HISTORICAL RESPONSE OF THE WAKARUSA RIVER CHANNEL TO ANTHROPOGENIC INFLUENCES

BY

Terri Lee Woodburn

Submitted to the graduate degree program in the Department of Geography and the Faculty of the Graduate School of the University of Kansas in partial fulfillment of the requirements for the degree of Master's of Arts.

____
William C. Johnson, Chairperson

Committee members

____
Wakefield Dort, Jr.

____
Steven Bozarth

Date Defended ____May 15, 2003_______

The Thesis Committee for Terri Lee Woodburn certifies
that this is the approved version of the following thesis:

HISTORICAL RESPONSE OF THE WAKARUSA RIVER CHANNEL
TO ANTHROPOGENIC INFLUENCES

____
William C. Johnson, Chairperson

Committee Members

____
Wakefield Dort, Jr.

____
Steven Bozarth

Date Approved ____April 18, 2008___________

Abstract

Terri Lee Woodburn, M.A.
Department of Geography, May 2008
The University of Kansas

Historical channel change for the Wakarusa River in east-central Kansas was assessed for both temporal and spatial transformations. Re-measurement of selected section-line channel crossings from the federal land surveys of 1855 and 1856 revealed significant channel widening occurring both immediately above and below Clinton Reservoir. Narrowing in the uppermost headwater region and in the lowest reaches of the Wakarusa River is indicated, but is not statistically significant. Aerial photographic evidence indicates that spatial channel position change between pre- and post- reservoir construction has been minimal. Prior work in Douglas County by Dort (n.d.) and comparisons of federal land surveys to modern aerial photography in Shawnee County indicates that there was a much more active channel between the time of Euro-American settlement and the 1950s when agricultural conservation practices were in affect.

Acknowledgements

I am deeply grateful, first and foremost, to my advisor, William C. Johnson, for his guidance and patience throughout this project. He has proven an invaluable source for teaching field techniques, giving focus to the thesis topic and for editorial support. I am thankful to my committee members, Wakefield Dort, Jr. and Curt Sorenson for their advice and editorial support. I also want to thank Steven Bozarth for taking time to be a reader on the committee during the final process toward the thesis completion and Terry Slocum for his clarification on statistical techniques needed for this study. My gratitude, as well, to the landowners that allowed me access to their properties along the Wakarusa River and to Kansas Applied Remote Sensing and the Natural Resource and Conservation Service for the use of aerial photography prints. Finally, to my husband, Brent Woodburn, of whom I am deeply appreciative for his support, patience and hours spent assisting with field measurements.

Table of Contents

List of Figures

List of Figures

List of Tables

Chapter 1
Introduction

Fluvial systems are ever-changing in response to climatic, vegetational and human influences. Alterations can be slow or rapid depending on controlling variables and stream morphology. Subsequent transformations may impact agricultural practices, transportation networks, municipal treatment facilities and housing developments that exist on terraces or floodplains. For this reason, past and present response behavior of a fluvial system must be identified in order to evaluate the suitability of a location for existing and future uses or construction. Comparison of historical records to modern channel data is essential to identify the responses of a specific river system to stimuli. The Wakarusa River is no exception. With the construction of a municipal sewage treatment facility adjacent to the Wakarusa River being considered at present time, there seems to be a lack of comprehensive historical channel-change data to help compose an informed decision for construction location.

Previous research for the Wakarusa River has offered sporadic information in regards to geologic history or channel change, but none of the studies have taken a complete look at historical channel responses to modern climate and anthropogenic influences. One previous study in the Wakarusa basin consisted of terrace and alluvial chronology assessment for an archaeological evaluation of sites surrounding Clinton Reservoir (Logan, et al. 1987), but required no documentation of historical channel change. A study of historical sediment movement completed by Johnson in 1979 included width change measurements for only a portion of the Wakarusa River channel and was a small segment of a study on several Midwestern stream systems. Changes in the position of the Wakarusa River were examined for Douglas County by Dort (n.d.), but historical information for the upper reaches of the river through Shawnee County was not included. An extension and amalgamation of this previous work will hopefully bring us one step closer to understanding historical channel change in the Wakarusa River and the controlling factors that are the driving forces of this change.

For the present investigation, three objectives are defined: 1) collect modern field measurements for comparison to historical width records from pre-Euro-American settlement; 2) document temporal and spatial channel change through historical time and for the shorter period immediately before and after reservoir impoundment; and 3) suggest possible factors responsible for spatial and temporal patterns.

Chapter 2
Previous Investigations

2.1 Channel Variables

Independent variables that control a fluvial system in its natural state have been discussed by several authors (e.g. Chorley 1957, Schumm and Lichty 1965, Schumm 1977, and J. R. L. Allen 1977). The lists of endogenic and exogenic variables differ slightly among these authors, but contain the same essential components: geology, climate, vegetation, local and basin-wide hydraulic conditions, and drainage basin morphology. Channel variables are inter-related, creating a complex system of interactions and responses to change through geologic time (Schumm 1977). When studying fluvial system change with respect to the historic time period, the list of influencing variables on a system may be limited to those variables in which rates of change would be rapid enough to show response within this relatively short time interval. Therefore, a focus on climate, vegetation, hydrologic controls such as discharge and sediment load, and, to some extent, geology may be sanctioned for post-Euro-American settlement periods of research.

Schumm (1968) proposed that alluvial rivers, such as the Wakarusa River, regulate channel dimensions in an attempt to attain a state of equilibrium, compensating for variation in discharge or sediment load transported by creating a change in channel width, depth, or water flow velocity. Variability in water and sediment runoff into a river system can be created by climate and land-use alterations. If a change in either of these variables causes a decrease in the density of vegetative cover, sediment load in the river system will increase, possibly producing an increase in channel depth or width. Depending on the variables that are altered at any given time, a number of possible changes to width, depth, and/or velocity may occur.

Many of the early studies did not account for anthropogenic influences that may cause fluvial system responses similar to those during natural conditions. Williams and Wolman (1984 p.1) stated that "the notion of adjustment and equilibrium implies that alluvial channels could be altered by significant manmade modifications, such as dams, in the regimen of water and sediment delivered". When studying a fluvial system affected by human alteration, statistical verification must be made to insure that change is beyond the natural variability of the fluvial system (Williams and Wolman 1984). Land-use changes, dam construction, and road construction are discussed in the anthropogenic section of independent variables that control fluvial system responses.

2.1.1 Geology

In bedrock-lined channels, the rate of change is minimal due to the resistance of the rock material, whereas alluvial channels are more easily affected by changes in the drainage basin. Alluvial channel banks consisting largely of clay-rich sediment will be more resistant than channel banks of sandy sediment due to differences in sediment cohesiveness (Schumm 1977). Banks of less cohesive sandy sediment respond more rapidly to water flow variations, leading to relatively prompt channel width changes. In silt- and clay-rich sediments, water flow adjusts to climate and land-use changes by altering the depth of a channel instead of width (Schumm 1960). Bedrock and soil types in the basin are important factors in the processes of river formation, but may be less determining factors for historical channel change than climate, vegetation, and anthropogenic influences.

2.1.2 Climate

As described by Knox (1983) and Schumm (1960), climate is a crucial determinant of sediment yield and runoff, and therefore is a principal controlling factor of channel morphometry. Variation in rainfall amount will alter the influx of water into the river system and may also alter vegetation type and density. Rivers will respond to a change in average climate conditions and also to the less frequent but larger flood conditions. Knox noted that frequency and magnitude of flood events are climatic subtleties, but they do generate an effect on the river system.

2.1.3 Vegetation and Land Use

The type and amount of vegetation affects the soil porosity, permeability, and infiltration. This, in turn, affects the amount of water runoff and how much sediment is delivered to the stream (Knox 1972). Anthropogenic influences are seen in changing land use of an area, such as transformation of native prairie into pastureland or cultivated land and the removal of woody vegetation along channel banks.

2.1.4 Anthropogenic Influences

There are a number of channel changes brought on by human activities that affect a fluvial system. Park (1977) introduced two main categories of human-induced channel change: direct and indirect. Direct changes are those that alter the channel profile or cross-section by engineering methods for channel stabilization including dikes, jetties, and the use of rip-rap or bank paving. Indirect changes affect the processes that control stream channel form (discharge and runoff) and include the construction of dams, roadways, vegetation alterations, and urbanization.

Williams and Wolman (1984) studied the channel width and depth changes of numerous channels following the alteration of water flow due to dam construction. In many cases there was a reduction in peak discharge, due to flow regulation, producing post-dam channel narrowing that persisted for some distance downstream. In addition to flow regulation, dams also contributed to the trapping of sediment from the upstream channel that allowed for scouring directly below the dam due to drastic depletion of sediment load (Williams and Wolman 1984, Gregory 1977, Park 1977).

2.2 Regional Studies

Authors of channel studies within the Great Plains and the Midwest have concluded that climate, geology, and land use produce different morphologic characteristics and responses in fluvial systems (e.g. VanLooy and Martin 2005, Sampson 2000, Martin and Johnson 1987, and Knox 1977). These and other studies incorporated the use of aerial photography, archival stream measurements, and modern field measurements to identify temporal and spatial changes.

Martin and Johnson (1987) proposed that climatic fluctuations within the sub-humid region in Kansas had resulted in a natural variability of alternately widening and narrowing of river channels. During dry years sediment was stored within the river channel, lending to the expansion of riparian vegetation cover. Sediment was then re-mobilized during a period of increased water flow within the channel. In explaining the channel narrowing and riparian vegetation changes along the river, Martin and Johnson documented the role of vertical and lateral accretion processes in channel migration and width changes. Vertical accretion is the deposition of sediment adjacent to low-water channels, where the resulting decrease of floodwater inundation may induce vegetation growth. The second process is lateral accretion that begins with channel bars becoming vegetated during dry periods, and, once vegetated, they become stable and divide the stream flow. The smaller of these two stream branches begins to aggrade and will eventually be abandoned and stabilized by vegetation; in the Medicine Lodge River, lateral accretion proved to be the dominant mechanism. In this river system, historical channel change was caused by both vegetation and climate shifts.

