THE UNIVERSITY OF TEXAS AT AUSTIN
CENTER FOR TRANSPORTATION RESEARCH

Technical Memorandum

To:	Shelley Pridgen, Project Manager
From:	David Maidment, Research Supervisor
Subject:	TxDOT Project 0-7095 – Technical Memorandum 2
Project Title:	Evaluate Improved Streamflow Measurement Technologies at TxDOT Bridges
Date:	July 31, 2021

Technical Memorandum 2: Watershed and Site Selection

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1. Introduction

An objective of TxDOT Project 0-7095, *Evaluate Improved Streamflow Management at TxDOT Bridges*, is to site 60 new radar streamflow measurement gauges on TxDOT bridges. The problem statement issued as part of the request for proposal for this project (Problem Statement 21-250) states: "The research team shall address the following:

1. Determine spatial distribution between gauge locations with a gauge network that is distributed and spaced to better represent the flow in the system, which will produce and improve the TxDOT Flood Forecast System. The distribution should be scalable to other watersheds.
2. Place 60 gauges in 4 watersheds on Texas state highway bridges. Watersheds will be selected based on historical and past flooding issues.
3. Determine the placement of gauges in the watershed to ensure both main stem and major tributary flow contribution to the system.
4. Determine placement of gauges at critical locations in the system. Consider the slope and soil type that affects response time in placement of gauges.
5. Determine gauge placement on bridges that are hydraulically suitable."

This project is a follow-on from an earlier TxDOT project (5-9054-01, *Streamflow Measurement at TxDOT Bridges*), referred to as "Streamflow I" (Maidment et al., 2019), in which 20 RQ-30 radar gauges were installed along a transect on or near IH-10 ranging from west of San Antonio to the Louisiana border. In the current project, referred to as "Streamflow II," the criteria specified in Problem Statement 21-250 indicate that the gauge sites should be selected on the basis of distribution within selected watersheds rather than along a highway.

In the Streamflow II project, the US Geological Survey (USGS) is responsible for upgrading and maintaining those RQ-30 radar gauges installed as part of Streamflow I whose continued operation is desired, as well as installing and maintaining 60 new RQ-30 gauges. These gauges measure both water surface elevation and surface velocity instead just water surface elevation, as is normally the case. Each gauge site has a surveyed stream cross-sectional area. By adjusting the surface velocity by a factor to estimate average stream velocity, and multiplying that by the cross-sectional area, a discharge value is created. The RQ-30 gauge is powered by a solar panel and reports through the cell-phone network. The equipment has a small footprint at the site and can be installed on the side of a bridge in a matter of hours.

Having a significant network of this type of gauges is new for the USGS, so a significant research objective is to evaluate the range of application of this method of streamflow measurement. Accordingly, the USGS intends to install and maintain the gauges in three tiers:

Tier 1 – Traditional Methods: 10 gauges. These shall be installed and maintained in a comparable manner to standard gauge sites. This includes regular stream gauging at the site to produce a stage-discharge rating curve. In this manner the calibration needed to adapt the velocity and depth measurements from the RQ-30 gauges to produce correct discharge measurements can be evaluated.

Tier 2 – Moderately Checked: 20 gauges. USGS professional field staff shall conduct site visits at 6- to 8-week intervals and conduct opportunistic visits with attention to flood-like or greater stages. This gauge height verification interval is consistent with national procedures. The USGS will also site one or more passive crest-stage gauges (CSGs) reasonably with regard to local hydraulic situations, to record the highest gauge height between successive site visits.

Tier 3 – Minimally Checked: 30 gauges. The USGS shall provide site visits for gauge-height-only verification approximately quarterly, and shall site one or more passive CSGs reasonably with regard to local hydraulic situations, to record the highest gauge height between successive site visits.

To make valid judgments about the accuracy of the streamflow information being provided by these different tiers of gauge maintenance, it is necessary that the gauging sites be suitable for producing good streamflow measurements. A very significant effort of both desk-based and field reconnaissance has been conducted by USGS staff to ensure that the sites selected will fulfill this criterion.

The project schedule calls for this report to be delivered by 31 July 2021. The process of selecting the gauge sites has taken longer in the project than originally anticipated, in part because of the amount of site-specific work needed to ensure that each site will provide good streamflow measurements. During this period, an RQ-30 gauge was installed on IH-10 at Cole Creek, at the request of the Beaumont District, whose results provided encouragement that good information on streamflow can be obtained in the coastal zone subjected to tidal influence, normally an area in which the USGS does not do stream gauging.

The first 30 gauging sites have been selected and the permits to install equipment are being processed by TxDOT. It is intended that the second set of 30 sites will be in the coastal zone where the flood risk is high. However, the specific location of these sites is still to be determined. Accordingly, this report should be considered as a provisional document that will be amended and completed once the second set of 30 site locations have been selected.

2. Watershed Selection

One type of watershed definition used in Texas by the Texas Water Development Board (TWDB) for 23 river and coastal basins is shown in Figure 2.1 (a). An alternative approach is the USGS Hydrologic Unit Code watershed hierarchy, whose HUC6 subdivision is shown in Figure 2.1 (b), and consists of 40 watersheds contained wholly or partly in Texas. When these two drainage delineations are compared, it can be seen that in East and South Texas they are very much the same. The differences come within the larger river basins such as the Rio Grande, Colorado, Brazos, and Trinity, where the HUC6 map has subdivided these basins into smaller basins. In North and West Texas, the HUC6 watershed map is fragmented by the Texas state boundaries, producing smaller watersheds within the Canadian and Red River basins.

(a) TWDB Major Basins(23) (b) USGS HUC6 Units (40) (c) Major Basins with HUC6 Subdivision

Figure 2.1 Subdivision of Texas into watersheds.

For this study, watersheds were delineated based on comparable land area, similar coastal regions, or being within the same river basin. In total, 20 watersheds were identified, ranging in land area from approximately 6,100 to 20,800 square miles. These watersheds are shown in Figure 2.2.

Project watersheds are comparable to the TWDB's 23 major river basins, except for the division of larger TWDB river basins and the combination of smaller, coastal TWDB basins. The larger Red, Trinity, Brazos, Colorado, and Rio Grande River Basins were all divided at least once. Many of the smaller coastal TWDB basins were combined, including the San Jacinto, San Jacinto–Brazos, and Neches–Trinity, which contain portions of the Cities of Houston, Galveston, and Beaumont. Other TWDB basin combinations include the San Antonio, Guadalupe, Lavaca, and their respective coastal basins, the Sulphur and Cypress basins, and the coastal Brazos–Colorado and Brazos basin.

These divisions or combinations were chosen to maintain a more consistent land area across all watersheds and to better combine and represent entire metropolitan regions, such as the Cities of Houston, Galveston, and Beaumont. A histogram of project watershed areas is shown in Figure 2.3. Watershed numbers are ordered starting in the southeast of the state (i.e., Houston–Galveston–

Beaumont watershed). Watershed numbers increase in a southwestern arc along the coast and follow similar subsequent arcs further inland.

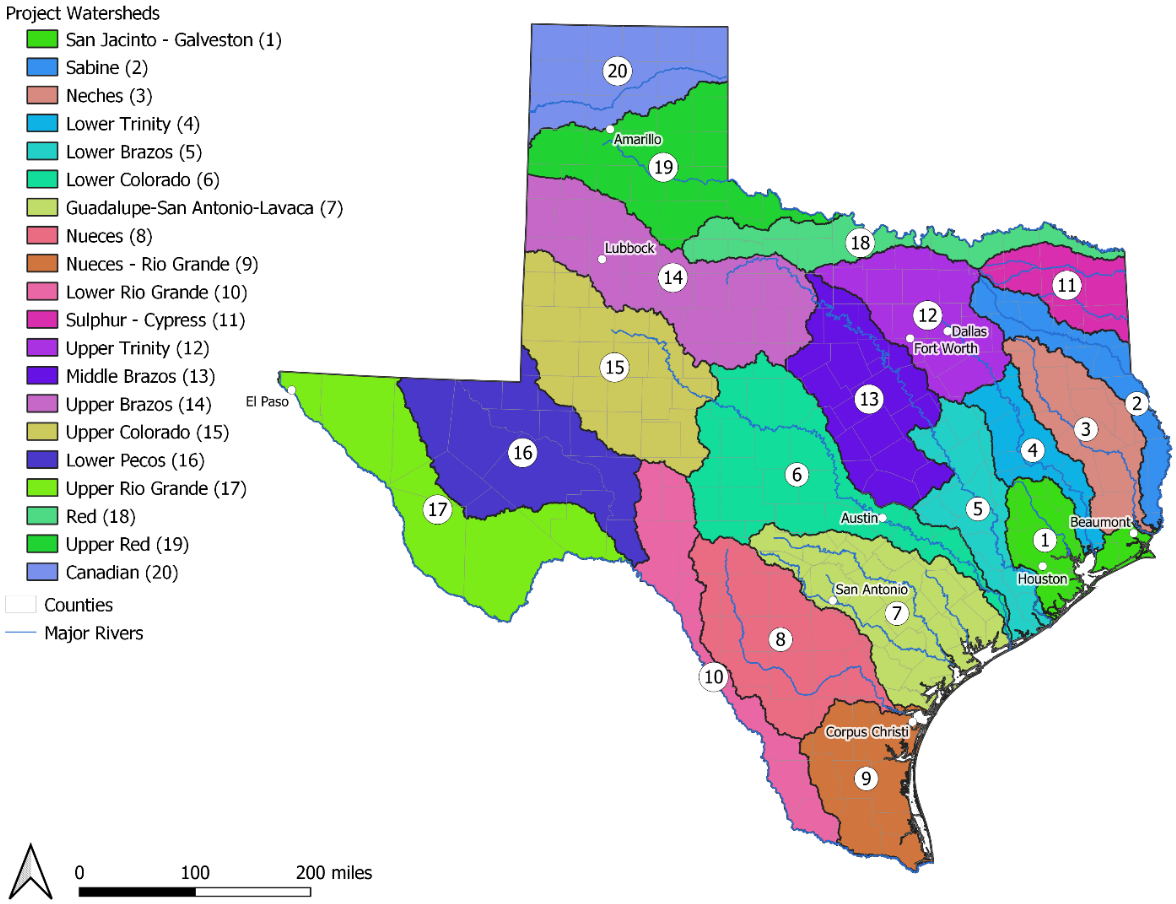


Figure 2.2. Project watershed names and numbers.

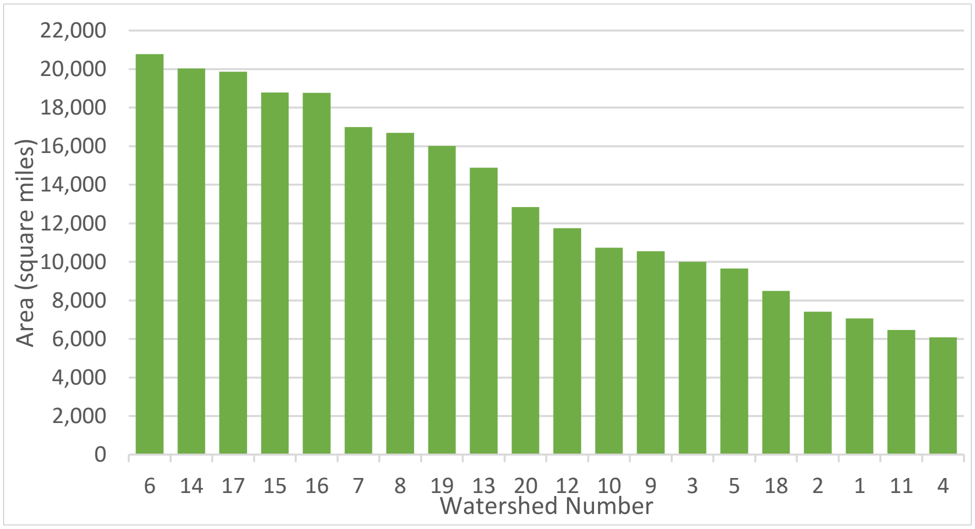


Figure 1.3. Histogram of project watershed areas.

Six statewide datasets were used to prioritize watersheds. These datasets are grouped into either a roadway or flood potential category and are listed in Table 2.1. Each dataset is discussed further in the sections below.

Table 2.1. List of watershed datasets, dataset groups and dataset sources.

Dataset Category	**Dataset**	**Dataset Source**
Roadway	Daily Vehicle Miles of Travel	TxDOT Roadway Inventory 2019
	Number of inclusionary bridges	TxDOT Bridges dataset 2020
	Number of flood related fatalities	NOAA Storm Events Database, Sharif et al. (2015)
Flood Potential	Terrain slope	ESRI Living Atlas
	Soil drainage	NRCS SSURGO
	100-year, 24-hour precipitation	NOAA Atlas 14 (Perica et al., 2018)

A number of additional datasets were considered but ultimately not used to prioritize watersheds. Some datasets that were considered but not included, such as annual average precipitation, were similar to an already identified watershed characteristic, i.e., 100-year 24-hour precipitation. The TxDOT Highway Condition Reporting System (HCRS), which reports road closures due to flooding, was considered but not included because it had inconsistent reporting at the county and watershed scale. There were a number of instances in this dataset where flooded roadways stopped at county boundaries, indicating variations in data reporting between counties. Many urban areas, such as the Dallas–Fort Worth (DFW) metroplex, Austin, and San Antonio had significantly less flood-related roadway closures when compared to other urban areas or even rural nearby counties. These inconsistencies may be due to local reporting methods and likely do not accurately reflect the true state of roadway floods in those regions, nor at the watershed scale.

2.1. Roadway-Related Watershed Datasets

Three roadway-related datasets were identified for watershed prioritization: Total Daily Vehicle Miles of Travel (DVMT), number of inclusionary bridges, and number of flood-related fatalities.

The DVMT dataset is from the TxDOT Roadway Inventory (2019) and was aggregated by watershed. This dataset, which is the daily number of miles traveled by all vehicles, including trucks, is calculated by multiplying a roadway segment's length by its annual average daily traffic (AADT). AADT is calculated using a volume count, axle factor, and seasonal factor. A watershed with a high DVMT value is a general indication of roadway importance and where a new bridge stream gauge would benefit not only the roadway it carries but its surrounding region. Watersheds with major Texas cities (e.g., DFW metroplex, Houston) and corresponding roadway infrastructure tend to have the highest DVMT values. A watershed with a high DVMT is ranked higher (i.e., more important) than a watershed with a lower DVMT value. Figure 2.4 shows the roadways with more than 5,000 DVMT and Figure 2.5 shows DVMT aggregated by watershed. The significance of the “Texas Triangle” of transportation between DFW, Houston, San Antonio, and Austin is readily apparent.

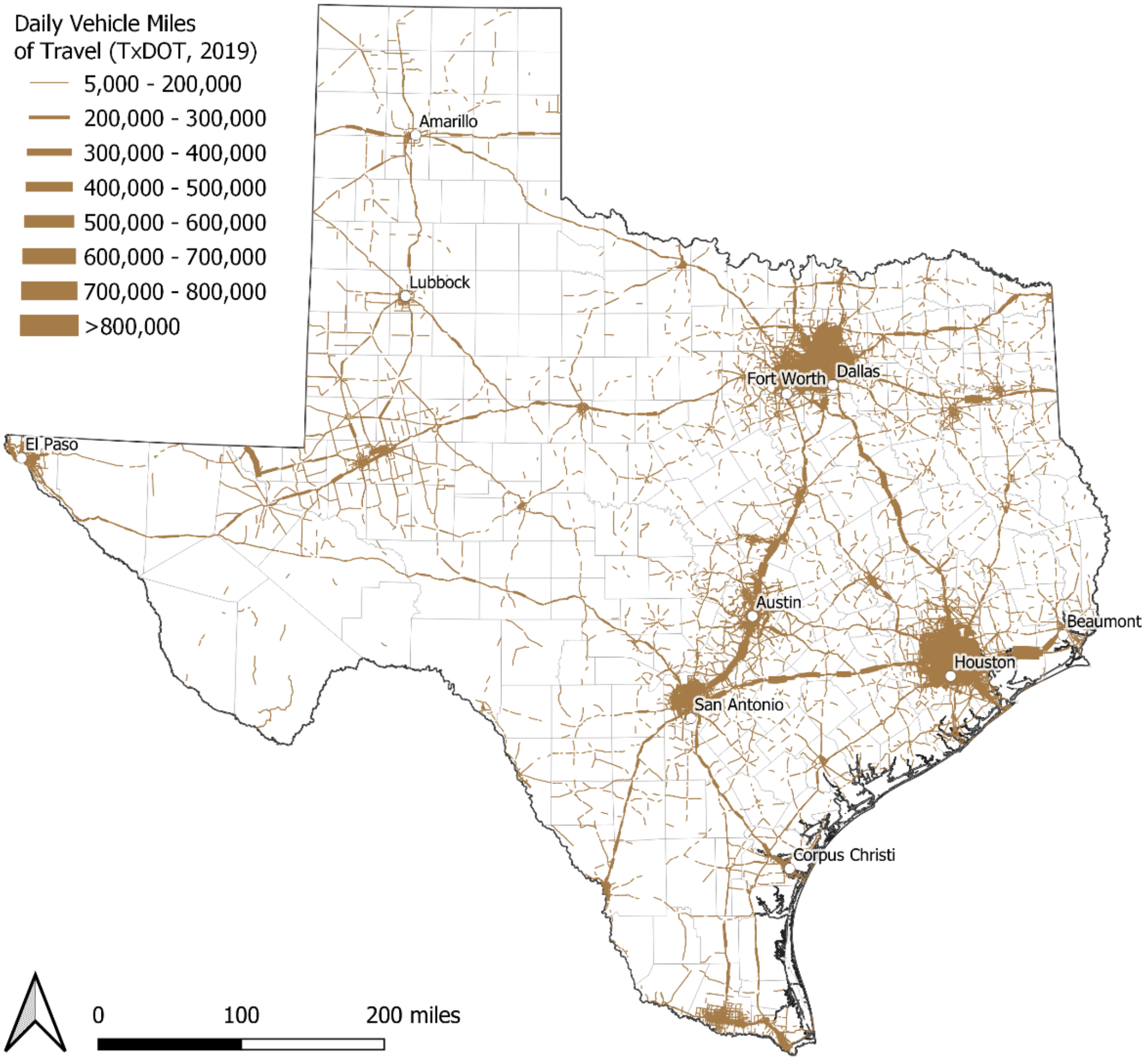


Figure 2.4. Total Daily Vehicle Miles of Travel (TxDOT, 2019). Only roadways with more than 5,000 DVMT are shown.

