Report P4C Flood Forecast System Operation

Project 0-7095 Evaluate Improved Streamflow Measurement at TxDOT Bridges

31 July 2022

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Introduction

This is the third of four progress reviews that are scheduled in the project concerned with progress on Task 4, Flood Forecast System Operation. The schedule of these reports is shown in Table 1. This report comes 23 months into a 36 month project, or after approximately 64% of the project duration.

Report	Due Date	Months from Project Initiation
P4A	April 2021	8
P4B	January 2022	17
P4C	July 2022	23
P4D	June 2023	34

Table 1. Schedule of P4 reports

In report P4A, the flood forecast system was described: "The goal of the flood forecast system for this project is to bring together in one system the observational data coming from stream gauges, and the forecasts coming from the National Weather Service, so as to produce improved real-time flood information for the TxDOT transportation system".

Project Context

In a teleconference held on 18 January 2022 with TxDOT and the NWS Southern Region Headquarters staff, it was agreed that TxDOT and NWS would operate using a principle of "shared services" in by which data and map services would be exchanged between the two agencies so that each would be supported by the information accessible to the other. This might be conceptualized as in Figure 1.

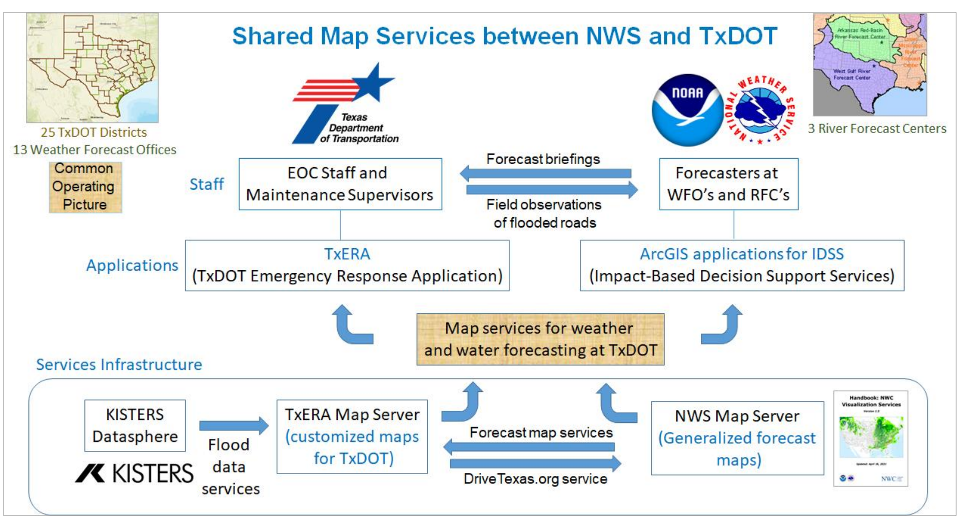


Figure 1. Interaction of National Weather Service, TxDOT and the Project 0-7095 research team.

The weather and water forecasting services provided by the National Weather Services are generalized products intended for a broad audience that includes the public and state and local emergency response agencies of which TxDOT is one. TxDOT's particular concern is with flooding of the state's road and bridge system for the principal highways providing connectivity across the state. As shown in Figure 2, TxDOT's field staff who monitor road conditions and manage road closures are organized by Maintenance Sections (orange lines) and coordinated by Districts (purple lines). Hence, it is not just a regional storm precipitation that matters but also specifically how much precipitation falls within each District and Maintenance Section boundary. A goal of this project is to augment NWS forecasting information by deriving products customized to support TxDOT's flood response in this spatial context.

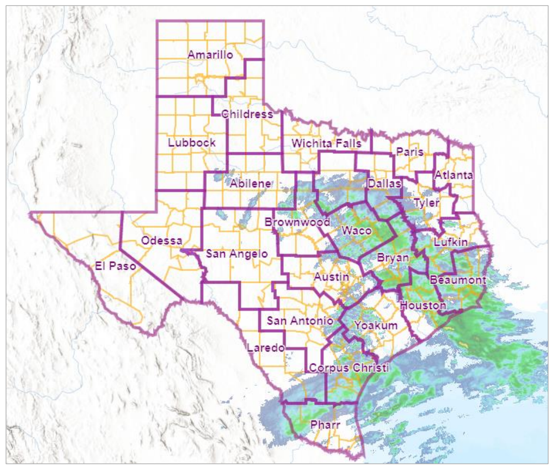


Figure 2. Precipitation Map overlaid on TxDOT District and Maintenance Section boundaries

On 5 July 2022, the National Water Center publicly released a set of 40 Hydro Visualization map services, as shown in Figure 3. These services can fit directly into TxERA and they conform exactly the framework of shared services which had earlier been agreed between the NWS Southern Region and TxDOT.

