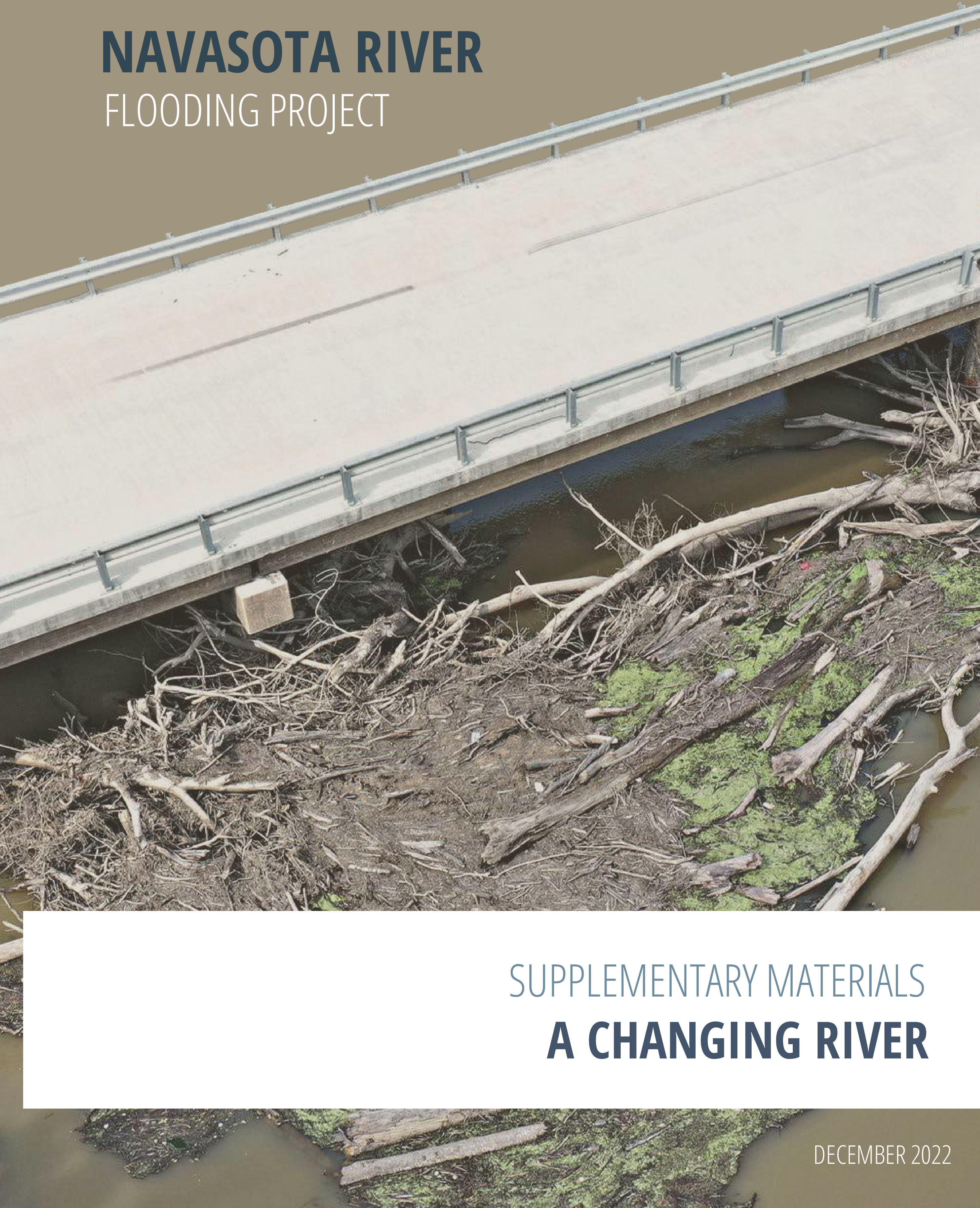
# NAVASOTA RIVER
FLOODING PROJECT



SUPPLEMENTARY MATERIALS
## A CHANGING RIVER

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# SUPPLEMENTARY MATERIAL: A CHANGING RIVER