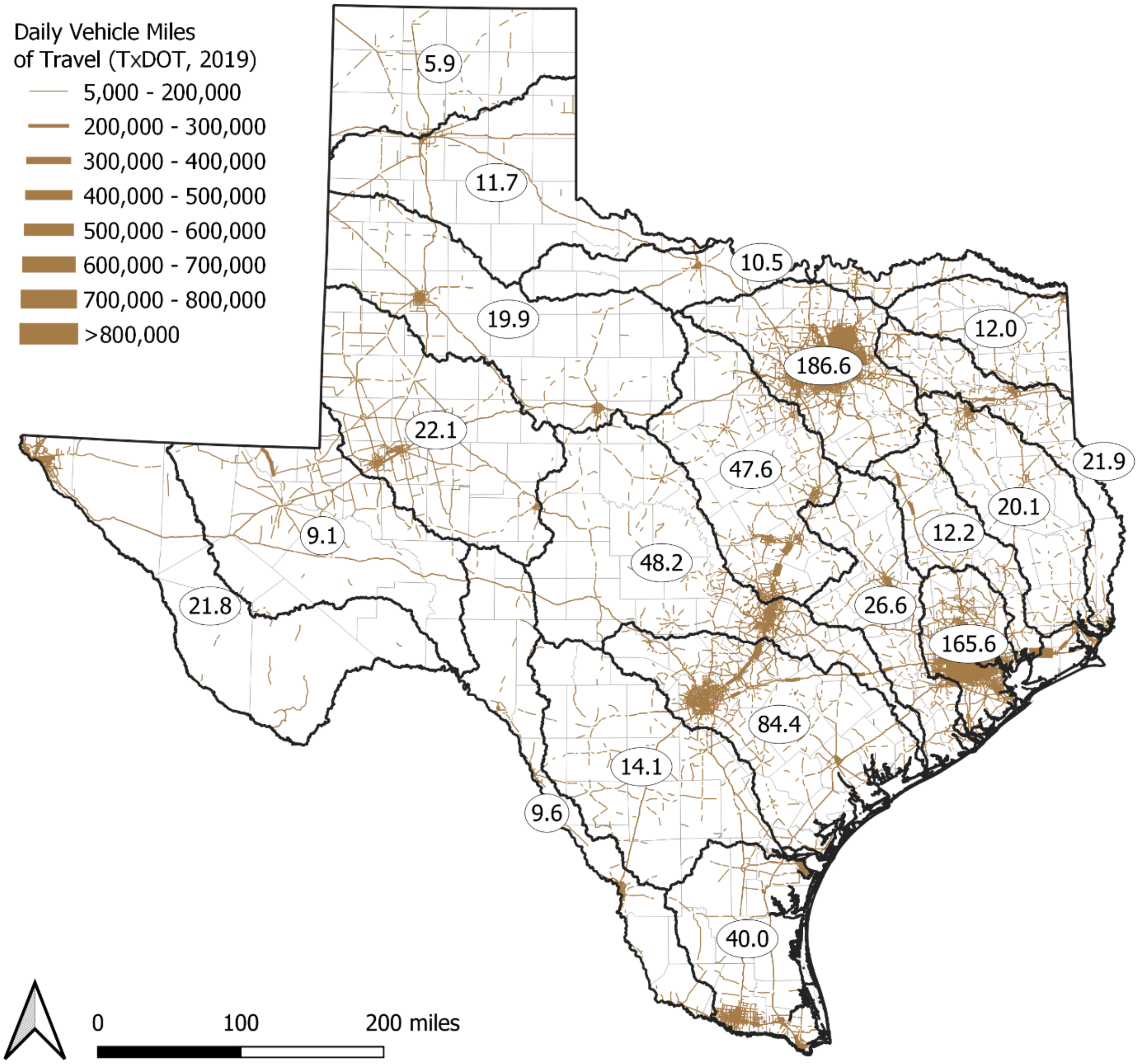


Figure 2.5. Total Daily Vehicle Miles of Travel (TxDOT, 2019), aggregated by watershed.

The TxDOT Bridges dataset (2020) was used as a starting point to determine sites possibly suitable for new stream gauges. In total, there are over 55,000 bridges in the TxDOT Bridges dataset, but many are not appropriate for stream gauge installation. These include bridges that are not over waterways, are culverts, are not a TxDOT on-system bridge, or are closed to traffic. With these criteria applied there are approximately 12,300 bridges that can be considered for stream gauge installation. These 12,300 "inclusionary" bridges were then summarized by watershed and are shown in Figure 2.6. Watersheds with major Texas cities (e.g., DFW metroplex, Houston) have the largest numbers of bridges. Watersheds with more bridges are ranked higher (i.e., more important) than watersheds with fewer bridges. This dataset is important because there must be sufficient bridges for the bridge prioritization and stream gauge selection process.

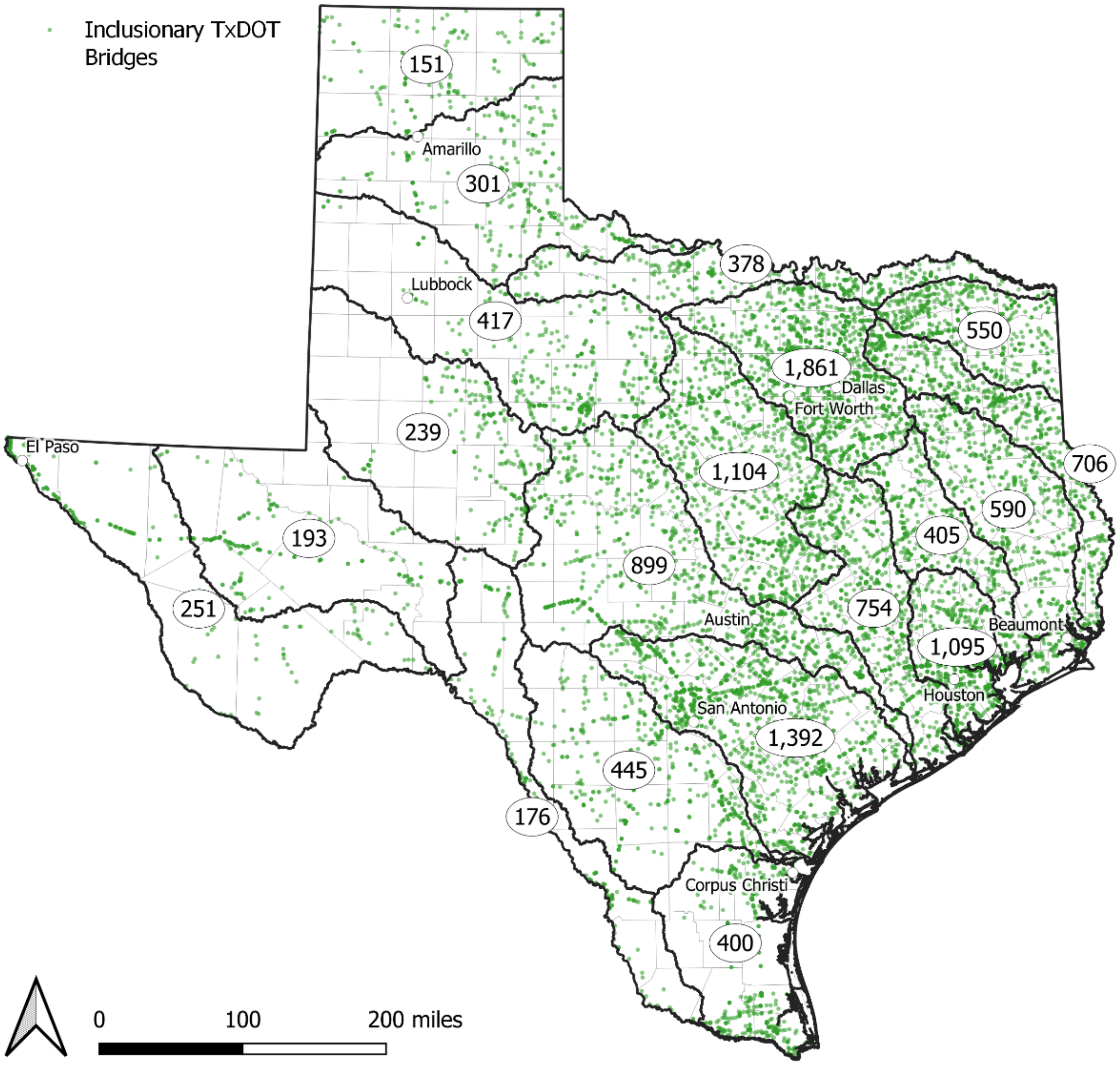


Figure 2.6. Locations of inclusionary TxDOT bridges. Number of bridges in each watershed are also shown.

The number of flood-related fatalities is a dataset compiled from two sources: Storm Events Database (NOAA 2021), and research by Sharif et al. (2015). This composite dataset provides the number of flood-related fatalities by county, from 1959 through May of 2016. Approximately 75% of flood-related fatalities are vehicle-related (Sharif et al., 2015). These vehicle-related fatalities may have occurred at low water crossing or bridges, but the dataset does not provide this level of detail. Watersheds with a higher number of flood fatalities could see a benefit from more accurate flood forecasting and new stream gauges. Figure 2.7 shows the number of fatalities by county and Figure 2.8 shows the number of fatalities in each watershed. Flood fatalities tend to be higher along the I-35 corridor, through the DFW metroplex, Austin, and San Antonio, and turning west towards Del Rio. Watersheds with higher flood fatalities are ranked higher (i.e., more important) than watersheds with fewer flood fatalities. To convert these data from the county level to a watershed scale, a weighted area average was used if a county overlapped more than one watershed.

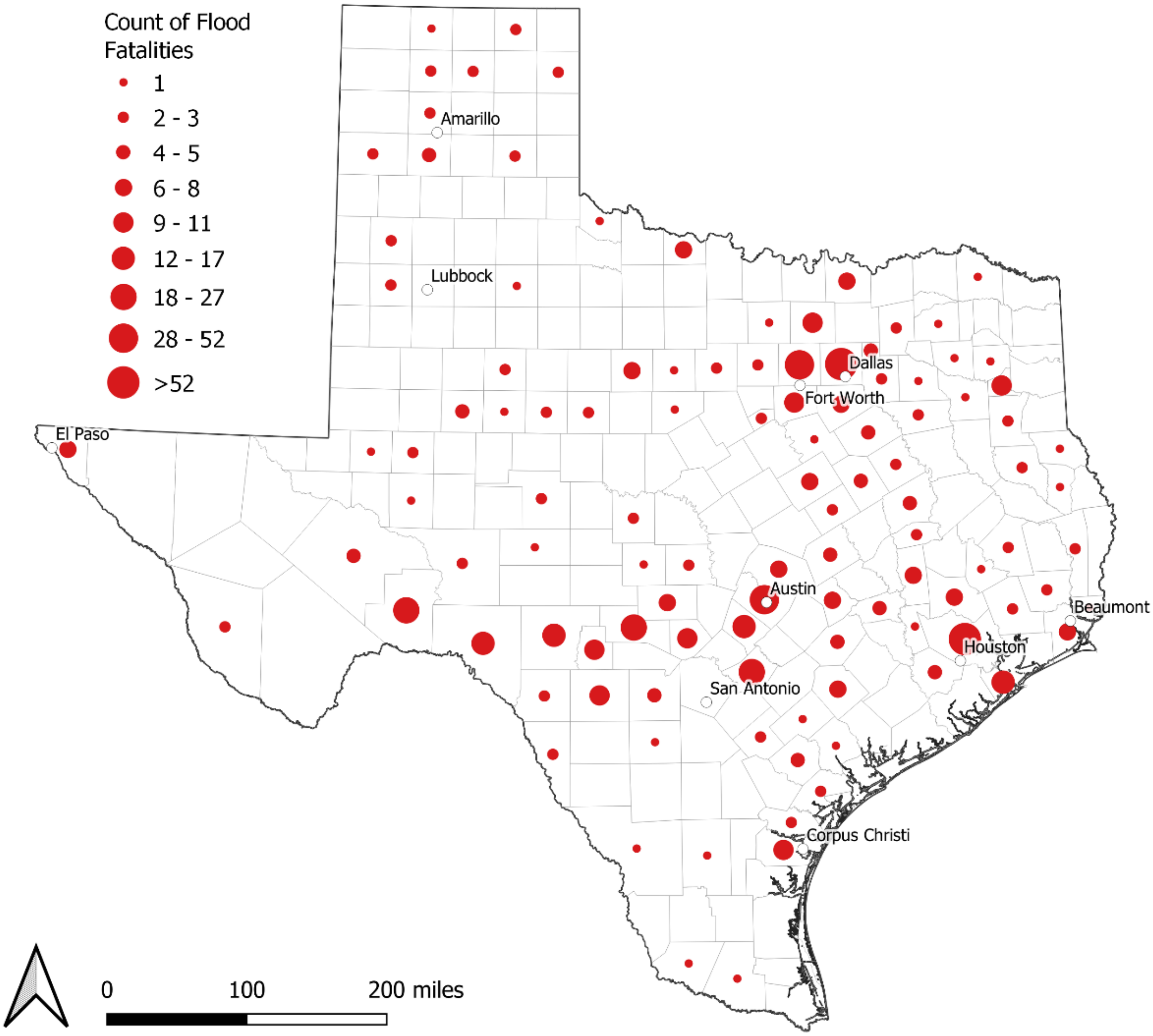


Figure 2.7. Number of flood fatalities by county.

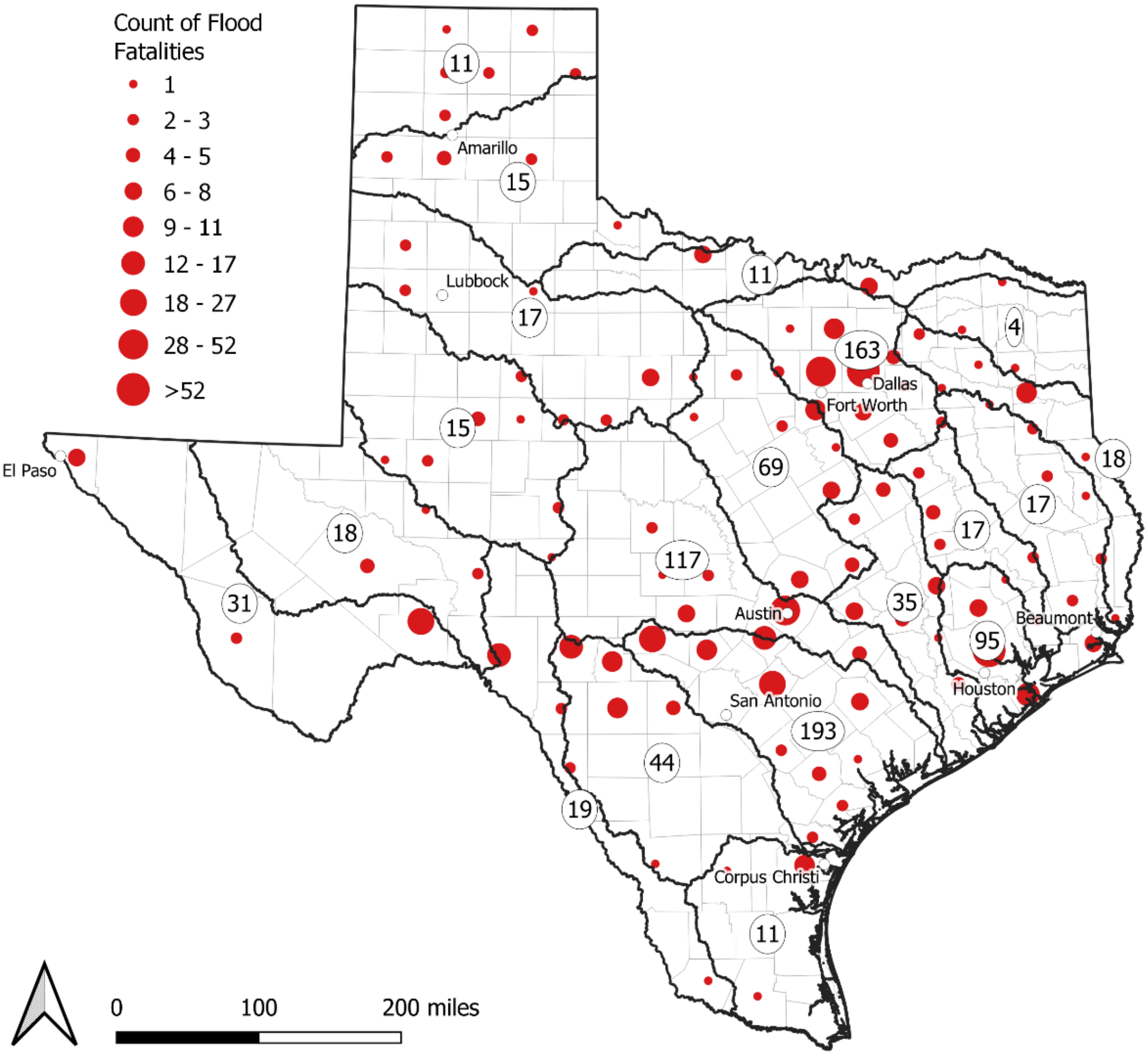


Figure 2.8. Number of flood fatalities by count, and aggregated by watershed (1959 – 2016).

2.2. Flood Potential Watershed Datasets

Three flood-related datasets were identified for watershed prioritization: terrain slope, soil drainage, and the 100-year 24-hour precipitation depth.

Terrain slope, measured in degrees, is a gridded dataset from the ESRI Living Atlas (2021). Regions with steep slopes are more prone to flash flooding, while regions with little slope, such as near the Gulf of Mexico, can have longer lasting flood events. Although both general types of flooding can benefit from new bridge stream gauges, improved forecasting for regions prone to flash flooding can improve emergency service response times. Figure 2.9 shows terrain slope across Texas, while Figure 2.10 shows terrain slope averaged across each watershed. Watersheds with higher average terrain slope are ranked higher (i.e., more important) than watersheds with a lower average terrain slope. Terrain slope tends to be higher in West Texas and to decrease near the coast.

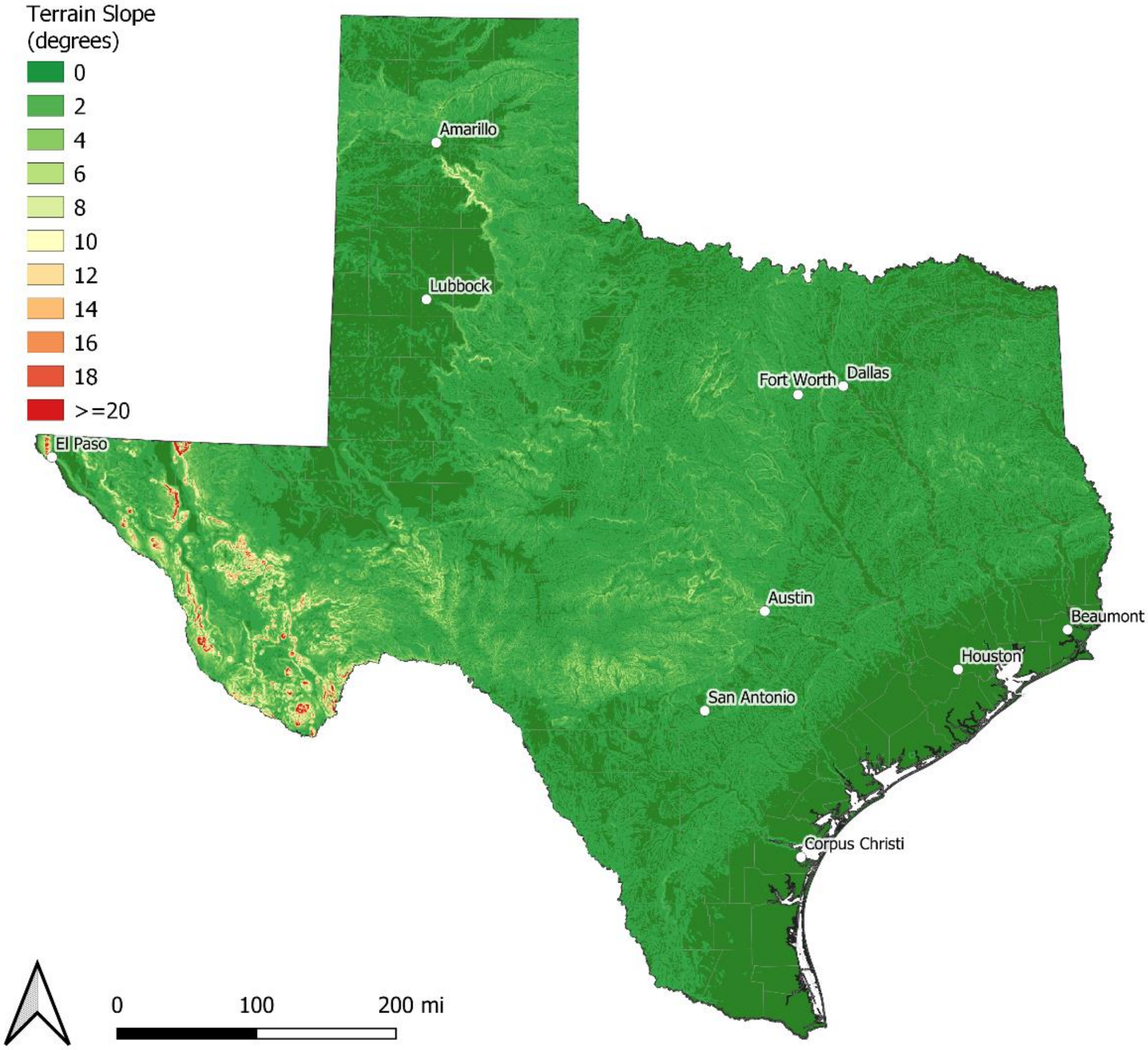


Figure 2.9. Terrain slope, in degrees.

