology of previous versions, OWP FIM 3.0 seeks to map NWM stream discharges to inundation extents with a modified version of the Height Above Nearest Drainage method for mapping stages. FIM 3.0 produces required datasets for generation of FIMs, which are relative elevations, reach-level catchments, rating curves and crosswalk tables, to convert the NWM discharge forecasts to inundation extents as a post-processing step. Computational tests estimate that producing these FIM required datasets for the continental U.S. will be around 600 total CPU hours. Only publicly available input datasets from the NWM or NHDPlusHR are required. The latest methods leveraged within FIM 3.0 include the use of consistent reach lengths and deriving FIM outputs at lower stream densities (downstream of River Forecast Center forecast points) to mitigate catchment boundary limitations. FIM 3.0 is primarily parallelized across Hydrologic Unit Codes (HUC) 4, 6, or 8 as processing units which can be selected by the user at run time. FIM capability improvements were measured by comparisons to engineering scale maps using contingency statistics. Future versions will support NWM geospatial dataset production, usage of Lidar elevations, and more advanced hydrological methods. FIM 3.0 is highly configurable, modular, and portable due to its software architecture and containerization. All software dependencies are open-source including GDAL/OGR, TauDEM, and RichDEM. The source code and Docker container are expected to be made available publicly for community review and development.

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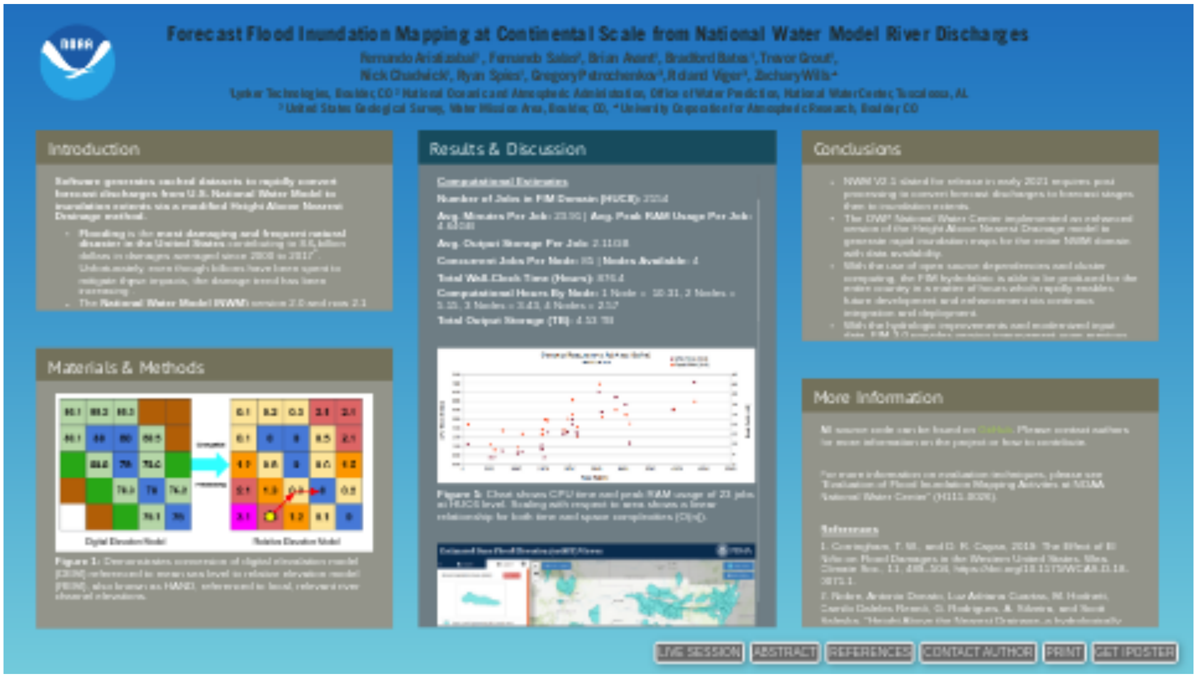

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INTRODUCTION

Software generates cached datasets to rapidly convert forecast discharges from U.S. National Water Model to inundation extents via a modified Height Above Nearest Drainage method.

