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REDUCED CHANNEL CONVEYANCE ON THE WICHITA RIVER AT WICHITA FALLS, TEXAS, 1900-2009

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Recent floods on the Wichita River at Wichita Falls, Texas, have reached higher stages compared to historical floods of similar magnitude discharges. The U.S. Geological Survey (USGS) has operated streamflow-gaging station 07312500 Wichita River at Wichita Falls, Tex., since 1938 and flood measurements near the location of the present gage were first made in 1900. Floods recorded in 2007 and 2008 at this gaging station, including the record flood of June 30, 2007, reached higher stages compared to historical floods before 1972 of similar peak discharges. For flood measurements made at stages of more than 18 feet, peak stages were about 1 to 3 feet higher compared to peak stages of similar peak discharges measured before 1972. Flood measurements made at stages of more than 18 feet also indicate a decrease in the measured mean velocity from about 3.5 to about 2.0 feet per second from 1941 to 2008. The increase in stage and decrease in streamflow velocity for similar magnitude floods indicates channel conveyance has decreased over time. A study to investigate the causes of reduced channel conveyance in the Wichita River reach from Loop 11 downstream to River Road in Wichita Falls was done by the USGS in cooperation with the City of Wichita Falls. Historical photographs indicate substantial growth of riparian vegetation downstream from Loop 11 between 1950 and 2009. Aerial photographs taken between 1950 and 2008 also indicate an increase in riparian vegetation. Twenty-five channel cross sections were surveyed by the USGS in this reach in 2009. These cross sections were located at bridge crossings or collocated with channel cross sections previously surveyed in 1986 for use in a floodplain mapping study by the Federal Emergency Management Agency. Four channel cross sections 3,400 to 11,900 feet downstream from Martin Luther King Jr. Boulevard indicate narrowing of the channel. The remaining channel cross sections surveyed in 2009 by the USGS compared favorably with cross sections surveyed in 1986 for the Federal Emergency Management Agency, with no substantial differences noted. Comparison of channel cross sections surveyed in 2009 to those from historic bridge plans indicate no change in cross section has occurred at most of the bridges from Loop 11 downstream to River Road in Wichita Falls, except for obstructions noted at the Scott Avenue bridge and Martin Luther King Jr. bridge. Although obstructions in the channel at these bridges only partially block flow, they could also be contributing to reduced channel conveyance. Step-backwater profiles were used by the USGS to verify channel roughness. The main channel roughness coefficients (Manning's n values) from 2009 surveys were virtually unchanged from those used in a 1991 hydraulic model done for the Federal Emergency Management Agency. The average overbank roughness coefficient (Manning's n value) was 0.15, more than double the value of 0.06 used in the 1991 hydraulic model. Increased overbank vegetation has resulted in higher stages conveying the same amount of discharge, particularly for discharges more than 4,000 cubic feet per second.

INTRODUCTION

In cooperation with the City of Wichita Falls, the U.S. Geological Survey (USGS) investigated the reductions in channel conveyance observed during floods at streamflow gaging-station 07312500 Wichita River at Wichita Falls, Tex. (the Loop 11 gage) in 2007 and 2008 and possible causes for the reductions in channel conveyance. Extreme flooding occurred on the Wichita River on June 30, 2007, inundating 167 homes in Wichita Falls. Continuous records of stage and discharge have been made at USGS streamflow-gaging station 07312500 Wichita River at Wichita Falls, Tex. (hereinafter the Loop 11 gage) since 1938. Stage is elevation referenced to an arbitrary datum (Langbein and Isseri, 1960, p.10; Rantz and others, 1982, p. 23). The datum of the Loop 11 gage is 924.26 ft above National Geodetic Vertical Datum of 1929. Discharge measurements at the Loop 11 gage location have been made sporadically beginning in 1900 and routinely since 1938. A record stage (since at least 1938) of 24.40 feet (ft) with a peak discharge of 10,100 cubic feet per second (ft^3/s) was recorded at the Loop 11 gage (Figure 1) on June 30, 2007. On August 19, 2008, flood stages of more than 20 ft (20.51 ft with a peak discharge of 6,940 ft^3/s) were again recorded at the Loop 11 gage. The floods in June 2007 and August 2008 reached higher stages compared to previous floods of similar peak discharge amounts, indicating channel conveyance was reduced in 2007 and 2008 compared to the channel conveyance during previous floods.

Discharge measurements made at the Loop 11 gage provide a detailed history of channel cross-section changes in the Wichita River at Loop 11. Since 1938, more than 1,000 discharge measurements have been made at the Loop 11 gage. These measurements typically have between 25 and 35 depth observations, from which a detailed cross section is defined. Comparison of these depth observations for similar discharge measurements over time provides insight to possible aggradation or degradation of the channel.

PURPOSE AND SCOPE

Using data from 1900 through 2009, this report documents and evaluates possible causes of reduced channel conveyance in a reach of the Wichita River from Loop 11 downstream to the bridge at River Road in Wichita Falls, Tex. (Figure 1). Included in the report are (1) a review of discharge measurement data from the Loop 11 gage; (2) interpretation of historical oblique and aerial photographs of the channel; (3) documentation of channel changes from historical cross sections at bridge locations and channel cross sections; and (4) hydraulic analysis of cross sections surveyed in 1986 and in 2009.