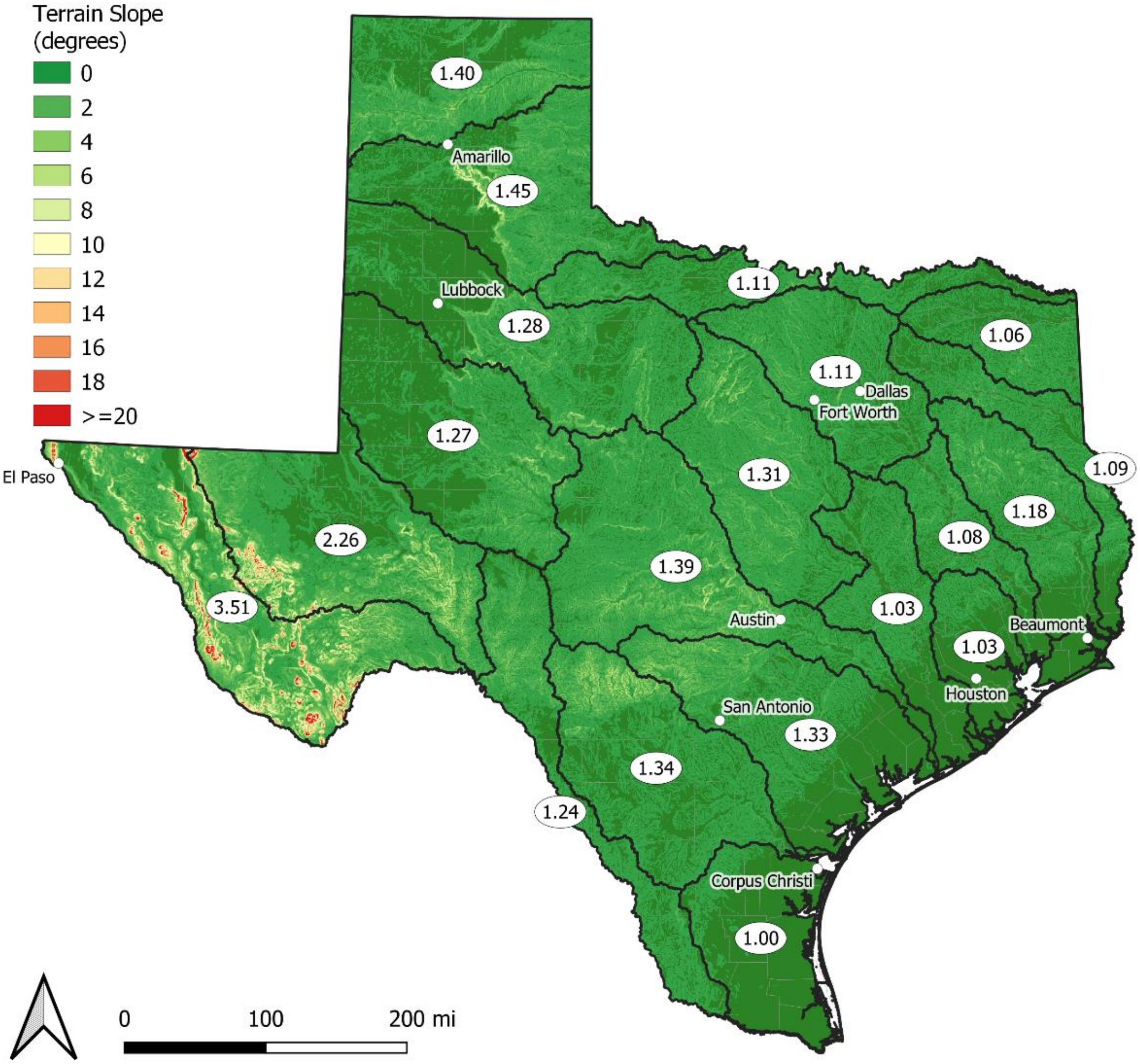


Figure 2.10. Terrain slope, in degrees, averaged by watershed.

Soil drainage is a gridded dataset within the Soil Survey Geographic Database (SSURGO) from the Natural Resources Conservation Service (NRCS); see (USDA 2021). Soil drainage values range from excessively drained soil (value of 0) to very poorly drained soil (value of 6). This dataset represents soil drainage and its potential to increase or decrease surface runoff and flooding. Although there are many factors related to a region's flood potential, in general good soil drainage can decrease flooding, while poor soil drainage can increase flooding. Figure 2.11 shows soil drainage across Texas, while Figure 2.12 shows soil drainage averaged across each watershed. Watersheds with higher soil drainage values (e.g., poorly drained soil) are ranked higher (i.e., more important) than watersheds with a lower soil drainage value. In general, coastal regions such as the Houston–Galveston–Beaumont area have poor soil drainage, while soil drainage improves further from the coast and west of the Cities of Dallas, Fort Worth, Austin, and San Antonio.

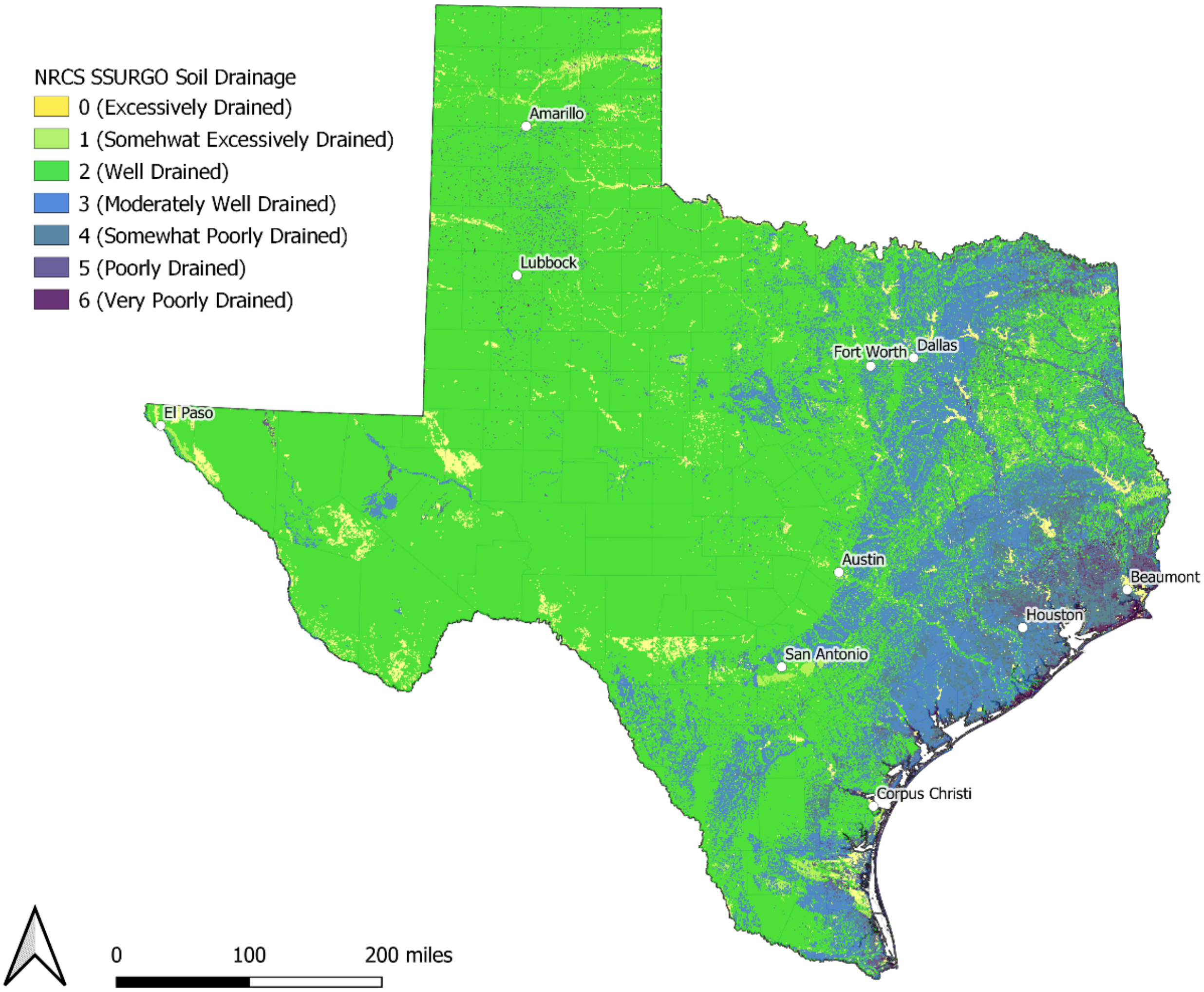


Figure 2.11. NRCS SSURGO soil drainage class.

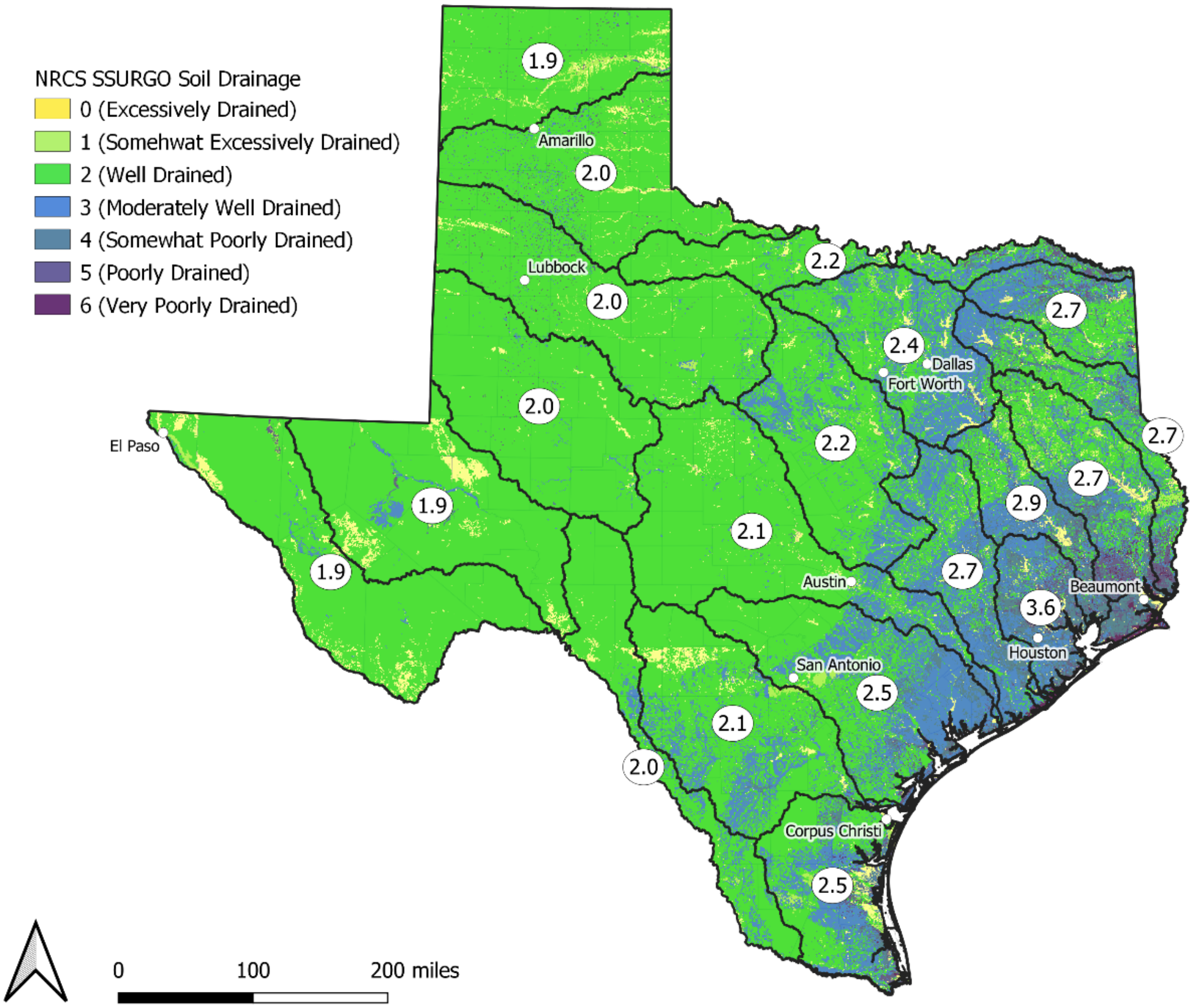


Figure 2.12. NRCS SSURGO soil drainage class averaged by watershed.

The 100-year 24-hour precipitation depth dataset is a gridded dataset from NOAA Atlas 14 (Perica et al., 2018). This dataset is a duration (24-hour) and recurrence interval (100-year) combination commonly used for hydrologic studies and design. In general, large precipitation depths, such as in the cities of Houston, Galveston, and Beaumont, indicate increased flooding potential, while decreased precipitation depths indicate less flooding potential, such as in the northern and western portions of the state. Watersheds with higher precipitation depths are ranked higher (i.e., more important) than watersheds with lower precipitation depths. Figure 2.13 shows the 100-year 24-hour precipitation depth across Texas, and Figure 2.14 shows this dataset's average value across each watershed.

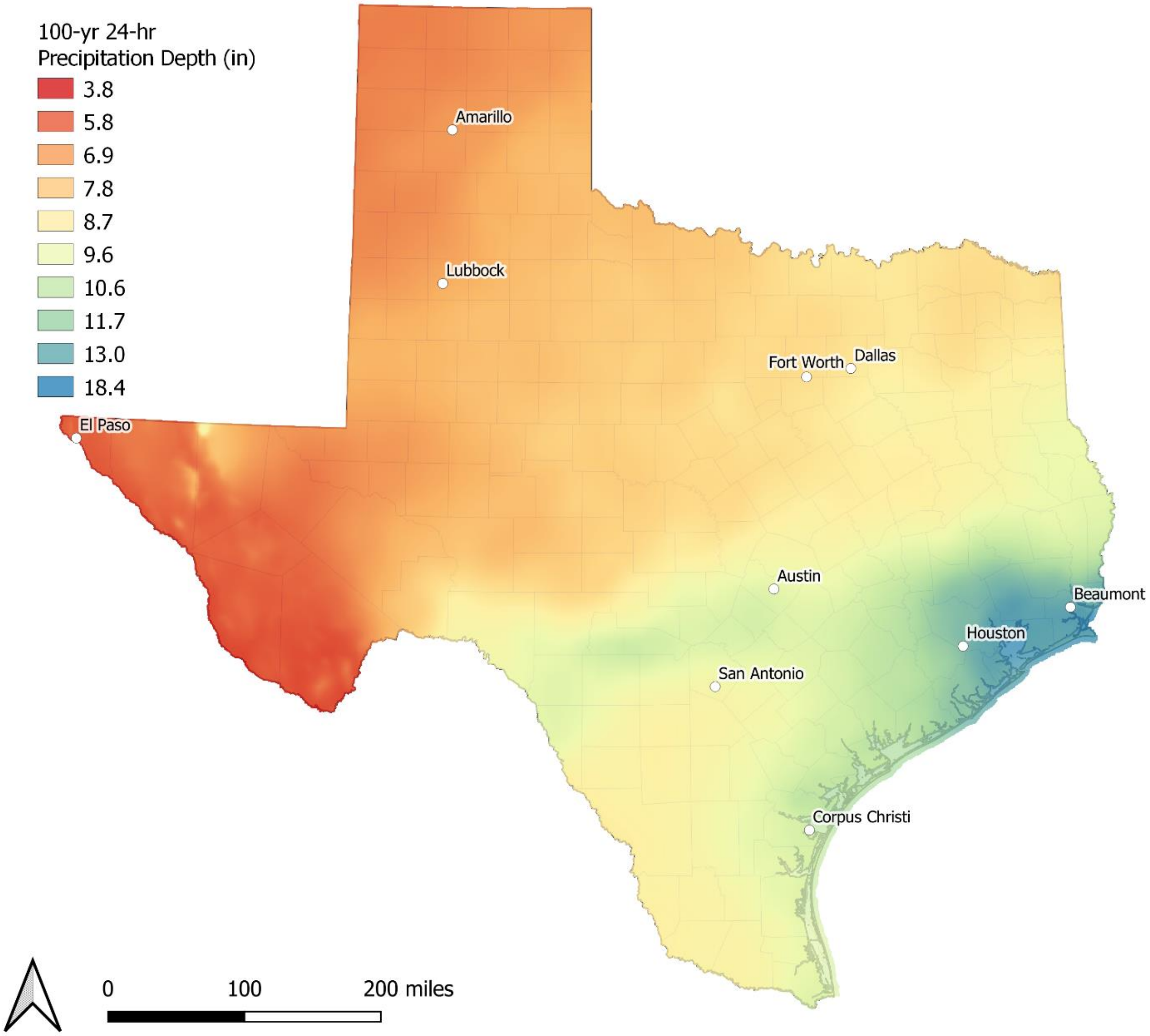


Figure 2.13. NOAA 100-year, 24-hour precipitation depth (inches).