Channel width change in the Platte River Basin in Wisconsin (Knox 1977) displayed sensitivity to human activity altering the riparian and valley bottom vegetation density and composition. A transformation from prairie grassland and forest to cultivated land led to channel narrowing in the main-stem of river systems with drainage areas greater than 155 km^2, while headwater widths increased. Narrowing in the lower reaches of the rivers was interpreted to be an influence of the Mississippi River's suspended load sediment being deposited in the confluence area of the Platte River and the Mississippi River, where water backed up into the smaller tributary. Knox attributed these morphologic changes to the removal of natural vegetation, leaving the landscape susceptible to changes in surface runoff and sediment yields caused by small-scale climatic variations.

The semi-arid region of southwest Kansas has proven to show a similar pattern of narrowing, but this is due to circumstances other than those in Wisconsin. VanLooy and Martin (2005) expanded Schumm and Lichty's 1963 work on the Cimarron River, focusing on the channel narrowing that began in the 1940s and continued to the present time. A decrease in annual peak flow was created by the reduced variability of annual moisture conditions and possibly groundwater removal for agricultural practices. Decreased peak flow caused channel narrowing and an expansion of riparian vegetation on the floodplain and within abandoned channels.

Chapter 3
Study Area

3.1 Geographical Setting

The Wakarusa River watershed contains 839 square kilometers (522 mi^2) of land in Douglas, Shawnee, Osage and Waubunsee counties. Located directly south of the Kansas River and flowing sub-parallel to it, the main channel of the Wakarusa extends eighty-one kilometers (50 mi) west to east through southern Shawnee and central Douglas counties before joining the Kansas River near the town of Eudora. The Wakarusa is a meandering alluvial river, with channel bed and bank exposures primarily consisting of clay- and silt-rich sediment. A few exceptions do occur: immediately below Clinton dam and near the confluence with the Kansas River, bed material becomes predominantly sand, and there are also a few short stretches of bedrock-lined channel downstream from the dam, only extending for a couple hundred meters at any one location. Annual discharge of the river, in its natural state, reflects the regional climate, deriving most of its water flow from precipitation events. Recently, discharge patterns were altered by the construction of Clinton Reservoir in western Douglas County in the 1970s to provide flood control, recreation and a reservoir for the water needs of the surrounding communities. Channel position and width changes along the main channel (Figure 1) are the focus of study, specifically both pre- and post-Euro-American settlement and immediately before and after dam construction.

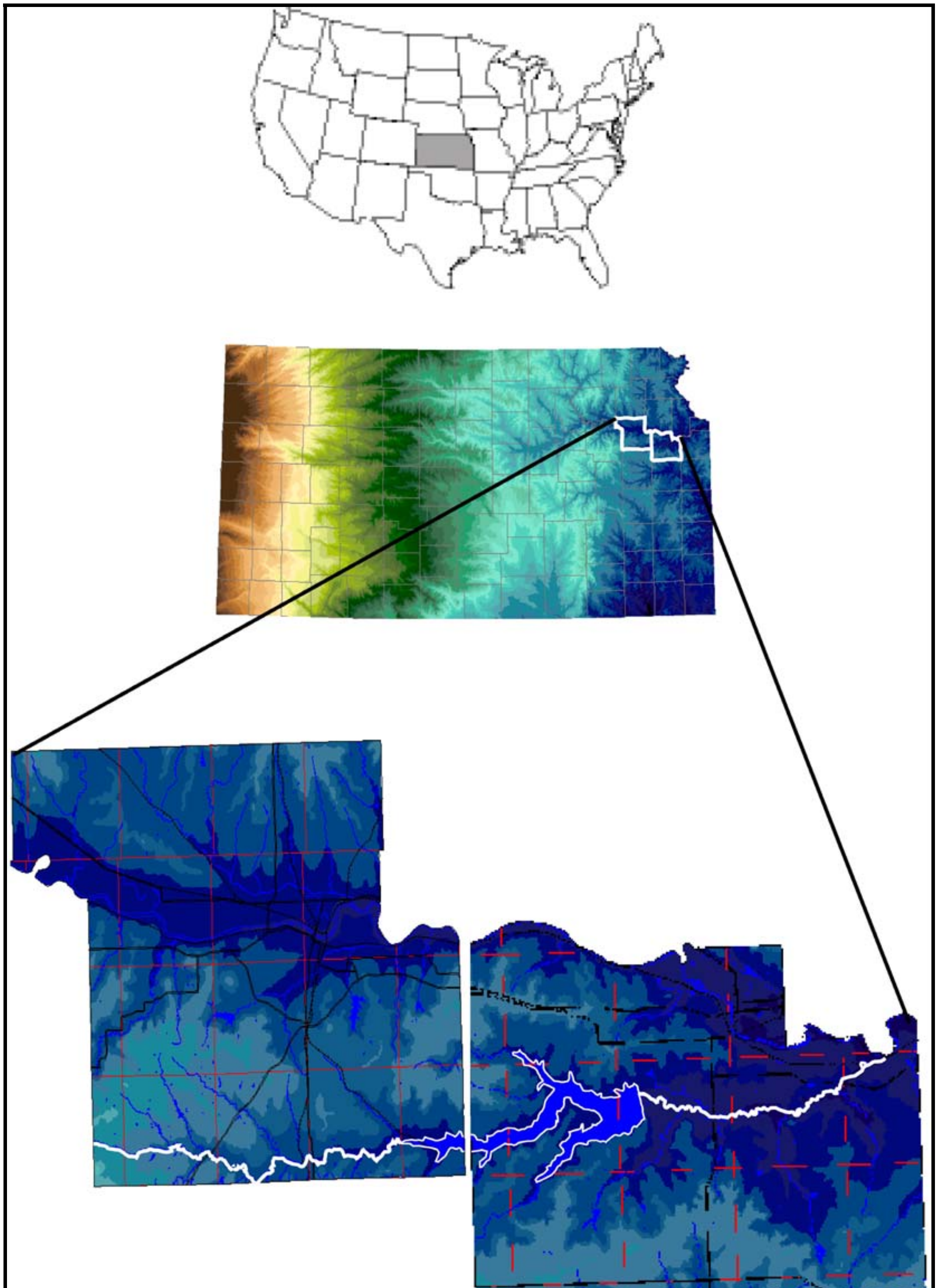


Figure 1: Main channel of the Wakarusa River running through Shawnee and Douglas Counties, Kansas. River channel and Clinton Lake are delineated in white. (DASC 2002)

3.2 Climate

Climate of the Wakarusa River basin is moist subhumid, with an average annual precipitation of 976 mm (38”), 65-70% of which falls during the growing season of April through September (Dickey, et al. 1977). Average temperatures for winter (December-February), spring (March-May), summer (June-August), and fall (September-November) are -0.8^{o} C (31^{o} F), 12^{o} C (54^{o} F), 25^{o} C (76^{o} F), and 13^{o} C (56^{o} F), respectively. Average seasonal precipitation is 103 mm (4”) during winter, 290 mm (11”) during spring, 328 mm (13”) during summer, and 255 mm (10”) during fall (NOAA 2005).

3.3 Geologic Setting

Regional bedrock consists primarily of thinly-layered units of limestone interspersed with shale, with units of sandstone occurring in the eastern portion of the watershed. These interbedded layers of sedimentary rock are mostly of the Upper and Middle Pennsylvanian System, while in the far western portion of the drainage basin, a small area of Permian-aged sedimentary rock is found (Figures 2 and 3). Bedrock dips slightly toward the northwest allowing for upland cuestas to be created due to differential erosion of the limestone, shale and sandstone beds (O’Conner 1960).

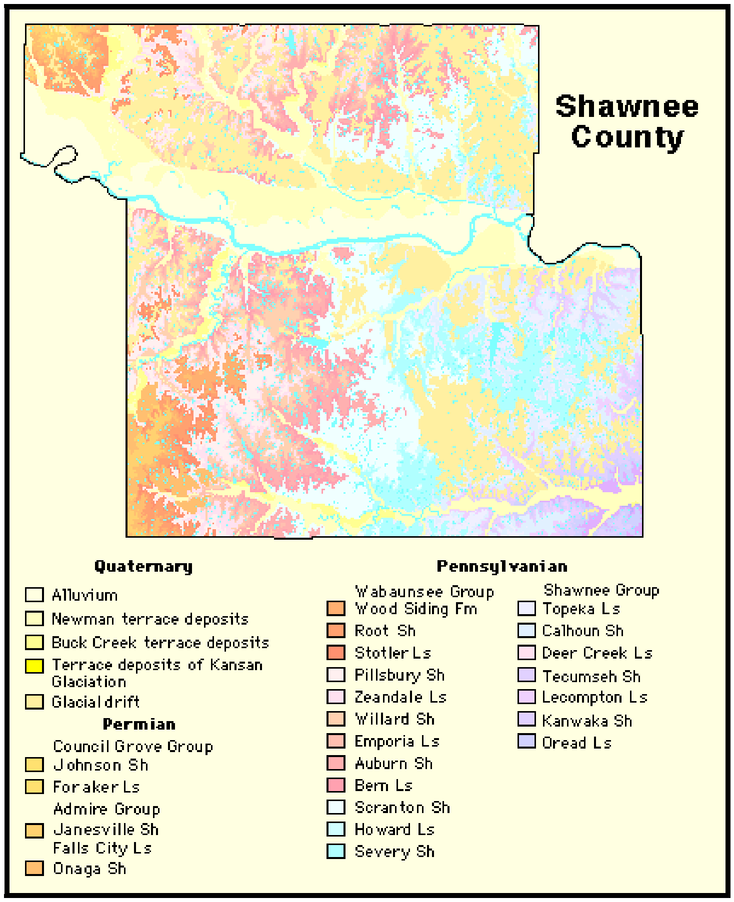


Figure 2: Shawnee County surficial geology. (Johnson, et al. 2001)

Quaternary glacial drift of the Kansan Stage is found in central Shawnee County (Figure 2) and, to a lesser extent, throughout Douglas County (Figure 3). Recent alluvium comprises the floodplain and low-terrace fills, whereas the Newman and Buck Creek terrace deposits consist of older alluvium of Illinoian and Pre-Illinoian stages (Figure 2 and 3; Abmeyer and Campbell 1970; Dickey, et al. 1977). The area of broad terrace deposits occurring near the confluence of the Wakarusa River with the Kansas River is attributed to the erodible nature of the weak Lawrence shale that underlies this area (Todd 1910).