- **Flooding** is the **most damaging and frequent natural disaster in the United States** contributing to 8.6 billion dollars in damages averaged since 2000 to 2017[1]. Unfortunately, even though billions have been spent to mitigate these impacts, the damage trend has been increasing[1].
- The **National Water Model (NWM)** version 2.0 and now 2.1 **forecasts river discharges** at a variety of time horizons at 2.7 million river reaches.
- Additional modeling efforts are required to **convert these discharges to stages and stages to inundation extents**.
- Office of Water Prediction (OWP) **Flood Inundation Mapping (FIM) Version 3.0** is a rapid FIM technique **based on enhancements to the Height Above Nearest Drainage (HAND) technique**.

MATERIALS & METHODS

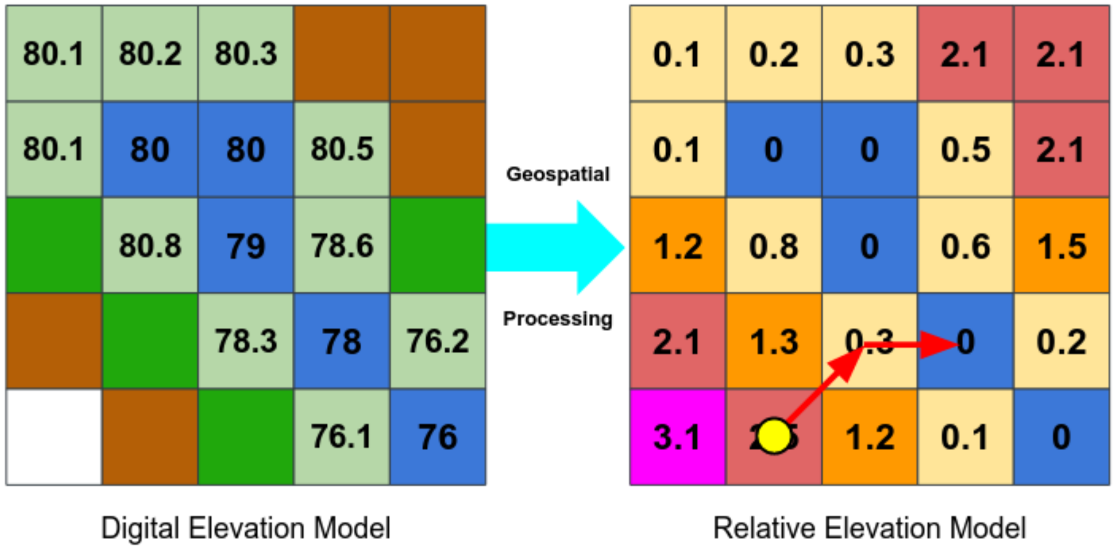

Figure 1: Demonstrates conversion of digital elevalation model (DEM) referenced to mean sea level to relative elevation model (REM), also known as HAND, referenced to local, relevant river channel elevations.