Medium Range Forecast	**21 Maps**
Rapid onset flooding	10 Day Arrival Time
	10 Day Duration
	Length flooded
Rapid onset probabilility	Day 1 probability
	Day 2 probability
	Day 3 probability
	Days 4-5 probability
	Days 1-5 probability
	Days 1-5 hotspots
High water arrival time	3-Day arrival time
	10 Day arrival time
	10 Day end time
High flow magnitude	3-Day Annual Exceedance Probability (AEP)
	5-Day AEP
	10-Day AEP
High water probability	Day 1
	Day 2
	Day 3
	Days 4-5
	Days 1-5
	Days 1-5 Hotspots

Short Range Forecast	**12 Maps**
Rapid onset flooding	18 hour arrival time
	18 hour duration
	18 hour length flooded
Rapid onset flooding probability	Hours 1-6 probability
	Hours 7-12 probability
	Hours 1-12 probability
	Hours 1-12 hotspots
High water arrival time	18 hour arrival time
	18 hour end time
High flow magnitude	18 hour AEP
High water probability	12 hour high water probability
	12 hour Hotspots
Current and Past Conditions	**5 Maps**
High flow magnitude	Annual exceedance probability
Anomaly	7-Day Average Streamflow Percentile
	14-Day Average Streamflow Percentile
Past 14 day Max high flow magnitu	Past 7-days AEP
	Past 14 days AEP
Main stem river forecasts	**2 Maps**
Forecast point	Max status -- forecast trend
Downstream river	

Figure 3. Hydro Visualization map services provided by the National Water Center
https://maps.water.noaa.gov/server/rest/services

Functions of Datasphere

The technical basis of the TxDOT Flood Forecasting system is a set of software and data functions called Datasphere, which resides on the Eastern United States facility of Amazon Web Services. It is maintained there by the KISTERS firm, whose parent company KISTERS AG https://www.kisters.de/en/ is based in Aachen, Germany, and KISTERS North America, based in Sacramento, California. Datasphere contains two kinds of information: observations and rasters. Observations are time series records of measured data at gauges, such as precipitation, water level and streamflow. Raster data are arrays of information distributed over space and time, such as a sequence of precipitation maps or flood forecasts defined for each reach of a stream network. Data from the TxDOT Flood Data Network built in this project are stored as observations data. Information from the National Weather Service weather and water forecasting system are stored as raster data. Note that use of the term “raster” in this context is different from the use of this term in GIS where it refers exclusively to data stored one value per cell in a dense cell mesh, such as a Digital Elevation Model or a photographic image.

Two mechanisms of Datasphere operation are illustrated in Figure 4. The first mechanism is the “Operations Engine” which supports real-time flood information and is based on web services requests for data (see Figure 5) from the ArcGIS Online mapping environment, such as for the latest values of gauge readings – “give me the latest value from all the gauges over the whole spatial domain”. This supports the creation of real-time flood maps in the TxDOT Emergency Response Application (TxERA. The second mechanism is the “Research and Planning Tools” which deal with extraction and analysis of historical information stored in Datasphere, such as past records of streamflow or water level or the retrospective flows of the National Water Model for the period 1979 to 2020, produced as part of the validation of the current National Water Model version 2.1. Such enquiries may include “give me the time series for this gauge” “give me all the time series from this observation network”. These requests are made using Python programming to access the Datasphere’s Command Line Interface. Datasphere also supports a visual portal for querying and viewing observations and raster data. This set of functions supports student research on such topics as forecast model error analysis.

