Upper Trinity River Silver Jackets Storm Shifting Report

May 2022

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1.0 Introduction

1.1 Purpose of Upper Trinity Storm Shifting Silver Jackets Project

The Silver Jackets program is a collaborative effort between state and federal entities that exists "to increase efficiency and coordination between the State and Federal governments in developing comprehensive and sustainable solutions for flood risk management in the State of Texas" (Silver Jackets 2022). As a means of facilitating this vision, the Upper Trinity Storm Shifting Project leverages the hydrologic technique of storm shifting, also known as storm transposition, to produce technical information capable of supporting emergency managers through the decision-making process. The storm shifting technique utilizes historical storm data as an input and relocates the storm to an optimized location that maximizes peak flow and flood extents at a downstream area of interest. The visualization of this process allows stakeholders to move beyond the constraints and in or out mindset of conventional 100-year regulatory flood maps.

At its core, storm shifting intends to provide informative, relatable, and non-regulatory data that is useful to understand and mitigate flood risk for communities. ***The purpose of the Upper Trinity Storm Shifting Silver Jackets Project is to utilize storms that have occurred within North Texas and estimate their resulting flood extents (and thus impacts to communities) if they had occurred over other areas.*** This report documents the storm shifting concept, study scope, and findings. The final data, maps, and contact information is available here: https://www.nctcog.org/envir/watershed-management/storm-shifting. Appendix A is a useful standalone factsheet to further describe and simplify this concept.

This project equips community leaders with data that can empower the decision-making process within the realms of non-regulatory planning and design guidance. However, the primary contribution of this project is to serve as technical support within the sector of Emergency Management through data that validates both hazard mitigation and emergency management action planning. In a tangible way, community leaders can witness the local impacts of flooding that are more significant than the standard of measure that has historically guided community action and planning. The penultimate results of this effort are better-informed community leaders and a more resilient community.

This project was truly a collaborative effort involving several project team members (i.e., sponsors) and key partners. Project team members included the North Central Texas Council of Governments (NCTCOG), The County of Dallas, Texas General Land Office (GLO), the Federal Emergency Management Agency (FEMA), and the U.S. Army Corps of Engineers (USACE). Additional partners included Dallas County Utility and Reclamation District, City of Irving, and the Town of Highland Park.

1.2 Storm Shifting Background

Initially published in 1988, Hydrometeorological Report (HMR) 55A, "Probable Maximum Precipitation Estimates-United States Between the Continental Divide and the 103rd Meridian," is the product of a joint study between the U.S. Department of Commerce National Oceanic and Atmospheric Administration, the U.S. Department of Army Corps of Engineers, and the U.S. Department of Interior Bureau of Reclamation and provides official guidance on the storm transposition process. Within this document, storm transposition is defined as "the transfer of total storm rainfall amounts from the location where they occurred to other areas where they could have occurred." Three primary overarching considerations guide the storm transposition process: 1) determining a storm of interest 2) determining the location of transposition and 3) performing necessary adjustments to the storm according to unique hydrologic conditions at the transposed location.

The viability of storms of interest is determined based on storm type compared to what has been historically observed within the region of interest. This method undermines the potential for transposing a storm to an area with prohibitive hydrologic conditions for the given storm type. Determining the transposed location, the site where the storm could have occurred, includes two methods: a grid and a transverse.

The grid method transposes storms on centered points of longitudinal and latitudinal intersection. The transverse method centers storms on the extreme limits of transposability. In simple terms, the storm shifting that was performed for this study I well within the meteorological bounds of the available technical guidance.

1.3 Statement of the Problem

Over the course of 48 hours in October 2015, Tropical Storm Patricia unleashed massive amounts of rainfall on the small town of Dawson, Texas, a mere 68 miles from the East Fork Trinity River (see *Image 1* for an illustration of Patricia's rainfall location relative to the Dallas-Fort Worth Metroplex). The surrounding area was devastated by point rainfall that exceeded 22 inches. The resulting runoff led to school and road closures, and emergency managers were thrust into action, conducting high water rescues from businesses, cars, and homes (KERA News 2015). While the nature of these effects is similar to other storms in terms of disruptiveness and devastation, the levee breach that occurred west of Interstate 45 coupled with the train that was derailed near Corsicana offer perspective towards the scale of destruction that was caused by Tropical Storm Patricia (KERA News 2015). It might seem unfathomable to consider that these effects could have been much worse if the storm had been centered over a more urban location that would further optimize destructive consequences.

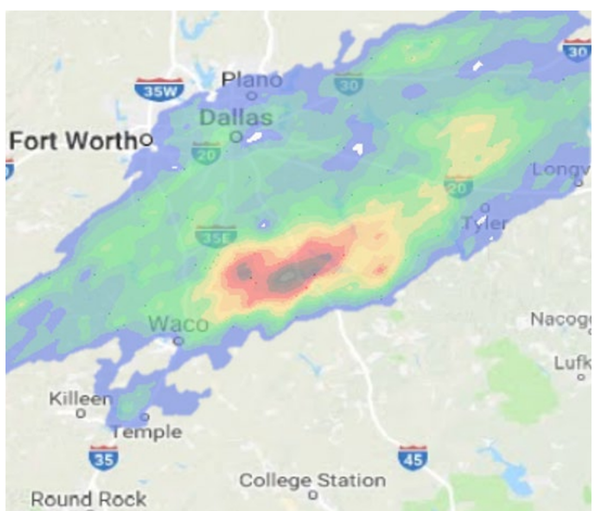

Image 1: Tropical Storm Patricia Rainfall Location

Within the worlds of emergency management and flood mitigation, it is understood that flooding does not stop at lines on a map. However, modelers and mappers are still tasked with gathering and depicting “best available information,” including running models using statistical flooding probabilities. This accounts for considerations such as levees, dams, and other control structures within a watershed, and then applies policy and other regulatory flood mapping standards to determine proximity to a floodplain. However, this methodology does not provide all sources of flooding or provide a complete picture of flood risk, especially with the increased frequency and magnitude of flood events during the current era. Climate variability, uncertainty in published floodplain estimates, and uncertainty surrounding the timing and location of significant storm events validate the drive to accumulate all available information in the realms of flood risk decision-making and emergency preparedness. This project offers an expanded purview for these realms, not to contradict the current model but to serve instead as a complementary piece of the decision-making process.

1.4 Scope

The Upper Trinity Storm Shifting Silver Jackets Project fundamentally consists of shifting previously observed storms such as Tropical Storm Patricia over selected areas of interest. Technical work includes modeling shifted, or ‘transposed’ rainfall totals, runoff hydrograph timing, and resulting flood inundations. These modeled results are intended to foster discussions on flood risk and to implement the data into planning for the areas of interest identified by the sponsor(s). A complete list of tasks as they were scoped at the beginning of this project are as follows:

1. **Determining Storm Number and Locations** - The number of storm locations that need to be analyzed will determine the number of storms that can be analyzed. Correspondingly, the number of storms that are analyzed will impact the number of locations that can be analyzed. A meeting will be held with the Sponsor to discuss the appropriate combination of locations/storms.
2. **Obtain Existing Data** - The USACE will coordinate with the sponsor(s) to obtain geo-referenced river models (HEC-RAS) and terrain data that will be used for floodplain delineation mapping.
3. **Storm Selection** - Storms will be selected for the storm shifting analysis. Storms will only be selected if they are determined to be within the appropriate storm shift region as determined by meteorological parameters and atmospheric mechanisms for North Central Texas. Final storm selection will only be made after coordination with the sponsor(s).
4. **Storm Shifting** - The selected storm will be shifted over the watershed of interest using the Vortex Transposer tool and then will be applied over the rainfall-runoff model (HEC-HMS), producing flow hydrograph information (peak flow, timing and duration of flood) in the area of interest.
5. **Inundation Mapping** - The peak flows from the rainfall-runoff model will be entered into the river/hydraulic model (HEC-RAS) from which resulting inundation maps will be developed.
6. **Documentation** - A report consisting of documentation of work performed will then be developed. The report will include documentation of technical analysis, support data, tables of results, tables, plates, etc.
7. **Post Analysis Collaboration** - The USACE will meet with the sponsor(s) and will explain the storm shift information that was developed and discuss how it can help with floodplain management and emergency preparedness.