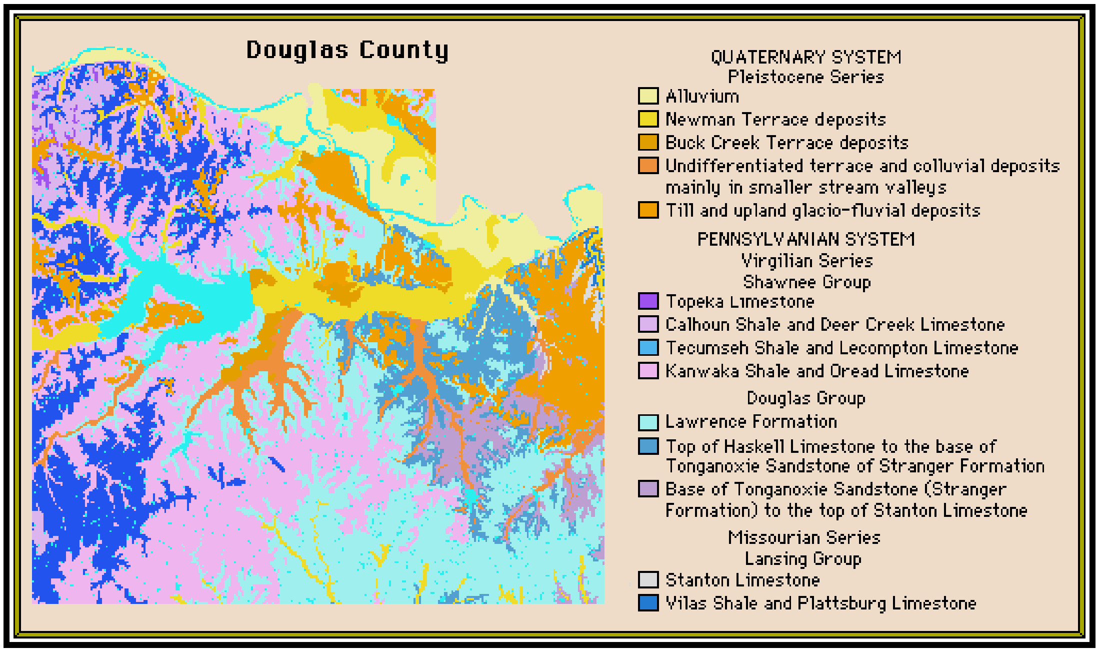


Figure 3: Douglas County surficial geology. (O'Connor 1992)

3.4 Soils

Soils of the Wakarusa River valley are classified into associations that correspond to distinct landscape positions including: alluvial plain, broad uplands, and narrow upland regions. The alluvial plain association of Wabash-Kennebec-Reading soils occupies terraces, bottom lands of the floodplains and natural levees throughout Shawnee and Douglas Counties (Abmeyer and Campbell 1970; Dickey, et al. 1977).

Sibleyville-Martin-Woodson and Pawnee-Woodson-Morrill soil associations are on upland areas with broad ridgetops and long, sloping side slopes located in the downstream portion of the Wakarusa River in Douglas County. These soils are formed in several parent materials, including loess, limestone, shale, sandstone, glacial till, glaciofluvial deposits, and old alluvium. The associations have high shrink-swell potential and slow percolation (Dickey, et al. 1977). Martin-Ladysmith is a similar soil association overlying limestone and shale on the broad uplands of Shawnee County adjacent to the western headwaters of the Wakarusa (Abmeyer and Campbell 1970).

Martin-Sogn-Vinland is the most extensive soil association and is found on narrow upland areas along the central region of the river. These soil types formed in interbedded limestone and shale with small areas of loess-derived soil. As with all upland areas in this county, slope soils are easily eroded, therefore a large percent of this land is used for pasture with less than half of the land being used for agriculture crops (Dickey, et al. 1977). The Martin-Pawnee-Labette association is also formed in limestone and shale, with small areas of glacial till. All upland soil associations consist of fine-grained sediments that are easily erodible, especially on narrow ridgetops with moderately steep side slopes (Abmeyer and Campbell 1970).

3.5 Vegetation

During the 1850s when Euro-American settlement occurred in the basin, the sparse growth of trees along the river and on bluffs was decimated as a result of the settlers' need for lumber. As the railroads came through the basin, supplies could be obtained elsewhere, and settlers began to replenish the tree population by planting orchards and shade trees (Charlton 2002). Regrowth and expansion of the forested areas is evident as early as the 1880s when C. S. Sargent (1884) gathered field data for his study of Kansas vegetation. Today, increases in forested areas are visible, and native grass communities have been lost to cultivated and pasture land. The Kansas Land Cover Map (Whistler, et al. 1991) depicts the forested regions along the upper drainages and small riparian areas near the Wakarusa River within Shawnee and Douglas Counties (Figure 4). A high concentration of cultivated cropland and pastureland is located on the floodplain, with slightly smaller tracts on upland areas. Urban growth in cities such as Lawrence and Topeka has led to a wholesale removal of vegetation cover.

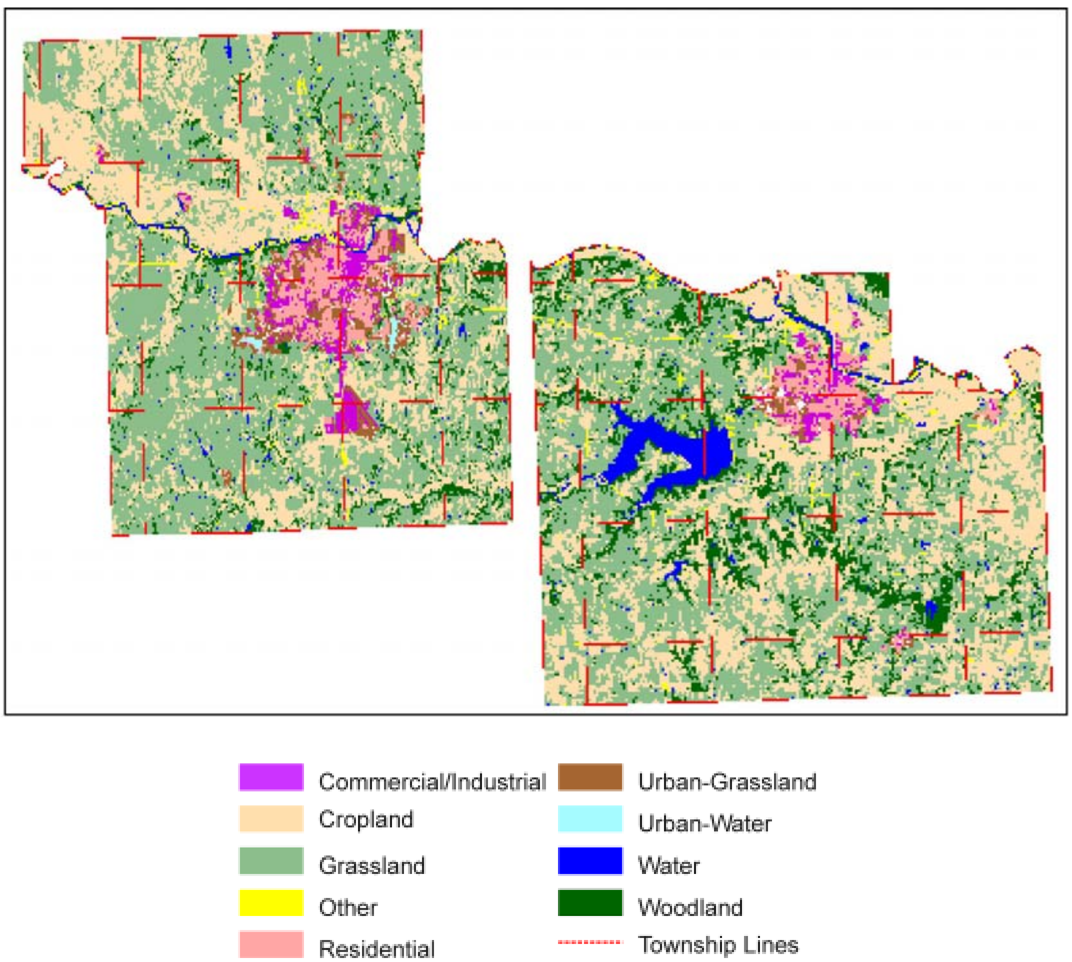


Figure 4: Land cover in Shawnee and Douglas Counties. (Whistler, et al. 1991)

3.6 Anthropogenic Influences

Historical channel change may be affected by more than natural variability of a river system or modern climatic fluctuations. Many influences on the river may occur by way of land-use change, urbanization, trail or bridge construction, water usage, and dam construction. A cultural history of the region in respect to these human influences should be considered as the possible explanation for historical channel change.