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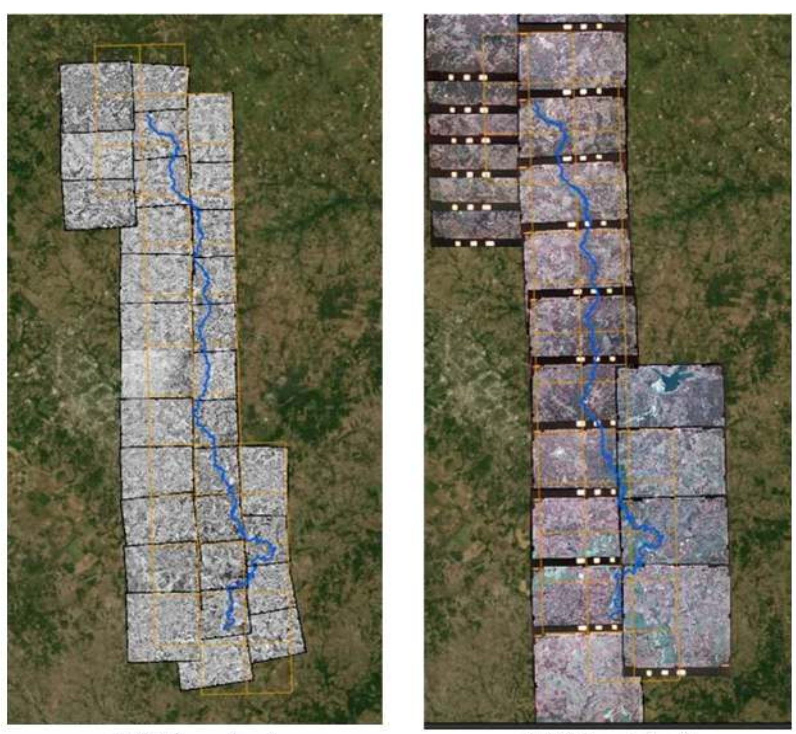
## METHODOLOGICAL OVERVIEW

River channel mapping is primarily conducted on a Geographical Information System (GIS) platform using imagery of different periods. Since historical aerial imagery is not spatially aligned, it is first geo-referenced against geo-control points. Finally, based on a series of geo-referenced imageries, changes in the sinuosity (flow path) of the Navasota River are evaluated.

### Data

Historical aerial photographs across the area of interest were ordered for 1972 (pre-dam), 1981 (post-dam), 1989/90, and 1995. In addition, modern aerial photography from the National Agriculture Imagery Program (NAIP) is available online from 2003 onwards annually with a high spatial resolution of 1 m. Tiles in the NAIP collection are natural color (red, green, and blue bands) or color near infra-red (red, green, blue, and near-infrared bands).

**Figure 1:** Sample of geo-referenced imagery for 1972 and 1981



1972 (pre-dam) 1981 (post-dam)

### Geo-Referencing

Historical aerial photographs were georeferenced (given spatial context for mapping) in ArcGIS Pro. All imagery was georeferenced to sub-meter resolution 2020 imagery to maintain consistency in photo alignment (Figure 1). Features common between the historical imagery and 2020 were used as control points to provide spatial reference, and consisted primarily of road and railroad intersections, and structures such as barns and homes. A spatial error of ±3 m was sought for each image. Once all images from a particular year were aligned, they were stitched together to create a seamless mosaic.

### Delineation of Riverbank Lines and Center Lines

Riverbank edges were first digitized over the geo-referenced imagery. In particular, a manual judgment was done by looking at the neighborhood at the locations with heavy woody canopy cover.

Following delineation of the riverbanks, the centerline was computed using the *Polygon to Centerline* tool in ArcGIS Pro. This tool produces a line that follows the geometric center between the left and right banks of the river.

