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90 Years of Erosion and Deposition on the Trinity River, Dallas, Texas

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ABSTRACT

The City of Dallas has initiated a design to realign and naturalize an eight mile reach of the Trinity River near downtown that has been relocated, channelized, and straightened over the past 90 years. As part of the channel realignment design process for the Trinity River Corridor project, we conducted historical geomorphic analyses, field measurements of bank erosion and floodplain sediment deposition, and numerical modeling of hydraulic and sediment transport characteristics of the river. Our analyses of bank erosion and lateral channel migration showed limited, localized erosion and relatively low rates of lateral migration. We also determined that the channel has maintained a dynamic equilibrium through a process of localized bank erosion and "repair." Field measurements of deposition rates and topographic analysis of historical floodplain sedimentation showed that there has been limited systematic deposition on the floodplain. These findings provided a critical foundation for the design of the Trinity River Corridor project.

Keywords: bank erosion, channel migration, flood protection, floodplain deposition, Trinity River

INTRODUCTION

The Trinity River in Dallas, Texas has experienced extensive change over the past century. The most rapid and widespread changes occurred during the construction of the original Dallas Floodway project in the late 1920s and the United States Army Corps of Engineers (USACE) reconstruction of the floodway in the 1950s. The proposed channel realignment element of the Trinity River Corridor Project will result in perhaps the most significant change to the Trinity River since the 1920s-era Dallas Floodway project. The Balanced Vision Plan for the Trinity River Corridor (City of Dallas, 2003) calls for restoration of channel meanders, creation of a mid-channel island, alterations to channel geometry, and general enhancement of aquatic and riparian habitat throughout the corridor, in addition to a wide variety of recreational, aesthetic, transportation, and other elements. In this paper we describe analyses of historical channel change, bank erosion and repair, bed material composition, and floodplain sedimentation analyses used to guide design of the river channel realignment element of the Trinity River Corridor Project.

HYDROLOGY AND GEOLOGY

The project area begins just downstream of the confluence of the Elm and West Forks of the Trinity River where the contributing watershed area is approximately 6,100 square miles (Figure 1). The climate is characterized as humid subtropical with hot summers and relatively mild winters. Average annual rainfall in the watershed is between 30 and 40 inches, and much of the annual precipitation occurs during thunderstorms, with occasional intense storms in the late spring and early summer. Discharge and stage in the Dallas change rapidly in response to precipitation in the urbanized watershed.

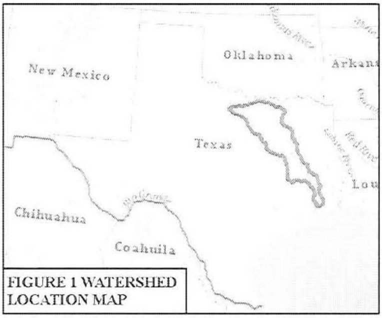

FIGURE 1 WATERSHED LOCATION MAP

Peak floods influenced many facets of the final channel realignment design, including erosion control measures, riparian vegetation planting schemes, recreational features, and operation and maintenance requirements. The largest annual peak flood in the Trinity River (184,000 ft^3/sec) occurred on May 26, 1908, during which the river was over 2 miles wide between West Dallas and downtown Dallas (Furlong et al., 2003). The smallest annual peak flood (4,540 ft^3/sec) occurred on May 28, 1978. Table 1 summarizes results from the flood frequency analysis conducted for the Trinity River at USGS gage #0805700 for the entire period of record as well as both pre- and post-1955 periods to illustrate the influence of upstream reservoirs on peak flows.