3.6.1 Early Trails

Cultural history of the basin can provide unique links between the settlers and the river. The great migration by way of the Oregon Trail began in 1841 and travelers came through the Wakarusa Valley from the southeast to Blue Mound, which was used as a lookout point. Trail crossings have been documented on the river, such as the Wakarusa Crossing of the Oregon Trail (Figure 5) and Blue Jacket's Crossing at the end of the territorial road from Olathe (Fitzgerald 1976).

At many locations, limestone and sandstone strata produce steep-sided creek banks that are difficult to cross, such as the banks of the river near Deichman's Crossing (Figure 6) and at Blue Jacket's Crossing (Figure 7). The prospect of having to cross this river most likely deterred many of the first travelers from going across the Wakarusa valley, but at some localities this same bedrock offered a solid river bottom for easier crossing as long as a path could be cut through the steep-sided banks (Harvey 1917).

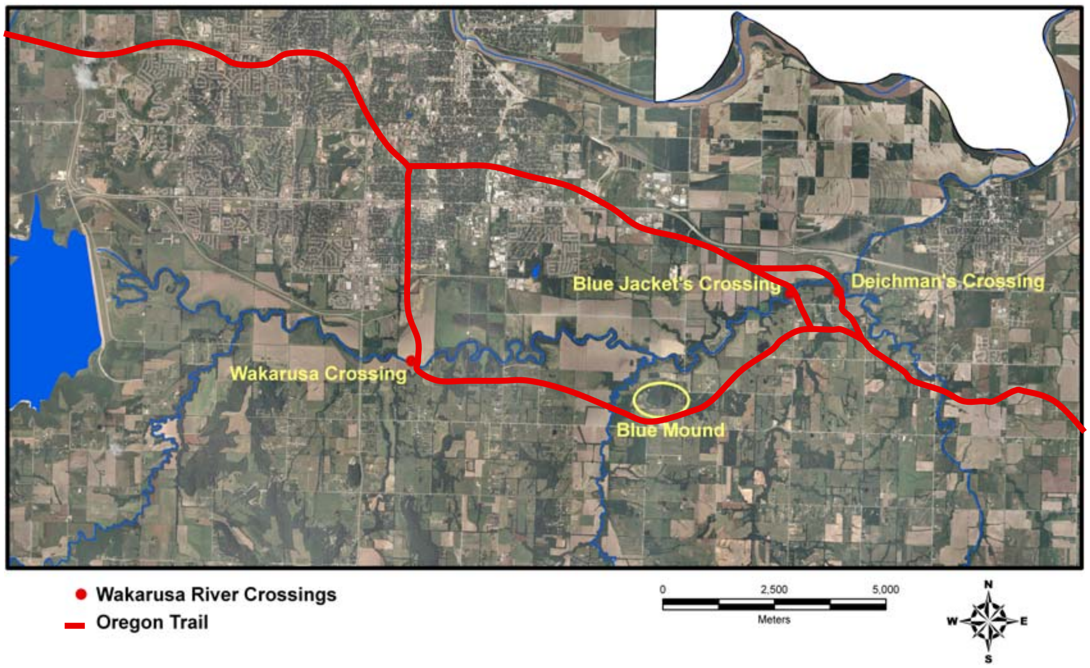


Figure 5: Oregon Trail and river crossing locations based on maps by Franzwa (1982) and Grauberger and McCleary (1997)

Figure 6: Deichman's Crossing, approximately 8 km East of Lawrence, in 1913. (http://www.ci.lawrence.ks.us/local_history/postcards/wakarusa.shtml)

Figure 7: Blue Jacket's Crossing at low-flow level, approximately 7 km East of Lawrence, photo taken in 2005.

A tribe of Sac and Fox Indians traveled through the basin in 1846. They came to what is now the Topeka area and moved south through present-day Berryton on their way toward the government land given to them in Lyon, Osage, and Franklin counties. Directly south of Berryton was the ford used to cross the Wakarusa River and where, in 1878, a locally renowned arched stone bridge made of local bedrock was built along the road then known as the Ottawa State Road (Harvey 1917).

3.6.2 Euro-American Settlement

People were drawn to settle in Kansas Territory by the Kansas and Nebraska Act of 1854 that opened the region to settlement by New England abolitionists and to competing pro-slavery communities in bordering states (Charlton 2002). The Act left the decision to be pro- or antislavery to the people who resided in the territory, resulting in a large migration of settlers into the Kansas Territory and an ensuing fight over slavery (Parker and Laird 1994).

Settlers began building communities along the banks of the Wakarusa River and its tributaries for the reliable source of water, lumber, and clay for brick making (Parker and Laird 1994). Towns settled along the river (from western Shawnee County to eastern Douglas County) were Auburn, Richland, Twin Mound, Belvoir, Lone Star, Clinton, Bloomington, Stull, Barbers Station, Sigel, Wakarusa, Franklin, and Eudora.

3.6.3 Railroads

The Atchison Topeka and Santa Fe Railroad (A.T. & S.F.) began building south of Topeka in 1868, heading toward the settlement of Carbondale where coal deposits had been found. The connecting St. Louis, Lawrence & Denver Railroad extended westward from Lawrence and joined the A. T. & S. F. Railroad at Carbondale, following along the Emporia stage route through the Wakarusa Valley. With the promise of profit and development, six small settlements arose within a few kilometers of each other along this short distance of connecting line. This branch of the railroad, along with some of the communities, was abandoned by 1894, surviving for only a little over twenty years (Parker and Laird 1994).

Two additional railways passed through the Wakarusa Valley: the Lawrence Branch of the Missouri Pacific Railroad approached from the east and crossed the river between Eudora and the Wakarusa's confluence with the Kansas River; and proceeding south from Lawrence, the Leavenworth, Lawrence and Galveston Railroad crossed the Wakarusa heading for Baldwin City (Cutler 1883).

3.6.4 Clinton Lake Project

Congress authorized the building of Clinton Dam on the Wakarusa by the Flood Control Act of 1962, and funding for the construction was approved in 1971 (U. S. Army Corps of Engineers 2002). By this time, several of the early settlements had been abandoned for many years. The original sites of Bloomington, Sigel, Clinton Station, Barbers Station, and Belvoir were inundated by Clinton Lake when the reservoir conservation pool level was reached (Parker and Laird 1994).

In August of 1975, Clinton Dam was finished, and initial filling of the lake began in 1977, taking about three years to reach the stage at which the lake could be used for recreational purposes (U. S. Army Corps of Engineers 2002). Today, Bloomington Park is on the southern shore of the lake near the surviving town of Clinton, and the only remaining relic from the Bloomington settlement is a limestone smokehouse, now being used as storage for the amphitheater.

Clinton Reservoir was built for flood control, water storage, and recreation. Water use by the City of Lawrence and other surrounding communities is estimated at 10 million gallons per day (U. S. Army Corps of Engineers 2002). The multipurpose pool extends 13 km up the Wakarusa River valley from the dam and is the normal water level kept for recreation and water usage, with the flood pool level extending 21 km.

Chapter 4
Research Design and Methodology

4.1 Research Design and Site Selection

Assessment of spatial and temporal channel change of the Wakarusa River involves data analysis from a number of resources, although, continuous temporal data from any one source was lacking. USGS streamflow-gaging stations can provide a good source of historical, site-specific channel information that may be used to infer conditions upstream and downstream of the gage location, but predictions of general stream conditions from site-specific data are best done when several gaging stations are available. Since there is only one long-term streamflow-gaging station on the Wakarusa River channel, change in river depth cannot be inferred from these limited data. Consequently, measurements of channel width and river position are the focus of this study while channel depth and the shape of the underwater channel are beyond the scope of the project.

Site selection for profile locations was based on accessibility and landowner permission, which allowed for seventeen sites to be measured (Figure 8). Accessibility was a limiting factor for section lines where no road access was available to the river or where thick underbrush vegetation inhibited access to the river even during winter months. All but one road that crosses the Wakarusa are along north-south oriented section lines, leaving many of the channel section-line crossings in areas where it would be very difficult to attain access to both river banks. Most sites selected were along roadways where access to both river banks was possible. A drawback to the ease of access is the effect of the bridge on water flow.

To decrease the effect of disturbance from bridges, measurements were taken approximately 150 meters upstream or downstream (depending on the accessible site) of the original section-line measurement. It is believed that this distance will provide measurements from a site that represents the section-line channel width but should be out of the flow interference.