2.0 Results

2.1 Determining Storm Number and Locations

A total of thirteen storms were initially identified as potentially viable options for transposition. The complete list of storms is available in *Table 1*. Locations of interest were initially limited to sections of the main stem Trinity River in Tarrant, Dallas, Kaufman, and Ellis counties. The final storm events and locations for this analysis were later selected based on project partner feedback.

Location/Storm Name	Date	Total Rainfall Depth	Rainfall Duration	Distance to Dallas County	Type of Storm
Meeker, OK	Oct-1908	16.2"	72 hours	146 miles	Convective
Hallett, OK	Sep-1940	24.0"	48 hours	192 miles	Convective
Warner, OK	May-1943	24.9"	72 hours	160 miles	Convective
Albany, TX – TS Amelia	Aug-1978	32.7"	55 hours	141 miles	Tropical
Clyde, TX – Hurricane Norma	Oct-1981	23.4"	72 hours	155 miles	Tropical
Joshua, TX	Jun-2000	11.4"	48 hours	55 miles	Convective
Mansfield, TX	Jul-2004	17.4"	48 hours	40 miles	Convective
Eakly, OK – TS Erin	Aug-2007	12.8"	48 hours	170 miles	Tropical
Tropical Storm Hermine	Sep-2010	14.3"	48 hours	150 miles	Tropical
Upper Trinity River	May-2015	~30"	30 days		
Nocona, TX – TS Bill	Jun-2015	13.6"	48 hours	75 miles	Tropical
Dawson, TX – Hurricane Patricia	Oct-2015	22.7"	48 hours	68 miles	Tropical
Harden City, OK	Sep-2018	16.6"	48 hours	92 miles	Convective

Table 1: List of Identified Potential Storms

2.2 Obtain Existing Data

The key data input needed for the storm shifting analysis included the precipitation gridded datasets for each of the potential storms of interest. Most of the more recent storm events were already processed by the West Gulf River Forecasting Center (WGRFC) and were readily available for retrieval in HEC-DSS gridded format. In some cases where the WGRFC data were not readily available for the historic storm event of interest, Analysis of Period of Record for Calibration (AORC) data, as prepared by the NOAA Office of Water Prediction, were retrieved instead.

For the hydrologic analysis, the existing HEC-HMS rainfall-runoff model developed as part of the Interagency Flood Risk Management (InFRM) Trinity Watershed Hydrology Assessment was retrieved. This model was extensively calibrated to large rainfall events and represents the most comprehensive, best available hydrologic model of the Trinity River.

For the hydraulic analysis, several existing HEC-RAS models were retrieved for further investigation into their potential to be used as part of this storm shifting study. These models included the steady state FEMA RAMPP model, the steady state FEMA East Fork RTO model, and the unsteady state Corps Water Management System (CWMS) model.

In addition, the city of Highland Park provided their CWMS model for the Turtle Creek area, which is a tributary of the Trinity River that is not covered by the aforementioned models. The Turtle Creek CWMS model consisted of both a HEC-HMS and HEC-RAS model.

2.3 Storm Selection and Locations of Interest

After eliciting feedback from the community on the locations of interest within the upper Trinity watershed along with the magnitude and types of storms to be utilized, five historic storms ranging from approximately 100-year to 1000-year plus return periods were chosen and are listed in *Table 2*.

Location/Storm Name	Date	Total Rainfall Depth	Rainfall Duration	Distance to Dallas County	Type of Storm
Joshua, TX	Jun-2000	11.4”	48 hours	55 miles	Convective
Nocona, TX – TS Bill	Jun-2015	13.6”	48 hours	75 miles	Tropical
Tropical Storm Hermine	Sep-2010	14.3”	48 hours	150 miles	Tropical
Mansfield, TX	Jul-2004	17.4”	48 hours	40 miles	Convective
Dawson, TX – Hurricane Patricia	Oct-2015	22.7”	48 hours	68 miles	Tropical

Table 2: List of Selected Storms for Analysis

Study partners helped identify four locations along the main stem of the Trinity River where it was deemed beneficial to see storms shifted to These locations include a point on the Elm Fork of the Trinity River representative of the Irving Flood Control District jurisdictional zones; the convergence of the West and Elm Forks of the Trinity River (close proximity to the Dallas Floodway), the Trinity River above Ten Mile Creek (in Southeastern Dallas County near larger floodplains), and the East Fork above Mustang Creek (adjacent to Seagoville, Texas, near areas of historic flooding concerns). Additionally, Exall Lake Dam, located on the Turtle Creek tributary, was also chosen as a location of interest by the Town of Highland Park (due to potential community flooding concerns) and was analyzed using a separate set of hydrologic and hydraulic models provided by the Town of Highland Park. The locations of interest are shown in *Image 2*.