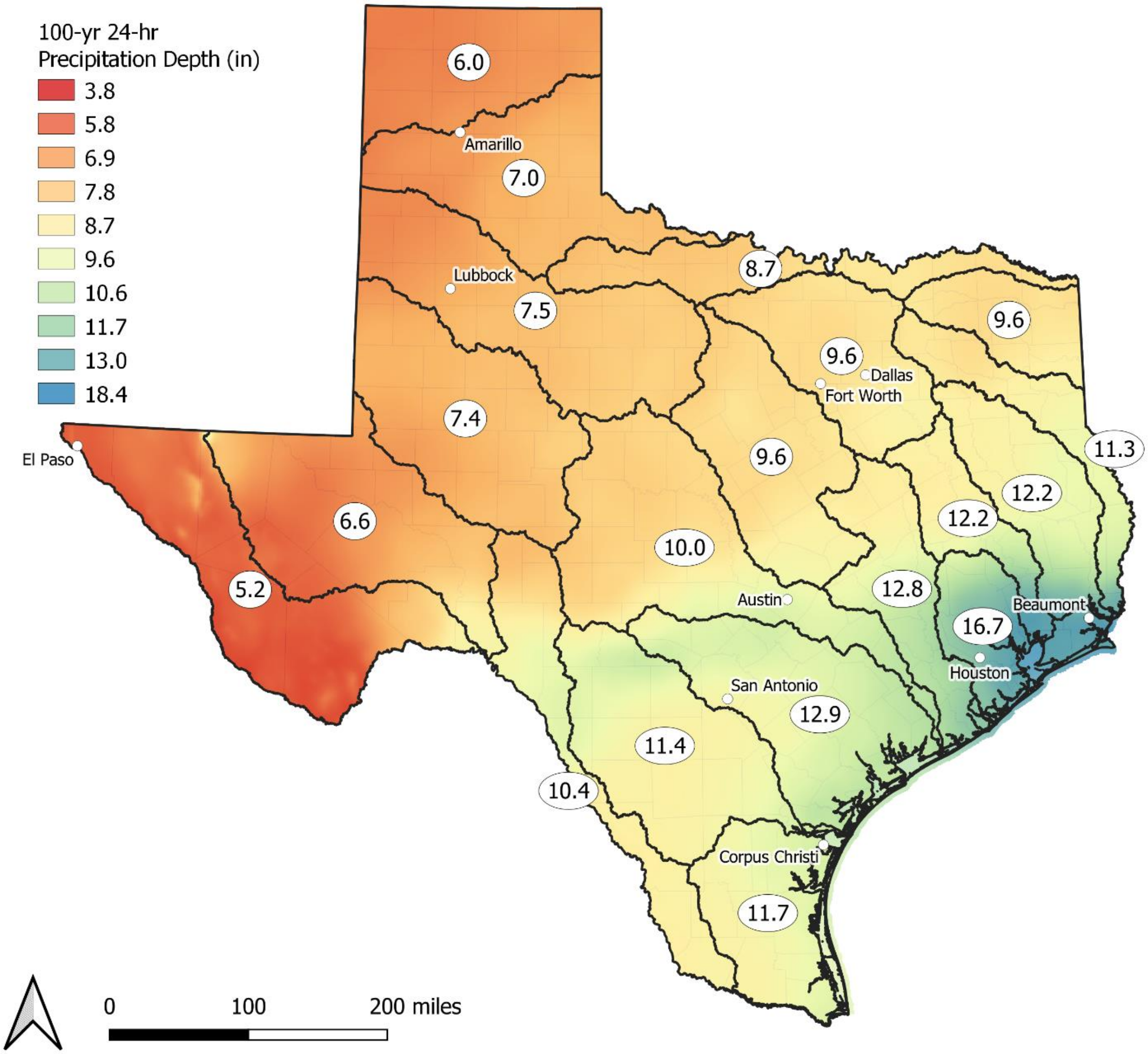


Figure 2.14. NOAA 100-year, 24-hour precipitation depth (inches) averaged by watershed.

2.3. Watershed Ranking

With six statewide datasets aggregated for each watershed, the datasets were then used to prioritize each watershed. For each dataset, watersheds were ranked from 1 to 20, with 1 being the highest ranked (i.e., most important) and 20 being the lowest ranked watershed.

Each dataset was assigned an equal weight, and an average of each watershed's rankings produced an overall watershed rank. This overall watershed ranking was organized into priority groups, as shown in Figure. The first priority group contains three watersheds; the second priority group contains four watersheds; the third priority group contains three watersheds; and the fourth priority group contains the remaining 10 lowest ranked watersheds.

Assigning different weights to each dataset was also considered, but there was little overall change to the first three priority watershed groups. In the end, equal weighting across all six datasets was found to be appropriate and produced reasonable priority groups.

The watersheds within the first priority group contain major metropolitan regions, including Houston–Galveston–Beaumont, San Antonio, and the DFW metroplex. Overall, these are watersheds that contain higher DVMT, high numbers of flood fatalities, and have increased flood potential. These watersheds also have a sufficient number of bridges for prioritization during the next portion of this project.

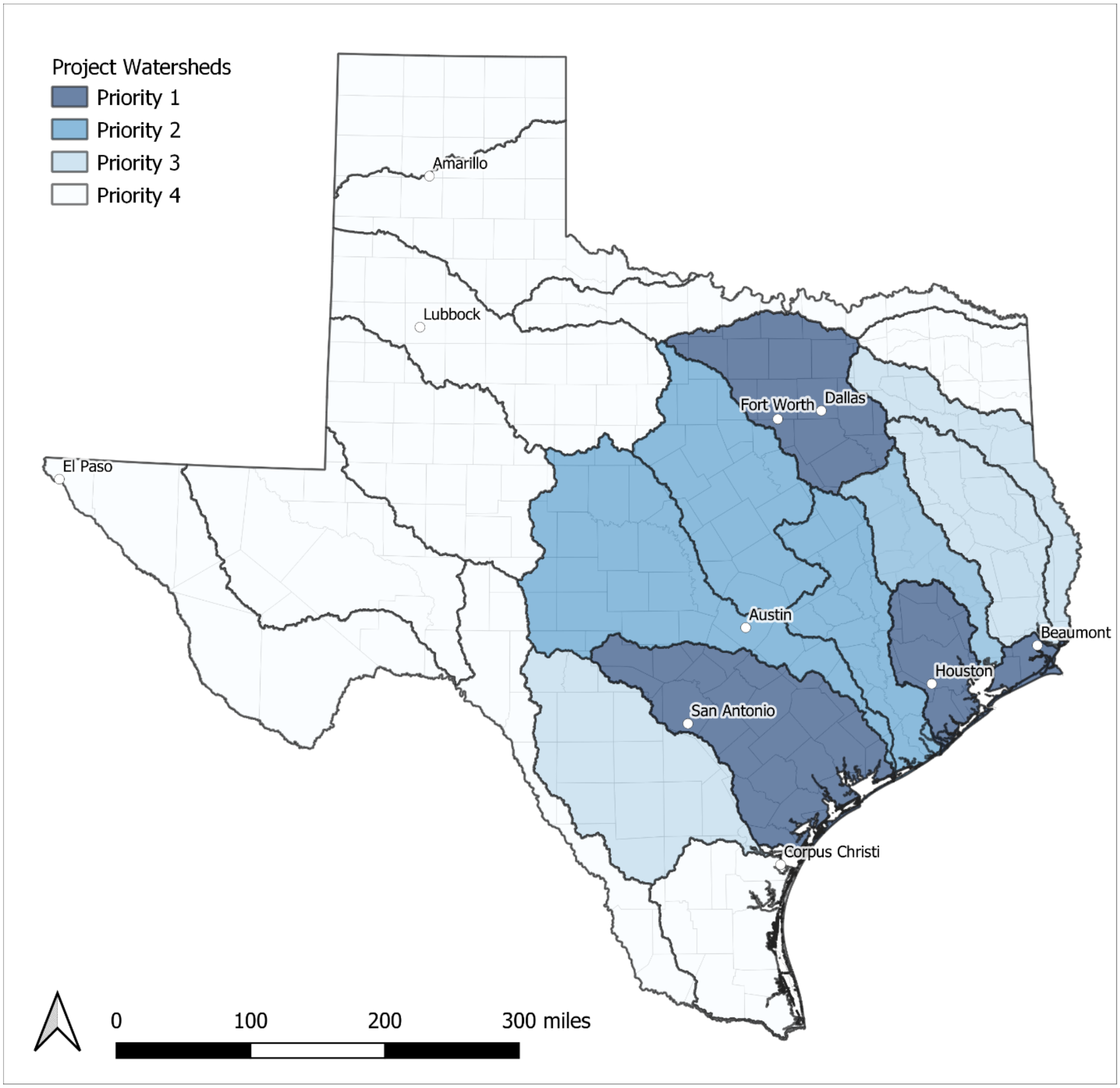


Figure 2.15. Project watershed priority groups.

2.4. Analytical Hierarchy Process

With 60 new stream gauge locations to be identified and equipment to be installed across priority watersheds, an objective framework may be useful to identify and rank new stream gauge locations. An objective, analytical framework called the analytic hierarchy process (AHP) was used as a first approach to identify bridges most susceptible to overtopping, resulting in economic losses and safety concerns. Flood risk elements were grouped into three categories (bridge vulnerability, economic loss potential from flooding, and watershed flood potential), each of which is related to available datasets of influencing factors, as shown in Figure 2.16.

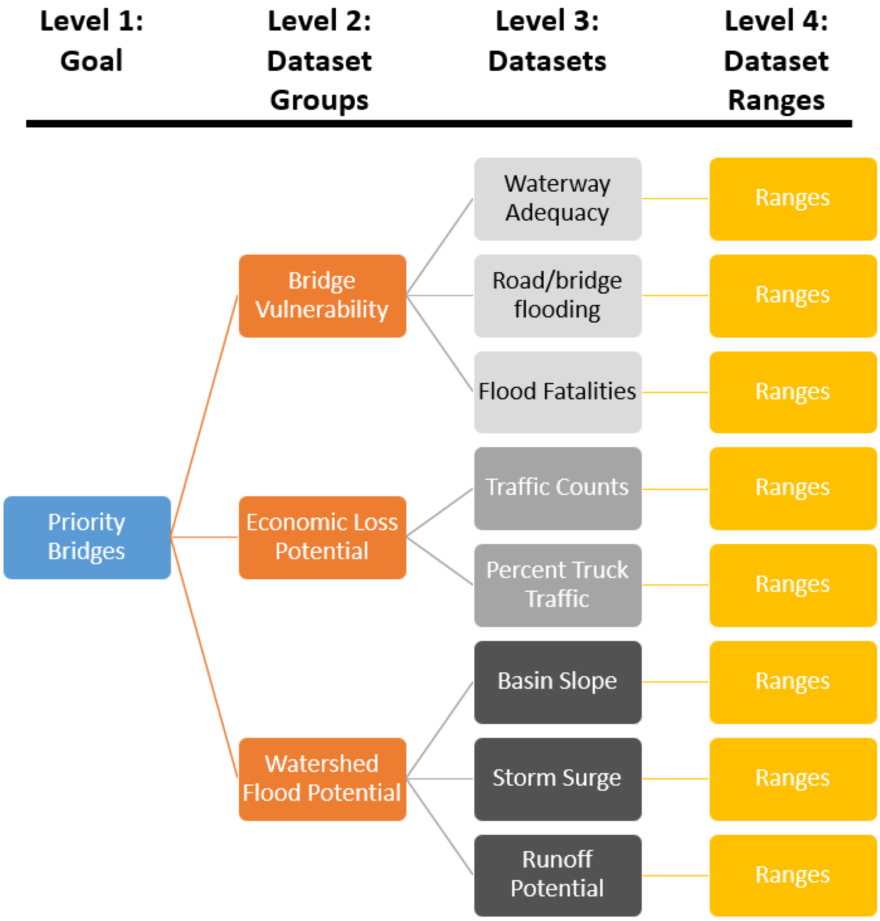
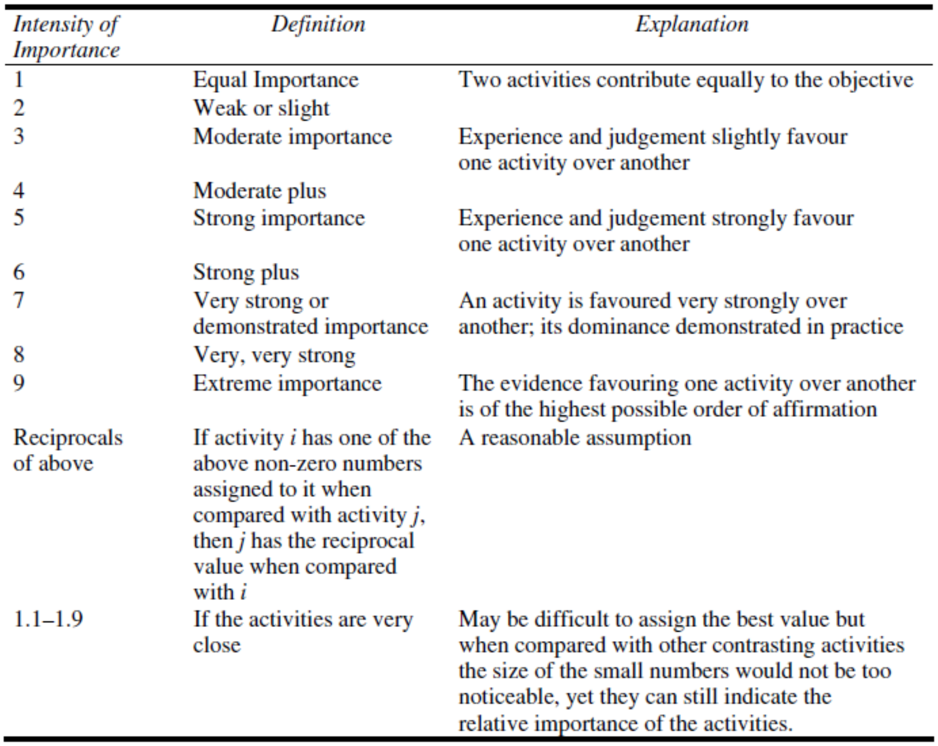


Figure 2.16. AHP decision hierarchy levels and elements (rectangles).

A weight for each hierarchy element is developed through an objective pairwise comparison process. This process leverages intensity of importance values (Table 2.2) to compare one dataset's level of importance over another dataset, or in other comparison scenarios (e.g., dataset groups, dataset ranges). These values are then normalized to produce a weight for each individual dataset (level 3), dataset group (level 2), or dataset range (level 3). Within levels 2 and 3, all element weights sum to 1.0. More information on this process and the AHP in general can be found in Saaty (2004). The end result of this computation is shown by the weights given in Table 2.3.

Table 2.2. Intensity of Importance values and explanations (Saaty, 2004).



Intensity of Importance	*Definition*	*Explanation*
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

Table 2.3. Overall dataset weights.

Group Name	**Dataset Name**	**Weight**
Bridge Vulnerability	Road/bridge flooding	0.31
	Waterway Adequacy	0.14
	Flood Fatalities	0.03
Economic Loss Potential	Traffic Counts	0.23
	Percent Truck Traffic	0.12
Watershed Flood Potential	Basin Slope	0.07
	Storm Surge	0.07
	Runoff Potential	0.03
	Total	**1.00**

After using the pairwise comparison process, each potential site gets assigned weights from each level and from within each dataset. How important a bridge is within each dataset (e.g., level 4 dataset range weights), and how important each dataset is with respect to other datasets and dataset groups, will determine a bridge's overall weight. The more important (higher weight) a bridge is within a highly ranked dataset will in general lead to a higher overall weight. This final composite weight is then ranked among all other bridges, with a ranking of 1 being the highest weighted bridge.

Figure 2.17 shows the top 150 ranked bridges in Texas as defined by AHP. Many (but not all) of the top AHP ranked bridges are located in the priority 1 and priority 2 watersheds, showing good alignment with the watershed prioritization process.

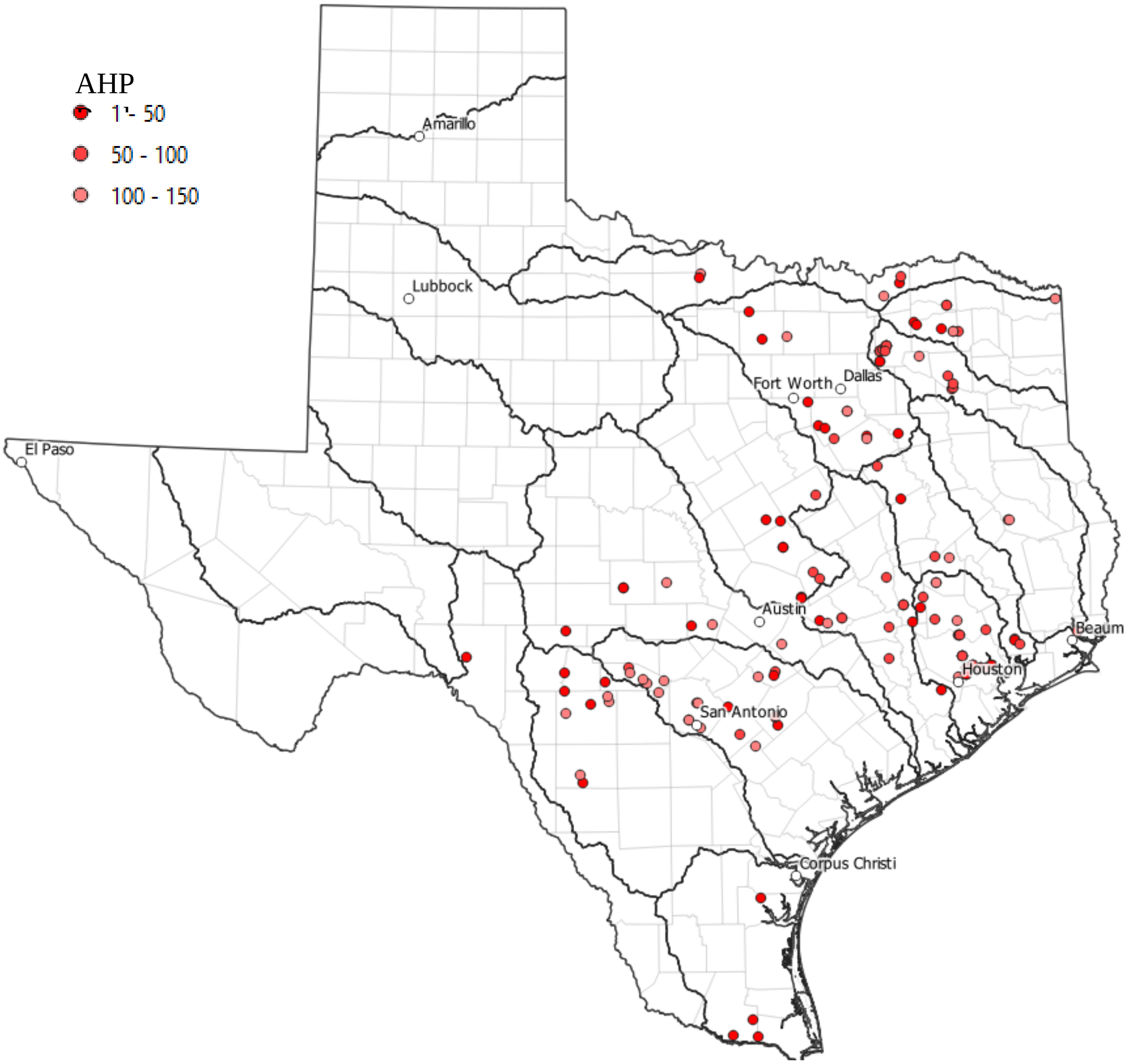


Figure 2.17. Top 150 ranked bridges across Texas.

2.5. Review by the Project Management Committee

The procedure for watershed and site selection just described was presented to the TxDOT Project Management Committee at the first Quarterly Review meeting held on 14 December 2020. The Committee concurred that the process for defining and prioritizing watershed is appropriate. In considering the watershed distribution presented in Figure 2.15, the Committee recommended that the Lower Trinity Basin should be added to the Priority 2 set of watersheds because it provides downstream hydrological connectivity between the Upper Trinity basin in the DFW area and the coast.

The Project Management Committee, in reviewing the map in Figure 2.17 of 150 top-ranked sites, felt that the layout of the sites was too dispersed, and another approach is needed to form “clusters” of sites within particular watersheds. Indeed, the selection of 150 priority bridge sites amounts to a little more than 1% of the more than 12,000 possible bridge sites in Texas, so the resulting selection is a relatively “thin” coverage over a large area. What is needed is another way to produce a denser concentration of selected sites within smaller areas.

3. Site Assessment

3.1. Conceptual Framework

In reassessing the approach to selecting sites, a conceptual model is proposed, as shown in Figure 3.1. This comprises three categories of needs for the distribution of project sites. TxDOT needs information across Texas that leads to early warning of flooding and actionable information concerning the flooding at bridges, culverts, and roadways. This does not apply just before or during a flood, but also after the waters have receded, to allow timely inspection of bridges to check for foundation scour before a closed highway is reopened. In order to achieve that across the landscape, the University of Texas needs a balanced and relatively uniform coverage of the stream network with gauge sites, so that by means of data assimilation and forecast adjustment, information from streamflow measurements at gauged bridges can be used to adjust forecasts at ungauged locations and achieve good flood assessment across the road and bridge network. To fulfill its objectives concerning the applicability of the RQ-30 gauge as a means of stream gauging, the USGS is seeking ideal measurement locations (a) that are on higher bridges that won't be flood-inundated, (b) that are on relatively straight reaches, (c) whose flow is mostly contained in the channel (and does not disperse widely in the floodplain), and (d) that have flow velocities greater than 1 ft/s, which is the lower limit of the velocity measurement range of the RQ-30 gauge.

