Report P3B: Flood Decision Support Gauge Network

Project 0-7095-01: Flood Assessment System for TxDOT (FAST)
30 June 2025, Amended 7 August 2025

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1. Introduction

This report, P3B, represents the second progress milestone in the ongoing FAST project—TxDOT's initiative to enhance flood awareness and mitigation through a strategic network of streamflow monitoring at select bridge crossings. The original phase, as outlined in the P3A report from June 2024, concentrated on initiating preliminary calibration efforts for the remainder of the RQ-30 gage network and integrating these gages into the Flood Decision System for TxDOT (FAST). The current phase builds upon these foundations by utilizing enhanced data coverage and focused hydrodynamic modeling to better understand and calibrate the RQ-30 gages.

The FAST project, officially launched on February 26, 2024, is a continuation of Project 0-7095 and Project 5-9054 before it. Collectively, these efforts reflect TxDOT's commitment to developing science-driven tools to reduce the risks posed by flooding at transportation infrastructure. This document outlines progress made during Months 5–16 of the project, with emphasis on sensor calibration, new ADCP data collection, site-specific hydrodynamic modeling, RQ-30 calibration software development, and integration with the Flood Decision Support Toolbox (FDST).

2. Status of RQ-30 Gauge Network and Integration into the Flood Decision Support Toolbox

Over the past year, the network of 80 RQ-30 radar streamflow gauges has been operational, with the majority successfully transmitting high-frequency surface velocity and water level data in real-time. As shown in Figure 1, the length of record at individual stations ranges from 2.47 years to 4.69 years, with an average of 3.49 years, and a total of 268 station-years of record collected.

While the gauges have demonstrated durability with minimal hardware-related interruptions, it is important to note that 3 gauges are currently not operational. USGS field crews have conducted periodic site visits in accordance with Subtask 3.1, focusing on equipment inspection, battery replacement, solar panel cleaning, discrete discharge measurements, and verifying elevation readings using installed wire-weight reference devices. All operational gauges have been checked and verified at least once in the past 12 months, and updated logs of field visits have been compiled. Corrections were applied where necessary to ensure consistent elevation referencing, utilizing independent wire-weight or surveyed benchmarks.

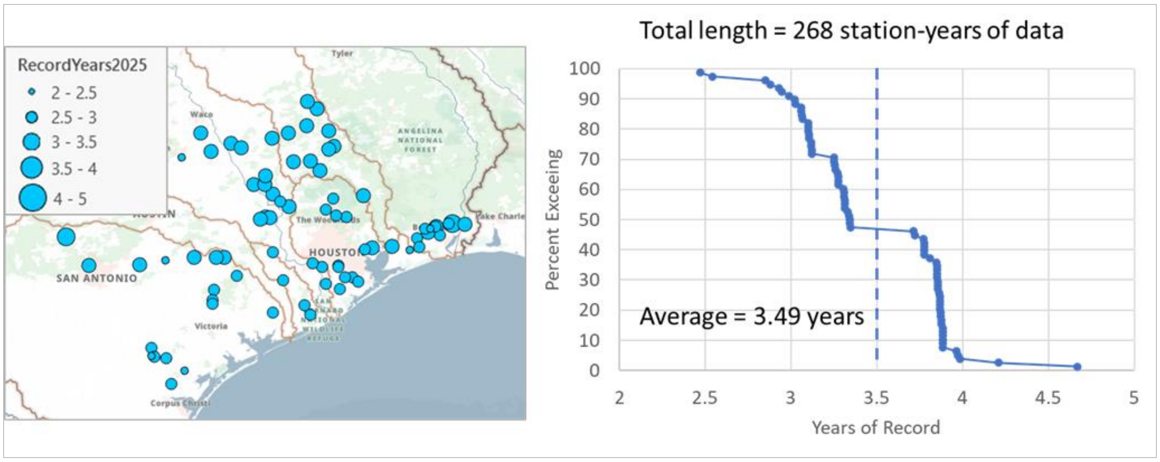

Figure 1. Length of record at RQ-30 Gauge Sites

Currently, 77 gauges are operational, while 3 are not. One gauge was removed after repeated vandalism despite efforts to secure it. Another site is temporarily offline due to ongoing bridge construction, and the third site is down because of equipment malfunction, compounded by safety concerns preventing access to the gauge.