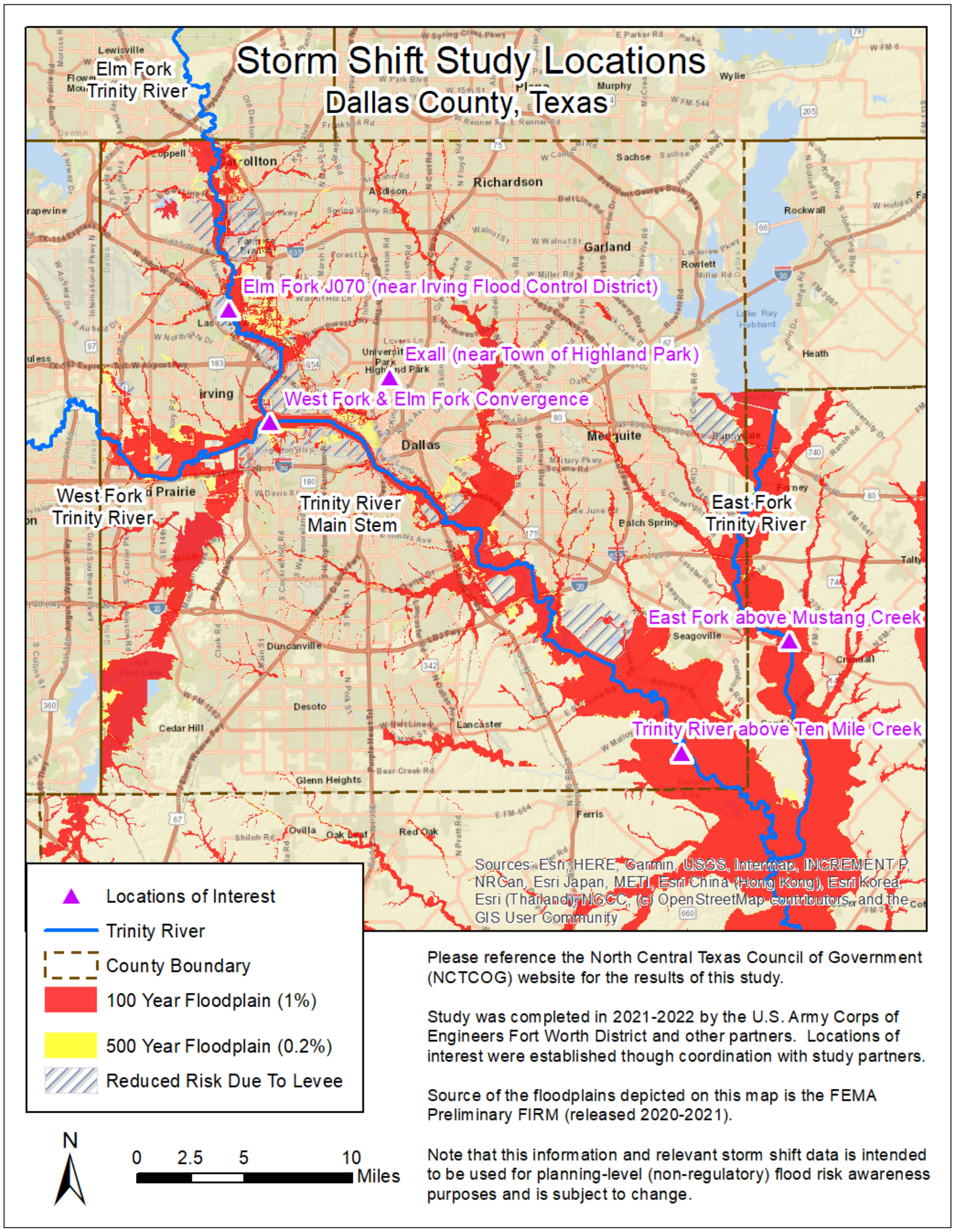

Image 2: Locations of Interest

2.4 Storm Shifting

2.4.1 Technical Process– Meteorology and Hydrology

The first general step in performing the storm transposition analysis was to process the observed gridded precipitation data for each storm of interest. HEC-MetVue meteorologic software was used to visualize the precipitation data and determine the longitudinal and latitudinal coordinates of the observed storm center (point of maximum cumulative precipitation depth). A rectangular boundary shapefile was then created using ArcGIS software, where the centroid of the rectangle was aligned with the observed storm center, and the sides of the rectangle were sufficient to cover the extent of the storm. Next, the Vortex Importer tool was used to clip the input gridded precipitation data to the rectangular boundary shapefile and export the data to a new DSS file. This process served to:

1. Reduce the retrieved precipitation data to only the temporal and spatial extents that were necessary for file size and computational efficiency.
2. Ensure that the observed storm center was located exactly in the center of the clipped grids for visualization purposes.
3. To write the processed, gridded precipitation data to DSS format (standard AORC data is in NetCDF format).

The base HEC-HMS rainfall-runoff model from the Trinity River InFRM study was then slightly re-configured to be used in this study. Based on discussions with local community partners, three distinct hydrologic scenarios were analyzed for each storm shifting event to capture the potential variability and uncertainty of initial basin conditions. Different runs and basin models were set up in HEC-HMS to reflect these scenarios which are outlined in *Table 3*. The existing 100-yr basin model, calibrated specifically to model large rain events of interest, was used for the best estimate scenario along with a Gridded Precipitation meteorologic model that was assigned to a "transposed" gridded DSS file. Copies of the 100-yr basin model were made for the dry scenario, and for the wet scenario and then the initial reservoir elevations, as well as the loss and baseflow parameters, were adjusted accordingly.

Hydrologic Scenario	Starting Reservoir Elevations	Loss and Baseflow Parameters
Dry Scenario	USACE reservoirs at 85% of conservation pool	Uses driest observed calibrated parameters from the Trinity InFRM study
Best Estimate Scenario	USACE reservoirs at top of conservation pool	Uses final, published 100-year Trinity InFRM parameters
Wet Scenario	USACE reservoirs at 85% of flood pool	Uses wettest observed calibrated parameters from the Trinity InFRM study

Table 3: An Outline of the Dry, Best Estimate, and Wet Scenarios

After processing the gridded precipitation data and preparing the HEC-HMS model for the storm shifting analysis, the second general step involved executing a Python script to perform the storm shifting optimization routine. The Python script was loosely based on the structure and optimization framework of the elliptical design storm scripts used as part of the Trinity River InFRM study (InFRM, 2021). It uses the Shuffled Complex Evolution optimization algorithm (Duan et al., 1993) to find the transposed storm center that leads to a maximum peak flow rate at each downstream point of interest. The optimization algorithm determines the new storm center location coordinates, and then the Vortex Transposer tool takes the precipitation data at the observed location and transposes them to the new storm center location. Furthermore, a transposition scale factor is applied to the transposed precipitation data. This is based on guidance found in Hydrometeorological Report (HMR) 55A to adjust the rainfall depths based on specific meteorological conditions inherit to North Central Texas. For each junction of interest, the storm was shifted to a new location, and the HEC-HMS model was computed a total of approximately 150 times which was found to be sufficient in converging on a storm center location that maximized peak flow rate downstream. For each storm and downstream location of interest, the optimization routine was performed three separate times to account for the dry, best estimate, and wet hydrologic scenarios.

In terms of adjusting the storm for suitability to the transposed location, four significant factors serve as the primary considerations for accurate transposition. The first, the moisture maximization factor, is "a ratio of precipitable water associated with the maximum persisting 12-hr 1000-mb dew point to that of the precipitable water associated with the representative persisting 12-hr 1000mb dew point in the storm situation" (NOAA, USACE, and the Bureau of Reclamation 1988). Horizontal and vertical transposition adjustments are then made to account for the changes in hydrologic conditions at the transposed location. A horizontal adjustment is required to account for the difference in moisture availability at the transposed site versus the original storm location. It is calculated using the ratio of precipitable water available at the maximum persisting dewpoint of the initial storm location divided by the precipitable water available at the maximum persisting dewpoint of the transposed location. The vertical adjustment considers the reduction in precipitation potential for areas of increased elevation. A final adjustment is performed to tropical storms, accounting for the diminished efficiency to produce precipitation as storm distance from the coast increases.

As the last general step in the hydrologic analysis, a second Python script was executed that transposes the observed storm to the previously determined optimized location and re-runs the HEC-HMS rainfall-runoff model so that the optimized model boundary conditions and outputs can be saved and analyzed. The technical work for the storm shifting hydrologic process is summarized in the workflow chart available in *Image 3*.