Table 1. Flood Frequency Analysis Results USGS Gage #08057000 (Trinity River at Dallas) for the period of record 1903 to 2007

Flood Flow Return Period (Years)	Complete Data Set Flood Discharge (ft^3/sec)	Complete Data Set Water Surface Elevation (ft)	Pre-1960 Flood Discharge (ft^3/sec)	Pre-1960 Water Surface Elevation (ft)	Post-1960 Flood Discharge (ft^3/sec)	Post-1960 Water Surface Elevation (ft)
1	3752	390.8	3122	389.7	4891	392.5
1.4	13307	400.2	12882	399.9	14320	400.8
1.5	14805	401.1	14517	401.0	15711	401.7
2	20845	404.4	21292	404.6	20988	404.4
5	41103	411.7	45497	412.9	36060	410.2
10	58937	416.2	68055	418.1	47247	413.4
20	79594	420.3	95188	422.9	58678	416.2
50	111970	425.4	139317	428.9	74370	419.4
100	140836	429.1	179939	433.3	86751	421.6
200	173957	432.7	227725	437.6	99605	423.6
500	225073	437.4	303474	443.2	117347	426.1

Geology

The project area lies in the Blackland Prairies geologic province which is characterized by low rolling terrain with chalk and marl bedrock formations. Upstream of the project area, the Trinity River drains the Grand Prairie province's low "stair-step" hills and flat plains underlain by calcerous and sandy bedrock. The uppermost reaches of the Trinity River watershed are in the North Central Plains province characterized by low north-south ridges with limestone, sandstone, and shale bedrock. The channel and floodway in the Project area are composed of alluvium consisting of sand, mud, and sparse gravel (Dallas Geological Society 1965 and Bureau of Economic Geology 1992, 1996, and 1999).

HISTORICAL CHANNEL ALIGNMENT CHANGE

To illustrate changes in channel alignment, we obtained, rectified, and analyzed historical topographic maps in a Geographic Information System (GIS). Figure 2 shows the 1891, 1920, and 1959 historical channel centerlines. The major change in the channel alignment between 1891 and 1920 is the channel confinement and secondary channel disconnection that occurred when a levee was constructed between the West and Elm Forks of the Trinity River. Between 1920 and 1959, the channel was straightened and the confluence of the Elm and West Forks was relocated 3.5 miles to the west (Furlong et al., 2003). Remnants of the old channel remain and connect tributaries to the pump stations that pump stormwater discharge from the tributaries into the Dallas Floodway. Within the floodway, the channel alignment from the 1928 project changed only slightly during reconstruction of the floodway from 1953 to 1960.

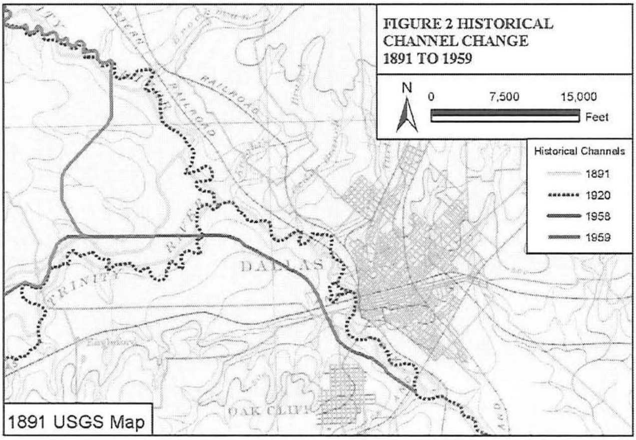

FIGURE 2 HISTORICAL CHANNEL CHANGE 1891 TO 1959

Bank Erosion

Initial observations from field reconnaissance in the floodway and review of aerial photographs identified bank erosion as an important channel process influencing long-term channel form. To determine the extent of bank erosion along the channel banks in the project area, we analyzed the 2005 aerial photographs in GIS and digitized areas of bank erosion as either "fresh" (an erosional surface that had not been revegetated), or "vegetated" (an erosional surface that had been revegetated). The 2005 aerial photographs were taken during a year of high peak flows (25,600 ft^3/sec on June 12, 2004, and 23,000 ft^3/sec on July, 30, 2004), and many of the erosion sites observed in the aerial photographs were likely impacted by these high flows. Peak daily flows of 35,700 ft^3/sec (March 20, 2006), 35,700 ft^3/sec (June 28, 2007), and 25,400 (March 19, 2008) occurred between the date of the aerial photos and the field verification. Because these high-flow events could have created additional erosion sites or scoured vegetation from channel banks, we field verified mapped erosion areas on aerial photographs and field maps and later digitized these observations in GIS.