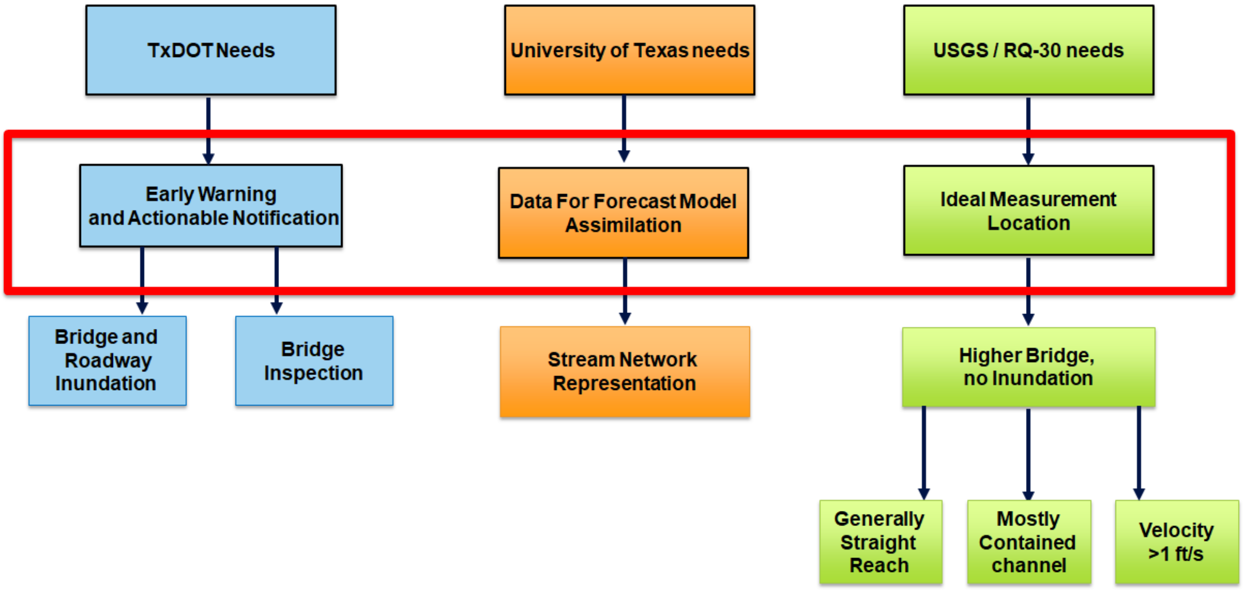


Figure 3.1. Conceptual framework for site selection.

One of the factors that influenced the creation of this conceptual model is the USGS assessment of the USGS stream gauges in the San Antonio watershed. The USGS has a set of criteria (Sauer & Turnipseed 2010; Turnipseed & Sauer 2010) that describe the quality of measurements at stream gauge sites. Poor, fair, and good sites have rankings of 1, 2, and 3, respectively. The goal of a streamflow measurement program is to have as much good quality data as possible. Figure 3.2

shows the relation of the stream gauge measurement quality score and the AHP ranking of the corresponding bridge. It is apparent that there is no relationship between these variables. This means that characteristics that make a site suitable for streamflow measurement have little in common with those that make it rank highly for flood risk assessment.

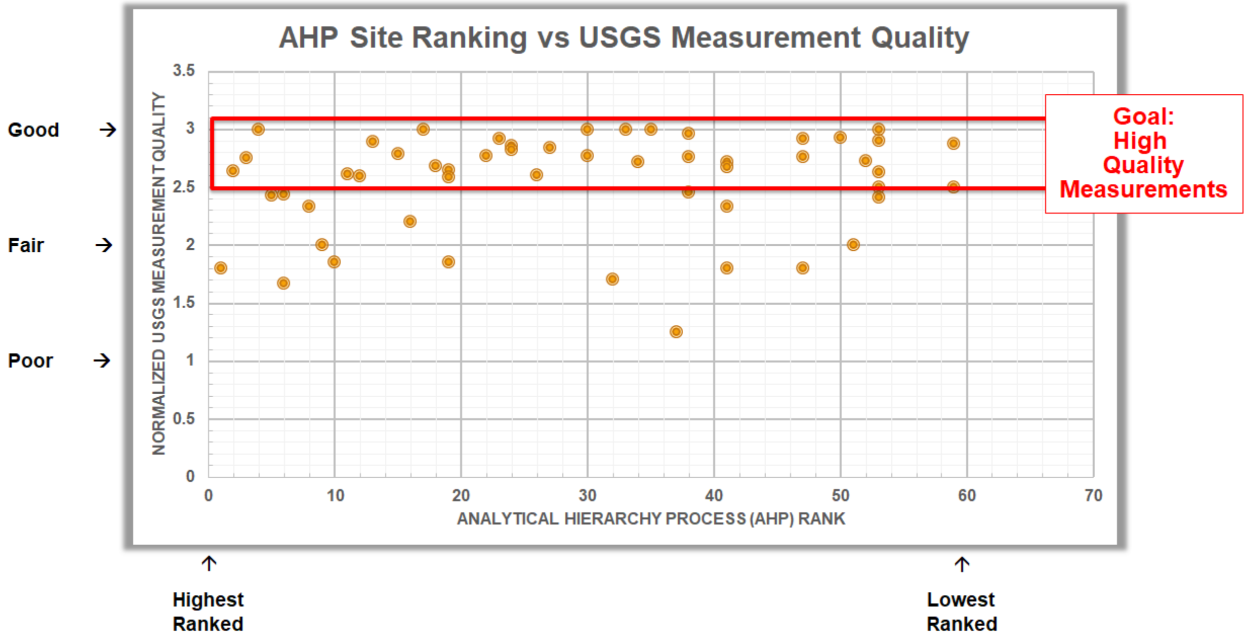
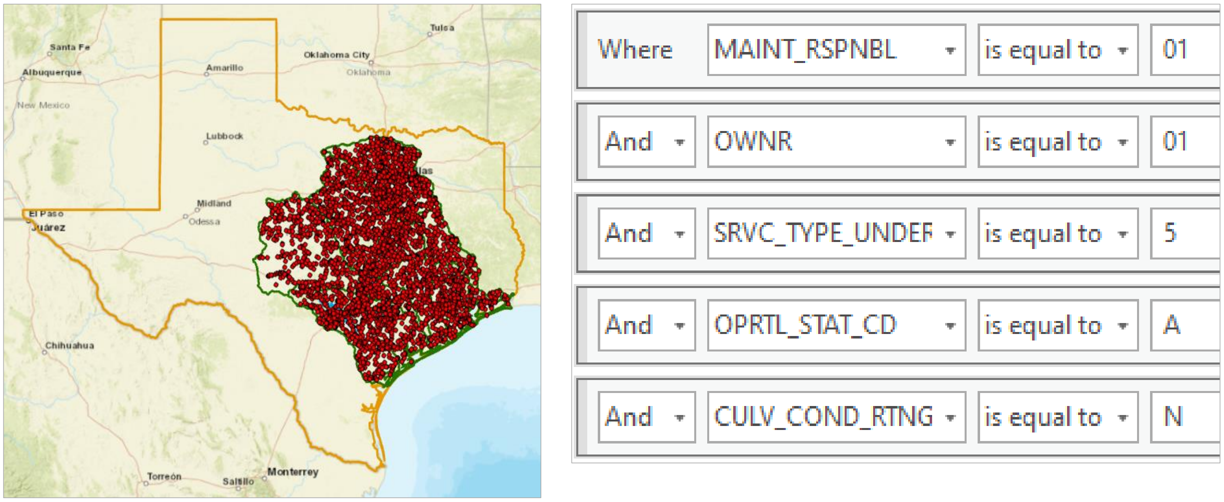


Figure 3.2. Relationship between AHP site ranking and USGS measurement quality.

3.2. Base Set of Bridges

To apply the conceptual framework for site assessment, it was decided to combine the Priority 1 and 2 watersheds shown into a single Priority Watershed Zone, and to examine all bridges within this region that satisfy a set of basic criteria. This zone covers approximately one-third of the area of Texas and three quarters of its traffic flow.

In considering the bridges contained within the National Bridge Inventory, these criteria include the bridge being “on-system,” which means that it is owned and maintained by TxDOT rather than a local city or county; it is a bridge over water rather than over another road; it is an open and operational bridge; and it is not a culvert. When these criteria are translated into a selection on the GIS coverage of TxDOT bridges, the result appears as shown in Figure 3.3 and results in 5,355 bridges being selected within the Priority Watershed Zone.



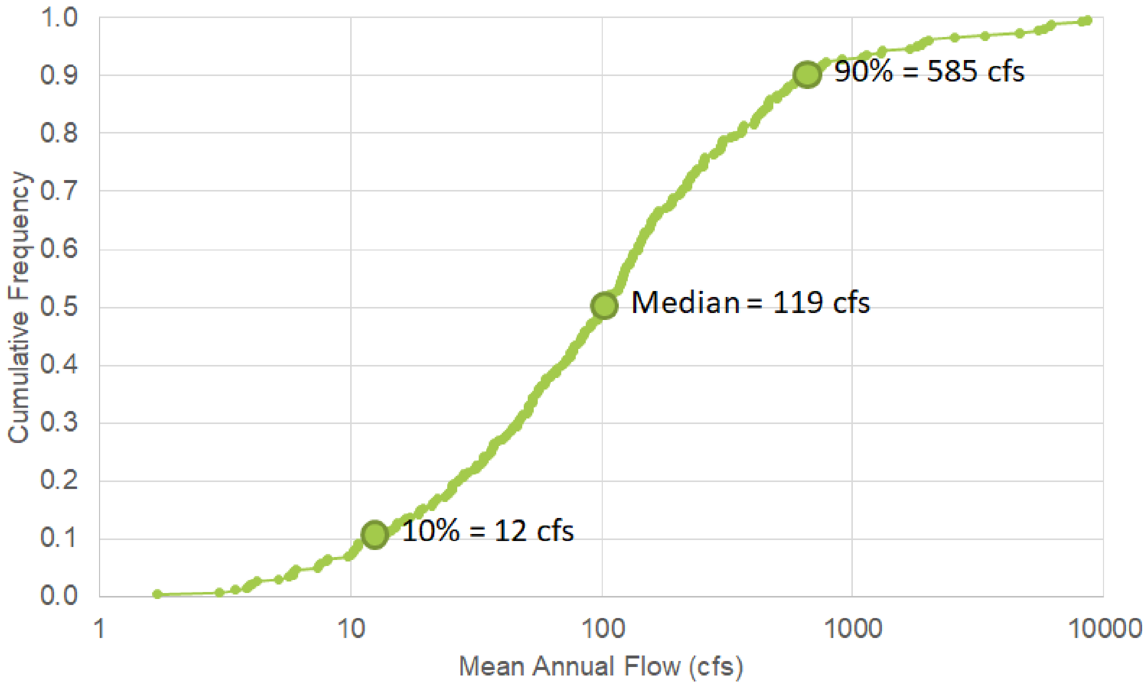
Where MAINT_RSPNBL is equal to 01
And OWNR is equal to 01
And SRVC_TYPE_UNDEF is equal to 5
And OPRTL_STAT_CD is equal to A
And CULV_COND_RTNG is equal to N

Figure 3.3. Selection of a base set of bridges.

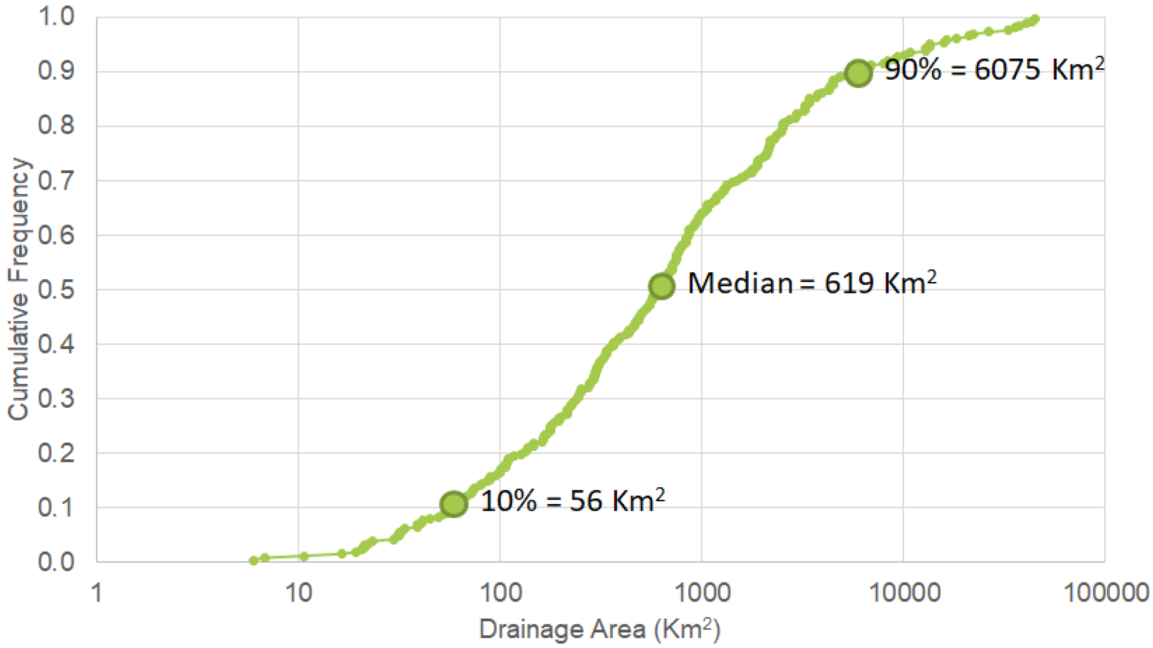
In assessing new gauging sites, it is useful to examine the characteristics of the existing USGS gaging sites in the watershed priority zone. The results of this assessment are limited to those sites having less than 10,000 cfs mean annual flow, and a drainage area of less than 50,000 km^2. The charts shown in Figure 3.4 show that the mean annual flow has a median value across the sites of 119 cfs, and a range from 10–90% of 12–585 cfs. The drainage area has a median value of 585 km^2 and a 10–90% range of 56–6095 Km^2. The mean annual flow and drainage area data just described are derived directly from the USGS data archive. These values were checked against the corresponding values found as attributes on the corresponding reach of the NHDPlus Medium Resolution geospatial dataset (McKay et al., 2012; US Geological Survey 2021), and there was good agreement between the two data sources.

The NHDPlus flowline dataset also records the stream slope, and as shown in Figure 3.4 (c), about 15% of the gauging sites have an associated stream slope of 0.00001, which is the minimum value in the NHDPlus where the stream slope is so flat that it cannot be determined more precisely. The spatial pattern of these low slope stream gauging sites shows that they are distributed throughout the watershed and not concentrated near the coast as might have been expected.

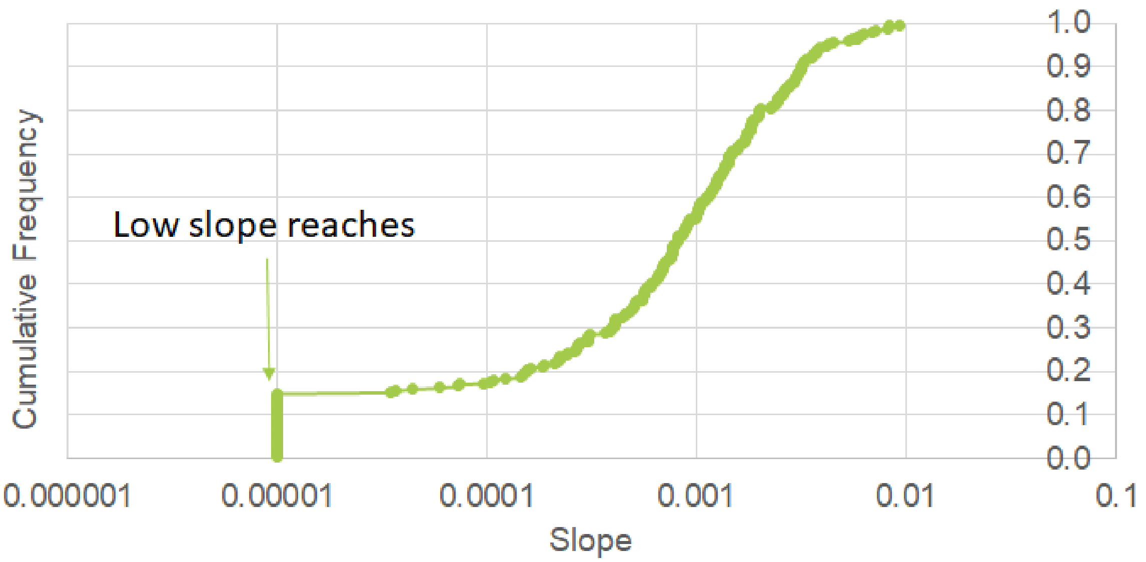
The gauged NHDPlus flowlines also have the Strahler stream order attributed to them, as determined from 1:100,000 scale stream mapping. As shown in Figure 3.4 (d), the streams on which USGS gauges are sited are concentrated in orders 3 and 4 (55% of total), and if streams of orders 2 and 6 are added, these constitute 88% of the total.



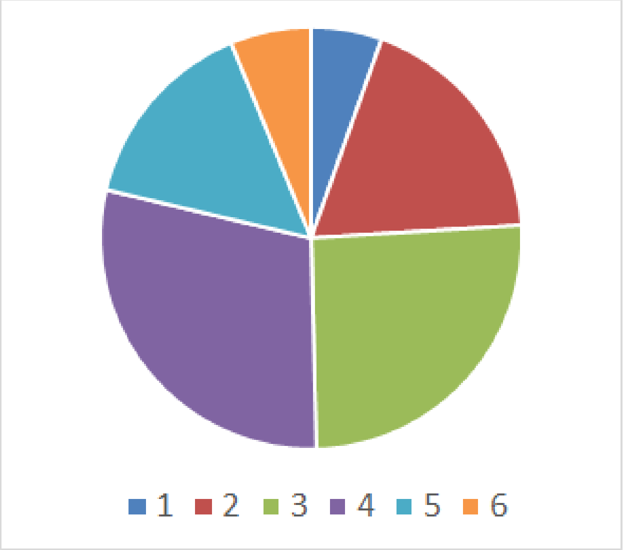
(a) Frequency distribution of mean annual flow at USGS gauging sites



(b) Frequency distribution of drainage area of USGS gauging sites



(c) Frequency distribution of channel slope derived from NHDPlus



(d) Distribution of stream order at USGS gauge sites derived from NHDPlus

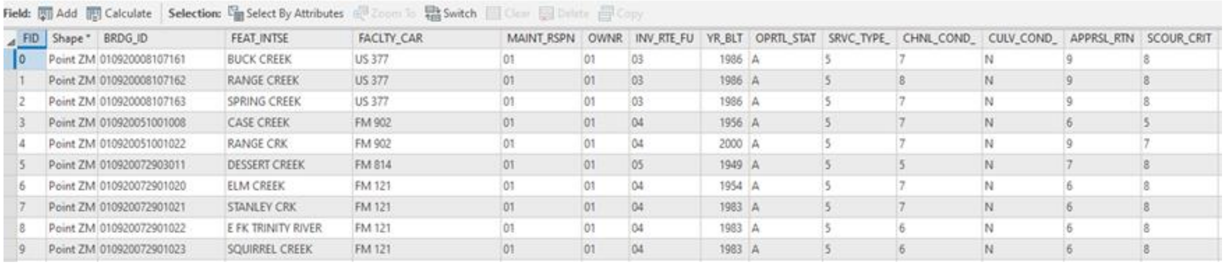
Figure 3.4. Characteristics of existing USGS gauging stations in the watershed priority zone.