The operational gauges are progressively being integrated into USGS's Flood Decision Support Toolbox (FDST), in alignment with Subtask 3.3. The FDST is a web-based system that visualizes inundation extents linked to streamflow conditions across the state. Of the 80 sites, 55 sites have been assessed for inclusion with 41 currently integrated into the FDST. Several have been successfully added, while others are still under review due to the absence of hydraulic models or incompatible topography.

Each site under consideration undergoes a model-fit check to ensure that synthetic or empirical rating curves can support the required flood mapping interface. Model development has faced delays at some locations where floodplain complexity or poor channel definition complicates curve derivation. Nevertheless, a pipeline has been established between field teams, modelers, and the FDST team to prioritize qualified sites for inclusion in upcoming toolbox updates.

3. ADCP Measurements and Site Calibration

Discharge calibration of the RQ-30 gauges is based on the k-factor method, which correlates surface velocity (measured by the radar) with mean channel velocity. This relationship is sensitive to both the cross-sectional geometry and the flow condition (in-bank or out-of-bank). Over the past year, USGS crews have continued to collect Acoustic Doppler Current Profiler (ADCP) measurements at a growing number of RQ-30 locations, focusing especially on sites with limited historical coverage, as shown in Figure 2. A total of 310 ADCP measurements at RQ-30 sites have been made as of 30 June 2025. The number of ADCP measurements has increased from 257 at 30 June 2024 to 310 as of 30 June 2025. The number of RQ-30 sites with at least one measurement has increased from 54 to 65, so there are only 15 sites now without any measurements compared to 26 a year ago.

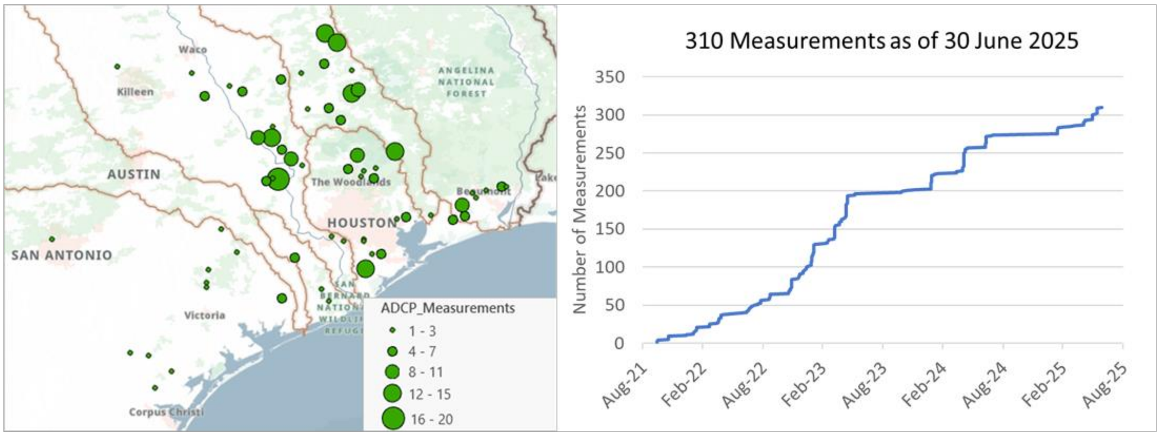

Figure 2. ADCP Measurements at RQ-30 gauge sites.

The distribution of the number of measurements per site is shown in Figure 3. The median number of measurements per site is 3 (for those sites that have at least 1 measurement). The largest number of measurements is 20 at site 081110006, New Year Creek nr Chappell Hill, Tx, which is a focus of our hydrodynamic modeling work, and which has a substantial and frequent road overflow on FM 1155.