APPROACH

More than 100 years of discharge measurement data are available for the Loop 11 gage. These data range from miscellaneous measurements made beginning in 1900 to continuous data available since March 1938. Cross sections from these discharge measurements were analyzed to determine if physical changes in the channel have occurred over time.

Aerial photographs taken during 1955–95 were analyzed to determine if any notable encroachment or channel changes were visible in the reach downstream from Loop 11. Aerial photographs from 1955, 1961, 1968, 1971, 1976, 1978, 1979, 1991, and 1995 were examined for evidence of development in the floodplain. The scale of these photos ranged from 1:12,800 to 1:32,000.

Since 1950, oblique photographs have been taken periodically by personnel of the USGS of the Wichita River channel at the Loop 11 gage. These photos were analyzed to determine if an increase

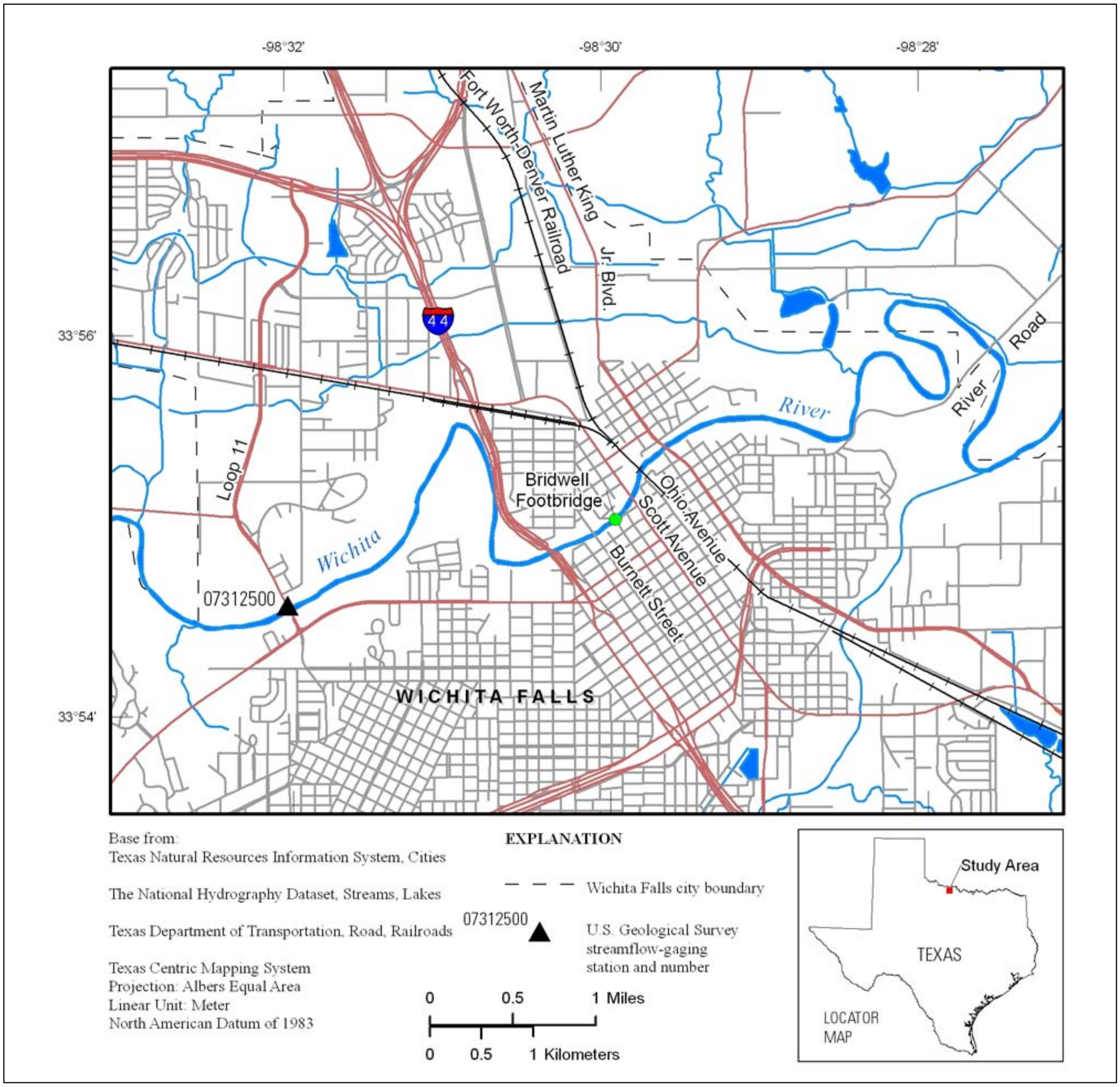

Figure 1. Location of the study area.

in vegetation in the channel or overbank in the reach of the river near the gage could be contributing to the elevated flood stages in 2007 and 2008 compared to historical flood stages for similar flood discharges.