In the case of NAIP imagery, normalized difference vegetation index (NDVI) and normalized difference water index (NDWI) were computed using red (R), green (G), and near-infrared (NIR) bands.

$$NDVI = \frac{NIR-R}{NIR+R} \qquad [1]$$

$$NDWI = \frac{G-NIR}{G+NIR} \qquad [2]$$

Then, for the NAIP imagery, automatic extraction of water bodies was done using four individual bands and two normalized indices. In this method, canopy disturbances were still there. The automated-delineated water bodies helped to digitize riverbank lines manually like it was done for the historical imageries. In case there is more than one river path, the main or dominant channel was mapped based on the continuous presence of water.

### Delineation of Swampy Areas

In areas that were swampy or flooded at the time of image acquisition, a best guess was made in channel delineation. This was achieved by looking at the river channel in the preceding and following decades and by observing the tree line that is still visible above the flooded area.

### Computation of Length, Area, and Sinuosity

Sinuosity, or meandering, is used to describe the flow path of a stream or river across the landscape. A more sinuous stream has more bends than one that is less sinuous. This is measured through the sinuosity index.

The sinuosity index (SI) is the relationship between the actual stream length and a straight-line length ("as the crow flies") [3].

$$SI = \frac{Stream\ Centerline\ Length}{Straight\ Line\ Length} \qquad [3]$$

A value of 1 would mean that the stream was a straight line, and higher numbers indicate increasing sinuosity.

Centerline length and sinuosity were calculated for the entire segment of the Navasota River between Brazos and Grimes counties, as well as on sub-segments of the river at major road intersections (see Table 1).

**Table 1:** Description of segments used in this study. Segments are delineated from downstream to upstream.

| Segment | Start | End |
|---|---|---|
| Entire | Brazos Confluence | State Highway OSR |
| A | Brazos Confluence | State Highway Highway 6 |
| B | State Highway 6 | Sulphur Springs Road |
| C | Sulphur Springs Road | State Highway 30 |
| D | State Highway 30 | Roese Road |
| E | Roese Rd | Long Trussel Road |
| F | Long Trussel Road | Democrat Rd |
| G | Democrat Road | State Highway 21 |
| H | State Highway 21 | State Highway OSR |

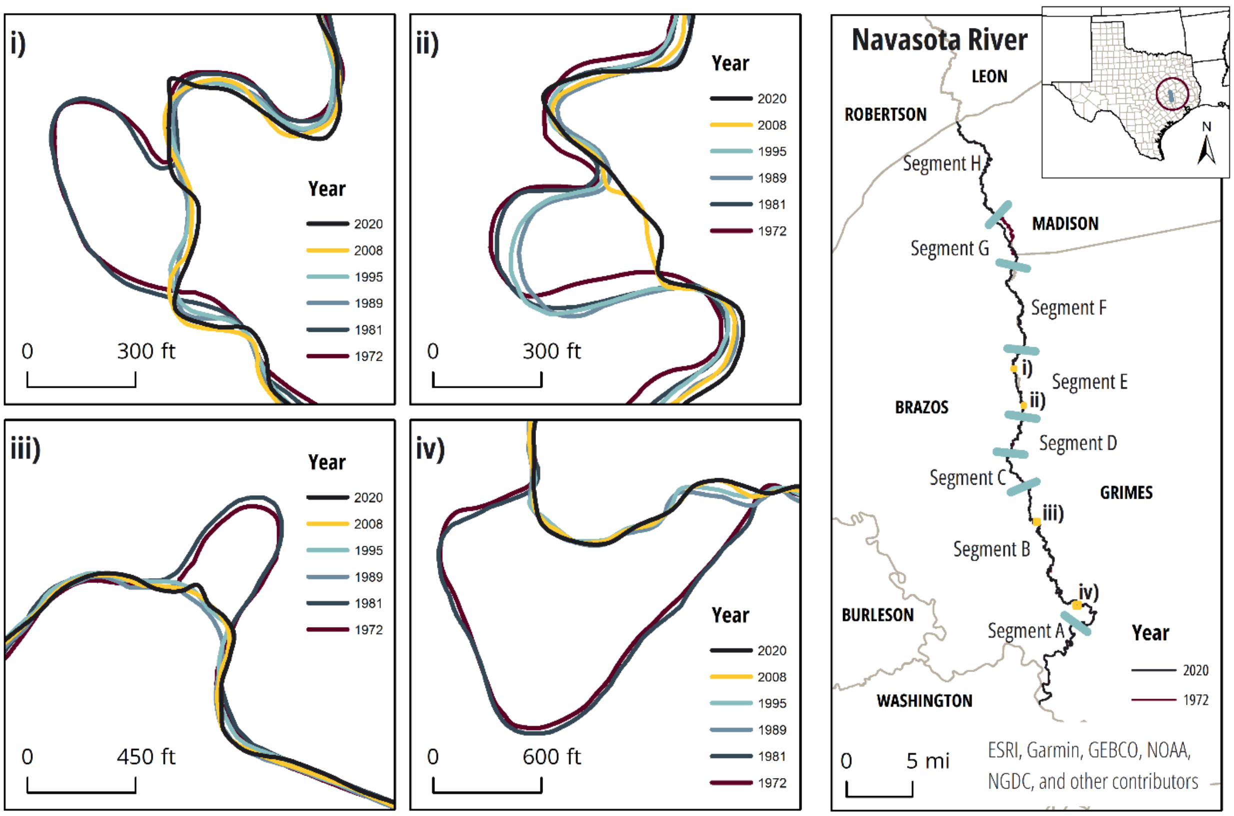
### Shifts in River Length and Sinuosity