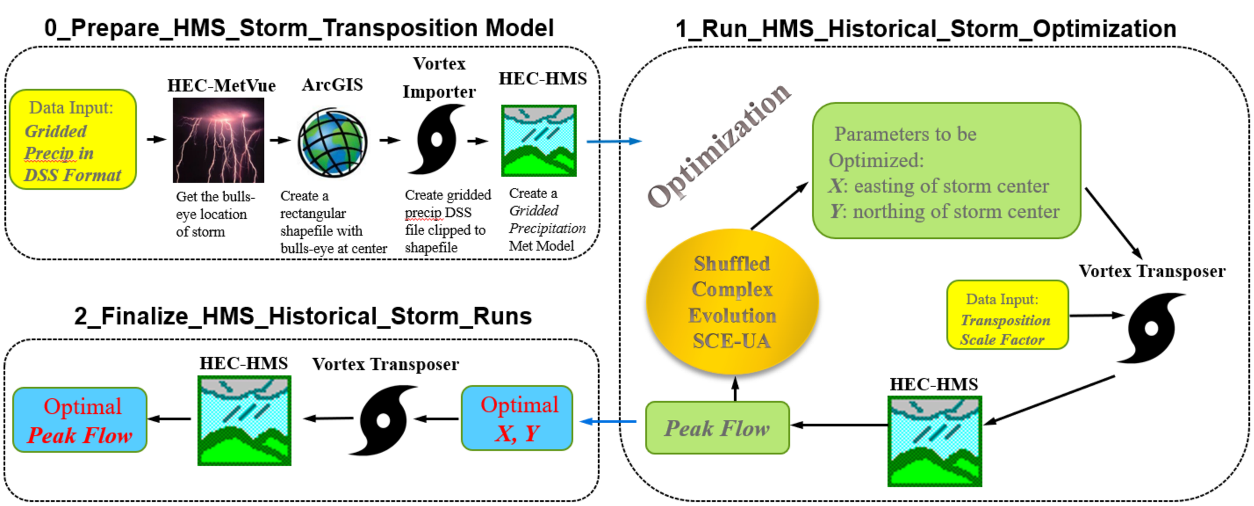

Image 3: Storm Shifting Meteorologic and Hydrologic Workflow

2.4.2 Optimization Results - Hydrology

As initially expected, the three different initial hydrologic scenarios led to noticeable differences in optimized peak flow downstream. The Tropical Storm Bill dry, best estimate, and wet scenario peak flow results illustrate these differences well and are summarized in *Table 4*. For comparison, the latest flow frequency estimates from the Trinity InFRM study are included.

Tropical Storm Bill resulted in approximately 13.6 inches of rainfall over a 48-hour timespan. Compared to NOAA Atlas 14 point precipitation frequency estimates in the Dallas-Fort Worth region, Tropical Storm Bill falls between a 200-year and a 500-year rainfall event. However, as demonstrated in *Table 4*, the resulting peak river flow at the downstream points of interest is estimated to range from below a 100-yr flood event to greater than a 500-yr flood event depending on the hydrologic scenario of the watershed (ranging from dry to wet initial conditions prior to applying the shifted storm). The best estimate scenario represents the scenario that is most likely expected if the shifted storm were to land in the optimized location specific to the downstream area of interest. While considerably less likely to occur, the dry and wet scenarios certainly fall within the realm of plausible outcomes. The results, given the three different hydrologic scenarios, serve to highlight some of the uncertainty of rainfall-runoff analysis. The same storm event can have vastly different impacts depending on the initial hydrologic condition of the watershed.

	Tropical Storm Bill Storm Shifting Results			Trinity InFRM Study Flow Frequency Results		
	Dry	**Best Estimate**	**Wet**	**100-yr**	**200-yr**	**500-yr**
Location	Peak Flow (cfs)	Peak Flow (cfs)	Peak Flow (cfs)	Peak Flow (cfs)	Peak Flow (cfs)	Peak Flow (cfs)
Elm Fork Junction 070	30,812	52,470	105,617	45,100	52,800	62,400
West and Elm Fork Convergence	94,591	147,774	192,214	113,800	140200	182,800
Trinity River above Ten Mile Creek	77,191	124,396	183,961	104,000	125,700	161,300
East Fork above Mustang Creek	50,333	60,982	124,231	57,200	72,200	96,100
Exall Dam	-	5,464	-	-	-	-

Table 4: TS Bill Dry, Best Estimate, and Wet Peak Flow Results

Image 4 (best estimate scenario) and *Image 5* (wet scenario) below highlight the different Tropical Storm Bill optimization results for the Elm Fork Junction 070 location near the Irving Convention Center. Each of the colored nodes represents a different storm center location that Tropical Storm Bill was shifted to as part of the optimization routine. The purple node represents the optimized storm center that led to the maximum peak flow results at Elm Fork Junction 070. For the best estimate scenario, the optimized storm center location as well as other storm center locations that led to significant peak flow results occur mostly downstream of Lewisville Lake and Grapevine Lake. In this scenario, the reservoirs are at the top of the conservation pool, and as a result, have the entire flood pool volume to absorb runoff caused by storm center locations that occurred above the dams. Conversely, in the wet scenario, the reservoirs are already mostly full at 85% flood pool. Therefore, the reservoirs are not in a condition to absorb as much rainfall runoff from storm center locations above the dams. In this wet scenario example, the optimized storm center, as well as other storm centers that led to significant peak flow results at Elm Fork Junction 070 are located well above both reservoirs. The extreme differences in optimized storm center locations as well as in the maximized peak flow results downstream highlight the significant role that USACE reservoirs play in the Dallas-Fort Worth region in mitigating the degree of flooding in downstream communities.