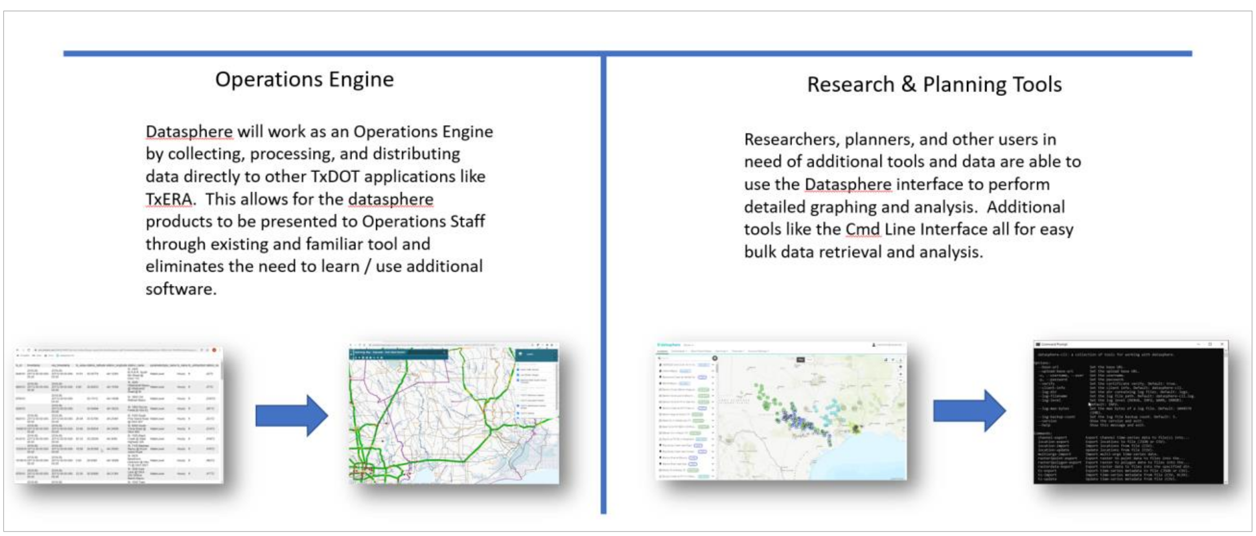


Figure 4. Datasphere supports real-time operations and retrospective research and planning analyses.