A reach of about 5 miles (mi) on the Wichita River from Loop 11 downstream to River Road in Wichita Falls was selected for hydraulic analysis. Cross sections surveyed in 2009 were compared to historical cross sections obtained from as-built bridge plans and from a HEC-2 model done in 1991 for the Federal Emergency Management Agency (FEMA) (Cindy Mosier, Halff Associates, written commun., 2009), hereinafter the 1991 FEMA HEC-2 model. Cross sections for the 1991 FEMA HEC-2 model were obtained by photogrammetry in 1986 (Koogle and Pouls Engineering, 1986; Federal Emergency Management Agency, 2000). The floodplain cross-section data and channel roughness were obtained from the 1991 FEMA HEC-2 model input file. Cross sections for bridge openings between Loop 11 and Martin Luther King Jr. Boulevard were obtained from as-built plans. Bridge crossings used in the model in the 5-mi reach of the Wichita

River downstream from and including the Loop 11 bridge include Interstate Highway 44, Burnett Street, Bridwell footbridge, Scott Avenue, the Fort Worth-Denver Railroad, Ohio Avenue, Martin Luther King Jr. Boulevard, and River Road (Figure 1).

Channel roughness coefficients (Manning's n values) were estimated (Barnes, 1967) for several cross sections surveyed in 2009 and compared with roughness coefficients estimated for the 1991 FEMA HEC-2 model. Long-term changes in channel conveyance caused by increases in channel roughness were assessed on the basis of changes in channel geometry and channel and overbank roughness.). In contrast, mean velocities of only about 2.1 ft/s were recorded during the large floods in 2007 and 2008.

More than 1,000 discharge measurements have been made at the Loop 11 gage (U.S. Geological Survey, 2009), and these data can be evaluated to help determine hydraulic changes that have occurred over time in the Wichita River channel (Figure 2). All discharge measurement data used for this analysis are stored in the USGS National Water Information System (NWIS) database online (U.S. Geological Survey, 2009). Width, area, and mean velocity for 13 flood discharge measurements were obtained from NWIS. These discharge measurements indicate no substantial aggradation has occurred on the channel bed or banks near the Loop 11 gage. Aggradation could explain an increase in stage for the same volume of discharge (Heitmuller and Greene, 2009). Discharge measurements for stages of more than 18 ft from 1938 to 2008 indicate a decrease in the measured mean velocity from about 3.5 ft/s in 1941 to about 2.0 ft/s in 2008. This reduction in velocity was accompanied by an increase in stage to convey similar discharges through the system.