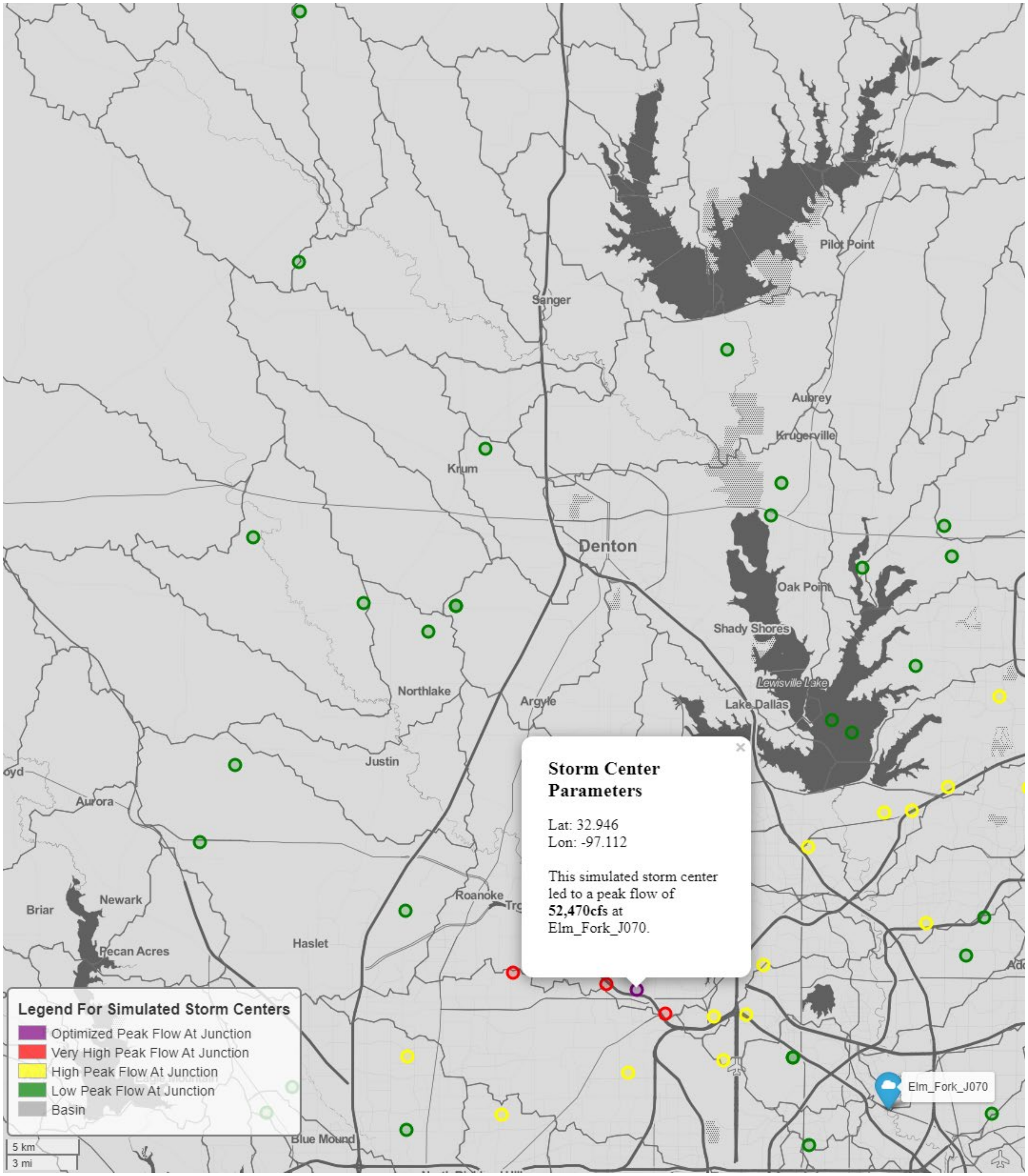

Image 4: Tropical Storm Bill Best Estimate Scenario Optimization Results at Elm Fork Junction 070

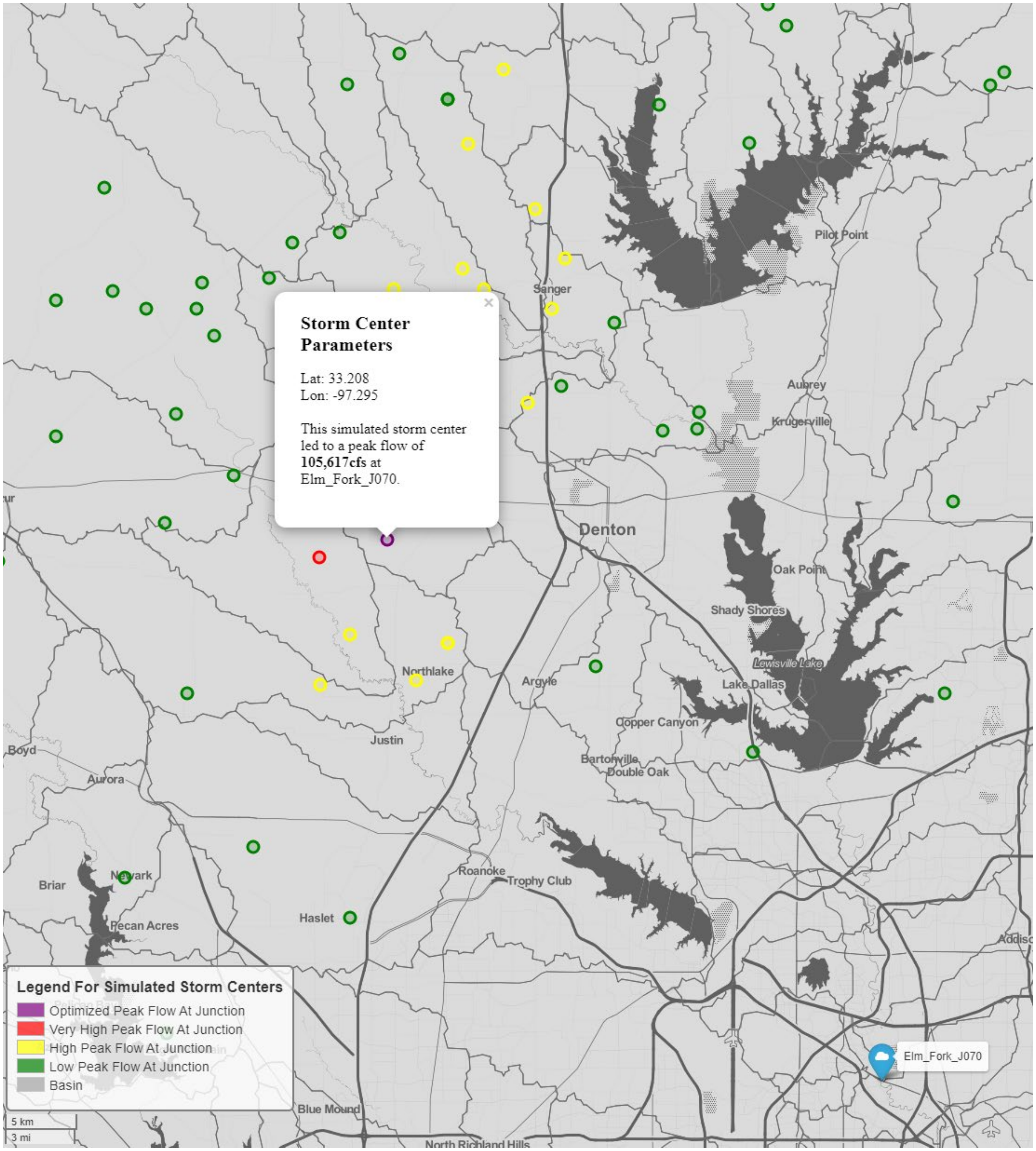

Image 5: Tropical Storm Bill Wet Scenario Optimization Results at Elm Fork Junction 070

2.5 Inundation Mapping

2.5.1 Technical Process – Hydraulics

The first general step of the hydraulics technical process involved investigating the Trinity River hydraulic models available in the region and choosing a model to use that best met the project needs and constraints. Ultimately, the Corps Water Management System (CWMS) Trinity River hydraulic model was chosen for this study. While not as detailed as some of the other available models, the CWMS model does account for the modeling of some significant hydraulic structures located along the mainstem of the Trinity River, such as bridges and levees. Furthermore, the CWMS model was designed to be able to handle large flood events without the need for further modification of the model geometry. Lastly, the CWMS model is an unsteady state model meaning that it can provide valuable timing information of a flood wave as it travels from upstream to downstream. This timing information can be extremely valuable to emergency managers in creating an action plan and is a benefit that is not provided by steady state models.

The second general step was to create HEC-RAS simulations for each combination of storm event, junction of interest, and hydrologic scenario. For each simulation, the optimized flow results from the HEC-HMS rainfall-runoff analysis were assigned as an input to the appropriate cross-sections within the HEC-RAS hydraulic model. Lastly, the unsteady HEC-RAS simulations were computed and the desired water surface elevation grids, depth grids, and inundation boundary shapefiles were generated as outputs. This is in addition to the standard stage hydrograph time-series information at each cross-section.

2.5.2 Results – Hydraulics

For each HEC-RAS simulation, the resulting inundation boundaries from the storm shifting analysis (blue) were plotted against the FEMA preliminary Flood Insurance Rate Map (FIRM) 100-year and 500-year inundation boundaries (yellow and red), as seen in *Image 6*. As a rule of thumb, the shifted storm events that were similar to a 100-year event in magnitude led to inundation results that were similar in extents to the FEMA preliminary 100-year inundations. It is important to note that the CWMS model is limited to modeling the main stem of the Trinity River. Therefore, its inundation output does not cover smaller headwater tributaries and cannot be used to compare with FEMA inundation extents that are present in upstream tributaries.