We measured significant areas of bank erosion downstream of any deviation in channel alignment, and at the downstream banks of stormwater outfall channels. Eroded banks had an average erosion depth of approximately 10 ft and a linear extent between 10 and 20 ft. The average volume of active bank erosion per site was 5,967 ft^3 and a total of 35,2674 ft^3 of bank material had been removed from the active erosion sites upstream of Sylvan Avenue (Figure 3).

FIGURE 3 INFRASTRUCTURE AND USGS GAGE LOCATIONS

We observed a pattern of bank erosion and repair by vegetation recruitment and deposition throughout the project area. At channel bends, pump station outfall channels, and flow obstructions such as bridge piers or large woody debris, strong eddies scour the bank and cause bank erosion along the existing channel. Pore pressure from rapidly receding peak flows may also cause bank failures and contribute to bank erosion along the existing channel. However, we observed widespread sediment deposition along eroded banks and subsequent vegetation recruitment and growth (which further decreases the velocity of flow over the eroded surface and increases sediment deposition rates). This phenomena appears to contribute significantly to the low lateral migration rates we measured by comparing historical channel margins. Figure 4 is a conceptual model that depicts the cycle of bank erosion and repair in the project area, and Table 2 is a summary of lateral channel migration rates in the project area. While a detailed investigation of channel erosion was not conducted in the Great Trinity Forest downstream of the project area, similar bank erosion and repair was observed along the channel in that reach.

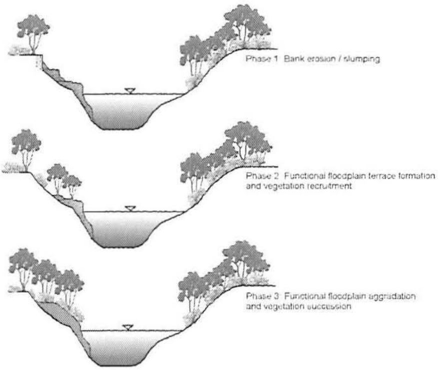

Figure 4: Conceptual model of bank erosion and natural "repair" through sediment deposition and revegetation

Table 2. Reach Average Migration Rate and Maximum and Minimum Bank Migration

Reach	**Period of Analysis**	**Average Migration (ft)**		**Average Migration Rate (ft/yr)**		**Maximum Migration Rate (ft/yr)**		**Minimum Migration Rate (ft/yr)**	
		Left Bank	**Right Bank**	**Left Bank**	**Right Bank**	**Left Bank**	**Right Bank**	**Left Bank**	**Right Bank**
Confluence to 1,500 ft Upstream of Hampton	1930-2005	19	65	0.25	0.87	0.56	2.13	0.01	0.17
1,500 ft Upstream of Hampton to Sylvan Street Bridge	1965-2005	26	21	0.64	0.52	1.88	2.58	0.10	0.05
Sylvan Street Bridge to Houston Street Viaduct	1965-2005	55	35	1.37	0.87	3.20	2.93	0.03	0.00
Houston Street Viaduct to DART Bridge (Multistage Channel)	1965-1984	22	26	1.14	1.35	3.95	3.58	0.05	0.16
DART Bridge to Highway 45 (Great Trinity Forest)	1965-2005	32	37	0.80	0.93	2.28	2.60	0.03	0.03

FLOODPLAIN SEDIMENTATION

Sediment transport

The Trinity River has a high suspended sediment concentration of approximately 920 milligrams per liter (mg/L) at the bankfull flow of 13,000 ft^3/sec, and a sediment transport rate of over 28,000 tons/day at that same flow. Overbank flows deposit significant quantities of silt in floodplain depressions, potentially requiring regular sediment management on trails, road surfaces, and other Project design features. There have been no significant channel migration problems documented in the last 50 years within the Project reach that would indicate that there has been a net loss of sediment from the Project reach transported either by normal daily flows or by flood events. The apparent stability of the channel in the Project reach and minor changes in the overbank topography in undisturbed areas also indicate that any sediment being supplied from the Dallas Floodway area is being transported through the project reach without significant deposition.