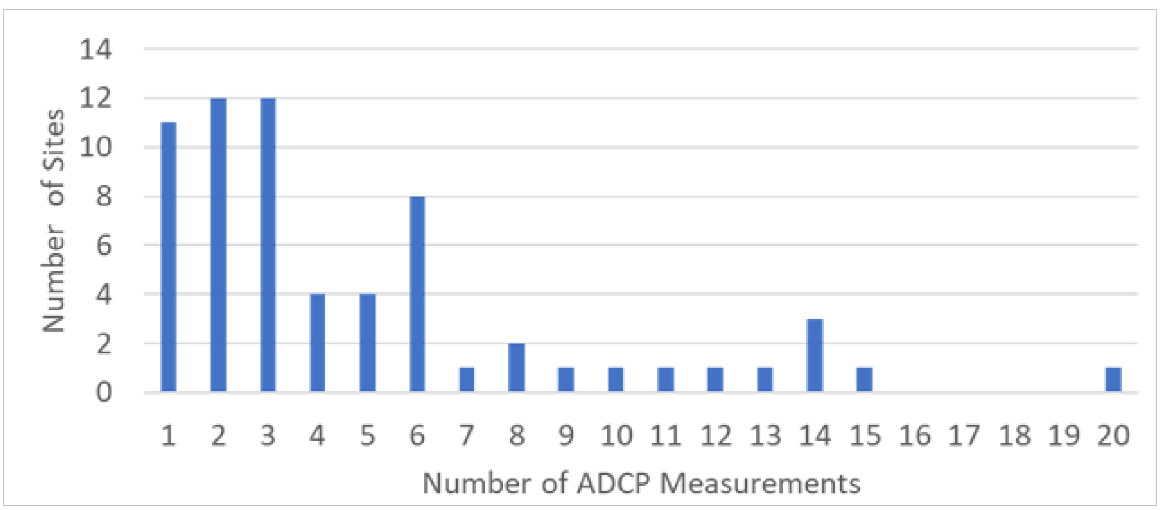

Figure 3. The number of ADCP measurements per site

The increased number of ADCP measurements brings the total number of sites with calibration-quality data to 34 (Figure 4). Measurements were strategically timed to capture both moderate and high-flow events, supporting Subtask 3.2 which calls for dual-condition calibration (one in-channel and one on floodplain).