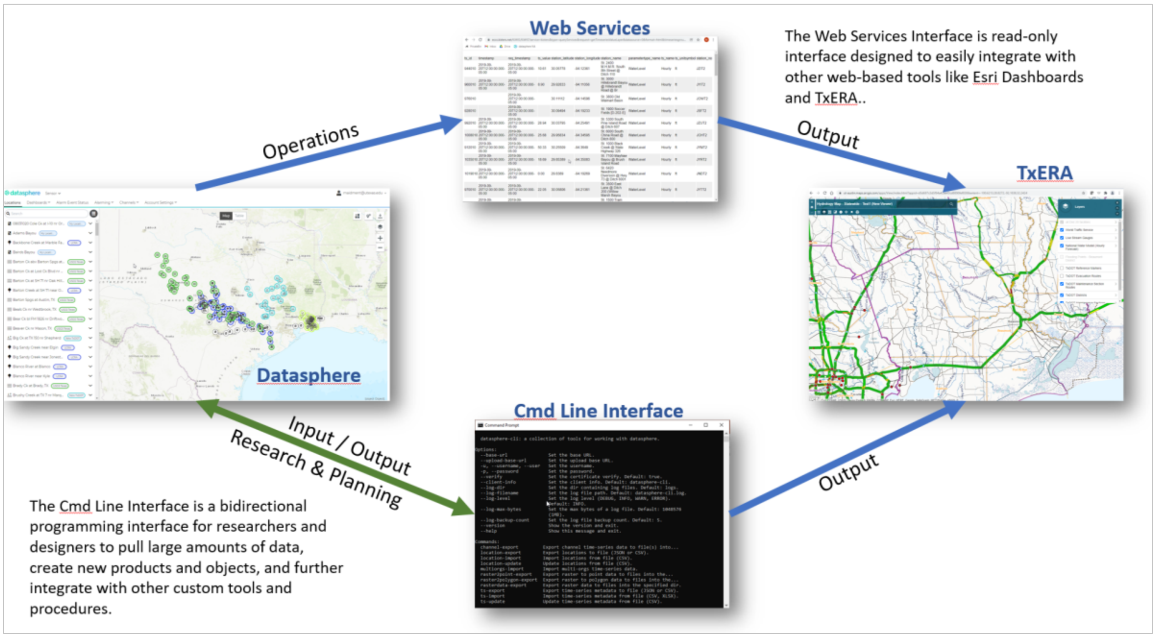


Figure 5. Mechanisms of operation of Datasphere

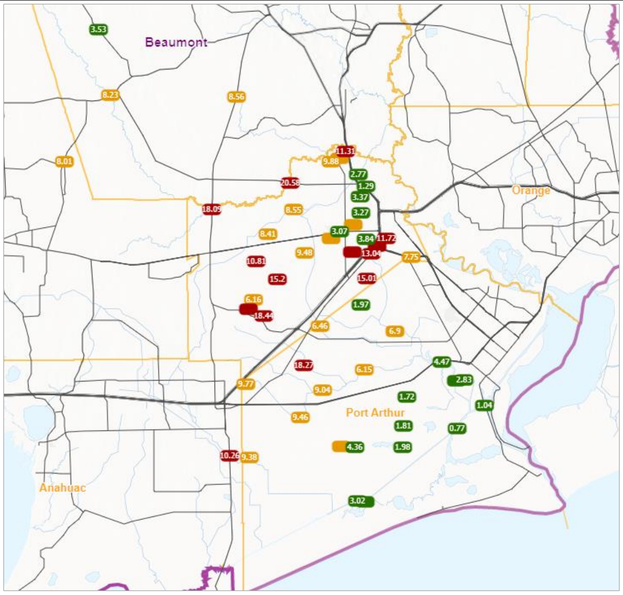
Example Application of Datasphere

An example application of Datasphere is shown below in Figure 6. In part (a) a data services call made to the Datasphere yields a time series value for each gauge in an observation network at one particular time during TS Imelda (10AM on 20 September 2019). The resulting time series values are compared to those measured prior to the storm and the water level rise determined. In part (b),this is visualized as a map service in ArcGIS and symbolized by Green-Orange-Red colors according to the amount of water level rise at the gauge. In this manner, TxDOT maintenance staff can see quickly which gauges have unusual behavior where flooding can be expected. This map service can be displayed in TxERA.

ts_id	timestamp	req_timestamp	ts_value	station_latitude	station_longitude	station_name	parametertype_name	ts_name	ts_unitsymbol	station_no
944010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	10.61	30.05778	-94.12361	St. 2400 M.H.M.R. South 8th Street @ Ditch 110	WaterLevel	Hourly	ft	JZIT2
960010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	8.90	29.92833	-94.11056	St. 3000 Hillebrandt Bayou @ Hillebrandt Road @ Br	WaterLevel	Hourly	ft	JYIT2
976010		2019-09-20T12:00:00.000-05:00		30.11112	-94.14596	St. 3800 Old Walmart Basin	WaterLevel	Hourly	ft	JOWT2
928010		2019-09-20T12:00:00.000-05:00		30.09494	-94.19233	St. 1900 Soccer Fields [D-202-E]	WaterLevel	Hourly	ft	JSFT2
992010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	28.94	30.03795	-94.25491	St. 5300 South Pine Island Road @ Ditch 607	WaterLevel	Hourly	ft	JZUT2
1008010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	25.68	29.95834	-94.34595	St. 6000 South China Road @ Ditch 800	WaterLevel	Hourly	ft	JCHT2
912010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	50.33	30.25509	-94.3649	St. 1000 Black Creek @ State Highway 326	WaterLevel	Hourly	ft	JYMT2
1035010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	18.69	29.85389	-94.35083	St. 7100 Mayhaw Bayou @ Brush Island Road	WaterLevel	Hourly	ft	JYRT2
1019010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	0.00	29.8389	-94.19269	St. 6420 Needmore Diversion @ Hwy 73 @ Ditch 8001	WaterLevel	Hourly	ft	JNDT2
970010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	22.05	30.05806	-94.21361	St. 3500 East Lane @ Ditch 200 (Willow Marsh Bayou	WaterLevel	Hourly	ft	JYTT2
922010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	21.95	30.16917	-94.19972	St. 1500 Tram Road @ Ditch 1002	WaterLevel	Hourly	ft	JZDT2
954010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	21.57	30.0675	-94.19889	St. 2700 Landis Drive @ Ditch 202B	WaterLevel	Hourly	ft	JZLT2
938010		2019-09-20T12:00:00.000-05:00		30.09707	-94.16831	St. 2120 Wellington Screwgates	WaterLevel	Hourly	ft	JWST2
986010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	14.64	29.75389	-94.37639	St. 4600 Spindletop Bayou @ State Highway 124 [Bri	WaterLevel	Hourly	ft	JYXT2
1002010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	5.43	29.83667	-94.09139	St. 5820 Port Acres Sportsman @ Marsh Ditch 551-C	WaterLevel	Hourly	ft	JPAT2
1045010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	60.77	30.25694	-94.56833	St. 800 Pine Island Bayou @ State Highway 105 (Ba	WaterLevel	Hourly	ft	JYKT2
1029010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	5.55	29.69099	-94.17094	St. 6800 Needmore Diversion Saltwater Barrier @ Di	WaterLevel	Hourly	ft	JNET2
1013010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	25.28	29.97226	-94.33743	St. 6200 South China Road @ Pine Tree Ditch 601	WaterLevel	Hourly	ft	JPTT2
1049010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	87.68	30.34861	-94.58806	St. 900 Little Pine Island Bayou @ State Highway 7	WaterLevel	Hourly	ft	JYLT2
948010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	11.12	30.03194	-94.08333	St. 2500 Highland Ave. @ Ditch 104	WaterLevel	Hourly	ft	JZJT2
980010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	17.27	30.12974	-94.15694	St. 4200 Concord @ Ditch 001	WaterLevel	Hourly	ft	JYAT2
932010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	17.38	30.11528	-94.16583	St. 2000 Folsom Road @ Hillebrandt Bayou [D-100]	WaterLevel	Hourly	ft	JZET2
964010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	17.60	29.93556	-94.23111	St. 3200 Glenbrook Dr. @ Ditch 407 @ Green Acres	WaterLevel	Hourly	ft	JZPT2
996010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	22.72	29.94778	-94.40028	St. 5500 F.M.1406 @ Ditch 500 North Fork Taylors B	WaterLevel	Hourly	ft	JZWT2
916010	2019-09-20T12:00:00.000-05:00	2019-09-20T12:00:00.000-05:00	39.80	30.09821	-94.40562	St. 1200 State Highway 326 @ Pine Island Bayou	WaterLevel	Hourly	ft	JZBT2