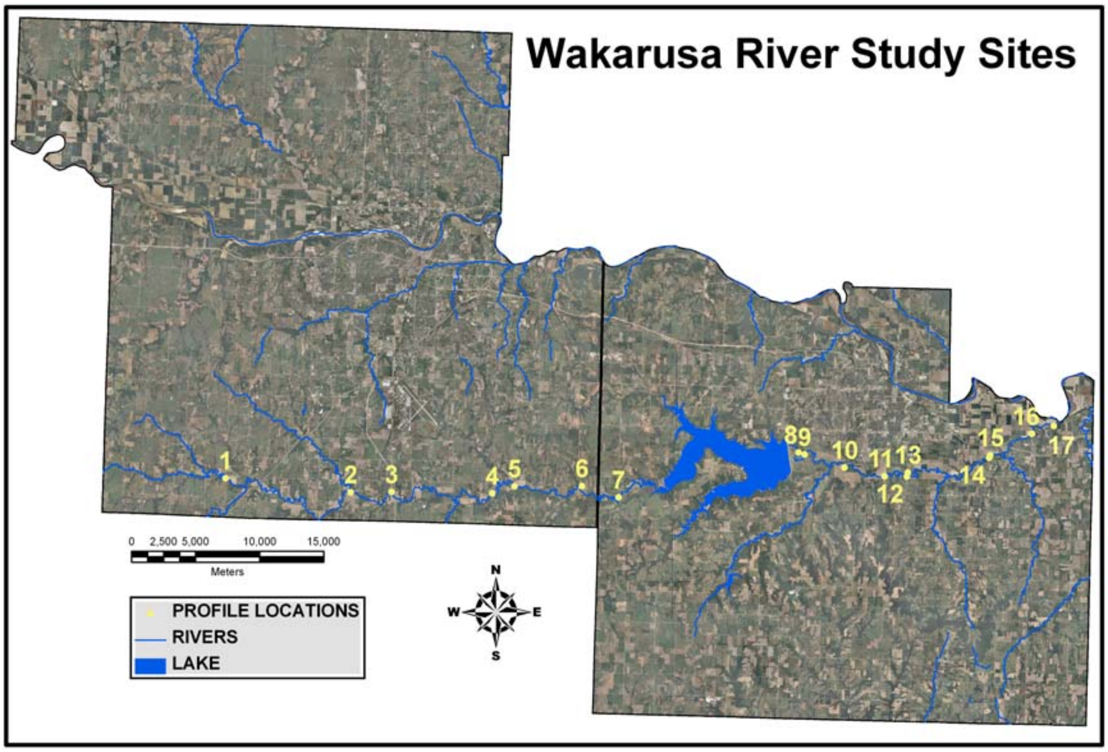


Figure 8: Stream-channel profile locations along the Wakarusa River

4.2 Channel Width Methodology

The baseline channel-width data are from the original federal land survey of the Wakarusa River basin conducted between December 1855 and June 1856, prior to extensive Euro-American settlement of the region. As surveyors positioned township and range lines, they recorded widths of all river and stream channels where section lines crossed them. Stream surveying instructions set by the Surveyor General were vague, stating that: “the courses of all navigable rivers, which may bound or pass through your district must be accurately surveyed and their width taken at those points where they may be intersected by township or sectional lines…” (Tiffin 1926, p. 248). It is uncertain whether the width measurements from the federal land survey were taken perpendicular to water flow or at whatever angle the section line happens to cross a particular channel. It is also unclear as to how the channel width was defined, therefore, federal land survey widths are compared to the three modern measurements of low-flow, active-channel, and bank-full widths. It is doubtful, however, that the original surveyors measured low-flow width from the few notes describing the channel. Connelly (1856b, p. 55) stated that at the time of measurement of section 6, T13S, R21E the channel had a “sandy level bottom subject to inundation”. Field notes from Bates and Mitchell (1855b, p. 83) indicated that section 27, T13S, R15E had “timber in creek bottom” indicating consistently low water levels. Due to these descriptions and the fact that the active-channel widths exhibit a distinct drop to the channel bottom, an assumption has been made that previous surveyors selected the active-channel width for measurements of the Wakarusa River. Original channel widths were measured in chains, with one chain equaling 20.13 meters.

Modern channel cross-section profiles for the Wakarusa River were acquired by the use of the stadia surveying method as described by Brinker and Wolf (1977). Using a Sokkisha C3A automatic level (28x) (Figure 9) and stadia rod, vertical and horizontal distances were derived from the stadia readings. Transects for river profiles were positioned at right angles to the channel flow, with measurements obtained for every break in slope to achieve an accurate cross-section profile for each site. A Garmin GPSmap 60Cx Global Positioning System (GPS) receiver was used to ascertain the location of each profile and elevation of the uppermost level of the bank at each site. For greater accuracy in GPS readings, average readings were taken in a five minute period. The Department of Natural Resources Garmin software application was used to transfer GPS data into ArcGIS point locations. In ArcMap, MrSID images were added to produce a site location map overlain on aerial photographs.

At sites where access to both sides of the river was unobtainable due to dense vegetation cover or where a landowner prohibited access, a Laser Technology TruPulse 200B laser rangefinder was used (Figure 9). This rangefinder allows for horizontal and inclined measurements by providing distance and degrees of inclination to a chosen point. With this information, a corrected straight-line distance can be calculated by multiplying the cosine of the inclination by the distance measured. Calculating the tangent of the degree of inclination gives the change in elevation for a profile.

When considering human alterations as a cause for channel change, Williams and Wolman (1989) stated the necessity for a statistical verification that any change is beyond the river systems' natural variability. In the present research, statistical analyses were used to compare original width measurements to modern channel cross sections. Given the lack of measurement description for the original data, widths are compared to three different measurements from the modern profiles: bankfull width, active-channel width, and low-flow width. A paired observations t-test was calculated for each of the three width comparisons as described by Burt and Barber (1996). These authors also described the number-of-runs test used to determine randomness or detect patterns that emerge on the calculated change in widths for all three measurements (1996). Outcomes of these tests will indicate if statistically significant differences exist in width between dates and if there is an overall pattern of change in the river system.

Figure 9: Laser rangefinder (left) and automatic level (right) used for distance and elevation measurements

4.3 Channel Position Methodology

Spatial and temporal change in channel position on the floodplain was determined using multiple years of 1:24000 scale aerial photography. Coverage for the two counties taken during the same time period is sparse, but images for the year 1959 are available in print from Kansas Applied Remote Sensing (KARS), and 1991 aerial photos are available in Digital Orthophoto Quadrangles (DOQs) format online from the Data Access and Support Center (DASC). While winter, leaf-off conditions are preferable for the most accurate definition of channel position, they were not available in photograph form.

Digital formats were produced for the 1959 prints by scanning the images. In order to compare 1959 digital scans with 1991 DOQs, coordinate information was created. Rectification was done by correlating ground control points from both image dates, giving the 1959 images the same coordinate information as the 1991 DOQs. Mosaics of the digital images were formed for both years with the use of ArcInfo. Channel position in each mosaic was digitized in ArcMap following along the center of the channel, continuing upstream to the point at which canopy cover from both banks were close enough to obscure the view of the channel. Digitized channel positions were overlaid onto one another in ArcMap to visually identify any spatial change between years. Ancillary data for channel position change come from a Kansas River study in which the Wakarusa River through Douglas County was documented from settlement time up to 1976 by Dort (n.d.). Dort's maps of position-change, along with 1941 aerial photos and an incomplete set of 1981 color infrared aerial photos for Douglas County, were visually compared to the digital mosaics of

1959 and 1991 for a corroborative, qualitative assessment of position change of the Wakarusa River in Douglas County. Because the only additional images found for Shawnee County were from 1981 at a small 1:60000 scale, very little detail was obtainable.

Chapter 5
Results

5.1 Site Selection

All sites were located near section-line crossings for comparison to widths measured in the original federal land survey. During field reconnaissance, it was noted that modern, and possibly previous, bridge construction for roadways is destructive to the natural channel cross section (Figure 10). The choice to take profile measurements upstream or downstream of a section-line bridge was necessary due to bridge effects on water flow patterns and due to channel dimension changes that may occur during bridge construction.

Figure 10: Bridge construction near Auburn, Kansas in April 2004, showing a secondary road built for construction access, cutting down through the channel bank and fill added to the channel bed. The original channel bed is indicated in red.

Since site selection was dictated by accessibility and landowner permission, some sites chosen are closer to one another than would be preferred in a purposive sample in which equally spaced sites would have been chosen (Figure 11). Nevertheless, the sets of closely-spaced sites proved to be useful in the overall study and are not redundancies. For example, sites 14 and 15 are upstream and downstream of the same section line. Site 14 is constricted by a bedrock bed and one bedrock bank, similar to the actual section-line crossing previously measured in the federal land survey. However, site 15, which is not constrained by bedrock, should show the representative width change that may have occurred in the area. Sites 12 and 13 are on the same landowner property 225.5 m (740 ft) from one another but cross over two different section lines as the channel meanders. Located below Clinton Reservoir is an abandoned remnant of the original channel (site 8) that may indicate any change that occurred prior to the flow change created by dam completion. The profile for site 9 is that of the original channel downstream of the reservoir outlet channel.

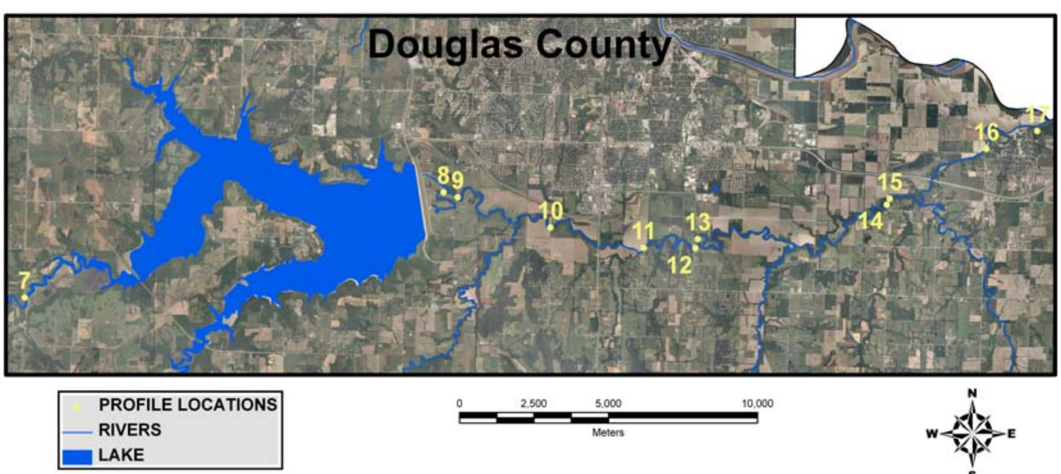


Figure 11: Study site locations along the Wakarusa River in Douglas County, Kansas

The outlet channel below the dam has not been chosen as a study site since it is a new, man-made channel. Original widths of the channel at the date of construction are not indicated here, but, nonetheless, cutbank and channel bed erosion has been occurring (Figures 12 and 13).