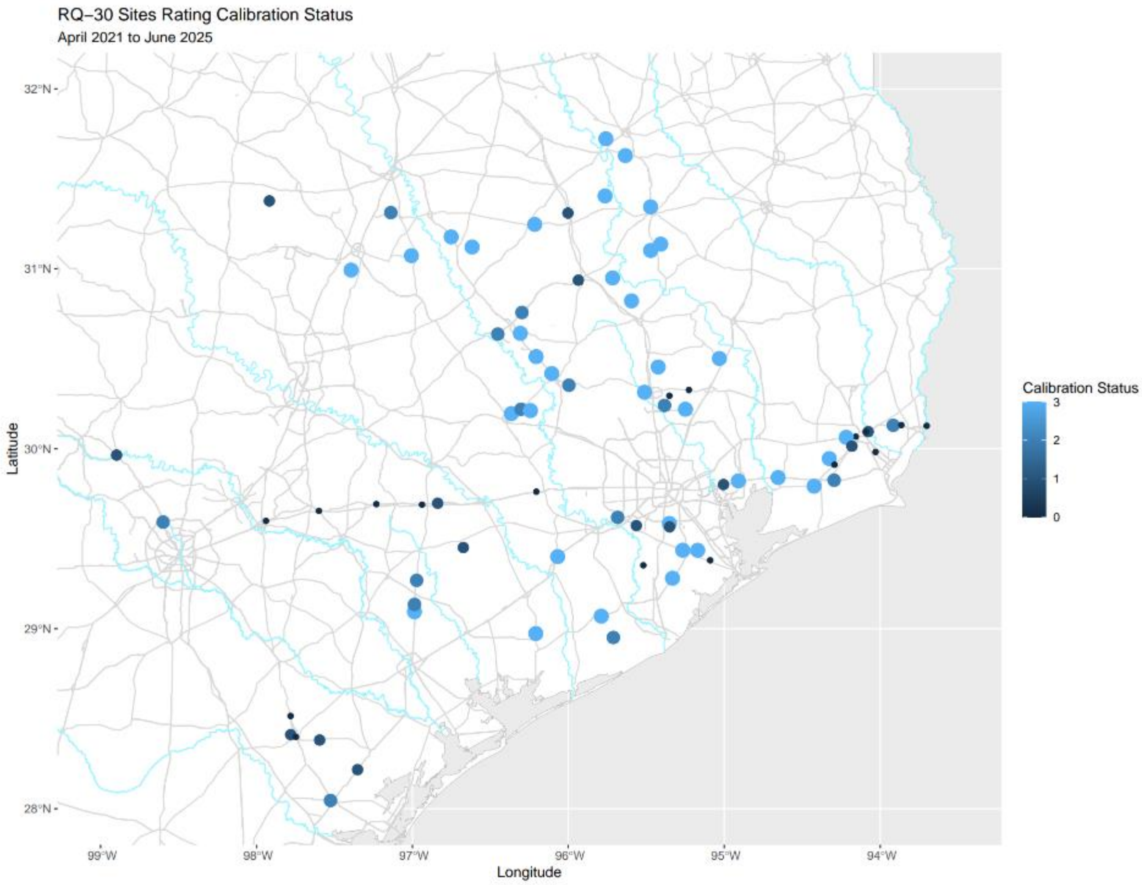

Figure 4. Map showing calibration status of RQ 30 sites.

In the process of deriving k-factors from this data, USGS has developed an internal software tool that is currently in the early stages of testing. This tool is designed for examining velocity profiles and plotting k-factor curves against stage. Although not initially planned, this tool is evolving into a supporting resource for creating stage-discharge relationships based on physical measurements and hydraulic theory as it undergoes further refinement and testing.

Moving forward, the calibration effort will continue to prioritize locations where road overtopping risk is high or where early ADCP results showed inconsistency, enabling progressive refinement of the network's reliability. Sites where RQ-30 and ADCP results are inconsistent are spread throughout the study area.

4. Bathymetry Surveys and Hydrodynamic Modeling Overview

To support modeling efforts, high-resolution bathymetric surveys have been completed at 10 selected RQ-30 sites. Surveys combine RTN-GPS and total station methods to resolve topography under bridges and flood-prone areas inadequately captured by airborne LIDAR.

These datasets underpin a new suite of hydrodynamic simulations using the International River Interface Cooperative (iRIC) Nays2dFlood and FaSTMECH solvers. With these models, project teams can simulate both steady-state flood peaks and unsteady events, generating insights into road overtopping, backwater effects, and the formation of transient flow paths.

5. Hydrodynamic Modeling of New Year Creek at FM 1155

Hydrodynamic modeling at the New Year Creek site near FM 1155 was conducted to explore the interaction between surface water elevation and surface velocity during flood events. This site was chosen due to its frequent flooding, existing high-resolution data, and its representation of complex TxDOT bridge crossings.

Special attention was given to the hydroflattening issue observed in LIDAR data, which had inaccurately represented channel depth under bridges. Corrected bathymetry was provided to Dr. Jon Nelson at River Mechanics to aid in the hydrodynamic model setup. The sites in question were resurveyed by U.S. Geological Survey staff.

Two modeling approaches were pursued using the iRIC platform:

- **FaSTMECH (steady-state modeling):** These runs were used to match observed peak flood conditions using measured surface velocity and elevation during events such as the March 2022 flood. These provided initial calibration checks and helped identify locations where the model diverged from field measurements.
- **Nays2dFlood (unsteady-state modeling):** With this tool, the team simulated synthetic triangular hydrographs to analyze the full rise and fall of a flood event. Simulations were conducted across a range of ramping speeds, exposing how discharge, surface elevation, and surface velocity do not follow a single curve, but rather a looping behavior known as hysteresis.