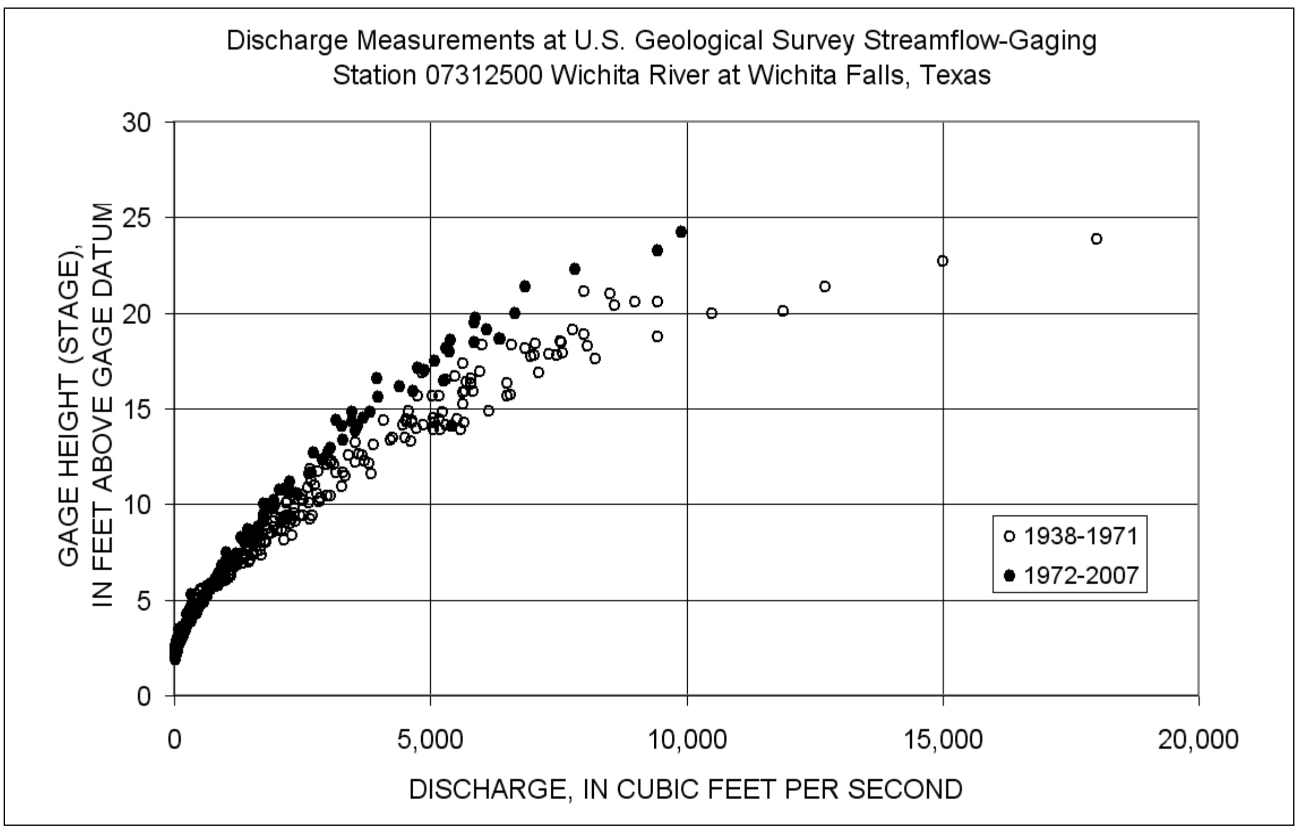

Figure 2. Changes in the stage-discharge rating indicated by measurements at U.S. Geological Survey streamflow-gaging station 07312500 Wichita River at Wichita Falls, Texas (Loop 11 gage) (U.S. Geological Survey, 2009).

A record peak stage (since 1938 when stage records were first kept) of 24.40 ft with an associated peak discharge of 10,100 ft^3/s was recorded on June 30, 2007, at the Loop 11 gage (Figure 1). On August 19, 2008, flood stages again peaked at more than 20 ft at the Loop 11 gage, cresting at 20.51 ft with an associated peak discharge of 6,940 ft^3/s. Peak flood stages measured for the peak streamflows in 2007 and 2008 were higher compared to the peak flood stages measured for similar magnitude floods in previous years. In 1955, 1957, and 1961, annual peak annual discharges ranging from 7,200 to 7,640 ft^3/s were recorded with peak stages ranging from 17.93 to

18.27 ft. Although the annual peak discharges of 1955, 1957, and 1961 were all slightly larger compared to the August 2008 flood of 6,940 ft^3/s, the peak stages associated with the floods in 1955, 1957, and 1961 were 2.24 to 2.58 ft lower compared to the peak stage of 20.51 ft associated with the August 2008 flood.

Annual peak discharges measured between 1938 and 2008 and miscellaneous flood measurements between 1900 and 1936 at the location of the Loop 11 gage (Figure 3) indicate the magnitude of annual peak discharges has decreased since the Lake Kemp and Diversion Reservoirs were completed on the Wichita River about 40 mi west of Wichita Falls in the mid-1920s. The two largest annual peak discharges since these two reservoirs were built measured 15,500 and 17,800 ft^3/s in June and October of 1941, representing water years 1941 and 1942, respectively. Before 1941, miscellaneous flood measurements of 50,000, 37,440, and 16,740 ft^3/s were recorded at the current (2009) location of the Loop 11 gage in 1915, 1901, and 1900, respectively. Prior to the July 2007 flood, which crested at 10,100 ft^3/s, none of the annual peak discharges since 1943 had exceeded 10,000 ft^3/s.

Aerial photographs taken in 1953, 1968, 1979, 1991, 2006, and 2008 were obtained from the Texas Natural Resources Information System (Tom Roehrig, Texas Natural Resources Information