https://eccc.kisters.net/KiWIS/KiWIS?service=kisters&type=queryServices&request=getTimeseriesValueLayer&datasource=0&format=html&timeseriesgroup_id=80753&metadata=true&timezone=America/Chicago&date=2019-09-20T15:00:00

(a) Time Series Value Layer data service from Datasphere



(b) Map service of the resulting water levels plotted in ArcGIS

Figure 6. Example Application of Datasphere.

Nexus Points

An important goal of this project is to convert flood forecasting on streams to flood impact on roads and bridges. A simple way to think about this is to intersect the TxDOT Road Inventory network with the network of streams and rivers forecast by the National Water Model, as shown in Figure 7. If the term "Nexus Point" is applied to the point of intersection between a road contained in the TxDOT Road Inventory, and a stream forecast by the National Water Model, then it turns out that there are 63,336 such Nexus points, which is much larger than the number of National Bridge Inventory bridges in Texas (about 27,000) because of many intersection points at culverts and low water crossings less than 20 ft in width, which are not included in the National Bridge Inventory.

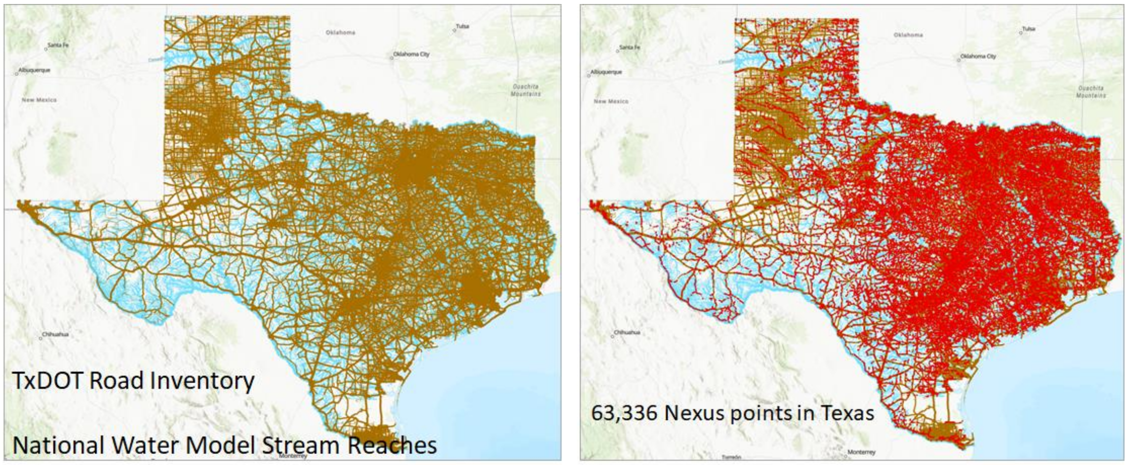


Figure 7. Nexus Points at the intersection of roads and streams.