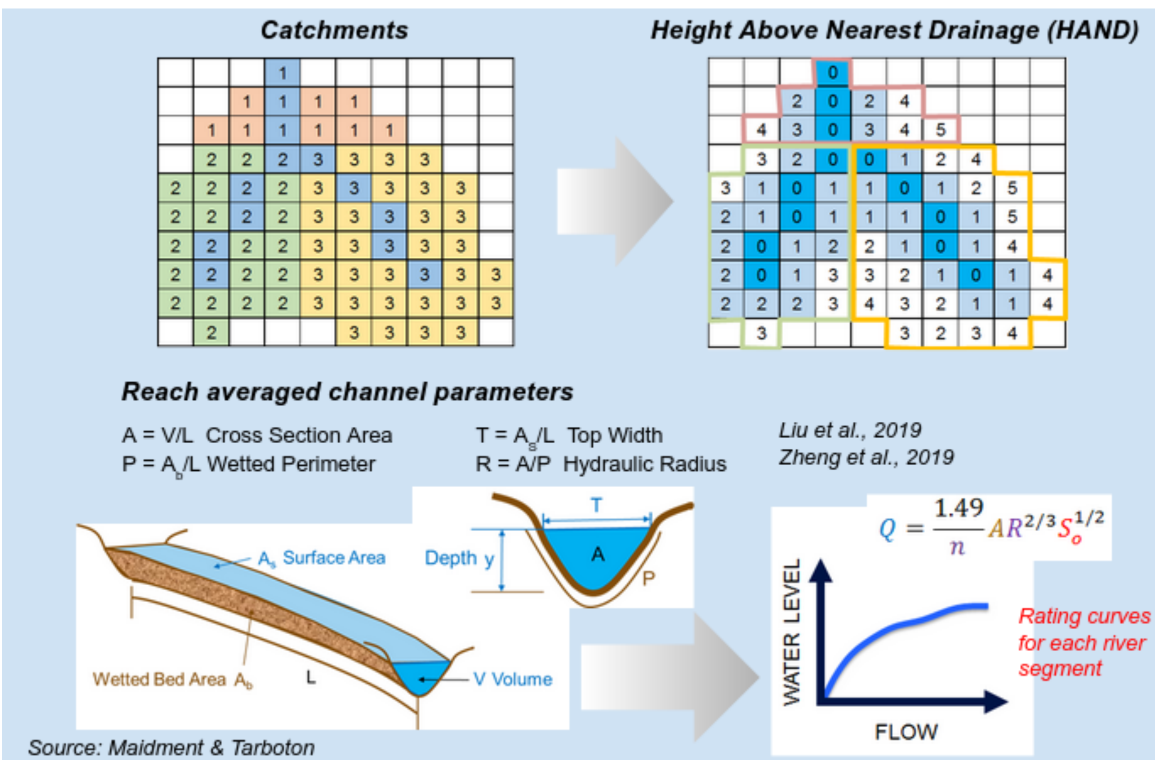

Figure 2: Demonstrates delineated stream reaches and catchments as well as relative elevation values known as HAND. Reached averaged channel parameters are sampled from HAND raster and inputed to Manning's equation to establish stage-discharge relationship.