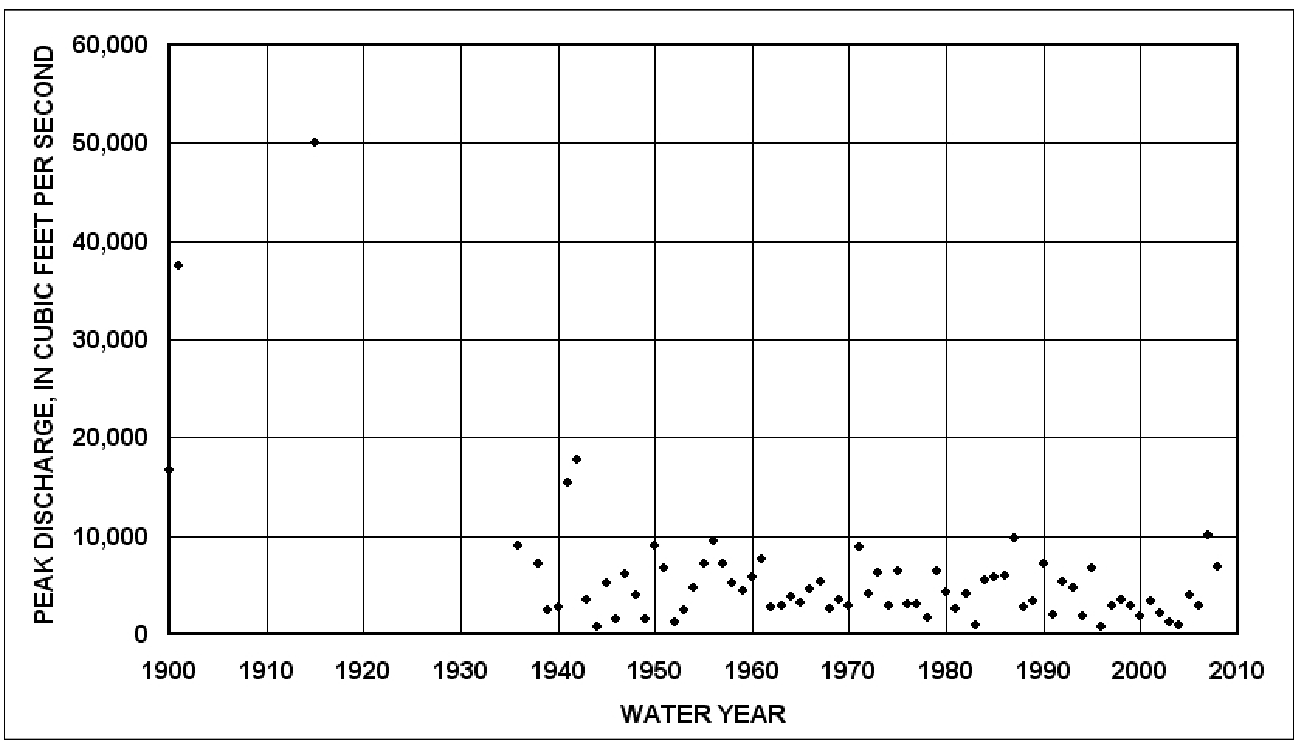

Figure 3. Annual peak discharges at U.S. Geological Survey gaging station 07312500, Wichita River at Wichita Falls, Texas (Loop 11 gage) (U.S. Geological Survey, 2009).

System, written commun., 2009). The goal of comparing aerial photographs taken between 1953 and 2008 was to discern temporal changes in features of the Wichita River channel including bedforms, meander migrations and lateral channel stability, riparian vegetation density, and possible channel encroachment. Notable changes within the study reach between 1953 and 2008 include a general increase in vegetation density in the riparian area along the Wichita River channel. The aerial photographs indicate an increase in vegetation along the banks and in the floodplain at Lucy Park, 1 to 2 mi downstream from Loop 11, between 1953 and 1991.

When reservoirs are constructed, riparian growth in downstream reaches often increases (see, for example, Shafroth and others, 2002; Heitmuller and Greene, 2009). Oblique photographs of the channel taken at the gaging station provide valuable information about changes in the channel shape and vegetative cover. Oblique photographs taken near the Loop 11 gage were compiled for 1950, 1961, 1975, and 2009 (Figure 4). The photographs indicate a substantial amount of riparian vegetation growth occurred between 1950 and 2009.

Channel conveyance at the nine bridges on Wichita River in the reach from Loop 11 to River Road was evaluated. For most bridges, comparison of the 2009 surveys of the channels and bridge openings at each bridge to those from bridge plans when the structures were first built indicates no change in cross section. Obstructions were noted at the downstream side of the Scott Avenue bridge (south span) and at the Martin Luther King Jr. bridge (north span). The obstructions only partially block flow but could reduce channel conveyance during floods.