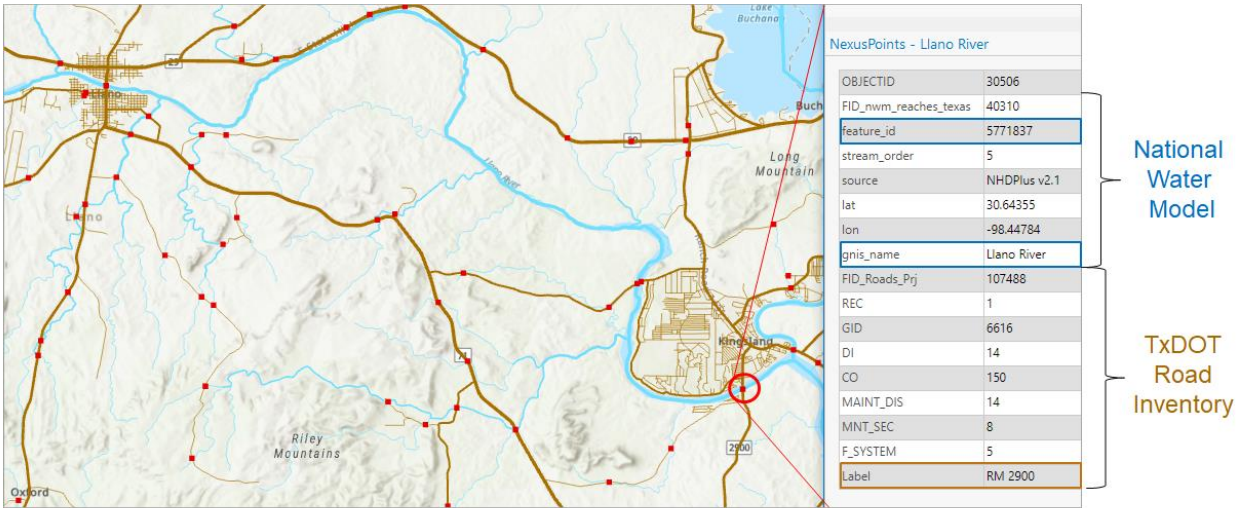


Figure 8. Nexus points in the Llano River Basin

An example of such a set of Nexus Points in the Llano river basin is shown in Figure 8. One particular point is highlighted – the Llano River at RM 2900 in Kingsland. This bridge was washed out on 16 October 2018 during a very high flood on the Llano River.

Figure 9 shows the forecasting for the Llano River at Llano for this flood recorded in real-time in the Kisters TxDOT forecast viewer as it existed in 2018 as an outcome of the Streamflow I project we had earlier with TxDOT. The stage height of the observations at the USGS gage (solid line) goes up to 40 ft, and the short range forecast from the National Water Model discharge converted to a stage height using a rating curve in the Kisters data system is at approximately the same level. This is a remarkable level of agreement given that the October 2018 flood on the Llano River was the largest since 1939.