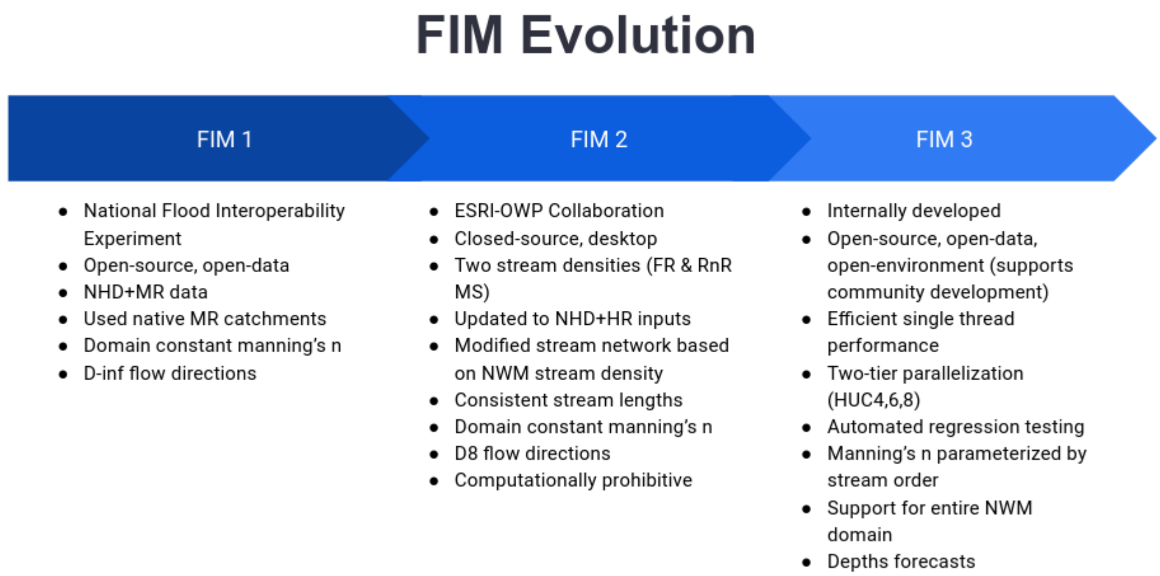

Figure 3: OWP FIM is based on the HAND method[2] originally implemented by the National Flood Interoperability Experiment (NFIE). Details the evolution of the technology and capabilities.

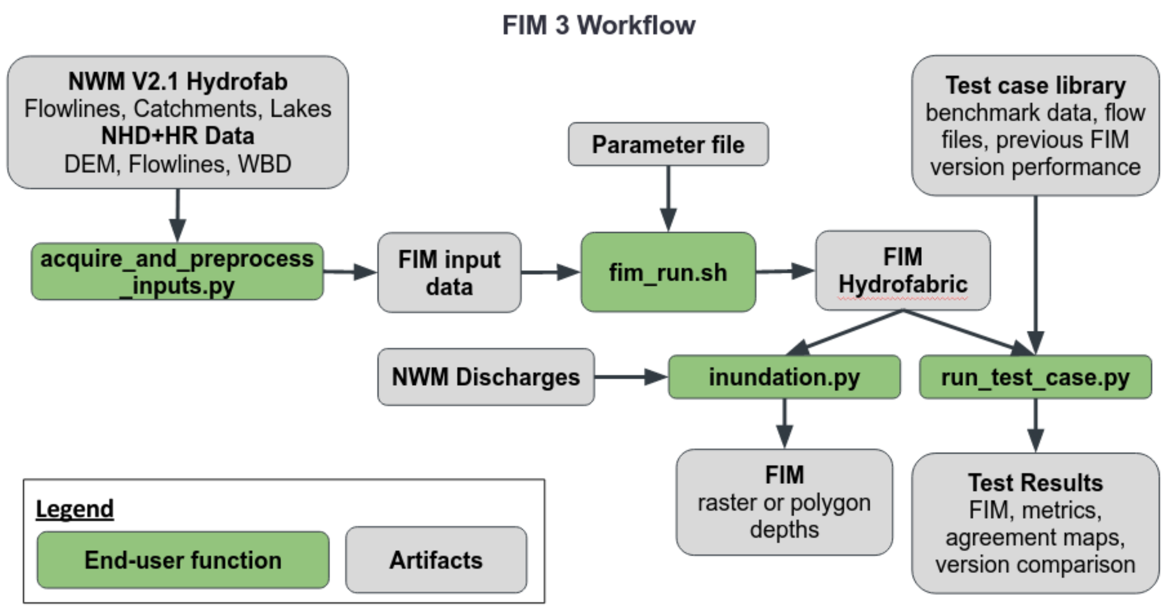

Figure 4: FIM 3 developer workflow and pipeline demonstrating preprocessing, hydrofabric production, inundation mapping, and test case evaluation.

The entire project depends on open source dependencies including Docker, TauDEM, RichDEM, and GDAL.