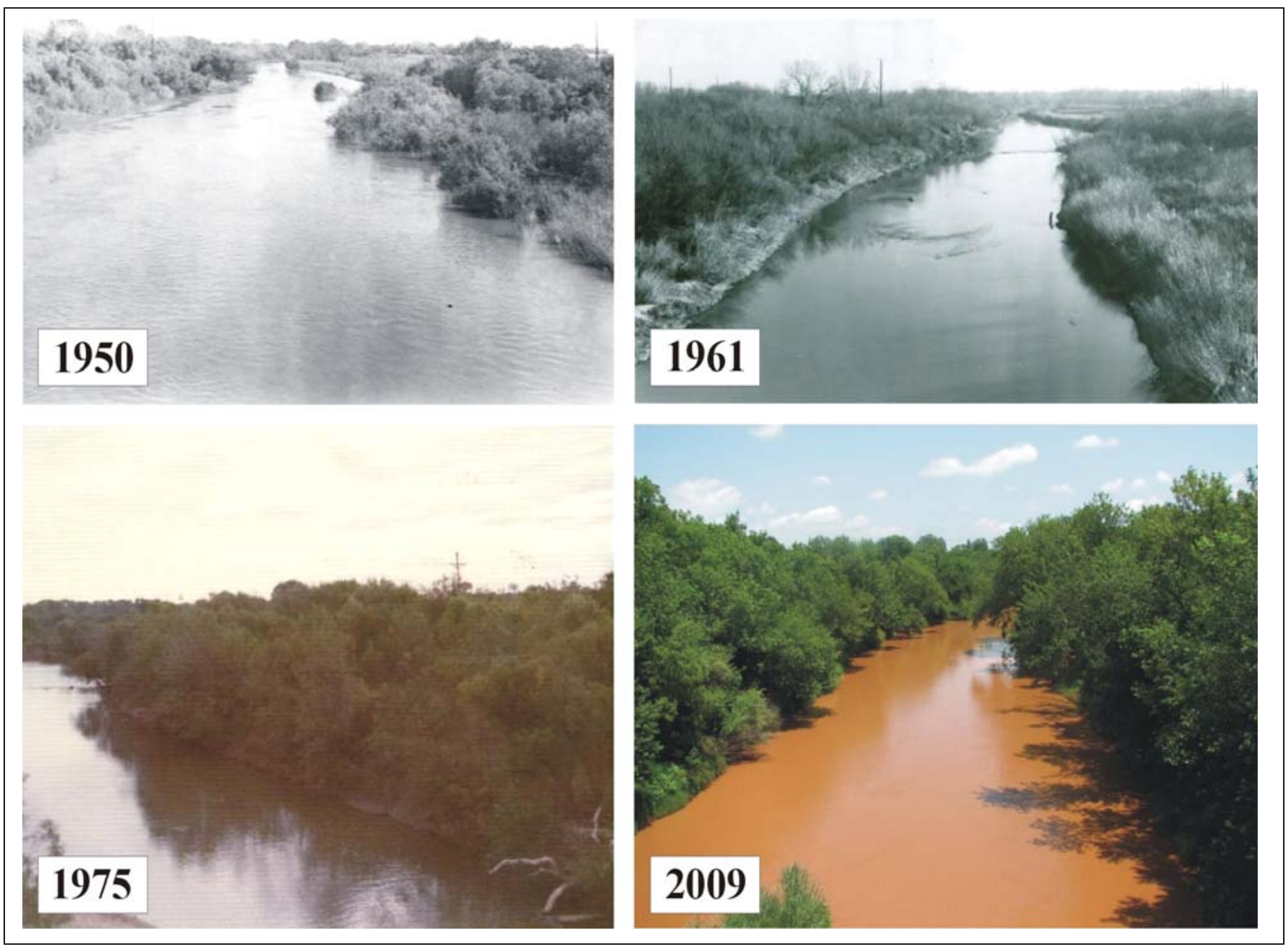

Figure 4. Oblique photographs taken looking downstream from U.S. Geological Survey streamflow-gaging station 07312500 Wichita River at Wichita Falls, Texas (Loop 11 gage).

Earth fill placed on the south overbank at the Scott Avenue bridge (the tree-covered mound under the bridge, extending to the walkway) (Figure 5) reduces channel conveyance during floods. The channel cross section from the 1929 plans compared to a cross section surveyed in 2009 under the Scott Avenue bridge indicates a decrease in the cross-sectional area from 1929 to 2009 and subsequently a reduced cross-section conveyance during floods. A long-term resident of the area indicated that a substantial amount of fill also was deposited on the north bank of the channel downstream from the Scott Avenue bridge in the early 1960s (Peter Pullin, oral commun., June 23, 2009).

The Martin Luther King Jr. bridge has an obstruction near the north span at the downstream side of the bridge from fill on the north bank of the channel. Historic plans (Davis Powell, City of Wichita Falls Engineering Section, written commun., June 10, 2009) indicate buildings were erected on this fill as early as 1950 but removed in later years. The earliest available cross section data are from the 1986 photogrammetric survey (Federal Emergency Management Agency, 2000). The obstruction downstream from the bridge on the north side of the channel was evident at the time this photogrammetric survey was completed.

Twenty-five channel cross sections were surveyed in 2009 on the Wichita River from the Loop 11 bridge to the River Road bridge. These cross sections were located at bridge crossings or at the same locations where cross sections were surveyed for the 1986 photogrammetric survey (Federal Emergency Management Agency, 2000). Four channel cross sections located 3,400 to 11,900 ft downstream from Martin Luther King Jr. Boulevard indicate narrowing of the channel. The remaining channel cross sections surveyed by the USGS in 2009 compared favorably with cross sections from the 1986 FEMA photogrammetric survey, with no substantial differences

Figure 5. Photograph looking downstream through the Scott Avenue bridge, from the south bank of the channel, February 23, 2009.

noted. Cross sections at the Loop 11 bridge are shown in Figure 6. Upstream from Martin Luther King Jr. Boulevard to the Loop 11 bridge, the cross section of the Wichita River channel appears stable.

Using step-backwater profiles, the USGS completed a hydraulic analysis in 2009 using the U.S. Army Corps of Engineers Hydrologic Engineering Center River Analysis System model HEC-RAS (U.S. Army Corps of Engineers, 2010), including an analysis of the channel and overbank roughness (Manning's n values). The main channel roughness coefficients from the 2009 surveys were unchanged from those used in the 1991 FEMA HEC-2 model (average Manning's n = 0.04). However, calibrated overbank roughness (average Manning's n = 0.15) for the 2009 step-backwater profiles is more than double the roughness (average Manning's n = 0.06) used in the 1991 HEC-2 model. This increase in overbank roughness is substantiated by the increase in riparian vegetation growth on channel overbanks. The loss in cross-section conveyance resulting from increased overbank roughness was computed for the 25 cross sections (Figure 7). Figure 7 shows that compared to results from the 1991 FEMA HEC-2 model, higher elevations representing larger streamflow stages were needed in the 2009 USGS HEC-RAS model to convey the same volume of water. This finding corroborates the evidence of changes in stage-discharge relations (Figure 2).