Besides the required bridge criteria noted in Figure 3.3, TxDOT recommended that several other bridge characteristics should also be considered in selecting sites. These include:

- Item 26, **Functional Classification** – high priority structures are more likely to have detailed hydrologic and hydraulic models (INV_RTE_FU values of 01, 11, 21 or 41 for Interstates; 12, 22, 42 for other freeways; 02, 13, 23, or 43 for other principal arterial roads)
- Item 27, **Year Built** – Newer bridges remain in service longer (YR_BLT > 1990)

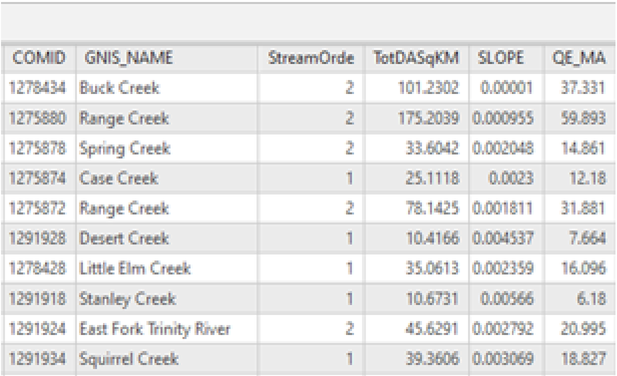
- Item 61, **Channel and Channel Protection** – Stable banks/channels should be preferable (CHNL_COND value of 7, 8, 9)
- Item 71, **Waterway Adequacy** – assuming that the gauge should be above the water surface (APPRSL_RTN value of 6, 7, 8, 9)
- Item 113, **Scour Critical Bridges** – avoid scour critical bridges to target a stable channel profile (SCOUR_CRIT value of 5, 7, 8)

A geospatial coverage of the base set of bridges was compiled with values from the National Bridge Inventory for these criteria, along with the required criteria from Figure 3.3, as shown in Figure 3.5 (a). To these values were added the corresponding characteristics from the NHDPlus stream reach that the bridge lies on, namely Stream Order, Total Drainage Area in Km^2, stream slope and mean annual flow in cfs (QE_MA), as shown in Figure 3.5 (b).



FID	Shape *	BRDG_ID	FEAT_INTSE	FACLTY_CAR	MAINT_RSPN	OWNR	INV_RTE_FU	YR_BLT	OPRTL_STAT	SRVC_TYPE_	CHNL_COND_	CULV_COND_	APPRSL_RTN	SCOUR_CRIT
0	Point ZM	010920008107161	BUCK CREEK	US 377	01	01	03	1986	A	5	7	N	9	8
1	Point ZM	010920008107162	RANGE CREEK	US 377	01	01	03	1986	A	5	8	N	9	8
2	Point ZM	010920008107163	SPRING CREEK	US 377	01	01	03	1986	A	5	7	N	9	8
3	Point ZM	010920051001008	CASE CREEK	FM 902	01	01	04	1956	A	5	7	N	6	5
4	Point ZM	010920051001022	RANGE CRK	FM 902	01	01	04	2000	A	5	7	N	9	7
5	Point ZM	010920072903011	DESSERT CREEK	FM 814	01	01	05	1949	A	5	5	N	7	8
6	Point ZM	010920072901020	ELM CREEK	FM 121	01	01	04	1954	A	5	7	N	6	8
7	Point ZM	010920072901021	STANLEY CRK	FM 121	01	01	04	1983	A	5	7	N	6	8
8	Point ZM	010920072901022	E FK TRINITY RIVER	FM 121	01	01	04	1983	A	5	6	N	6	8
9	Point ZM	010920072901023	SQUIRREL CREEK	FM 121	01	01	04	1983	A	5	6	N	6	8

(a) Criteria from National Bridge Inventory



COMID	GNIS_NAME	StreamOrde	TotDASqKM	SLOPE	QE_MA
1278434	Buck Creek	2	101.2302	0.00001	37.331
1275880	Range Creek	2	175.2039	0.000955	59.893
1275878	Spring Creek	2	33.6042	0.002048	14.861
1275874	Case Creek	1	25.1118	0.0023	12.18
1275872	Range Creek	2	78.1425	0.001811	31.881
1291928	Desert Creek	1	10.4166	0.004537	7.664
1278428	Little Elm Creek	1	35.0613	0.002359	16.096
1291918	Stanley Creek	1	10.6731	0.00566	6.18
1291924	East Fork Trinity River	2	45.6291	0.002792	20.995
1291934	Squirrel Creek	1	39.3606	0.003069	18.827

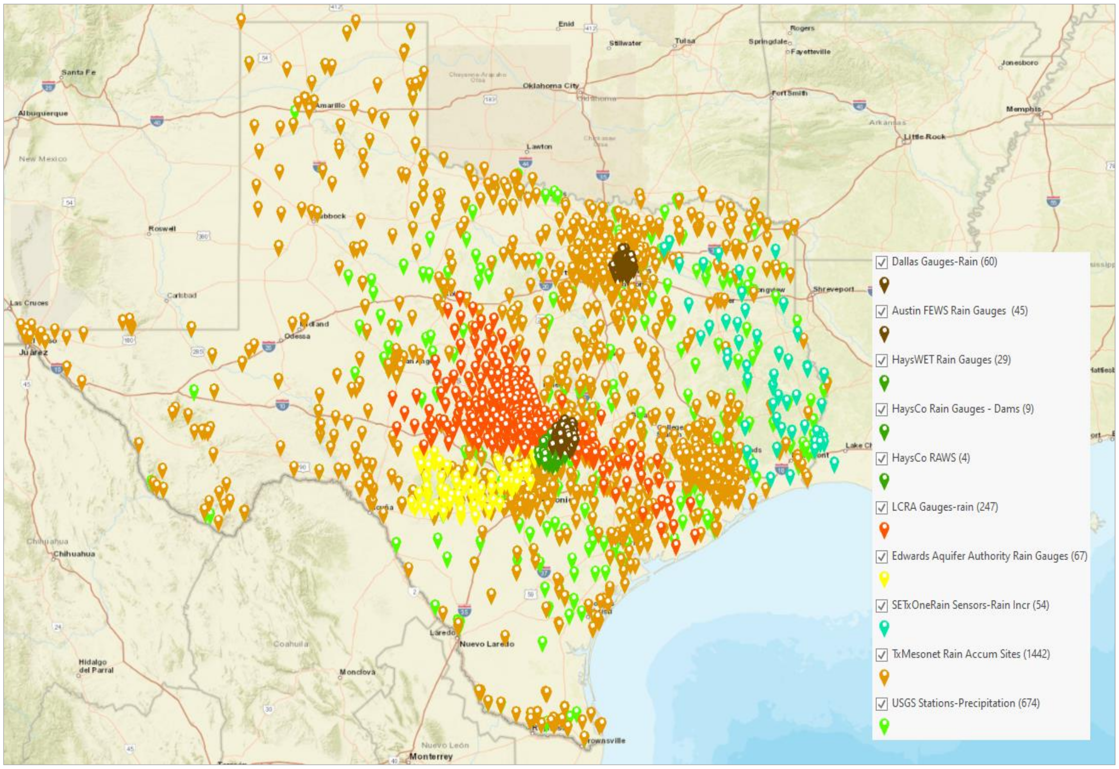
(b) Criteria from the National Hydrography Dataset

Figure 3.5. Characteristics of the base set of bridges.

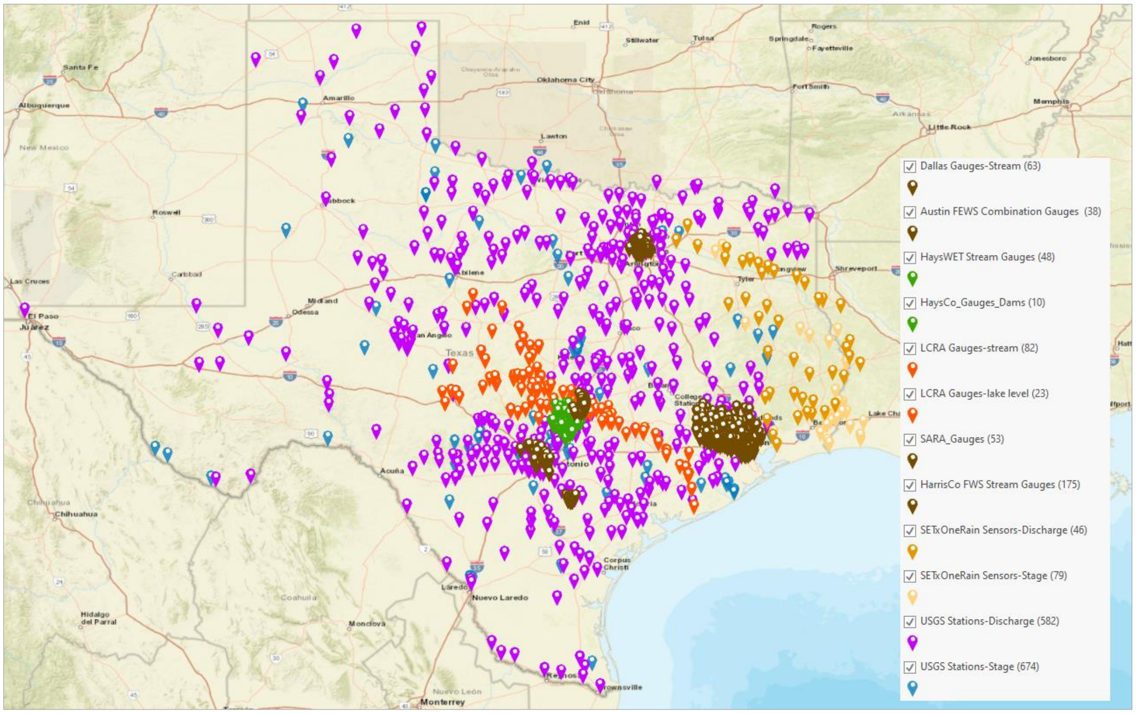
This coverage was supplied to the USGS, who carried out a desktop and field reconnaissance to identify a selected set of stream gauge sites in the priority watershed region.

3.3. Existing Gauge Networks

The project agreement calls for the development of a Texas Watershed Gauge Location Map to identify the locations of existing gauge networks. Locations of 2631 rain gauges distributed over 10 rain gauge networks are shown in Figure 3.6 (a), and 1873 water level and stream gauges distributed over 12 gauge networks are shown in Figure 3.6 (b). This is a thorough but not exhaustive coverage of gauges, as there are some other, smaller networks not shown in these maps. It is apparent that the main metropolitan areas are already well gauged by the cities located there.



(a) Existing rain gauge networks (total of 2631 gauges)



(b) Existing water level and stream gauge networks (total of 1873 gauges)

Figure 3.6. Existing rainfall, water level and stream gauge networks.

4. Desktop and Field Reconnaissance of Sites

4.1. Desktop Reconnaissance

Sites for installation of gauging stations were selected with the intent to meet the criteria defined in Figure 3.1, namely to provide information for flood warning, obtain a relatively uniform spatial distribution to support good data assimilation, and serve as good locations for streamflow measurement. In particular, the intent of the reconnaissance process is to achieve, to the greatest extent possible, ideal conditions for installation and measurement. Remote site evaluation through desktop reconnaissance is an effective means of narrowing a pool of potential sites by using available imagery such as flood overlays and topographic maps in combination with a sound understanding of the stream gauging process. Google Earth was used to view and evaluate sites remotely based on the following:

- Local channel characteristics and hydraulic features
- Bridge and roadway characteristics
- Overall employee safety during measurement or maintenance

Although a final decision was not made based on a single criterion, sites could be omitted if they possessed too many substandard attributes. It is rare for a site to exhibit every ideal condition and therefore sites were assessed based on the best of the conditions available for a specific gauge application and location.

Google Earth was used to visualize each prospective site location with a primary focus on achieving discharge measurement. Additionally, a site was also accepted for further assessment if reliable stage and velocity data could be obtained. The following ideal conditions were considered:

- Generally straight stream reach, approximately 300 ft upstream and downstream
- Flow confined to one channel or bridge opening at all stages
- Lacks proximity to upstream or downstream confluence
- Does not have obvious hydraulic features affecting uniform flow

Straight stream reaches help to ensure flow is uniform across the entire width of the stream (Rantz, 1982). The RQ-30 gauge works best for discharge measurement where the surface velocity point measurement responds consistently as the stage changes. Straight channels with parallel streamlines help to ensure the RQ-30 has the best chance of reading a point velocity that is representative of the overall channel velocity distribution. If a channel is turning near a bridge, flow will be pushed to the outside of the bend, rendering the sensor less effective for determining uniform velocities at a complete range of stages. An example of both an ideal and less ideal site location in terms of stream reach can be seen in Figure 4.1.

Figure 4.1. Examples of straight vs. curved stream reaches at bridges.

It is beneficial for the stream to be contained to a single channel. The RQ-30 assesses discharge based on a single point velocity taken at the bridge location. The further the spread of stream flow from the sensor location, the more difficult it becomes to confidently assess discharge because the point velocity measured may no longer represent a uniform channel. Ideal sections are those that are generally parabolic, trapezoidal, or rectangular. Figure 4.2 shows an example of an ideal and a less ideal stream reach in terms of containment to a single channel.

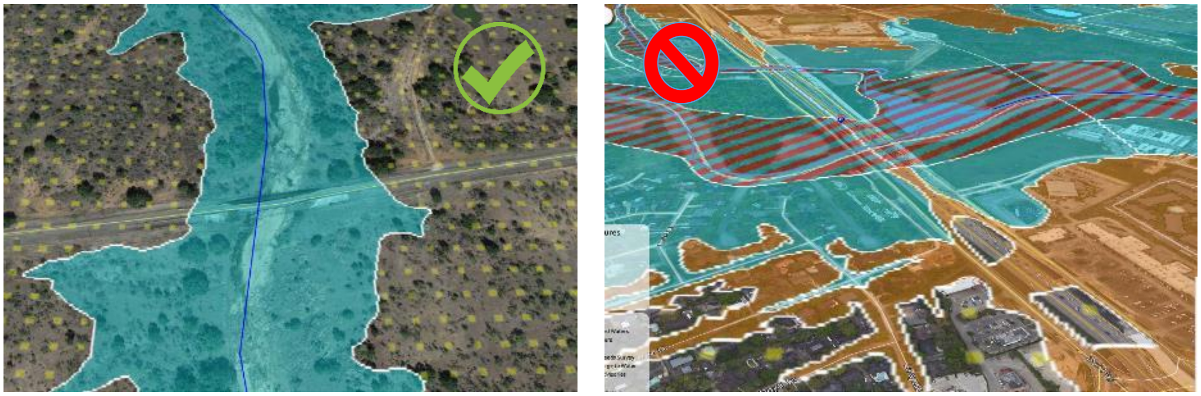


Figure 4.2. Examples of contained vs. uncontained flooding at bridges.

If a stream floods beyond its banks, it may flow around the gauging site by means of culverts or overflow channel bridges. If a significant amount of flow bypasses the gauging site, the stage/velocity relationship of the entire channel may no longer be valid or predictable. In addition to Google Earth, Google Street View can be used to view and identify possible bypasses that would otherwise go undetected. In many cases, flow bypasses alone are not enough to exclude a site completely from consideration because useful stage and velocity data may still be obtained at the gauged bridge.

Confluence of rivers or streams in close proximity to the gauging location can cause abnormal velocity patterns due to disturbed hydraulics. Locations having a confluence within two to three stream-widths were not considered for a full range discharge site. Disturbances at these particular sites create unpredictable horizontal velocity distributions and vertical velocity profiles over a range of flow conditions.

Google Earth imagery is used to observe streambeds free of large rocks, heavy vegetation, and other obstructions that could create extreme turbulence or slack water. Excessive turbulence and slack water may cause the RQ-30 to record velocities not representative of the entire channel. If possible, it is preferable to have sites free of obstruction at all stages. Figure 4.3 is an example of an upstream drop structure that may cause turbulence not suitable for velocity measurements at a bridge.

Figure 4.3. Example of upstream drop structure that may cause turbulence for measurement.

It is necessary to ensure the structure receiving the gauge sensor does not become inundated during high flow situations. The most common installation of an RQ-30 is on the guardrail of a bridge structure. Inundation may cause damage to the equipment and in some cases destroy it beyond repair. Using Google Street View, ground level images are used to look at bridges to find flood debris resulting from inundation. If the bridge shows signs of inundation from these images, it is assumed overtopping of the bridge is a frequent occurrence and the RQ-30 will not be a viable option. Furthermore, bridges that have flood depth gauges are assumed to be routinely inundated and are excluded from the final perspective gauge set. Figure 4.4 is an example image of debris on a guardrail and the aforementioned flood gauge indicator sign.

Figure 4.4. Example of a bridge with flood debris and a depth gauge.

A further consideration is employee safety during maintenance or measurement. Each gauge will need to be visited to make stage verifications, discharge measurements, perform maintenance, or a combination of these. Bridges located on inaccessible flyovers, high-speed roadways with no shoulders, or bridges that are likely to be dangerous during flash flooding are not preferred and are excluded from the potential list of gauging sites.

4.2. Field Reconnaissance

Following desktop reconnaissance, visits were made to each of the selected site locations to assess their current status and record details pertaining to a future installation and operation. Field reconnaissance is an important final assessment because on-site conditions may have changed since the imagery used for a desktop reconnaissance was taken. Field reconnaissance is also used to acquire important information used in the planning and operation of an eventual installation.

One important observation while conducting a field reconnaissance was of the bridge guardrail. The RQ-30 gauge installation package requires a stable mounting location to ensure it does not move or become damaged in the event of guardrail impact. A solid concrete guardrail as pictured in Figure 4.5 is preferrable, although other railings are considered.

Figure 4.5. Examples of concrete guardrails (preferred).

Field reconnaissance is also important to assess information not available from desktop reconnaissance. For instance, features underneath the bridge deck are not visible from aerial imagery. Bridge piers that collect considerable debris or have unidentified tributaries and drainage can disturb the natural flow of a stream, which could cause erroneous velocity readings to be collected from the RQ-30. These features were noted and considered in the final site selection.

The measurability of the channel is paramount to the RQ-30's ability to measure discharge. The ability of high flow and low flow measurements were considered; however, high flow was favored for the purpose of this project.

Pools of water that are stagnated like in Figure 4.6 produce little velocity and are very difficult to accurately measure. Since "Tier 1" sites are to be assessed at all ranges of stage, low flows must be measurable. Figure 4.7 shows an ideal stream that is both measurable and has a velocity distribution necessary for the RQ-30.