River shifting over time was observed by overlaying the centerlines from each year and observing areas of major shifts. In this way, it is possible to identify areas where oxbows are created (thus shortening the river), new meanders are created (extending the river), and channel shifts occur (which could potentially shorten or lengthen the river).

## KEY FINDINGS

### River Channel Shifts

**Figure 2:** Synopsis of river channel shift across the Navasota River over time. Four representative locations are highlighted in four subplots i) to iv). Segments A to H are eight river segments used in this study. Details on these river segments are in Table 1.

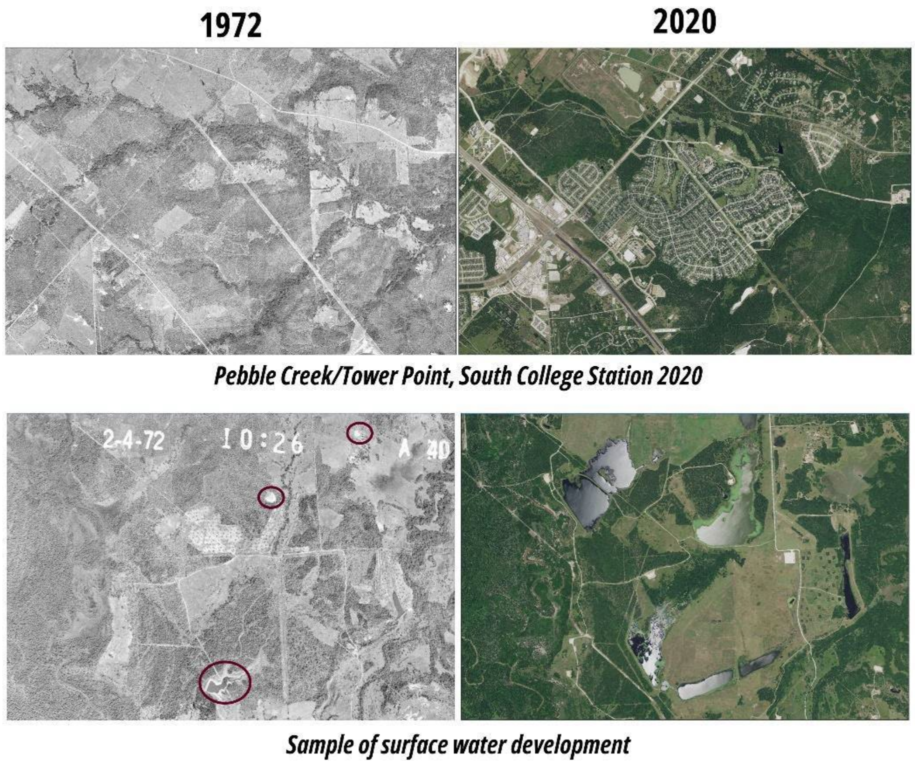



The lower portion of the river (State Highway 21 to Navasota, TX) is braided with many channels. It was found that there was an eastward shift in the river at State Highway 21. Both channels were present in 1972, but the dominant channel shifted based on the presence of water. The current drought may make the primary channel more evident.

### Land-Use Changes Across the Catchment

Imageries confirm extensive urban development south of College Station, and there is much more surface water (ponds/lakes) in 2020 than in 1972 (see Figure 3).

**Figure 3**: Sample locations showing a substantial development of urban land and surface water. Circles indicate the extent of surface water in 1972, compared to extensive development apparent by 2020.




## Quantitative Evaluation of River Shifting

The Navasota River between Brazos and Grimes counties has shortened by 2.68 miles since 1972. Most of this change comes from Segment G between Democrat Road and State Highway 21 (Figure 4). There was a major shift in the main channel between 1972 and 2020. In the 1972 imagery, there are two distinct channels at State Highway 21 (there are two bridges on the highway as well); however, the western-most channel is very thin compared to the eastern channel in 1972. The width of this smaller segment grew by a factor of 2.5 (18 feet to 47 feet) from 1981 to 1995, at which point the channel shift appears to have occurred. By 2020, the new channel was about 66 feet wide. Both channels still have water present, but it is apparent that the older channel now has dry portions, and probably only receives continuous flow under severe rainfall events.