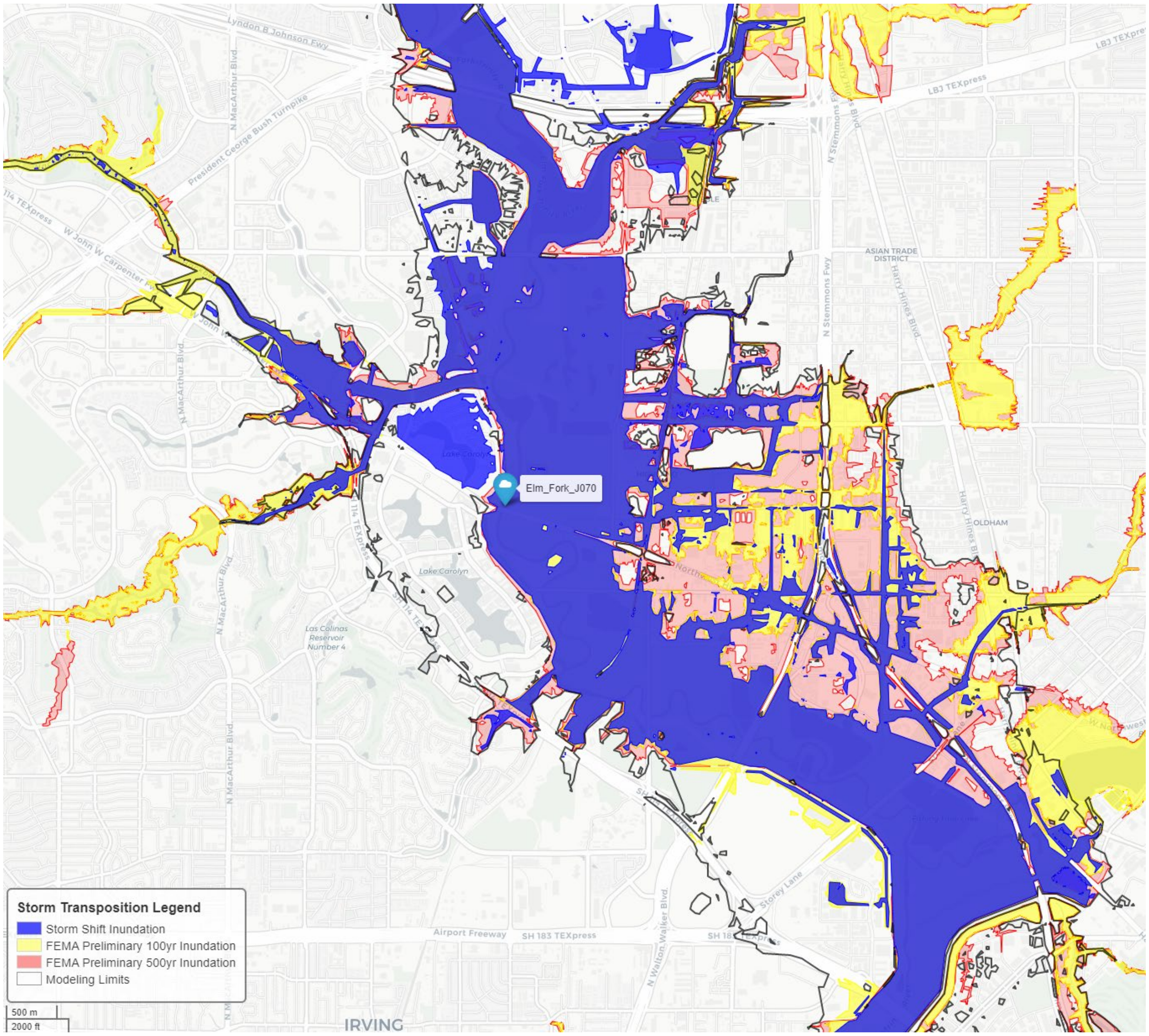

Image 6: Tropical Storm Bill Best Estimate Inundation Results at Elm Fork Junction 070

The differences in the timings and the peaks of the stage hydrographs for the three different hydrologic scenarios are illustrated in *Image 7*. The best estimate scenario at Elm Fork Junction 070 as a result of the Tropical Storm Bill optimized storm center is shown in solid blue, whereas the dry and wet scenarios are shown in dashed light blue and dark blue lines, respectively. Notice how the timing of the peak of the wet scenario occurs later in when compared to the peaks of the best estimate and dry scenarios. This is because the optimized storm center from the wet scenario occurred further away (upstream of Lewisville Lake and Grapevine Lake), thus taking more time for the flood wave to arrive at the Elm Fork Junction 070 location near the Irving Convention Center. *Image* 7 further demonstrates the ability of the two reservoirs to absorb much more of the upstream runoff in the best estimate and dry scenarios, resulting in less severe peak stages and downstream impacts.

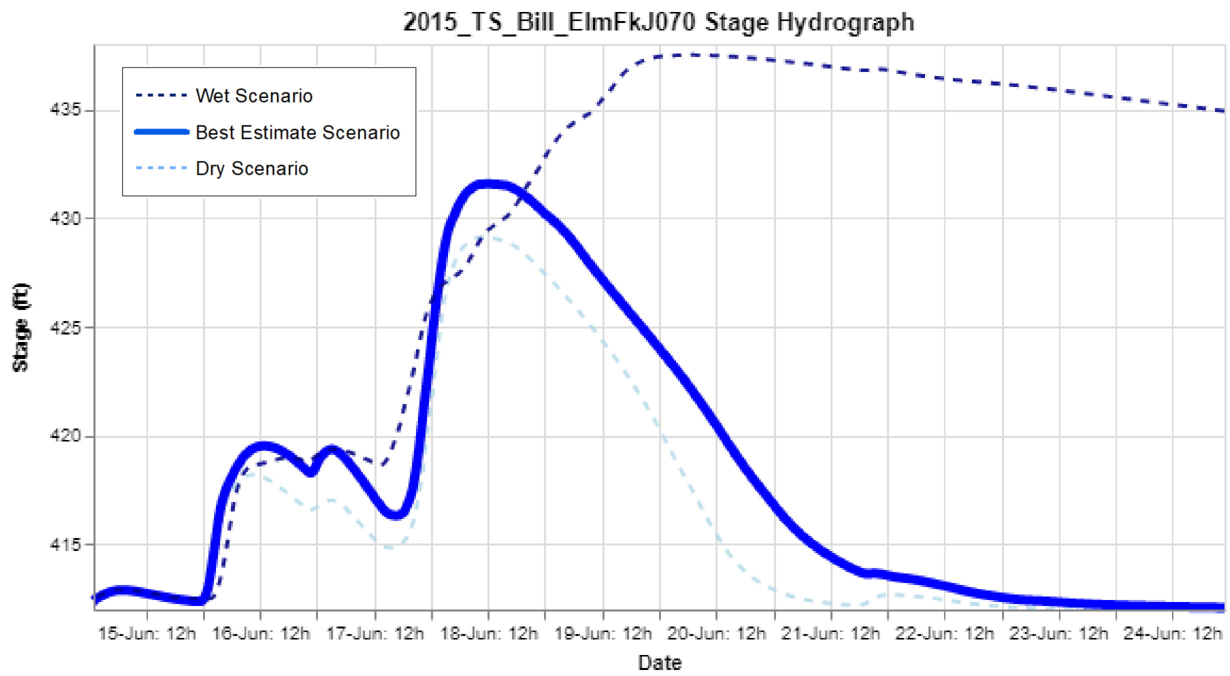

Image 7: Tropical Storm Bill Stage Hydrograph Results at Elm Fork Junction 070

2.6 Documentation

Reporting documentation, spatial data, and interactive HTML maps that highlight the hydrologic and hydraulic storm shifting results are hosted by the North Central Texas Council of Government (NCTCOG), at the following website: https://www.nctcog.org/envir/watershed-management/storm-shifting

2.7 Post Analysis Collaboration

Initial results have been presented to sponsors of the Upper Trinity Silver Jackets Storm Shifting Project and USACE is addressing comments as they are received.