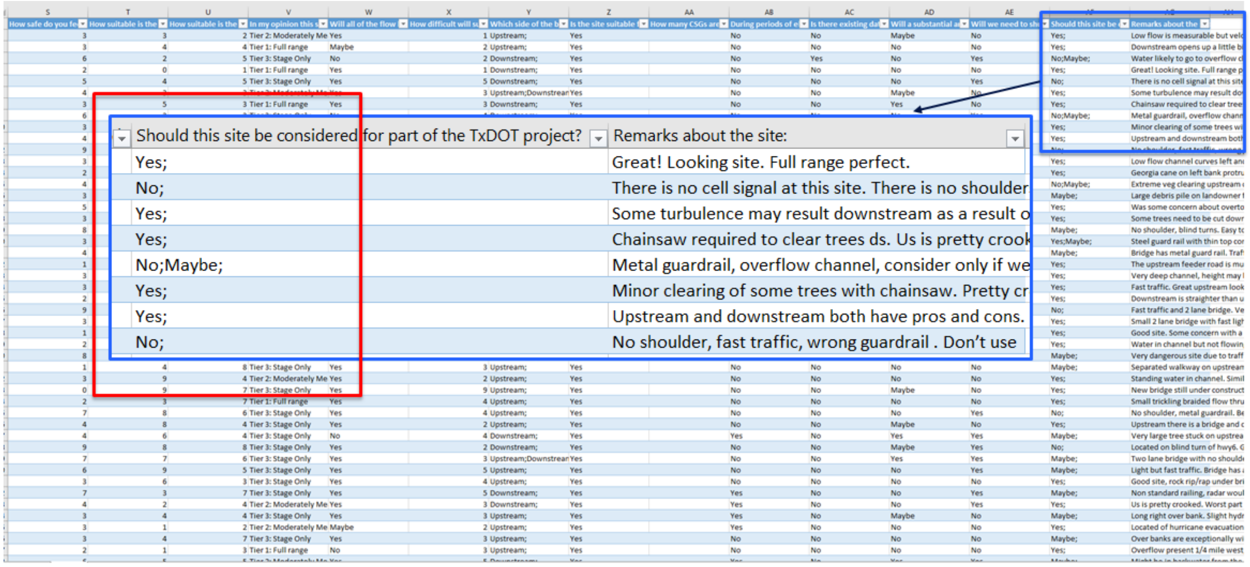
Figure 4.6. Example of slow-moving stream (not preferred).

Figure 4.7. Example of well-moving stream (preferred).

More importantly, since the main focus of the project is on flooding and inundation, an assessment of the high flow measurability was made. The preferred method of discharge measurements made from a bridge is by using an Acoustic Doppler Current Profile (ADCP). This type of measurement requires a clear cross section normally on the downstream side of a bridge to make multiple passes to acquire velocity and bathymetric data. Sites that are overgrown with trees and brush make the measurement process difficult and, in some cases, impossible. Figure 4.8 shows the difference between an ideal high flow measurement section and one that would not be suitable.

Figure 4.8. Example of clear (preferred) vs. overgrown cross section (not preferred).

The information collected during field reconnaissance was compiled into an extensive spreadsheet that recorded the answers to the key questions just described, and contained an overall assessment of site suitability, as shown in Figure 4.9. A map containing all the sites classified as "Yes" was created and the spatial pattern of possible TxDOT gauge sites was combined with that of the existing USGS gauge sites to assess overall site coverage in the region.

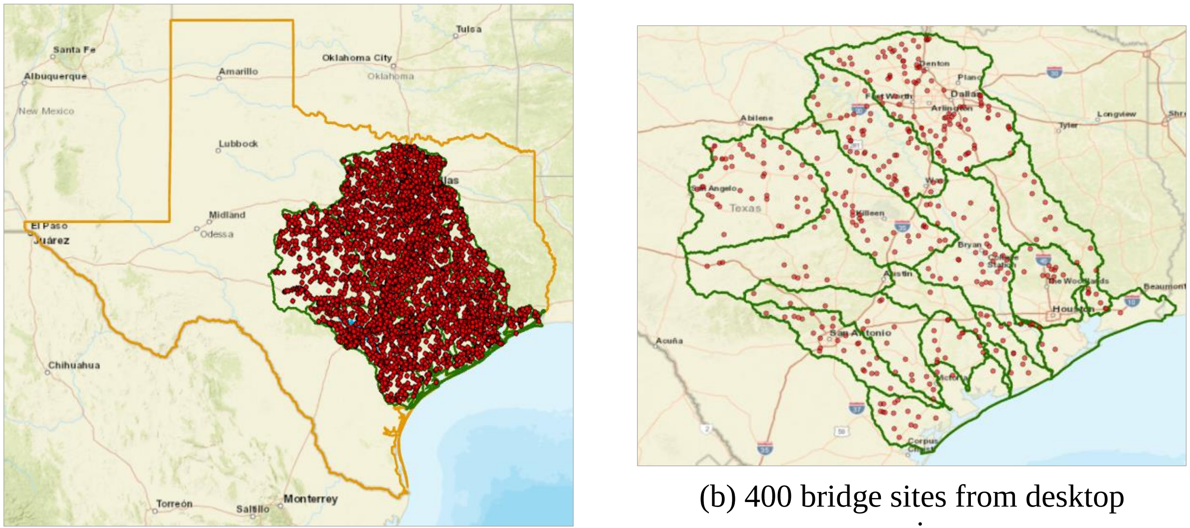


Should this site be considered for part of the TxDOT project?	Remarks about the site:
Yes;	Great! Looking site. Full range perfect.
No;	There is no cell signal at this site. There is no shoulder
Yes;	Some turbulence may result downstream as a result o
Yes;	Chainsaw required to clear trees ds. Us is pretty crook
No;Maybe;	Metal guardrail, overflow channel, consider only if we
Yes;	Minor clearing of some trees with chainsaw. Pretty cr
Yes;	Upstream and downstream both have pros and cons.
No;	No shoulder, fast traffic, wrong guardrail . Don't use

Figure 4.9. Summary spreadsheet for the results of field reconnaissance.

5. First Set of 30 Sites Selected

The base set of 5,355 bridges in the priority watershed area is shown in Figure 5.1 (a) and the 400 bridge sites that resulted from the desktop reconnaissance are shown in Figure 5.1 (b). Approximately 1 in 13 bridges were selected as potential stream gauge sites. The watersheds shown in this figure use the USGS HUC6 boundaries.



(b) 400 bridge sites from desktop reconnaissance

(a) Base set of bridges

Figure 5.1. Characteristics of the base set of bridges.

Once the desktop reconnaissance was completed, the question arose regarding a method of partitioning the basins in Figure 5.1 so that field reconnaissance could be undertaken on one group of basins rather than on all of the 400 potential gauge sites. One factor in making this assessment is the trend in flood factors going inland from the Gulf coast. As shown in Figure 5.2, the coastal plain is a region of flat slope, poor drainage, and high rainfall intensity, and those flood risk factors diminish as you go inland.

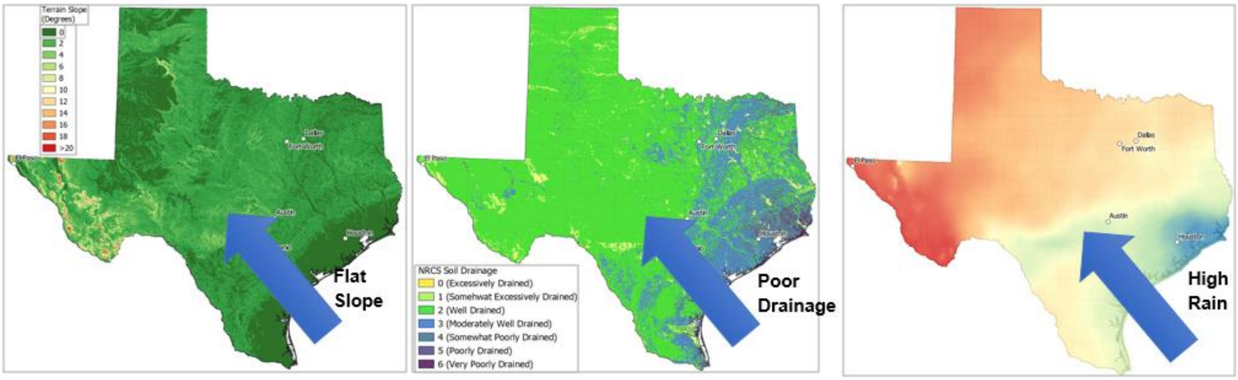


Figure 5.2. Trend in flood characteristics.

This thought process led to the partitioning of the HUC6 basins into three groups: the Lower, Middle, and Upper groups, as shown in Figure 5.3. The number of potential gauge sites in each group is 60, 100, and 240 in the Lower, Middle and Upper groups, respectively. The original intention was to have 100 potential sites and to reduce that to 60 actual site locations through field reconnaissance. As there are 100 potential sites in the Middle group of basins, this group of basins suggested itself as a good candidate for a first assessment.

● Potential gauge sites identified by USGS

HUC6 Group	Number of Potential Gauge Sites
Lower	60
Middle	100
Upper	240
Total	400

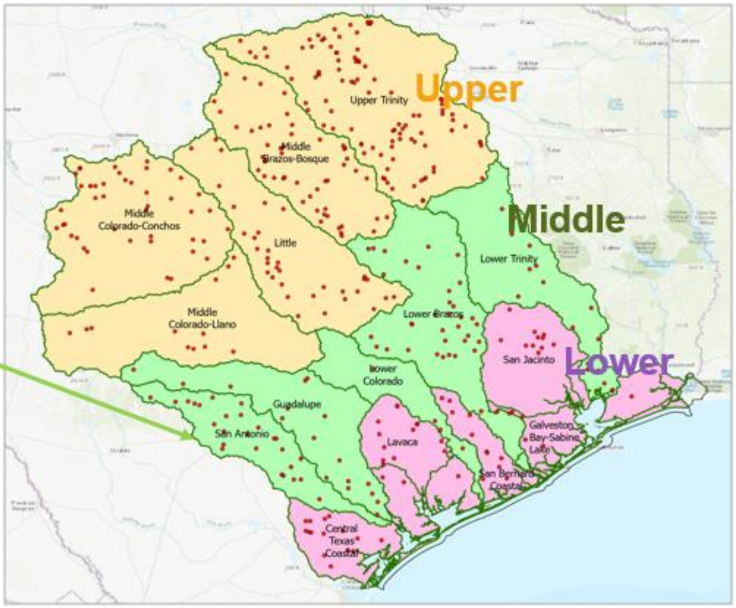


Figure 5.3. Three groups of HUC6 basins.

Another consideration bearing on this decision is that the Colorado basin is being used as the testbed for data assimilation in the project, as shown in Figure 5.4. The intent in the testbed is to use the rainfall and streamflow networks installed by the Lower Colorado River Authority as an augmentation to the USGS streamflow dataset now ingested into the National Water Model, and to produce an updated and improved forecast for the basin. It is apparent from Figure 5.4 that the San Antonio, Guadalupe, Lower Brazos, and Lower Trinity basins are parallel watersheds to the Lower Colorado in which such assimilation methods using data from TxDOT gauges could be applied.

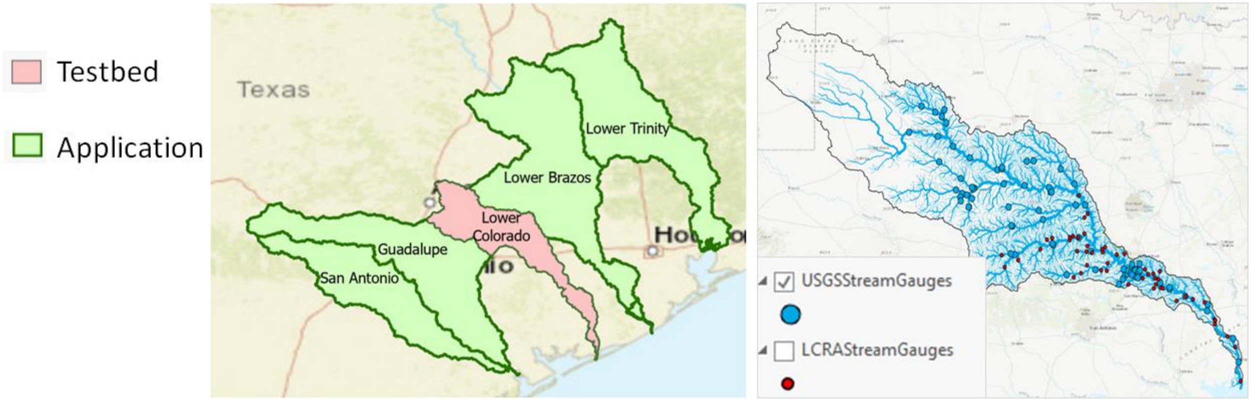


Figure 5.4. Testbed and application basins for data assimilation.

A further consideration concerning the choice of watershed in which to site gauges is the location of hurricane evacuation routes. Obtaining information about the flood threat to such routes is a high priority in the event of an evacuation of a part of the coast during a hurricane event. As shown in Figure 5.5, these routes are located in the area of the Lower and Middle basin groups but not the Upper basin area.

A final factor bearing on the decision as to which group of basins to select is that stream gauging in the coastal zone is complicated by the inability to move water downstream because of the very flat topography and resulting backwater effects—indeed, some rhythmic variation in water surface elevations are observed in gauges installed on IH-10 during the Streamflow I project that arise from backwater effects upstream of tidal variation at the coast.

The combination of all these considerations led to the selection of the Middle group of five basins as the focus area for field reconnaissance to select bridges for stream gauge sites. When considering the existing density of USGS gauges in these basins, it became apparent, as shown in Figure 5.6, that the Lower Brazos and the Lower Trinity basins have a relatively low gauge density compared with the San Antonio, Guadalupe, and Lower Colorado basins. Indeed, the Lower Colorado basin has the highest concentration of existing stream gauges because the Lower Colorado River Authority operates its own stream gauging network in that basin, in addition to the network operated by the USGS.

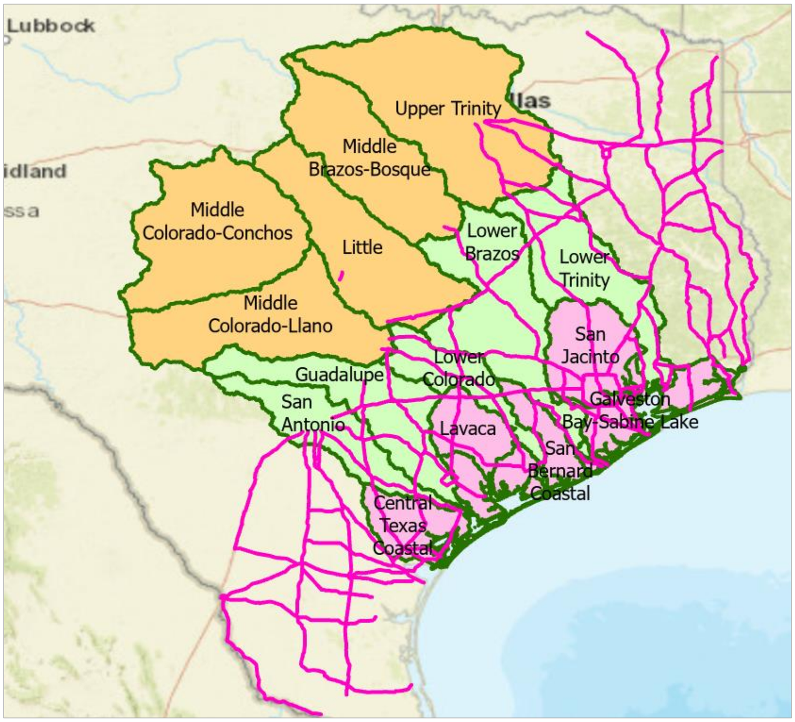
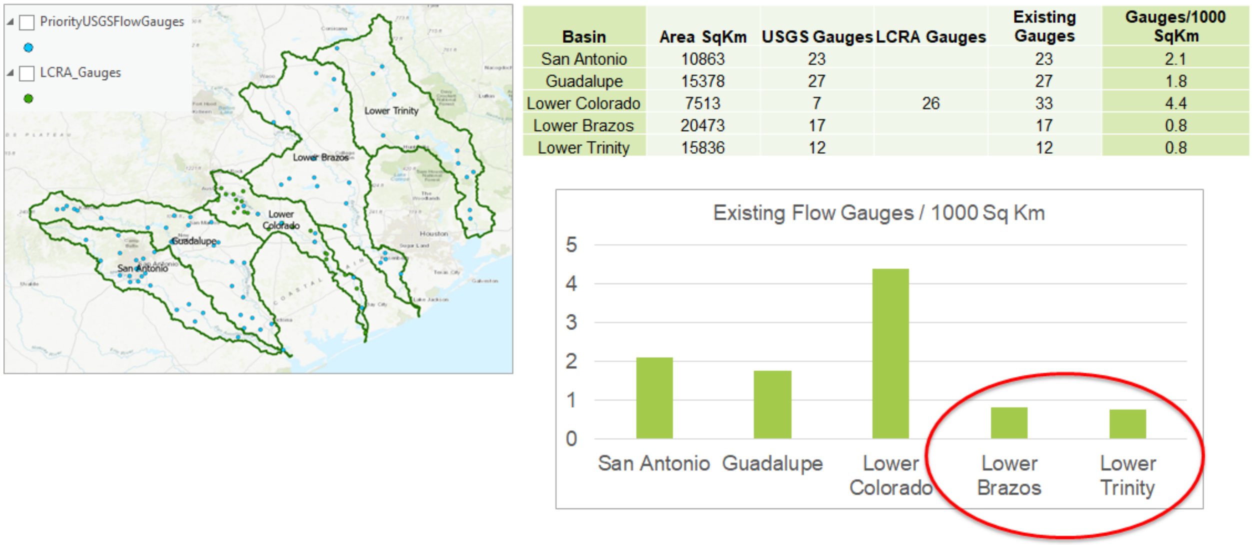


Figure 5.5. Hurricane evacuation routes.



Basin	Area SqKm	USGS Gauges	LCRA Gauges	Existing Gauges	Gauges/1000 SqKm
San Antonio	10863	23		23	2.1
Guadalupe	15378	27		27	1.8
Lower Colorado	7513	7	26	33	4.4
Lower Brazos	20473	17		17	0.8
Lower Trinity	15836	12		12	0.8

Figure 5.6. Density of existing USGS gauges in the Middle group of basins.

The USGS field assessment showed that the Lower Brazos and Lower Trinity basins are a region that would yield good streamflow measurements, and where the gauges can be relatively uniformly spread over the drainage area, as shown in Figure 5.7, which shows the locations of the newly recommended gauge sites (labeled 201-230) and those sites where gauges were installed in the previous Streamflow I project (101-120).

This information is also presented as an ArcGIS StoryMap at https://arcg.is/veW9T0. The StoryMap provides five live web maps that summarize the project watersheds, the 400 potential sites, the gauge site locations for the Streamflow I and Streamflow II projects, and the existing networks for precipitation, water level, and streamflow recording in Texas.