Tables 2 and 3 present the summary of river length and sinuosity at different sections over time. Figure 5 shows the temporal variation of river length anomaly and sinuosity. A positive value of river length anomaly denotes it is lengthier than a temporal-average river length from 1972 to 2020, whereas a negative value denotes it is shorter than the temporal-average. The river length anomaly for the entire segment shows that 1995 imagery showed the most decline across the study period. This indicates that along with a noticeable shortening of river length, change in river meandering occurred at many locations with a slight increment of river lengths at different locations. A shortened river channel is associated with negative consequences including increased risk of flooding downstream, faster velocity, and increased erosion and sediment/debris transport. However, the straightening effect for a small reach of the river diminishes rapidly as flood wave travels through unmodified (cutoff) reaches, as these unmodified reaches act as a strong dampening effect.[1]

**Table 2**: River length at different sections over time and the total change from 1972 to 2020

| Segment | 1972 | 1981 | 1989 | 1995 | 2008 | 2020 | Total Change (mi) |
|---|---|---|---|---|---|---|---|
| Entire | 84.32 | 84.35 | 83.75 | 80.83 | 81.30 | 81.64 | -2.68 |
| A | 11.34 | 11.47 | 11.52 | 11.59 | 11.72 | 11.82 | 0.48 |
| B | 23.38 | 23.30 | 22.60 | 22.58 | 22.83 | 22.81 | -0.57 |
| C | 4.19 | 4.16 | 4.21 | 4.19 | 4.20 | 4.20 | 0.01 |
| D | 5.21 | 5.24 | 5.13 | 5.06 | 5.14 | 5.14 | -0.07 |
| E | 7.49 | 7.52 | 7.42 | 7.37 | 7.45 | 7.52 | 0.03 |
| F | 10.80 | 10.79 | 10.80 | 10.82 | 10.98 | 11.06 | 0.26 |
| G | 8.79 | 8.74 | 8.88 | 5.99 | 5.56 | 5.62 | -3.17 |
| H | 13.11 | 13.12 | 13.20 | 13.21 | 13.42 | 13.46 | 0.35 |

The river sinuosity in the study area in 1972 ranged from 1.57 to 2.11, indicating river segment lengths were moderately to greatly meandering. By 2020, the sinuosity index ranged from 1.40 to 2.05, indicating an overall loss of meandering in the river. Segment G (Democrat Road to Highway 21) had the greatest reduction from 2.11 in 1972 to 1.40 in 2020, going from the segment of greatest sinuosity, to the lowest. This can have noticeable implications for the ability of the stream to hold and transfer water, as a meandering stream has greater storage capacity than a straight-line stream and has a greater ability to slow down flow.