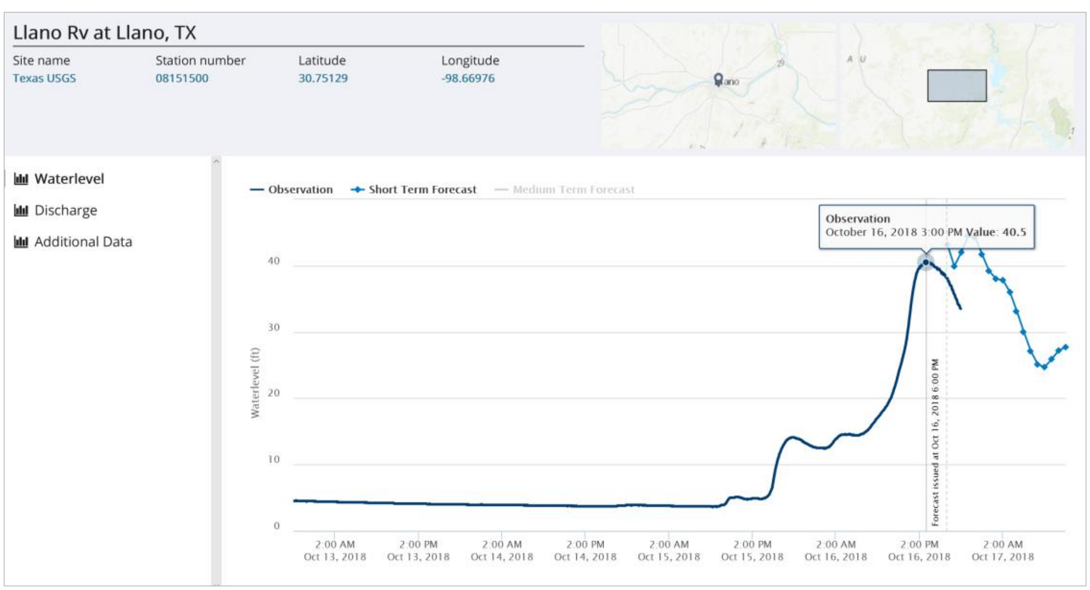


Figure 9. Forecasting on the Llano River at Llano on 16 October from the Kisters TxDOT forecast viewer produced in the Streamflow I project.

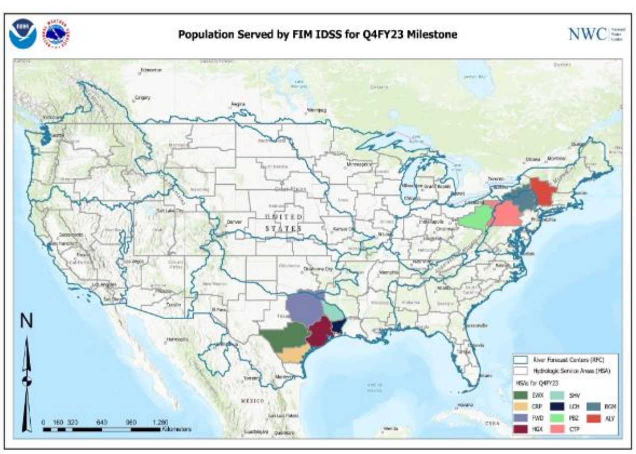
The intention is to be able to provide comparable forecasts where and when they are needed at bridges threatened by future floods.

Flood Impact on Bridges

For real-time flood inundation mapping to be fully informative for the road transportation system the bridge infrastructure needs to be restored into the flood modeling and mapping process. There are several levels at which this can be done:

a. By defining a bridge deck terrain using LIDAR point clouds and creating a "dual terrain model" at bridges that includes both the bare-earth terrain and the bridge terrain. The "Dual Terrain" data are used to create the flood inundation map so the bridge is not always inundated as now. This approach does not mean changing the flood model itself, just the way the output flood inundation map is drawn from it.
b. Extending the bridge deck terrain using estimates of "bridge thickness" developed by TxDOT – this allows for bridge warnings when water is approaching the low chord of the bridge
c. Including a simplified bridge representation of the bridge into the flood model itself so that the backwater effect of the bridge structure itself is being modeled.
d. Including a detail bridge representation into the flood model.

At present, only the first alternative appears feasible to be applied "at scale" across the bridge network in Texas, and even that is going to take some significant further development to be realized. The stage estimates presented in Figure 9 were generated by using the Height Above Nearest Drainage method. The HAND method is also the standard in the National Weather Service's flood inundation mapping system, presently operational within the NWS data infrastructure, and projected for deployment to about half of Texas in Q4 of FY 2023, as shown in Figure 10. The area shown covers all or part of the areas served by six Weather Forecast Offices (Austin/San Antonio, Corpus Christi, Houston/Galveston, Lake Charles and Shreveport), and a portion of the service area of the West Gulf River Forecast Center. This area includes about a hundred of the approximately two hundred HUC8 watershed areas covering Texas.



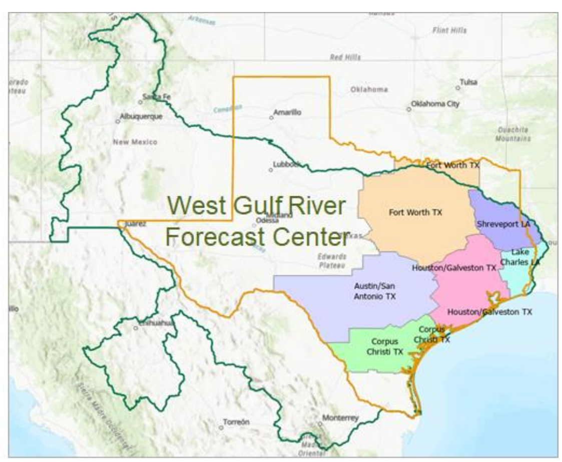


Figure 10. Proposed area of deployment of real-time flood inundation mapping services in Texas in Q4 of FY 2023

It is feasible to extract from the Dual Terrain model at a bridge a "bridge envelope" that describes the vertical profile of the stream cross-section and the bridge deck. The HAND value for a bridge is height difference between the minimum elevation of the stream cross-section and the minimum elevation of the bridge deck. If bridge envelopes, and HAND values are computed for each TxDOT bridge, and if HAND-based rating curves are available for all stream reaches in the Kisters Datasphere, then the potential for a flood forecast to reach the bottom of the bridge deck can be determined.