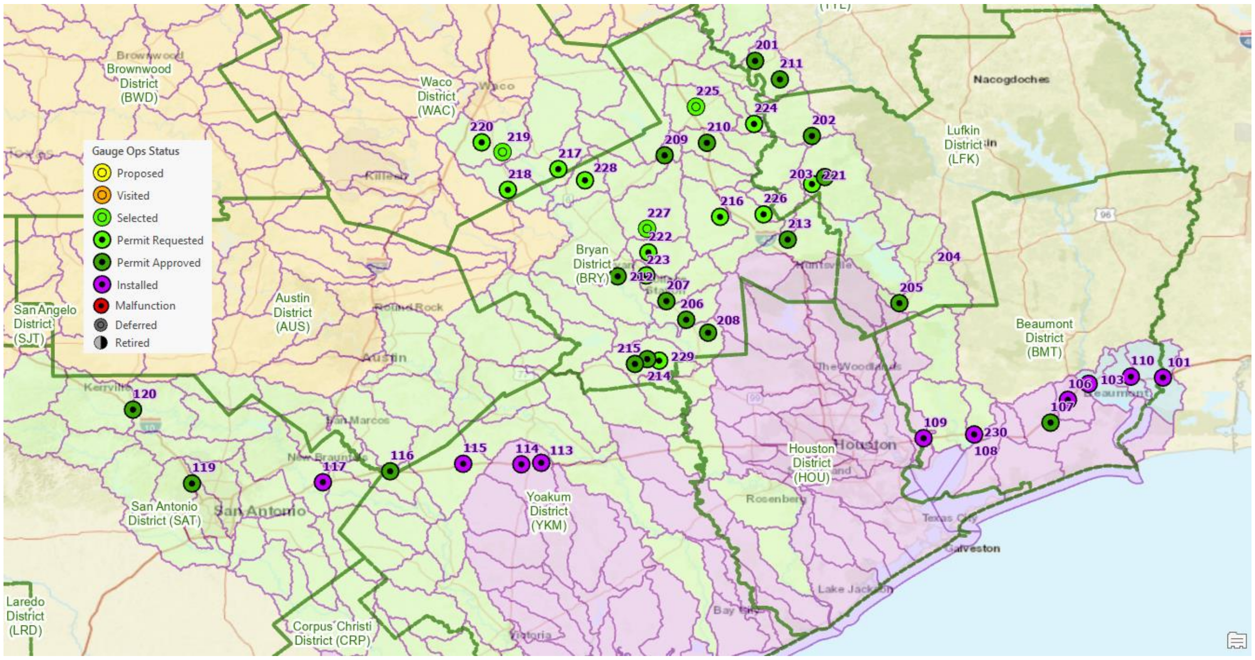


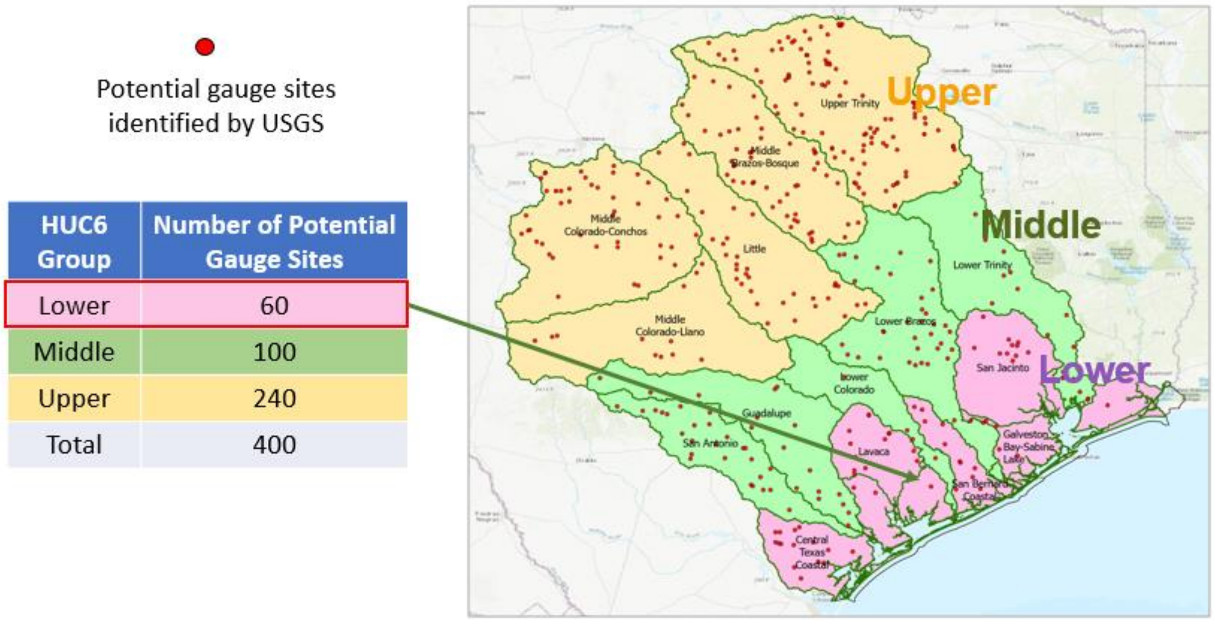
Figure 5.7. Gauge sites from the Streamflow I project (101-120), and first set of new sites (201-230), status as of July 28, 2021.

The “yield” of 30 good gauging sites in the Lower Brazos and Lower Trinity basins contrasted with a sparser distribution of good sites in the San Antonio and Guadalupe basins, where only 9 good sites were found after field reconnaissance by the USGS. The spatial distribution of the selected TxDOT gauging sites combined, with the existing USGS gauging sites in the Lower Brazos and Trinity basins, produced a gauge density of approximately one stream gauge per HUC10 watershed. Gauge sites were taken from a few HUC10 watersheds that had higher gauge density and relocated to new selected locations in HUC10 watersheds with no gauge coverage so as to achieve a reasonably uniform gauge coverage of the Lower Brazos and Trinity basins. The addition of 30 new gauge sites there to the nearly 30 existing USGS gauges means that the gauge density in this area is approximately doubled by the installation of the gauges in this project.

Permission was requested for installation of 30 gauges in the Lower Brazos and Lower Trinity basins at a meeting of the TxDOT Project Management Committee on 5 May 2021. Approval was given for this decision by the RTI Project Manager soon afterwards. Permits have been requested for these sites and the gauges are presently being installed. The Streamflow I gauges are also being retrofit with better brackets and recalibrated. Some of them are being moved to different locations. The Appendix to this report specifies the locations and ancillary information about both the

Streamflow I gauge sites being retained and the 30 new sites being added as part of this Streamflow II project.

Once those gauges are installed and operational, attention will turn to the identification of the second group of 30 gauge sites. These will likely be selected in the Lower group of basins (Figure 5.8) because of the high incidence of flood risk there, and from observations as the project proceeds that stream gauging in areas where flow backwater occurs is more feasible with the RQ-30 gauge than with conventional USGS stream gauging methods. The USGS methods require a unique rating curve connecting stage height and water discharge.



HUC6 Group	Number of Potential Gauge Sites
Lower	60
Middle	100
Upper	240
Total	400

Figure 5.8. Likely location for the second set of 30 gauge sites in the Lower group of basins.

6. Conclusions

Siting gauges that will form part of a stream gauge network has always been a subject of some uncertainty. A traditional gauge network, such as that of the USGS, is built up incrementally with gauges sited for various reasons in various locations. In this project, we are attempting to site gauges collectively as part of a system that will satisfy three objectives: (1) provide good streamflow information to allow testing of the RQ-30 radar stream gauge by the USGS; (2) be relatively uniformly distributed over the watershed so that the flow forecasts throughout the river and stream network can be improved through data assimilation; (3) be located to so as to improve flood warnings especially in areas of high flood risk.

In this research project, existing basin boundaries of the TWDB and the USGS were used to divide Texas into 20 drainage areas. For each drainage area, data were compiled for six weighting factors, three representing traffic considerations (Daily Vehicle Miles Travelled, Number of Bridges, and Number of Flood Fatalities), and three representing flood risk factors (Slope, Soil Drainage, and 24-hour, 100-year Rainfall Intensity). Equally weighting each of these factors and ranking the 20 drainage areas from highest to lowest ranks led to the selection of a priority watershed zone, located primarily around the "Texas Triangle" of heavy traffic routes connecting DFW, Houston, San Antonio, and Austin, and extending down to the Gulf coast. This zone covers about one-third of the area of Texas and contains about three-quarters of the state's traffic flow.

The base set of a little more than 5,000 TxDOT bridges within this priority zone was selected, examined by the USGS using a desktop evaluation procedure employing Google Earth, and reduced to a set of 400 priority locations that appeared to be potential gauge sites. The priority watershed zone was divided into three groups of HUC6 basins—a Lower, Middle, and Upper group—according to proximity to the Gulf coast. Choosing initially the Middle group of basins, the USGS performed a field reconnaissance of approximately 100 sites, and selected 30 sites in the Lower Brazos and Lower Trinity basins as good gauge site locations that are relatively well distributed across those drainage areas. Permits for installation of gauges at these sites have been requested and most are approved. The installation of the gauges at these sites is taking place. The TxDOT stream gauge network will approximately double the density of streamflow measurement in these basins.

A further set of 30 gauge sites are still to be selected, likely from the Lower group of basins adjacent to and inland from the Gulf coast. As this task has yet to be completed, this is a provisional report that describes the tasks completed as of 31 July 2021, the required date for this Technical Memorandum 2 report to be submitted as part of the project agreement. It is expected that once the second set of 30 gauge sites is selected, the provisional report will be revised to include the locations of these sites and any further information arising from the process of selecting them.

Acknowledgements

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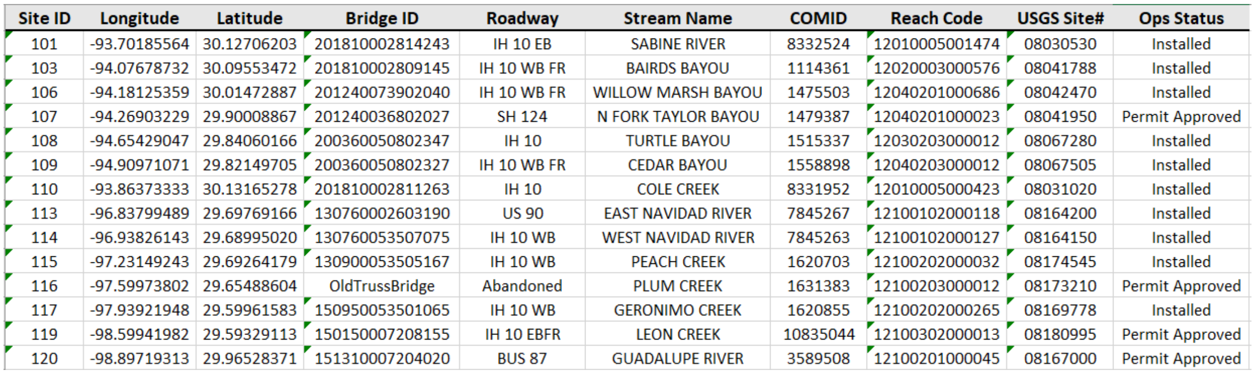
Appendix – Selected Gauge Sites

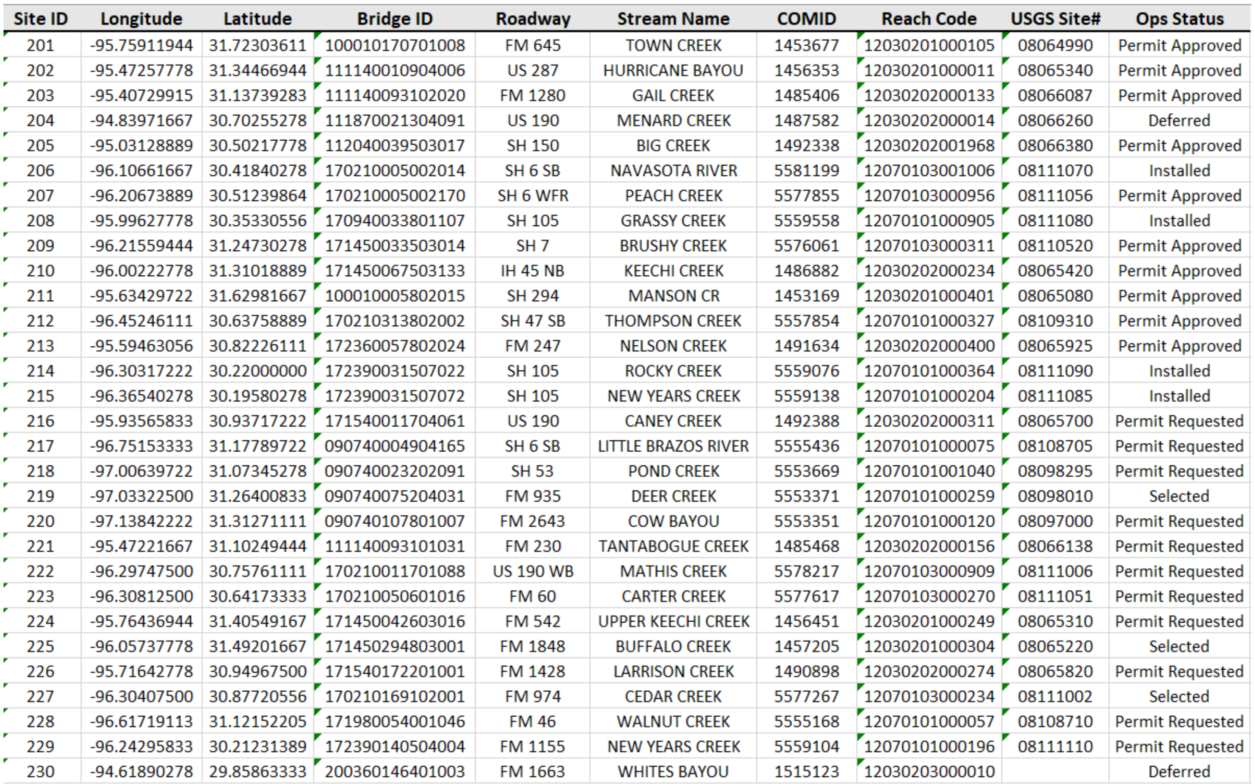
Listing of Selected Gauge Sites, Status as of July 29, 2021

For those sites being maintained from Streamflow I



Site ID	Longitude	Latitude	Bridge ID	Roadway	Stream Name	COMID	Reach Code	USGS Site#	Ops Status
101	-93.70185564	30.12706203	201810002814243	IH 10 EB	SABINE RIVER	8332524	12010005001474	08030530	Installed
103	-94.07678732	30.09553472	201810002809145	IH 10 WB FR	BAIRDS BAYOU	1114361	12020003000576	08041788	Installed
106	-94.18125359	30.01472887	201240073902040	IH 10 WB FR	WILLOW MARSH BAYOU	1475503	12040201000686	08042470	Installed
107	-94.26903229	29.90008867	201240036802027	SH 124	N FORK TAYLOR BAYOU	1479387	12040201000023	08041950	Permit Approved
108	-94.65429047	29.84060166	200360050802347	IH 10	TURTLE BAYOU	1515337	12030203000012	08067280	Installed
109	-94.90971071	29.82149705	200360050802327	IH 10 WB FR	CEDAR BAYOU	1558898	12040203000012	08067505	Installed
110	-93.86373333	30.13165278	201810002811263	IH 10	COLE CREEK	8331952	12010005000423	08031020	Installed
113	-96.83799489	29.69769166	130760002603190	US 90	EAST NAVIDAD RIVER	7845267	12100102000118	08164200	Installed
114	-96.93826143	29.68995020	130760053507075	IH 10 WB	WEST NAVIDAD RIVER	7845263	12100102000127	08164150	Installed
115	-97.23149243	29.69264179	130900053505167	IH 10 WB	PEACH CREEK	1620703	12100202000032	08174545	Installed
116	-97.59973802	29.65488604	OldTrussBridge	Abandoned	PLUM CREEK	1631383	12100203000012	08173210	Permit Approved
117	-97.93921948	29.59961583	150950053501065	IH 10 WB	GERONIMO CREEK	1620855	12100202000265	08169778	Installed
119	-98.59941982	29.59329113	150150007208155	IH 10 EBFR	LEON CREEK	10835044	12100302000013	08180995	Permit Approved
120	-98.89719313	29.96528371	151310007204020	BUS 87	GUADALUPE RIVER	3589508	12100201000045	08167000	Permit Approved

For the 30 new sites being installed as part of Streamflow II



Site ID	Longitude	Latitude	Bridge ID	Roadway	Stream Name	COMID	Reach Code	USGS Site#	Ops Status
201	-95.75911944	31.72303611	100010170701008	FM 645	TOWN CREEK	1453677	12030201000105	08064990	Permit Approved
202	-95.47257778	31.34466944	111140010904006	US 287	HURRICANE BAYOU	1456353	12030201000011	08065340	Permit Approved
203	-95.40729915	31.13739283	111140093102020	FM 1280	GAIL CREEK	1485406	12030202000133	08066087	Permit Approved
204	-94.83971667	30.70255278	111870021304091	US 190	MENARD CREEK	1487582	12030202000014	08066260	Deferred
205	-95.03128889	30.50217778	112040039503017	SH 150	BIG CREEK	1492338	12030202001968	08066380	Permit Approved
206	-96.10661667	30.41840278	170210005002014	SH 6 SB	NAVASOTA RIVER	5581199	12070103001006	08111070	Installed
207	-96.20673889	30.51239864	170210005002170	SH 6 WFR	PEACH CREEK	5577855	12070103000956	08111056	Permit Approved
208	-95.99627778	30.35330556	170940033801107	SH 105	GRASSY CREEK	5559558	12070101000905	08111080	Installed
209	-96.21559444	31.24730278	171450033503014	SH 7	BRUSHY CREEK	5576061	12070103000311	08110520	Permit Approved
210	-96.00222778	31.31018889	171450067503133	IH 45 NB	KEECHI CREEK	1486882	12030202000234	08065420	Permit Approved
211	-95.63429722	31.62981667	100010005802015	SH 294	MANSON CR	1453169	12030201000401	08065080	Permit Approved
212	-96.45246111	30.63758889	170210313802002	SH 47 SB	THOMPSON CREEK	5557854	12070101000327	08109310	Permit Approved
213	-95.59463056	30.82226111	172360057802024	FM 247	NELSON CREEK	1491634	12030202000400	08065925	Permit Approved
214	-96.30317222	30.22000000	172390031507022	SH 105	ROCKY CREEK	5559076	12070101000364	08111090	Installed
215	-96.36540278	30.19580278	172390031507072	SH 105	NEW YEARS CREEK	5559138	12070101000204	08111085	Installed
216	-95.93565833	30.93717222	171540011704061	US 190	CANEY CREEK	1492388	12030202000311	08065700	Permit Requested
217	-96.75153333	31.17789722	090740004904165	SH 6 SB	LITTLE BRAZOS RIVER	5555436	12070101000075	08108705	Permit Requested
218	-97.00639722	31.07345278	090740023202091	SH 53	POND CREEK	5553669	12070101001040	08098295	Permit Requested
219	-97.03322500	31.26400833	090740075204031	FM 935	DEER CREEK	5553371	12070101000259	08098010	Selected
220	-97.13842222	31.31271111	090740107801007	FM 2643	COW BAYOU	5553351	12070101000120	08097000	Permit Requested
221	-95.47221667	31.10249444	111140093101031	FM 230	TANTABOGUE CREEK	1485468	12030202000156	08066138	Permit Requested
222	-96.29747500	30.75761111	170210011701088	US 190 WB	MATHIS CREEK	5578217	12070103000909	08111006	Permit Requested
223	-96.30812500	30.64173333	170210050601016	FM 60	CARTER CREEK	5577617	12070103000270	08111051	Permit Requested
224	-95.76436944	31.40549167	171450042603016	FM 542	UPPER KEECHI CREEK	1456451	12030201000249	08065310	Permit Requested
225	-96.05737778	31.49201667	171450294803001	FM 1848	BUFFALO CREEK	1457205	12030201000304	08065220	Selected
226	-95.71642778	30.94967500	171540172201001	FM 1428	LARRISON CREEK	1490898	12030202000274	08065820	Permit Requested
227	-96.30407500	30.87720556	170210169102001	FM 974	CEDAR CREEK	5577267	12070103000234	08111002	Selected
228	-96.61719113	31.12152205	171980054001046	FM 46	WALNUT CREEK	5555168	12070101000057	08108710	Permit Requested
229	-96.24295833	30.21231389	172390140504004	FM 1155	NEW YEARS CREEK	5559104	12070101000196	08111110	Permit Requested
230	-94.61890278	29.85863333	200360146401003	FM 1663	WHITES BAYOU	1515123	12030203000010		Deferred