[1] Campbell, K.L., Kumar, S., & Johnson, H-P.(1972). Stream Straightening Effects on Flood-Runoff Characteristics. *American Society of Agricultural and Biological Engineers, 15*(1), 94-98.https://doi.org/10.13031/2013.37839.

**Table 3:** River sinuosity at different sections over time

| Segment | 1972 | 1981 | 1989 | 1995 | 2008 | 2020 | Total Change |
|---|---|---|---|---|---|---|---|
| Entire | 1.89 | 1.89 | 1.88 | 1.81 | 1.82 | 1.83 | -0.06 |
| A | 1.71 | 1.72 | 1.73 | 1.73 | 1.76 | 1.77 | 0.06 |
| B | 2.10 | 2.10 | 2.03 | 2.03 | 2.05 | 2.05 | -0.05 |
| C | 1.57 | 1.56 | 1.58 | 1.57 | 1.57 | 1.57 | 0.00 |
| D | 1.65 | 1.66 | 1.62 | 1.60 | 1.63 | 1.63 | -0.02 |
| E | 1.58 | 1.58 | 1.56 | 1.55 | 1.57 | 1.58 | 0.01 |
| F | 1.73 | 1.73 | 1.73 | 1.73 | 1.76 | 1.77 | 0.04 |
| G | 2.11 | 2.10 | 2.13 | 1.49 | 1.38 | 1.40 | -0.71 |
| H | 1.69 | 1.69 | 1.70 | 1.68 | 1.71 | 1.71 | 0.02 |

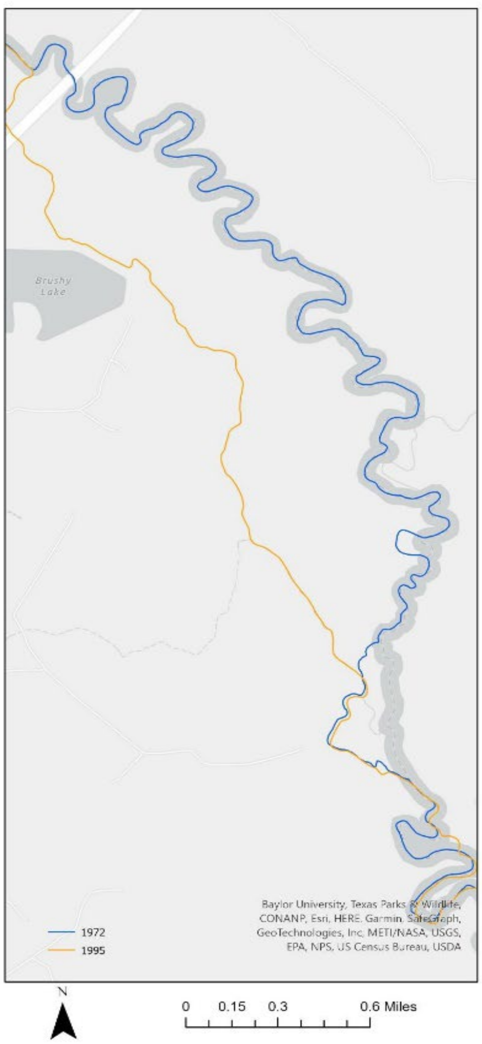



**Figure 4:** Westward shift of the Navasota River south of State Highway 21. Both channels are present in 1972, however, over time the western (yellow) channel has become more pronounced, while the eastern (blue) channel shows signs of only carrying water during high flow rainfall events.

**Figure 5:** Temporal evolution of river length anomaly (brown) and sinuosity (blue) at different segments