Sediment Traps

Because the suspended sediment load in the Trinity River is relatively high, an understanding of the rate of sediment deposition on the floodplain is critical to the design of and planning for Project features and maintenance on the floodplain. We placed sediment traps, consisting of 1.5 ft square artificial turf patches, along transects on the active floodplain to quantify sediment deposition. This method has been shown to be the most cost-effective means of riparian sedimentation analysis in a recent study of methods for quantifying contemporary sediment deposition within water bodies and their margins (Steiger et al., 2003). We established four cross sections along the Project reach with two to five sediment traps placed on the floodplain on each side of the channel (Figure 5). We deployed the sediment traps in the following configuration: one sediment trap at the top of bank floodplain terrace, one sediment trap proximate to the levee toe, and up to three sediment traps on the floodplain.

We revisited sediment traps after flows overtopped the channel banks (typically flows greater than approximately 13,000 ft^3/sec) and measured average sediment deposition in quadrants on each trap. Two overbank flows recorded at the USGS Trinity River at Dallas, Texas gage (08057000) occurred on April 25, 2008 (14,300 ft^3/sec) and June 12, 2009 (30,700 ft^3/sec). The April 25, 2008 peak discharge overtopped the channel banks but did not inundate the entire floodplain. The larger June 12, 2009 peak discharge resulted in higher flows on the floodplain. We checked the sediment traps in the field on May 2, 2008, after the 14,300 ft^3/sec discharge event. Because the peak discharge did not completely inundate the floodplain, the sediment traps at the upstream most transect near the confluence and the sediment traps on the west/right bank near Sylvan Bridge were not checked. Six sediment traps were not located. Of the thirteen sediment traps that were relocated, only one had measurable sediment after the April 25, 2008 event. Sediment trap 1:2 is located on a terrace between the low flow channel and the floodplain on the Corinth Transect and 127.6 in^3 of sediment covered 2/3 of the sediment trap. The remaining twelve sediment traps had an immeasurable dusting of silt.

We checked the sediment traps a second time after the June 12, 2009, 30,700 ft^3/sec event. This event inundated the floodplain from the downstream most transect near the Corinth Street Bridge to the upstream most transect near the confluence. Of the 29 sediment traps deployed, 24 were relocated. Sediment trap 1:2 was deployed on a low bench and may have been washed away or buried with sediment. Sediment traps 3:5, 3:6, and 3:7, were not located. Of the 24 relocated sediment traps, 14 were covered with a measurable amount of sediment. The remaining ten sediment traps only contained an immeasurable dusting of sediment that was too small to measure. The volume of sediment deposited on the sediment traps ranged from 0.03 in^3 to 5.58 in^3.

To illustrate sediment deposition patterns on the floodplain, we plotted the locations of the sediment traps on a base map with graduated symbols and scaled the symbol sizes proportional the volume of deposited sediment. Figure 5 shows the volume (in cubic inches) of deposited sediment divided into seven categories (0-0.01, 0.02-0.10, 0.11-0.50, 0.51-1.00, 1.01-2.50, 2.51-6.00, 6.01-127.56). Sediment deposition was concentrated at the top of bank of at least one bank of the active channel at each transect. Sediment deposition also occurred close to the toe of the levee on the right/west bank at the Confluence, Sylvan, and Corinth transects. The largest amount of deposited sediment was observed on the low flow bench at the Corinth transect.