Conclusions

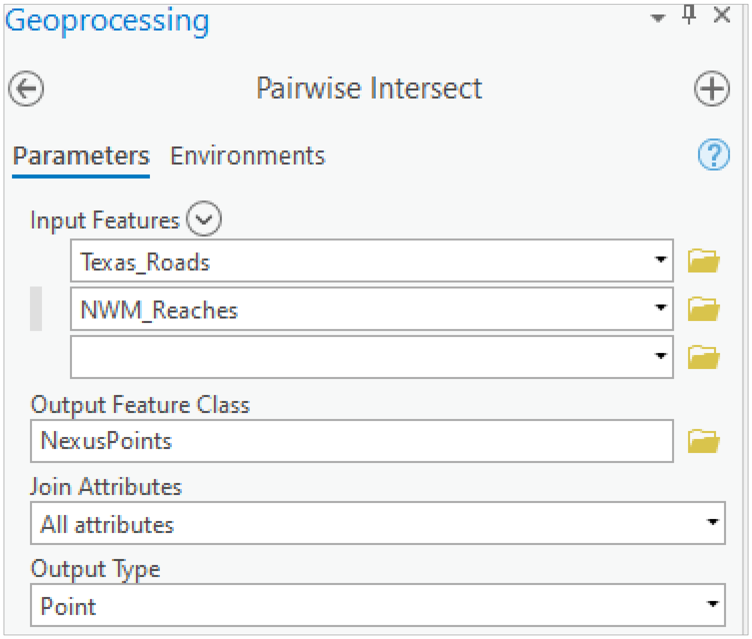
The new Hydro Visualization map services provided by the National Water Center can be directly incorporated into TxERA to show various components of the forecast streamflow. What the Streamflow II project has to do is to translate this forecast into flood impact on roads and bridges. The flood impact on roads will be obtained by translating landscape-scale flood inundation mapping, not yet publicly available but scheduled next year into inundation of roads, and the flooding of bridges will be assessed by directly computing the forecast discharge at each stream-road Nexus point using the Datasphere, converting that into a water surface elevation using a rating curve, and comparing that to critical bridge elevations derived from the bridge envelope. The Datasphere will also be used to compute TxDOT specific forecast information products such as forecast precipitation over TxDOT Districts and Maintenance Section areas, which can then be displayed in TxERA. The capacity to perform these functions will be illustrated in the Austin flood emergency response exercise scheduled for September 2022.

Appendix 1. Road-Stream Nexus Points

The roads used to define the Road-Stream Nexus Points shown in Figure 7 are taken from the TxDOT Roadway Inventory https://gis-txdot.opendata.arcgis.com/datasets/txdot-roadway-inventory/explore?location=31.061298%2C-100.081515%2C7.08 Following the recommendation of Michael Chamberlain of TxDOT TPP, this data layer is filtered using the query: RDBD_ID IN ('GS', 'RG', 'AG', 'BG', 'LG', 'MG', 'PG', 'SG', 'XG', 'YG', 'TG') OR (RDBD_ID = 'KG' And (MED_TYPE = 0 Or HWY_DES1 NOT IN (0, 3, 4, 5))) OR HSYS IN ('LS','CR'). This query reduces the number of road features by about 4%, from 836,658 in the original dataset to 806,330 in the reduced dataset.

The streams used are the nwm_reaches feature class from the National Water Model Hydro Fabric Version 2.1 http://www.nohrsc.noaa.gov/pub/staff/keicher/NWM_live/web/data_tools/NWM_channel_hydrofabric.tar.gz When intersected with the boundaries of Texas, there are 95,908 features in the stream reaches dataset.

The Nexus Points are selected using the Pairwise Intersect tool in ArcGIS Pro as shown below. This creates points at the intersection of the road and stream lines, and carries all the attributes of both the road and stream feature classes onto the Nexus Points dataset.


Geoprocessing
Pairwise Intersect
Parameters
Environments
Input Features
Texas_Roads
NWM_Reaches
Output Feature Class
NexusPoints
Join Attributes
All attributes
Output Type
Point