These results led to the creation of a lookup library of discharge-elevation-velocity combinations tied to ramping behavior. This dynamic library provides a new type of rating curve that responds not only to instantaneous readings but also to how fast conditions are changing.

Additionally, ongoing sensor data from the RQ-30 was used to evaluate these modeled relationships in near-real-time. The comparison confirmed that surface velocity and stage height cannot be treated as fully dependent variables—especially during rising and falling limbs of a hydrograph, as shown in Figure 5.

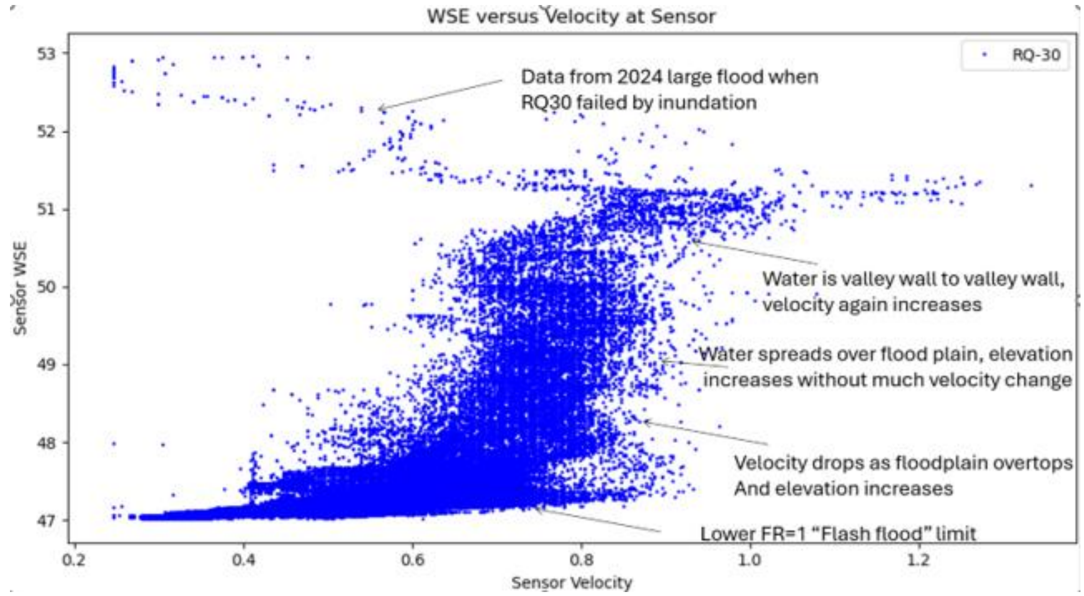

Figure 5. Plot showing relation between surface velocity and stage during a storm event.

The modeling work directly supports Subtask 3.4 (Velocity – Stage Height Interaction) and can set the stage for further applications at other sites. Additional refinement will include assessing whether 3D modeling or simplified machine learning techniques can be layered onto the dynamic rating curve framework to accelerate implementation.

6. Evaluation of relation between velocity and stage height at select gauge sites

To further support Subtask 3.4 (Velocity – Stage Height Interaction) additional work was completed to evaluate the relation between these two parameters at select gauge sites during storm events. Data collected at the RQ-30 sites were used to evaluate how hydraulic aspects compared with those that are assumed to be present at many upland streams where traditional stage-discharge rating curves are appropriate models. In these settings, for practical purposes water-surface elevation (stage) is uniquely related to stream discharge and is a function of the channel size, slope, and roughness (friction). It is understood that factors other than these (Holmes, Jr., 2018) can influence how much discharge passes a given location at a given stage, which would leave to stage-discharge ratings that do not have unique relation between stage and discharge (i.e. can have multiple discharge values for a given stage).