RESULTS & DISCUSSION

Computational Estimates

Number of Jobs in FIM Domain (HUC8): 2154

Avg. Minutes Per Job: 23.91 | **Avg. Peak RAM Usage Per Job:** 4.64GB

Avg. Output Storage Per Job: 2.11GB

Concurrent Jobs Per Node: 85 | **Nodes Available:** 4

Total Wall-Clock Time (Hours): 876.4

Computational Hours By Node: 1 Node = 10.31, 2 Nodes = 5.15, 3 Nodes = 3.43, 4 Nodes = 2.57

Total Output Storage (TB): 4.53 TB

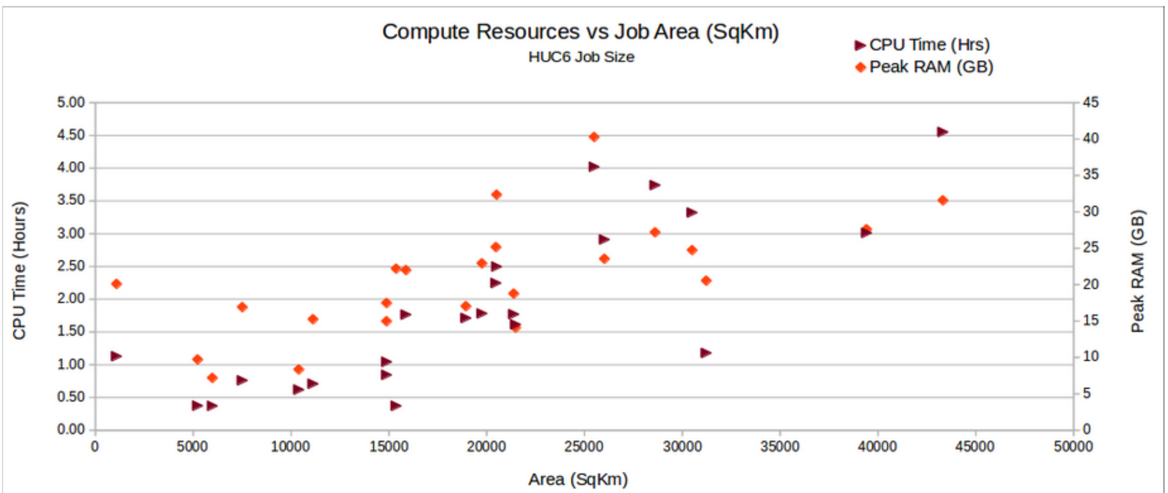

Figure 5: Chart shows CPU time and peak RAM usage of 23 jobs at HUC6 level. Scaling with respect to area shows a linear relationship for both time and space complexities (O(n)).

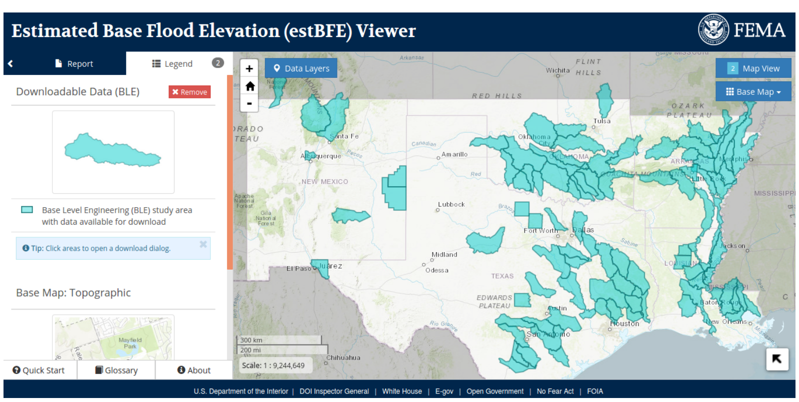

Figure 6: Estimated Base Flood Elevation Viewer source of validation HUC8 sites. FEMA provides inundation extents and cross sections at 100yr and 500yr recurrence intervals.

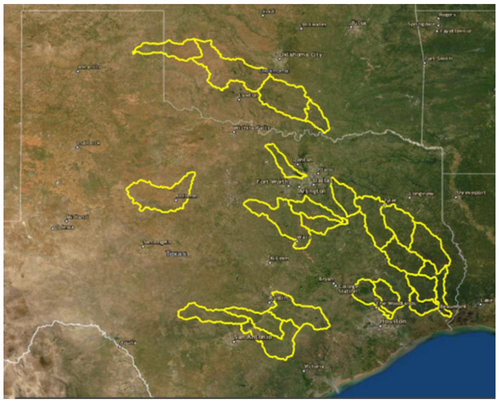

Figure 7: 23 sites where data was compiled and prepared for evaluation. Cross section data used to generate discharges via intersection with NWM reaches.