3.0 Modeling Limitations and Next Steps

3.1 Modeling Limitations

Hydrologic and hydraulic processes are made up of many complex interactions between the atmosphere, lithosphere, and hydrosphere. As such, any modeling effort to replicate these interactions will inevitably introduce errors and have some limitations in terms of application. In addition, a unique aspect of this storm shifting study is that it introduced extreme storms to the region, some of which were of a magnitude not yet experienced in the Dallas metroplex. Furthermore, since the storms were transposed, there were no observed flow or stage data to calibrate each of the specific events to. The best solution was to use existing hydrologic and hydraulic models that had previously been calibrated to large storm events. The budgetary and time constraints associated with this study did not allow for significant model edits and improvements.

The Trinity InFRM HEC-HMS model utilized in this study had previously been calibrated to and validated for multiple, large storm events. Nonetheless, some of the transposed storms, such as Tropical Storm Patricia, were considerably larger than any of the calibration events. To account for the large flows that the transposed storms generated, some of the routing reach storage-discharge tables were extrapolated linearly to allow the HEC-HMS computations to proceed to completion. This extrapolation method is not ideal and may not accurately capture reach conveyance at large flows. As such, the flow and stage results associated with the more extreme transposed events have a greater degree of uncertainty than those associated with the less extreme events.

Regarding hydraulics, the Trinity CWMS HEC-RAS model was well-suited to handle all the transposed storm events, even the Tropical Storm Patricia wet scenario event. However, the model was only calibrated to one large event. Furthermore, the model was only designed to model flows and depths on the mainstem portions of the Trinity River. Its applicable coverage does not extend into smaller tributaries along the Trinity. Lastly, while the model does account for some significant hydraulic structures such as bridges and levees, there are structures that are missing in the model that could impact computed depths and inundations. The left bank (east side) of the East Fork just above the confluence is one area that likely does not accurately depict inundation boundaries, especially for the larger events. The levee on this side of the river was modeled using levee station nodes within the HEC-RAS cross-sections. Some of the levee station nodes were overtopped and others were not which yielded unrealistic, jagged inundation interpolations between cross-sections. Computed inundation boundaries and depths in this section of the modeling domain should be viewed with skepticism.

3.2 Next Steps

While storm shifting is a powerful, insightful tool that trades time for space, special consideration should be given to enforcing transposition limits and scale factors to ensure that the characteristics of a storm at its observed location (such as storm type, magnitude, duration, etc.) can reasonably be expected to occur when it is shifted to an alternate location. As discussed in section 1.2, this storm shifting study adopted methodology from HMR 55A to account for varying meteorologic characteristics across a spatial domain. One potential methodology to explore in a future storm transposition study would be to account for varying meteorology across a spatial domain by normalizing and de-normalizing gridded precipitation based on a NOAA Atlas 14 point precipitation frequency grid. For example, the observed gridded precipitation data from a large, approximately 100-year storm event could be normalized based on the 100-year 48-hour precipitation frequency grid. Then, after transposing the storm to a new location, it could be de-normalized based on the precipitation frequency depths at the new location. This alternate methodology could be seamlessly implemented and automated within the current scripting framework developed for this study.

Regardless of the methods and framework used to process and transpose gridded precipitation data, if the models that the transposed storms are applied to are suspect, then the output results will also be suspect. While the hydrologic and hydraulic models that were used were well-constructed, thoroughly vetted, and applicable to achieve the intended goals of this study, there are a few areas that could be addressed in future studies to improve confidence in the model output. For the HEC-HMS runoff model, the storage-discharge curves associated with several of the modified-puls routing reaches should be extended based on results generated from a hydraulic analysis. This would improve the computational accuracy of water volumes being conveyed through the system during extreme rain events. In terms of hydraulic modeling, there are several areas where the CWMS HEC-RAS model should be improved upon. Geometric improvements that may impact the computed depths include the addition of missing bridge structures and the conversion of existing 1D storage areas to 2D storage areas. 2D storage areas are better suited to modeling the movement of water behind levee structures. Computed inundations along the East Fork of the Trinity River, particularly along the left bank above the confluence with the main stem, would be much improved by removing the levee station nodes from the cross-sections, ending the cross-sections at the top of the levee, and adding a 2D flow area behind the levee. This approach would offer a much more realistic portrayal of levee overtopping and would result in more accurate and realistic inundation boundaries. Lastly, the CWMS HEC-RAS model was calibrated previously to only one large rain event. To improve confidence in the calibrated model parameters, future calibrations and validations should include multiple, large storm events.

Beyond these technical considerations, there is also a need to share this storm shifting concept and methodology across the floodplain management community to continue to improve and maximize its use. One example is collaborative coordination of this storm shifting concept through the Interagency Flood Risk Management (InFRM) program. The InFRM team brings together federal agencies with mission areas in water resources, hazard mitigation, and emergency management to leverage their unique skillsets, resources, and expertise to reduce long-term flood risk throughout the region. Additional state and local engagement are necessary through project sponsors, partners, and other key stakeholders. The result of this exposure is to ultimately increase community flood risk awareness and resiliency and to continue to expand and refine this storm shifting capability.

4.0 Software and References

4.1 Software

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UPPER TRINITY STORM SHIFTING