For this analysis a script was developed to retrieve in-situ data from the USGS database and, using hydrographer input, to separate these data into those collected during the rising limb of a storm hydrograph (start of rise to the peak) and those collected during the recession limb (peak to end of event) of the hydrograph. Initially, stage and surface velocity were the only two parameters that were retrieved and used to develop graphs for each site in the RQ-30 project. Example plots for select sites are shown in Figure 6 and Figure 7, where surface velocity in feet per second are shown on the x-axis and stage (or gage height) in feet are shown on the y-axis. Figure 6 shows examples where the stage-velocity data are very similar, in magnitude and shape, during the rising limb and recession limb. This would be expected at sites where the stage-discharge relation is stable throughout the range of conditions and does not change due to hysteresis. Figure 7 shows two sites where the stage-velocity data do not show close agreement when comparing those collected during the storm rise and those during the recession. This shows that for a given stage value, the surface velocity can have more than one value depending on when in the event it occurs and, likely, the discharge would also be variable.

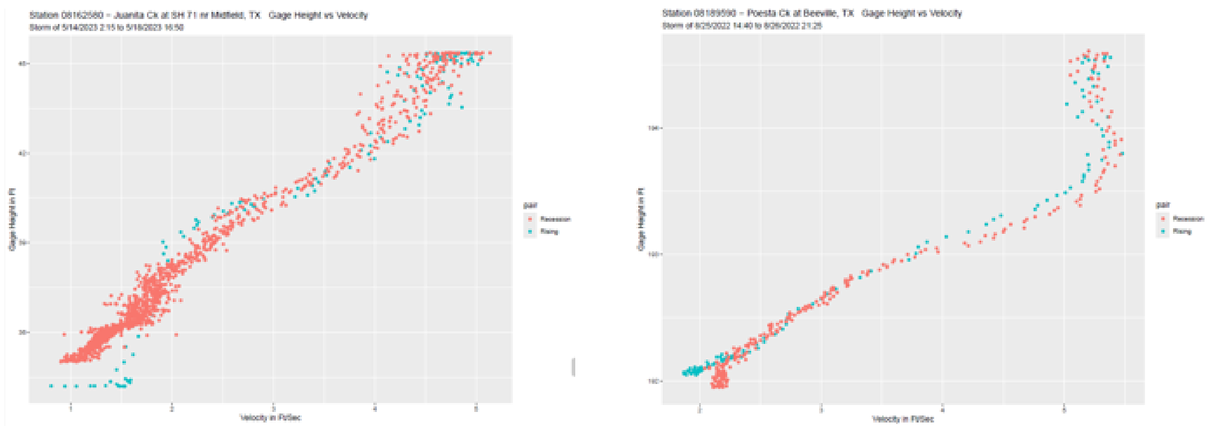

Figure 6. Surface velocity in feet per second versus gage height in feet for USGS station 08162580 – Juanita Ck at SH 71 nr Midfield, TX during storm of May 14, 2023 to May 18, 2023 and USGS station 08189590 – Poesta Ck at Beeville, TX during storm of August 25, 2022 to August 26, 2022. Data for rising and recession limbs of hydrographs show close agreement.

Figure 7. Surface velocity in feet per second versus gage height in feet for USGS station 08189718 – Chilitipin Ck at US 77 nr Sinton, TX during storm of May 13, 2023 to May 15, 2023 and USGS station 08102730 – Leon Rv at FM 436 nr Little River-Academy, TX during storm of April 9, 2024 to April 12, 2024. Data for rising and recession limbs of hydrographs show different patterns.

To investigate this further, additional data from the RQ-30 were retrieved from the USGS database. In this case, the discharge computed by the RQ-30 using proprietary algorithms was retrieved for each of the sites shown in Figures 6 and 7. The same method of separating the data between rising and recession was followed. In this case, the stage-discharge data were plotted. Figures 8 and 9 show the same sites and storm events that are shown in Figures 6 and 7. As expected, the patterns are very similar to those shown when evaluating velocity and stage, since velocity is highly correlated to discharge in a stream.