Table 1: Binary contingency statistics for all 23 HUC8 test cases. Notable improvments in detecting inundation (Probability of Detection) with only a marginal change in over prediction (False Alarm Ratio). Overall the performance of the FIM versions improve with every version change (Critical Success Index and Matthews Correlation Coefficient).

All test cases	100yr			500yr		
Metric	**FIM 1**	**FIM 2**	**FIM 3**	**FIM 1**	**FIM 2**	**FIM 3**
TPR	60.28	62.39	70.15	62.66	65.23	72.22
CSI	52.86	56.16	58.40	55.70	59.22	61.52
FAR	18.89	15.09	16.61	16.63	13.46	15.12
MCC	65.21	68.57	70.15	67.20	70.60	72.22

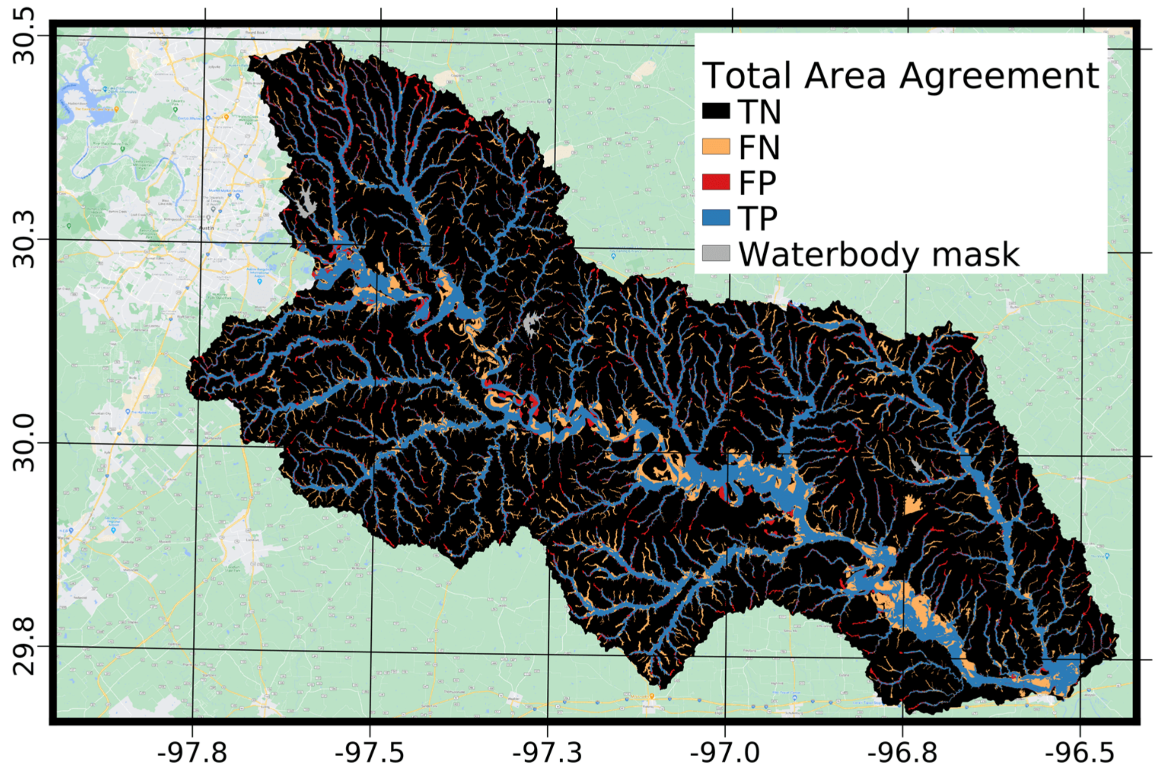

Figure 8: Agreement map with True Negatives (TN), False Negatives (FN), false positives (FP), true positives (TP), and water body exclusion mask for HUC 12090301 south east of Austin, TX on Colorado River. Performance for FIM 3.0 compared to FEMA BFE 500yr extents.