SUMMARY

In cooperation with the City of Wichita Falls, the U.S. Geological Survey (USGS) investigated the reductions in channel conveyance observed during floods at streamflow gaging-station 07312500 Wichita River at Wichita Falls, Tex. (the Loop 11 gage) in 2007 and 2008 and possible causes for the reductions in channel conveyance. The Wichita River reached flood elevations

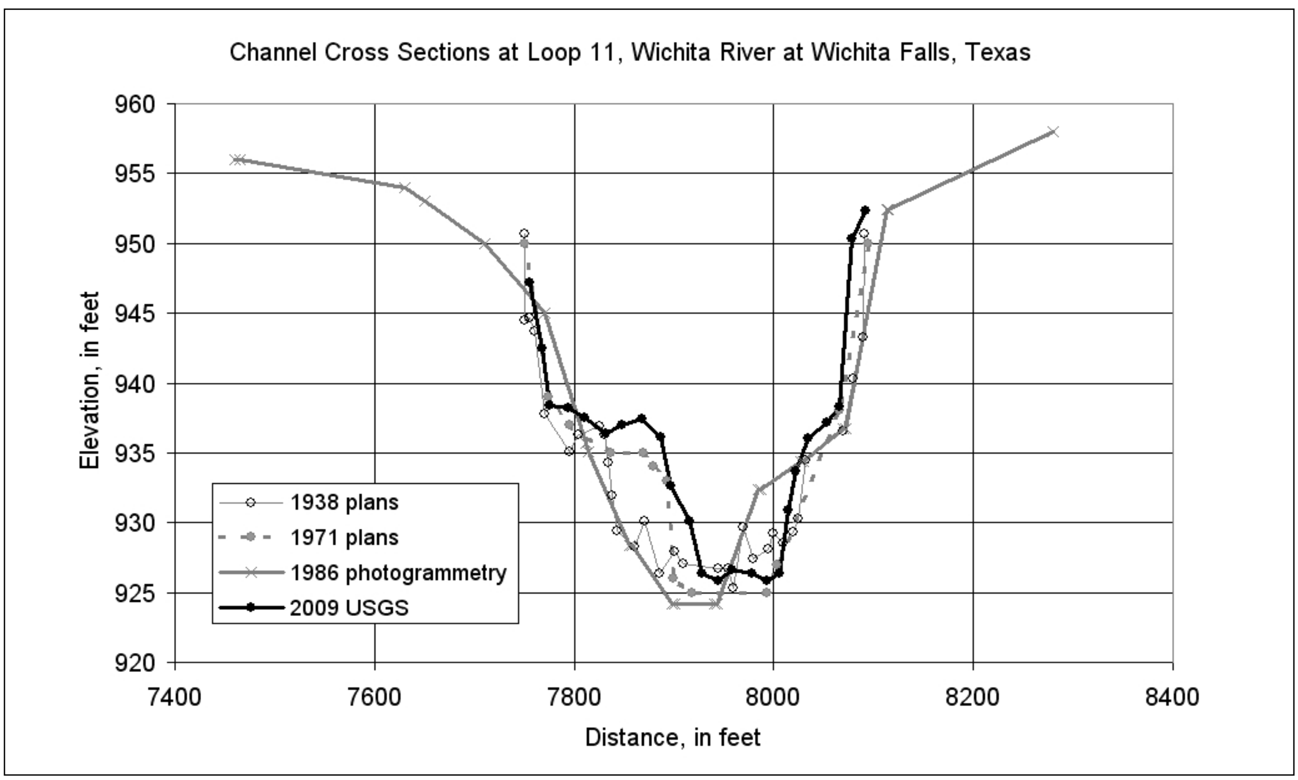

Figure 6. Channel cross sections at the Wichita River at U.S. Geological Survey streamflow-gaging station 07312500 Wichita River at Wichita Falls, Texas (Loop 11 gage) (U.S. Geological Survey, 2009). Datum of gage is 924.26 ft above National Geodetic Vertical Datum of 1929.