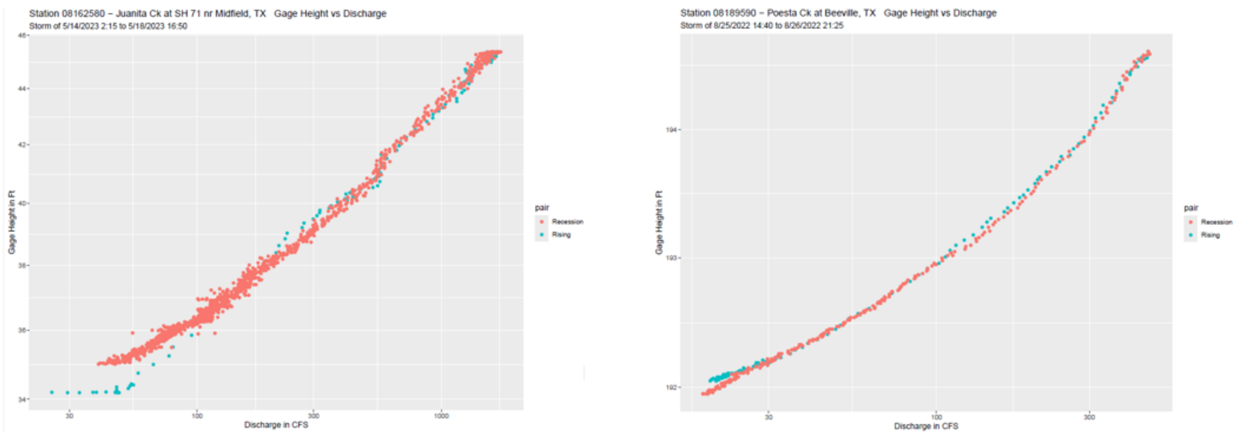

Figure 8. Discharge in cubic feet per second versus gage height in feet for USGS station 08162580 – Juanita Ck at SH 71 nr Midfield, TX during storm of May 14, 2023 to May 18, 2023 and USGS station 08189590 – Poesta Ck at Beeville, TX during storm of August 25, 2022 to August 26, 2022. Data for rising and recession limbs of hydrographs show close agreement.

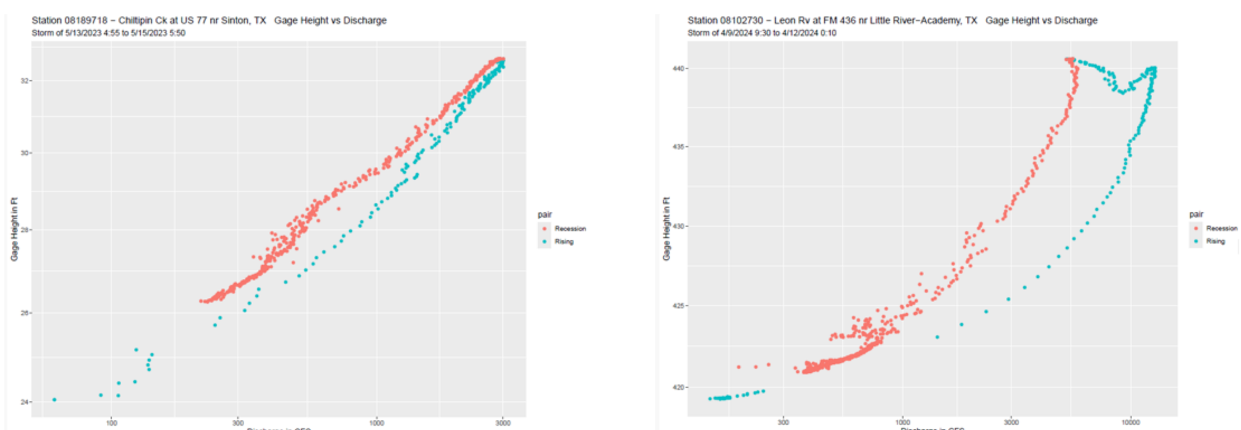

Figure 9. Discharge in cubic feet per second versus gage height in feet for USGS station 08189718 – Chilitipin Ck at US 77 nr Sinton, TX during storm of May 13, 2023 to May 15, 2023 and USGS station 08102730 – Leon Rv at FM 436 nr Little River-Academy, TX during storm of April 9, 2024 to April 12, 2024. Data for rising and recession limbs of hydrographs show different patterns.