Figure 12: Cutbank erosion on the north side of the channel located downstream from the reservoir outlet, April 2004

Figure 13: Channel bed erosion located downstream from the reservoir outlet, April 2004

5.2 Channel Width

Topographic profile dimensions for each of the 17 sites were calculated in Excel using the stadia readings and laser rangefinder data to produce a channel cross-sectional profile for each site (Appendix 1, pgs. 68-73). Plates for each site, including photographs and cross section profiles, are found in Appendix 1, pages 51-67 (Figure 14). General Land Office (GLO) data from the original federal land survey corresponding to the sites selected are compiled in Table 1, with complete Wakarusa River width information from the GLO listed in Appendix 2.

Table 1: Original Federal Land Survey Data from the GLO (Bates and Mitchell 1855; Brockett 1856; Burge 1856; Card 1856; Connelly 1856; and Derrick 1856)

Location description	width (chains)	width (meters)	corresponding site
Sec. 4/5, T13S, R21E	2.50	50.33	17
Sec. 5/6, T13S, R21E	2.50	50.33	16
Sec. 12/13/14, T13S, R20E	2.15	43.28	15 &14
Sec. 17/20, T13S, R20E	2.50	50.33	13
Sec. 20/19, T13S, R20E	3.00	60.39	12
Sec. 19/24, T13S, R20E	0.75	15.1	11
Sec. 14/15, T13S, R19E	0.60	12.08	10
Sec. 16/17, T13S, R19E	0.60	12.08	9 & 8
Sec. 25/26, T13S, R17E	0.50	10.07	7
Sec. 27/22, T13S, R17E	1.00	20.13	6
Sec. 30/25, T13S, R17E	1.00	20.13	5
Sec. 25/26, T13S, R16E	1.07	21.54	4
Sec. 30/25, T13S, R16E	1.75	35.23	3
Sec. 26/27, T13S, R15E	0.80	16.10	2
Sec. 26/27, T13S, R14E	1.40	28.18	1

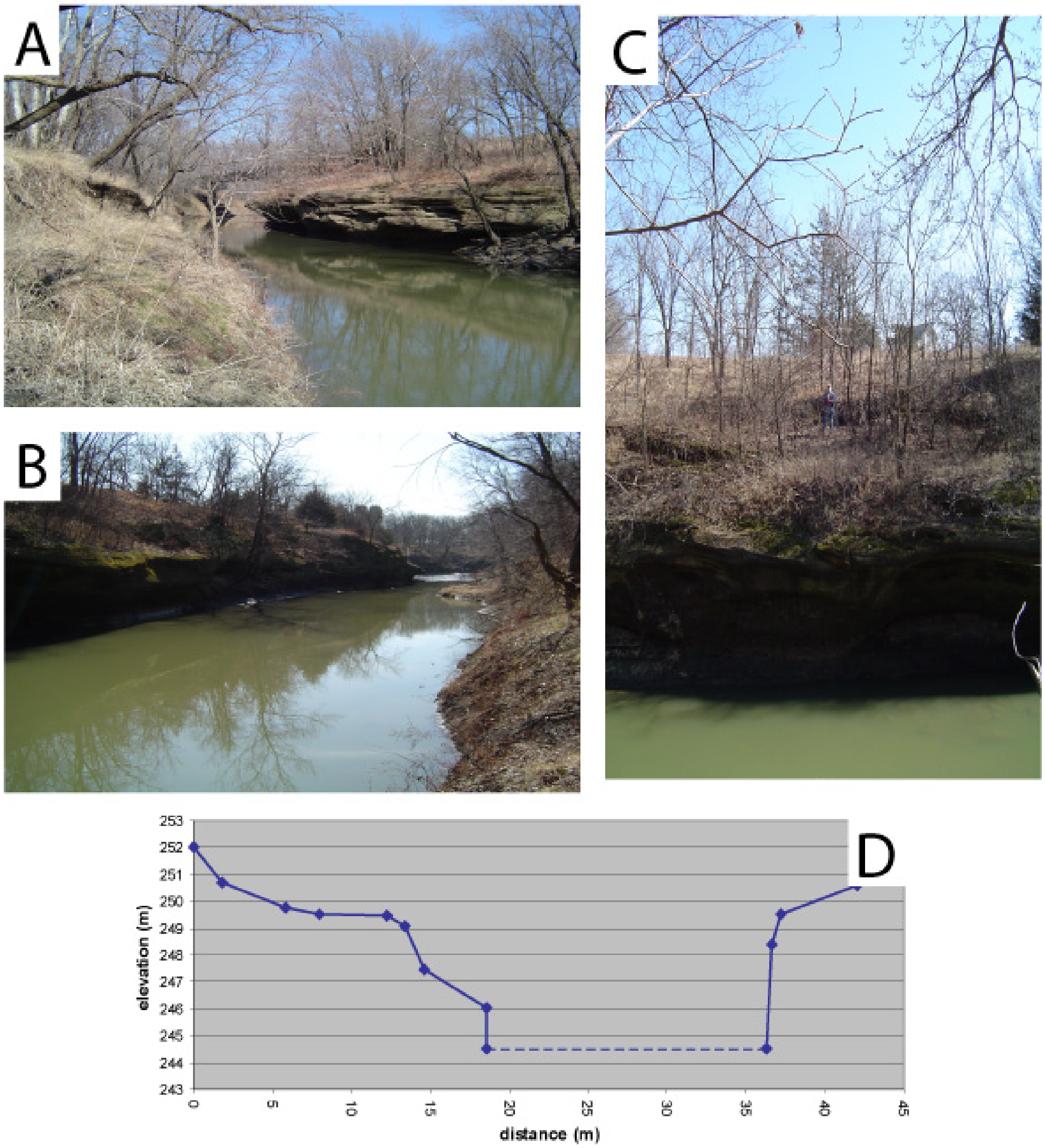


Figure 14: Example of site #14. Site location: 38.92607°N 95.1495°W. A) Downstream toward section line, B) upstream view, C) sandstone outcrop on the south bank, and D) cross section profile facing downstream; dashed line indicates water surface

Statistical analysis comparing GLO widths and modern profile dimensions were completed using SPSS software to determine if any significant change in width has occurred since Euro-American settlement. Two measurements for the same site but from differing dates are considered paired observations for which a paired t-test was the optimal choice for statistical analysis. A comparison of GLO data and modern width measurements required three paired t-tests to compare all possible width measurements the surveyors may have taken. Normal distribution requirements were met for all data. An alpha value (significance value) of 0.15 was used, and, with three iterations, the alpha value for each test was 0.05, a 95% confidence interval. For this test, the null hypothesis is $\mu_1 - \mu_2 = 0$ (no difference), with an alternate hypothesis that $\mu_1 - \mu_2 \neq 0$ (change has occurred). The null hypothesis is rejected if the prob-value (probability value) is less than the alpha level. Table 2 presents the t statistic and prob-value for each of the three width comparisons.

Table 2: Paired t-test of the paired differences

Paired Differences	Mean	Std. Deviation	t	Prob-Value
Pair 1: GLO – bankfull	-1.81824	21.48184	-0.349	0.732
Pair 2: GLO – active channel	4.92118	20.59930	0.985	0.339
Pair 3: GLO – low flow	12.24471	21.68936	2.328	0.033

Low-flow width has a prob-value of 0.033 that is less than the alpha level of 0.05, thus the null hypothesis is rejected. This denotes a significant difference between GLO width measurements and the modern low-flow width. Given the previous postulation that early surveyors did not measure width in accordance to water surface, this outcome is not unexpected. For bankfull and active-channel widths, the prob-values are greater than the alpha, indicating no significant changes from the GLO measurements; the null hypothesis is accepted.

A number-of-runs test was used to examine randomness for change between GLO measurements and each of the modern widths, indicating statistical patterns of change. Negative change correlates to channel narrowing, while positive change is indicative of widening. Tables 3, 4 and 5 show each of the width comparisons with the calculated difference and a positive or negative indication assigned to each channel change. The number-of-runs test defines a run as being an unbroken sequence or a repetitive pattern; results are given in Table 6.

Table 3: Bankfull width comparison to GLO measurements with positive (channel widening) or negative (channel narrowing) change indicated and number-of-runs calculated.

Site	GLO Width (m)	Bankfull Width (m)	Difference	Sign	Runs
1	28.18	27.13	-1.05	-	1
2	16.1	21.65	5.55	+	2
3	35.23	27.59	-7.64	-	3
4	21.54	30.67	9.13	+	4
5	20.13	28.51	8.38	+	4
6	20.13	27.13	7	+	4
7	10.07	41.31	31.24	+	4
8	12.08	14.78	2.7	+	4
9	12.08	32.2	20.12	+	4
10	12.08	65	52.92	+	4
11	15.1	9.35	-5.75	-	5
12	60.39	21	-39.39	-	5
13	50.33	17.39	-32.94	-	5
14	43.28	43.87	0.59	+	6
15	43.28	29.88	-13.4	-	6
16	50.33	53.66	3.33	+	6
17	50.33	40.45	-9.88	-	7
mean	**29.45**	**31.27**	**1.82**		
std. dev.	**16.93**	**14.11**	**21.48**		

Table 4: Active-channel width comparison to GLO measurements with positive or negative channel width change indicated and number-of-runs calculated.

Site	GLO Width (m)	Active Channel (m)	Difference	Sign	Runs
1	28.18	19.2	-8.98	-	1
2	16.1	21.65	5.55	+	2
3	35.23	27.59	-7.64	-	3
4	21.54	27.13	5.59	+	4
5	20.13	28.51	8.38	+	4
6	20.13	27.13	7	+	4
7	10.07	41.31	31.24	+	4
8	12.08	14.78	2.7	+	4
9	12.08	32.2	20.12	+	4
10	12.08	32.07	19.99	+	4
11	15.1	3.65	-11.45	-	5
12	60.39	14.94	-45.45	-	5
13	50.33	11.29	-39.04	-	5
14	43.28	23.79	-19.49	-	5
15	43.28	22.25	-21.03	-	5
16	50.33	29.06	-21.27	-	5
17	50.33	40.45	-9.88	-	5
mean	**29.45**	**24.53**	**-4.92**		
std. dev.	**16.93**	**9.84**	**20.60**		

Table 5: Low-flow width comparison to GLO measurements with positive or negative channel width change indicated and number-of-runs calculated.