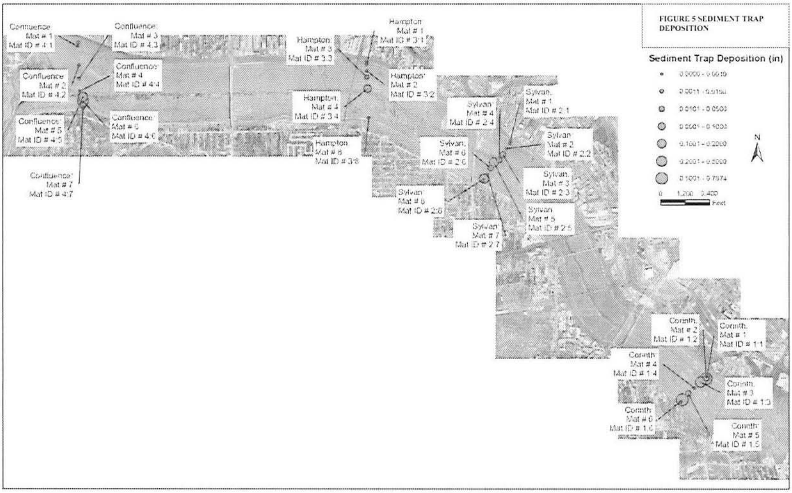
FIGURE 5 SEDIMENT TRAP DEPOSITION

We compared observed sediment deposition downstream of Westmoreland to the existing conditions sediment transport model results for a 24 hour flow at 25,000 ft^3/sec to validate model performance. Figure 6 shows the location of the sediment traps for the downstream three transects and the sediment transport modeling results downstream of Westmoreland. In general, the model shows deposition at the channel margins, near the toe of the levees, downstream of outfall channels, and across the floodplain immediately downstream of Westmoreland. The existing conditions sediment transport model was not calibrated at high flows for sediment deposition and thus the results in Figure 6 are best interpreted as depositional patterns and not actual depths listed in the legend. The depths presented are likely high and may reflect a modeled settling velocity that is too high. However, the patterns of the modeling results correlate with the general patterns observed from the sediment traps. Deposition across the floodplain in the Trinity River Corridor is likely much less than observations at select sites, such as the Sylvan parking lot and boat launch, suggest. Of the 24 relocated sediment traps after the 30,700 ft^3/sec event, only 6 sediment traps collected more than 1 in^3 of sediment. Large volumes of sediment deposition at sites such as the Sylvan parking lot and boat launch are likely the result of local hydraulic conditions that create depositional environments and are not characteristic of the entire floodplain.

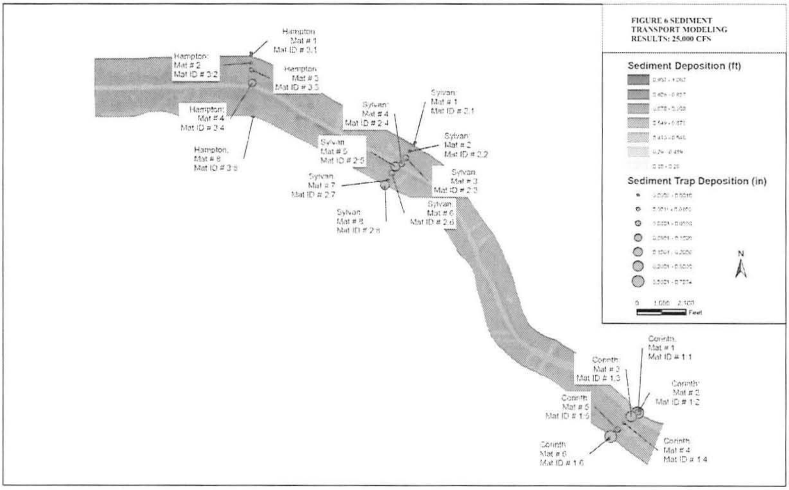

FIGURE 6 SEDIMENT TRANSPORT MODELING RESULTS: 25,000 CFS

CONCLUSION

There is general consensus among river and riparian enhancement design practitioners that to be sustainable, river corridor designs must be founded on fluvial geomorphic principles. We used the geomorphic observations and analyses of erosion and deposition described above to inform the river realignment and riparian enhancement design for the Trinity River. During the design process, we considered geomorphic principles to determine data requirements, and then collected additional geomorphic data on sediment characteristics and transport, hydraulic conditions, and channel bed and bank features. Based on the assessment of geomorphic data, we developed a sustainable river realignment and enhancement design that includes a meandering planform that is similar to pre-disturbance conditions. Based on the low bank erosion and floodplain sediment deposition rates determined through the analyses described above, we expect the proposed river and riparian enhancements to be dynamically stable during the design life of the project

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