The results of this analysis indicate that collection and analysis of surface velocity data are very important to determine whether hysteresis exists at a stream location. The magnitude and occurrence of hysteresis may change at a given site based on other factors, such as the magnitude and duration of a storm event, as well as other local issues that affect the flow dynamics. For station 08102730 – Leon Rv at FM 436 nr Little River-Academy, TX the difference in the rise and fall may be explained by the fact that the gage is located just upstream of the convergence with the Lampasas River and variable backwater conditions may occur during storm events. Evaluation of local conditions at station 08189718 – Chilitipin Ck at US 77 nr Sinton, TX do not indicate any obvious reasons for the loop behavior of the rating.

7. Summary of Purpose, Approach, and Lessons Learned

Hydrodynamic modeling at New Year Creek was initiated to address the limitations of traditional rating curves, which assume that water surface elevation and velocity rise and fall in a fixed, predictable relationship. At this and many other RQ-30 sites, rapid changes in flow during storm events revealed that this assumption is often invalid. Flow velocity and elevation frequently behave independently, especially during flash floods or rapidly changing flows, resulting in significant errors if using conventional methods.

To solve this, a more nuanced, dynamic model was developed. A combination of steady and unsteady hydrodynamic models (FaSTMECH and Nays2dFlood) was used to simulate flood behavior under a wide range of conditions. Extensive field surveys by the USGS corrected issues in LIDAR-based topography (particularly the hydroflattening effect), ensuring accurate bathymetry inputs for the models.

The simulations produced a comprehensive library of flow conditions, which related surface velocity and elevation, and their rates of change, to both discharge and road inundation. This approach allows discharge to be inferred more accurately in real time, even when flow conditions change quickly.

This work led to several important conclusions. First, the dynamic rating curve approach works well and reflects the complexity of real-world stream behavior. Second, LIDAR hydroflattening can significantly bias modeling if not corrected. Third, road inundation predictions can be directly linked to modeled discharge using predefined hydrographs. And finally, machine learning and 3D modeling may offer valuable enhancements in the future, especially for more complex sites. From a research perspective, to obtain the most precise hydrodynamic modeling results, correct bathymetry is always needed. For this project, these data have been collected at the RQ-30 sites selected for modeling that are most affected by hydroflattening, and no further bathymetry data collection is envisaged.

8. Future Work

Work over the next year will prioritize finalizing Python tools to derive discharge and inundation from dynamic model libraries, and evaluating the potential for machine learning to generalize the dynamic rating curve concept across the network. The level of effort required to use IRIC at the Chappell Hill site for 2D modeling was significantly larger than originally anticipated. Adding the vertical variation of the velocity around the bridge itself using 3D modeling could yield some insight. However, for road overtopping flows, the water spreads out very widely in the floodplain and the horizontal variation of the discharge, velocity and depth is the critical component for quantifying flood conditions. We propose to use 2D HEC-RAS to complete the hydrodynamic modeling of the remaining selected RQ-30 sites.

9. Conclusion

During this reporting period, the FAST project's technical components have shown notable progress. With ongoing ADCP measurements and the development of dynamic hydrodynamic modeling, the tools being refined have the potential to enhance the accuracy of discharge estimation and road inundation forecasting. The upcoming final P3C report will consolidate these developments and outline a pathway toward operational deployment.

10. References

Holmes, Jr., Robert R., 2018, River rating complexity, Proceedings of the international conference on fluvial hydraulics (River Flow 2016), St. Louis, Missouri, July 11-14, 2016, CRC Press, p. 679-686, accessed June 1, 2025 at https://pubs.usgs.gov/ja/70193968/70193968.pdf.