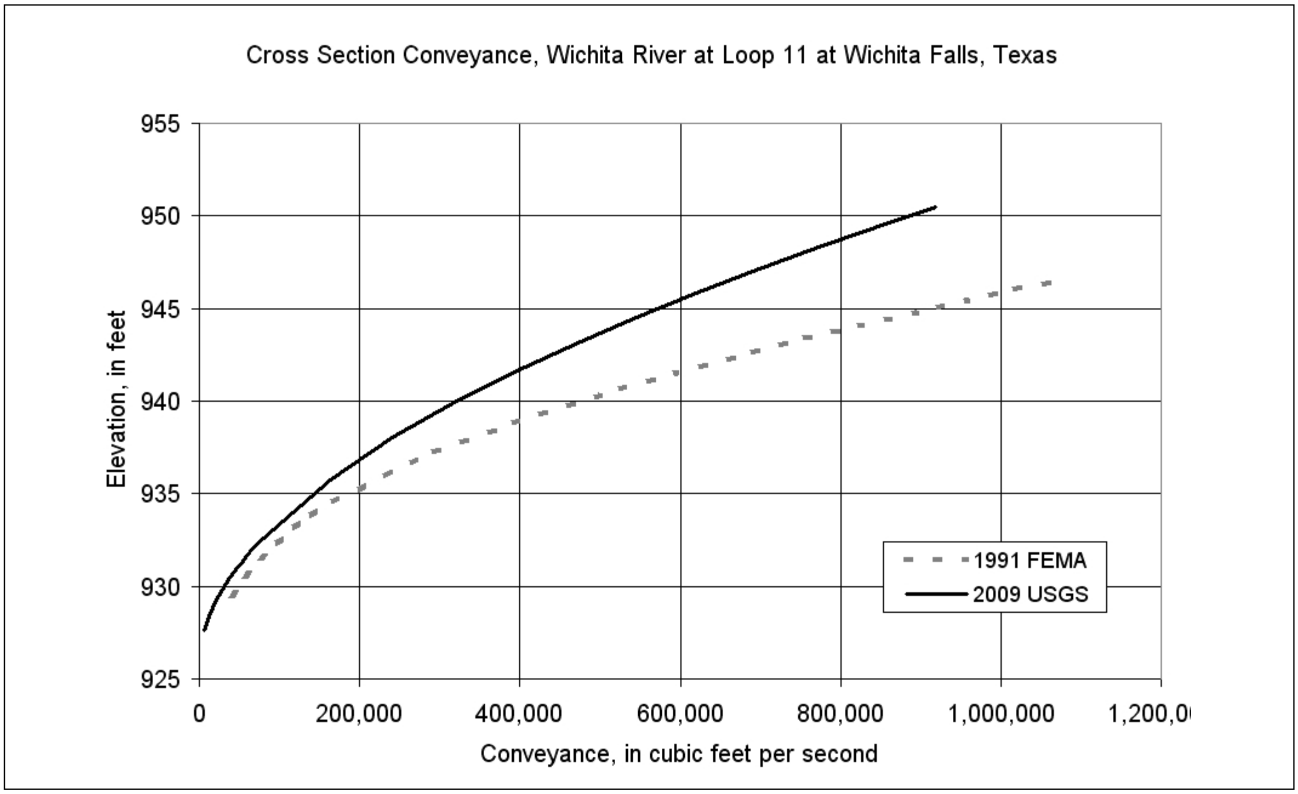

Figure 7. Cross-section conveyance computed from 1991 Federal Emergency Management Agency (FEMA) HEC-2 model (1991 FEMA) and 2009 U.S. Geological Survey HEC-RAS model (2009 USGS) at U.S. Geological Survey gaging station 07312500, Wichita River at Wichita Falls, Texas (Loop 11 gage). Datum of gage is 924.26 ft above National Geodetic Vertical Datum of 1929.

(stages) of more than 20 ft that caused flooding in Wichita Falls on June 30, 2007, and again on August 19, 2008. The floods in June 2007 and August 2008 reached higher stages at the Loop 11 gage compared to the stages of previous floods of similar peak discharge amounts. The record stage of 24.40 ft recorded by the Loop 11 gage on June 30, 2007, was for a peak discharge of 10,100 ft^3/s. In comparison, the previous record stage (since 1938 when records of stage were first kept) of 24.00 ft on Oct. 3, 1941, was for a discharge of 17,800 ft^3/s. On August 19, 2008, flood stages of more than 20 ft (20.51 ft with a peak discharge of 6,940 ft^3/s) were again recorded at the Loop 11 gage. In 1955, 1957, and 1961, annual peak annual discharges ranging from 7,200 to 7,640 ft^3/s were recorded at the Loop 11 gage with associated peak stages ranging from 17.93 to 18.27 ft. Although the annual peak discharges of 1955, 1957, and 1961 were all slightly larger floods compared to the August 2008 flood of 6,940 ft^3/s, the peak stages associated with the floods in 1955, 1957, and 1961 were 2.24 to 2.58 ft lower compared to the peak stage of 20.51 ft associated with the August 2008 flood.

For flood measurements made at stages of more than 18 ft, the peak stages were about 1 to 3 ft higher compared to the peak stages of similar peak streamflows (discharges) measured before 1972. An analysis of discharge measurements made at Loop 11 in Wichita Falls from 1941 to 2008 showed that mean velocities have decreased from 3.5 to about 2.0 ft/s.

Aerial photographs dated from 1953 to 2008 were used to identify changes in about a 5-mi reach of Wichita River channel from Loop 11 to River Road. An increased amount of vegetation was noted on the channel banks from photos taken from 1950 to 2009 at the gaging station located at Loop 11.

A comparison of channel cross sections from original bridge plans with channel cross sections surveyed in 2009 indicate an obstruction exists at the Scott Avenue bridge (south span) and at the Martin Luther King Jr. Boulevard bridge (north span). Four channel cross sections located 3,400 to 11,900 ft downstream from Martin Luther King Jr. Boulevard indicate narrowing of the channel. The remaining channel cross sections surveyed by the USGS in 2009 compared favorably with cross sections from the 1986 Federal Emergency Management Agency photogrammetric survey, with no substantial differences noted. Upstream from Martin Luther King Jr. Boulevard to the Loop 11 bridge, the cross section of the Wichita River channel appears stable. There is an increase in riparian vegetation along the main channel and an increase in vegetation on the floodplain.

Step-backwater profiles were used to verify channel roughness coefficients (Manning's n values). The main channel roughness from 2009 surveys was virtually unchanged from those used in the hydraulic model developed in 1991 for the Federal Emergency Management Agency using a U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) model, HEC-2. Calibrated overbank roughness (average Manning's n = 0.15) for the 2009 step-backwater profiles is more than double the roughness (average Manning's n = 0.06) used in the 1991 HEC-2 model. Reduction in cross-section conveyance at high stage has occurred because of increased vegetation in the overbanks. Obstructions in the channel at some of the bridges in the study reach could also be contributing to reduced channel conveyance by partially blocking flow.

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