CONCLUSIONS

- NWM V2.1 slated for release in early 2021 requires post processing to convert forecast discharges to forecast stages then to inundation extents.
- The OWP National Water Center implemented an enhanced version of the Height Above Nearest Drainage model to generate rapid inundation maps for the entire NWM domain with data availability.
- With the use of open source dependencies and cluster computing, the FIM hydrofabric is able to be produced for the entire country in a matter of hours which rapidly enables future development and enhancement via continous integration and deployment.
- With the hydrologic improvements and modernized input data, FIM 3.0 provides version improvement upon previous FIM.
- Future work will be focused on developing solutions for the catchment boundary issue experienced along the junctions of higher order streams and their tributaries.

MORE INFORMATION

All source code can be found on GitHub (https://github.com/NOAA-OWP/cahaba). Please contact authors for more information on the project or how to contribute.

For more information on evaluation techniques, please see "Evaluation of Flood Inundation Mapping Activites at NOAA National Water Center" (H111-0026).

References

1. Corringham, T. W., and D. R. Cayan, 2019: The Effect of El Niño on Flood Damages in the Western United States. Wea. Climate Soc., 11, 489–504, https://doi.org/10.1175/WCAS-D-18-0071.1.

2. Nobre, Antonio Donato, Luz Adriana Cuartas, M. Hodnett, Camilo Daleles Rennó, G. Rodrigues, A. Silveira, and Scott Saleska. "Height Above the Nearest Drainage–a hydrologically relevant new terrain model." Journal of Hydrology 404, no. 1-2 (2011): 13-29.

3. Office of Water Prediction (OWP)

4. National Flood Interoperability Experiment (NFIE)

5. Garousi-Nejad, I., Tarboton, D. G.,Aboutalebi, M., & Torres-Rua, A.(2019). Terrain analysis enhancements to the Height Above Nearest Drainage flood inundation mapping method. Water Resources Research, 55 , 7983–8009. https://doi.org/10.1029/2019WR0248375.

6. Zheng, X., D.G. Tarboton, D.R. Maidment, Y.Y. Liu, and P. Passalacqua. 2018. “River Channel Geometry and Rating Curve Estimation Using Height above the Nearest Drainage.” Journal of the American Water Resources Association 54 (4): 785–806. https://doi.org/10.1111/1752-1688.12661.

7. Barnes, Richard. 2016. RichDEM: Terrain Analysis Software. http://github.com/r-barnes/richdem

8. TauDEM

9. Federal Emergency Management Agency (FEMA) Base Level Engineering (BLE)

10. Verdin, James; Verdin, Kristine; Mathis, Melissa; Magadzire, Tamuka; Kabuchanga, Eric; Woodbury, Mark; and Gadain, Hussein, 2016, A software tool for rapid flood inundation mapping: U.S. Geological Survey Open-File Report 2016–1038, 26 p., http://dx.doi.org/10.3133/ofr20161038.

11. United States Geological Survey (USGS) National Hydrography Dataset Plus High Resolution (NHDPlusHR). https://www.usgs.gov/core-science-systems/ngp/national-hydrography/nhdplus-high-resolution

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REFERENCES

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6. Zheng, X., D.G. Tarboton, D.R. Maidment, Y.Y. Liu, and P. Passalacqua. 2018. "River Channel Geometry and Rating Curve Estimation Using Height above the Nearest Drainage." Journal of the American Water Resources Association 54 (4): 785–806. https://doi.org/10.1111/1752-1688.12661.

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