Site	GLO Width (m)	Low Flow (m)	Difference	Sign	Runs
1	28.18	17.37	-10.81	-	1
2	16.1	15.4	-0.7	-	1
3	35.23	21.19	-14.04	-	2
4	21.54	24.84	3.3	+	2
5	20.13	24.24	4.11	+	2
6	20.13	24.09	3.96	+	2
7	10.07	36.01	25.94	+	2
8	12.08	1.53	-10.55	-	2
9	12.08	15.91	3.83	+	3
10	12.08	24.76	12.68	+	3
11	15.1	3.32	-11.78	-	4
12	60.39	1.15	-59.24	-	4
13	50.33	4.38	-45.95	-	4
14	43.28	17.68	-25.6	-	4
15	43.28	18.29	-24.99	-	4
16	50.33	18.16	-32.17	-	4
17	50.33	24.18	-26.15	-	4
mean	**29.45**	**17.21**	**-12.24**		
std. dev.	**16.93**	**9.68**	**21.69**		

Table 6: Number-of-Runs test

Difference Value:	Bankfull	Active Channel	Low Flow
Number of Runs	7	5	4
Z statistic	-0.991	-1.997	-2.454
Prob-Value	0.322	0.046	0.014

The null hypothesis for a number-of-runs test states that a series of observations is generated by a random process; this hypothesis will be rejected if the prob-value is less than the alpha of 0.05. Based on the prob-values, patterns of positive and negative differences between GLO widths and the active-channel and low-flow widths are not generated by a random process; there is a pattern of change occurring due to a given external force(s). Differences in GLO and bankfull widths, however, are being generated by a random process; statistically, there is no discernable pattern of change that has occurred. All three of the runs tests demonstrate different statistical patterns but a visual comparison of the same data as a whole portrays a more unified pattern (Table 7).

Descriptions of the anomalies found in these three regions substantiate this selected pattern of change. Region one corresponds to general narrowing in the headwater area of sites 1-3. Inconsistent widening of bankfull and active-channel width at site 2 is accounted for by its profile location. The only accessible profile position was between a tributary and a low-water crossing (concrete apron) that could create unnatural conditions for erosion. Above and below Clinton Reservoir in the central portion of the river (region two, sites 4-10) consistent widening is occurring. Low-flow width narrowing at site 8 is the only exception and is due to the fact that the profile measures a channel section that has been cut off by the construction of Clinton Reservoir. The dam outlet bypasses this portion of the river; therefore, the only water flow in this channel is runoff from a very small area below the dam. This indicates that prior to dam construction widening had occurred at this site but only by 2.7 m since pre-Euro-American settlement. Overall narrowing has occurred at sites 11-17 of the downstream area (region three), with only a slight bankfull widening indicated at sites 14 and 16 (0.59 m and 3.33 m respectively), while narrowing is seen with their incised-channel and low-flow widths.

Table 7: A visual estimation of regional channel change based on overall positive or negative transformations.

Site	Bankfull	Active Channel	Low Flow	Regional Change
1	-	-	-	1
2	+	+	-	1
3	-	-	-	1
4	+	+	+	2
5	+	+	+	2
6	+	+	+	2
7	+	+	+	2
8	+	+	-	2
9	+	+	+	2
10	+	+	+	2
11	-	-	-	3
12	-	-	-	3
13	-	-	-	3
14	+	-	-	3
15	-	-	-	3
16	+	-	-	3
17	-	-	-	3

Subsequent to the runs test and visual pattern comparison, paired t-tests were again employed to compare width differences in the three regions of change (upstream portion of the mainstem, above and below Clinton Reservoir, and downstream). Tables 8, 9, and 10 denote prob-values for the regional differences indicating possibilities of width change depending on the measurement position used by the original federal land surveyors. All three width measurements indicate that there has been no statistically significant change in the upstream portion of the mainstem. T-tests performed with only sites 1 and 3, to account for the anomaly of site 2, also indicated no significant change has occurred. Individual measurements indicate a slight narrowing at the upstream sites, but these changes have been shown to be within the natural variability of the river system.

Table 8: GLO and modern bankfull width differences

Paired Differences	Mean	Std. Deviation	t	Prob-Value
Pair 1: Upstream (sites 1-3)	1.04667	6.5950	0.275	0.809
Pair 2: Above & Below Lake (4-10)	-13.0950	10.59952	-3.026	0.029
Pair 3: Downstream (11-17)	13.9200	16.33975	2.254	0.065

Table 9: GLO and modern active-channel width differences

Paired Differences	Mean	Std. Deviation	t	Prob-Value
Pair 1: Upstream (sites 1-3)	3.690000	8.03007	0.796	0.510
Pair 2: Above & Below Lake (4-10)	-12.50500	10.95686	-2.796	0.038
Pair 3: Downstream (11-17)	23.94429	13.41500	4.722	0.003

Table 10: GLO and modern low-flow width differences

Paired Differences	Mean	Std. Deviation	t	Prob-Value
Pair 1: Upstream (sites 1-3)	8.51667	6.95941	2.120	0.168
Pair 2: Above & Below Lake (4-10)	-5.09833	11.71632	-1.066	0.335
Pair 3: Downstream (11-17)	32.26857	15.64883	5.456	0.002

As indicated previously, low-flow width was likely not the measurement taken by the original federal land surveyors. This is supported once more by the prob-value indicating no statistically significant change occurring above and below Clinton Reservoir. With both bankfull and active channels showing statistically significant widening, low-flow width would presumably show similar change unless water surface widening has occurred and are now similar to the original channel measurements.

There has been statistically significant negative change in both active-channel and low-flow widths in the downstream portion of the mainstem as compared to the original federal land survey. Bankfull widths have not shown statistically significant change in the downstream region since this time, but site specific changes indicate that some channel narrowing has occurred but must be within the systems natural variability. This indicates that the original surveyors presumably measured the stream at the bankfull width.

Qualitative comparisons of the entire river between 1959 and 1991, along with additional photo years available, show an outcome similar to the statistical analysis. There is no detectible width change in the upstream portion of the river or the downstream portion. Visual confirmation of widening just above Clinton Reservoir is first illustrated in the color infrared image from 1981, and further expansion is seen in the 2006 color infrared image (Figures 15, 16, and 17).

Figure 15: Channel width in 1941 above where present-day Clinton Reservoir is located (KARS 1941)

Figure 16: Channel width increase seen in 1981 after reservoir impoundment. Red arrows indicate areas where water flow is beyond previous channel banks (NRCS 1981)

Figure 17: Continued channel width increase showed in the 2006 NAIP image (DASC 2007)

5.3 Channel Position

Digitized channel positions from the available aerial photographs are visually compared in Figure 18. Leaf-on conditions in both years decreased the ability to digitize the complete main channel. The 1991 DOQs showed lessened contrast in gray tones, therefore it was not possible to digitize the channel location as far upstream as in the 1959 images. The middle region of the 1991 channel is where Clinton Reservoir has inundated the channel; the channel above and below the lake was digitized along with the outline of the reservoir.

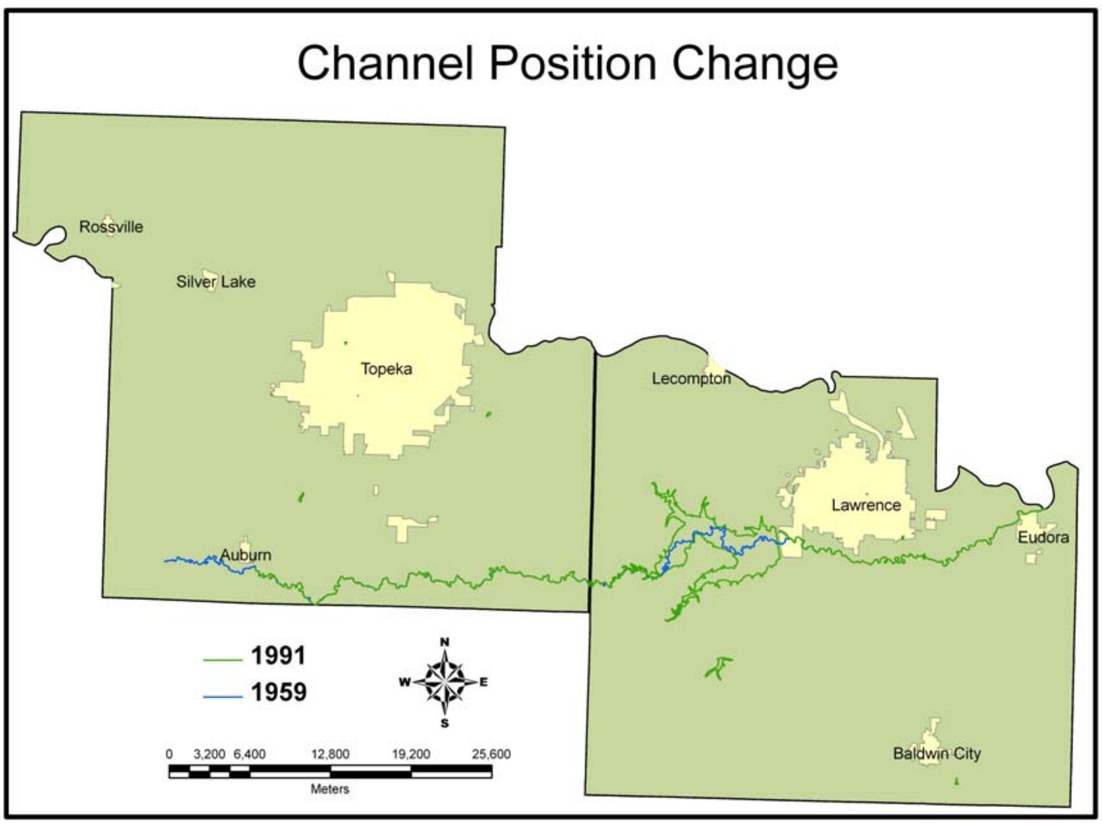


Figure 18: Lack of position change shown by the digitized Wakarusa River channel position in 1959 (blue) and 1991 (green).