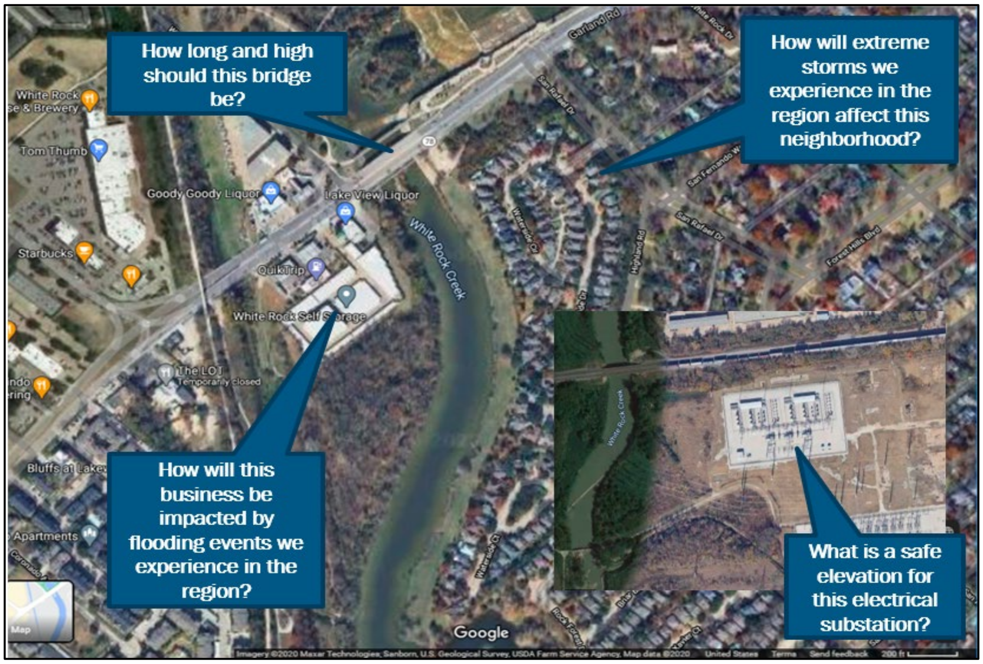
SILVER JACKETS
Many Partners, One Team

Purpose

The Upper Trinity River Silver Jackets Storm Shifting Project is intended to contribute to the viability of community resiliency and flood hazard mitigation strategies. This is accomplished by shifting historical storms over nearby locations to generate compelling real-world examples of flood risk that can be compared against hypothetical estimates such as 100-year and 500-year floodplain maps. Through key partnerships, statistically significant storms from North Texas were selected and moved over areas of interest using the process of storm shifting.

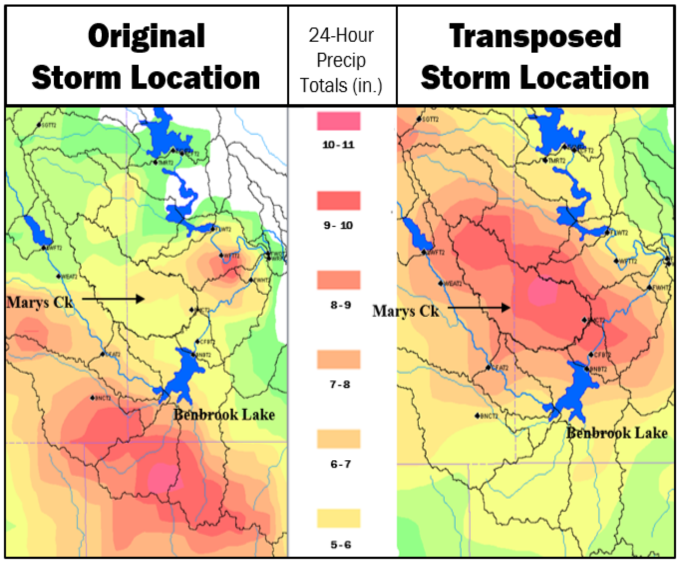
Why should I care?

Current flood mapping products perpetuate a misconception that flooding stops at the lines on a map. This “in or out” misconception can be explained in part by the limited flood scenarios and lack of historic data contributing to flood map development. Determining a more complete picture of flood risk and filling in these information gaps requires a different strategy. Storm shifting is that strategy, providing informative, relatable, and non-regulatory data to help communities better understand their own flood risk and further empower them to mitigate disastrous effects.



Background

The Silver Jackets program is a collaborative effort between various stakeholders tasked with developing comprehensive and sustainable solutions for flood risk management in Texas and across the Nation. The project team, shown above, in coordination with partners from Dallas County Utility and Reclamation District, City of Irving, and Town of Highland Park, identified several locations along the Upper Trinity River as areas of interest for this study.

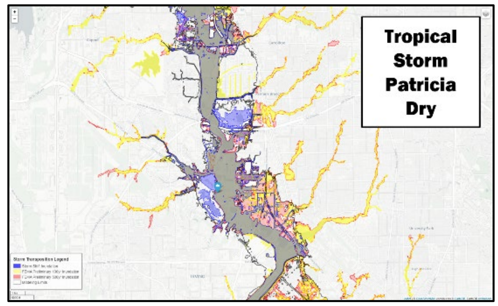


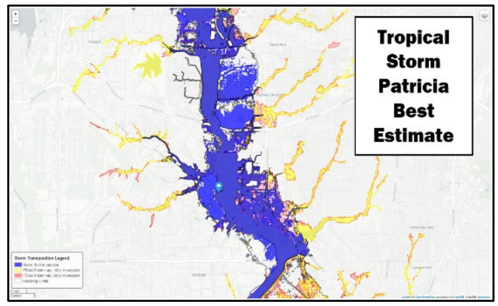
Modeling Approach

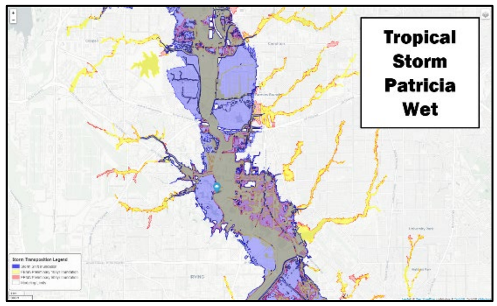
A total of five historic storms, ranging from approximately 100-year to 1000-year events, were selected for shifting, or 'transposition'. The historical storms were then transposed to an optimized location that maximizes peak flow and flood extents at the downstream area of interest. Three hydrologic scenarios were simulated to account for variability within the watershed due to seasonal and other effects: dry (drought-type), best (most likely) estimate, and wet (soils are saturated and lakes are full).

Results

For each hydraulic model simulation, the resulting flood extent, or 'inundation' boundary from the storm shifting analysis (blue) were plotted against recently published FEMA preliminary 100-year and 500-year inundation boundaries (yellow and red) in the examples to the right. In general, the shifted 100-year storm events show inundation results similar to the FEMA preliminary 100-year inundations. However, comparison of the three different hydrologic scenarios show noticeable differences in inundated areas and underscores how much variability exists in rainfall-runoff flood modeling. The takeaway is that the same storm event can result in vastly different impacts, depending on the initial hydrologic condition of the watershed.

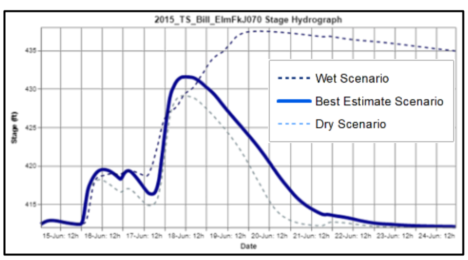


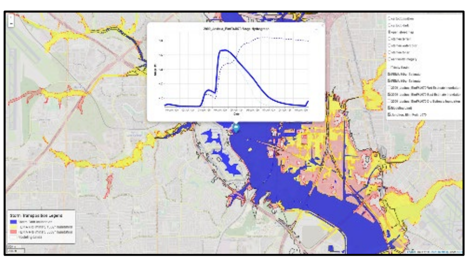




Application

Data from this study is available for download at the link below and includes a full report and interactive HTML maps for all the selected storms and areas of interest. Flood layers can be toggled on/off in the upper right corner of the map, and additional peak flood timing and stage (stream elevation) information is viewed by clicking the point of interest icon (see example below). These features provide emergency managers and others with another valuable tool in the development of disaster response, emergency plans, and mitigation activities.





For More Information:

To access study report, data, and additional information please visit: https://www.nctcog.org/envir/watershed-management/storm-shifting

- **Includes presentation and overview maps**
- **Interactive HTML flood maps**
- **Downloadable GIS shapefiles**

*Engineering models, depth grids, and water surface elevation grids, available upon request.