Based on the 1959 and 1991 aerial photo images, little change has occurred between pre- and post-dam construction. There were only two major channel position changes during this time period. The first is a meander cutoff, occurring after dam construction, located above the modern lake position (Figures 19 and 20). The second is the change in channel length observed at the confluence with the Kansas River (Figure 21). In recent years, movement of the Kansas River has decreased the length of the Wakarusa channel, but over the longer period since 1941 the confluence has been shifting to the northeast and the river has elongated.

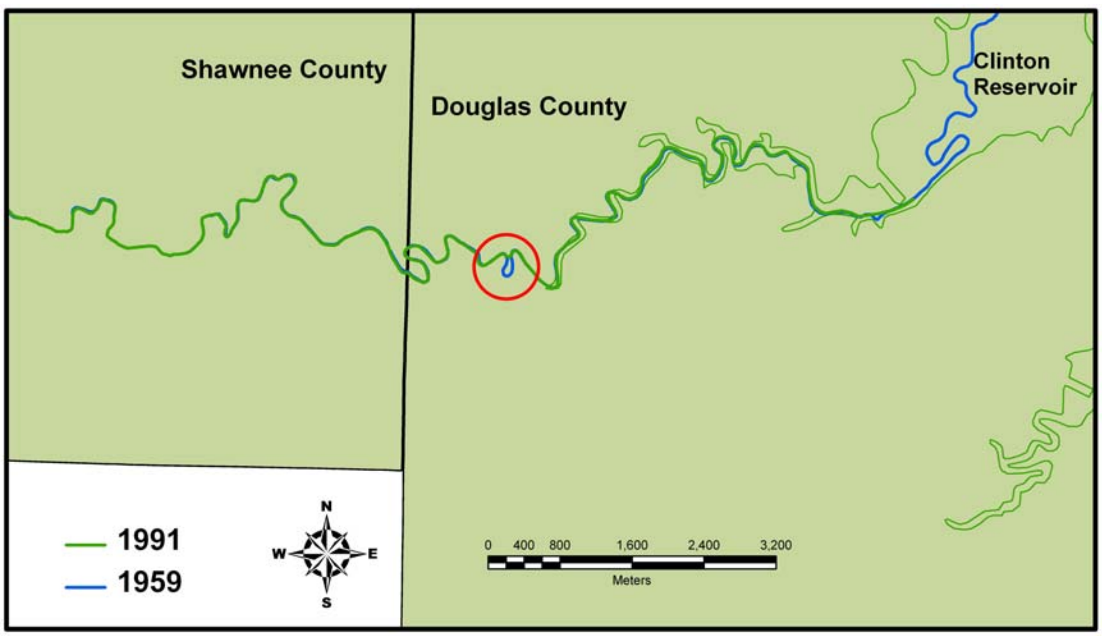


Figure 19: Meander cutoff above Clinton Reservoir

Figure 20: 2006 NAIP image of a meander cutoff forming an oxbow lake located in Douglas County, 3 km upstream of Clinton Reservoir. (DASC 2007)

Figure 21: 2006 NAIP imagery showing the decrease in channel length at the confluence with the Kansas River. Riparian vegetation is still visible where the previous bank existed. (DASC 2007)

As documented by Dort (n.d.) (Appendix 3), position change in Douglas County has occurred consistently in historic time but is not illustrated by this restricted time period of 1959 to 1991. A greater indication of channel position change in Shawnee County is observed through a qualitative comparison of GLO plat maps and modern channel locations. The plat maps were not digitized for inclusion due to the lack of accuracy in stream positions within section boundaries. Channel locations as they crossed section lines are accurately positioned in reference to section corners, but within the sections there is no reference system. There was inconsistency in mapping techniques between surveyors of differing townships that showed indications of inexact channel position records. Some surveyors would represent the channel as a generalized, wavy line as compared to seemingly more precise drawings that appeared similar to a normal meandering river. Examples of section-line position change in areas of Shawnee County are provided in Figures 22, 23, 24 and 25 below. Throughout the two counties, there are numerous indications of river straightening, meander cutoffs, and some more drastic shifts in location changes.

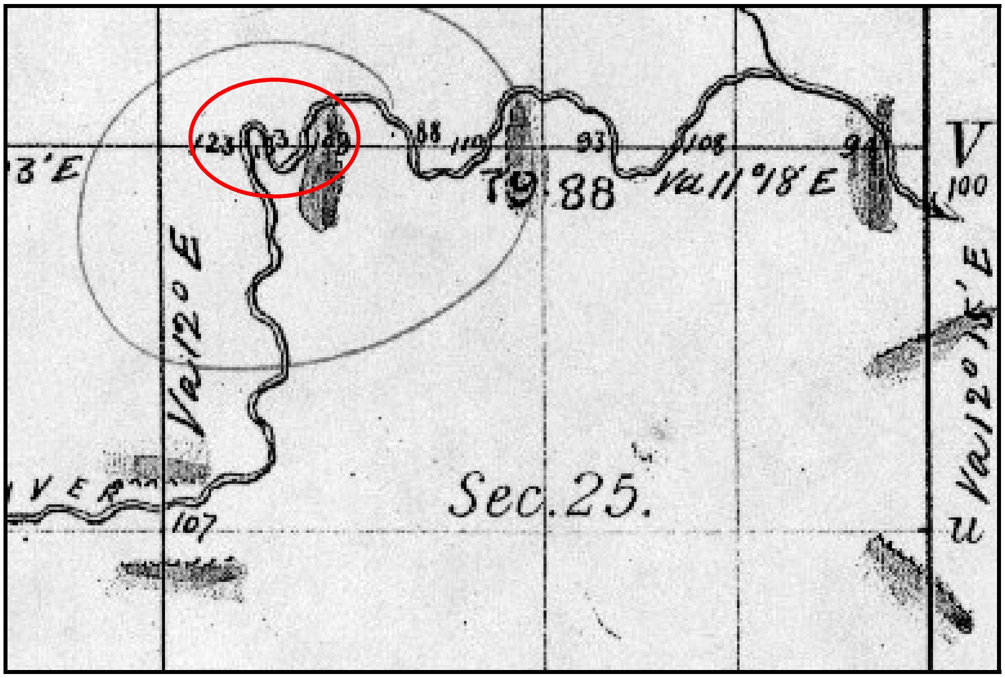


Figure 22: GLO meander locations crossing the section line between sections 24 and 25, T. 13 S., R. 16 E. in Shawnee County (Brockett 1856)

Figure 23: Modern meanders along section line have shifted and a previous meander has been cutoff between sections 24 and 25, T. 13 S., R. 16 E. in Shawnee County (DASC 2002)

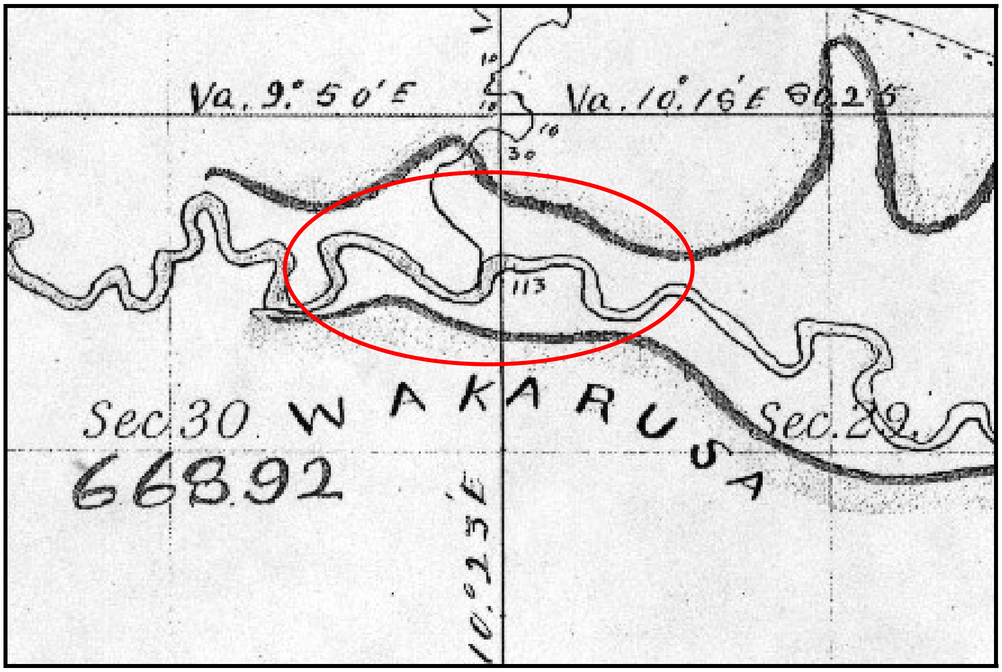


Figure 24: GLO meandering river in sections 29 and 30, T. 13 S., R. 17 E. in Shawnee County (Derrick 1856)

Figure 25: Modern river has straightened and shifted southward against the valley wall in sections 29 and 30, T. 13 S., R. 17 E. in Shawnee County (DASC 2002)

Chapter 6
Conclusions

Spatial and temporal measurements of the Wakarusa River have indicated minimal change occurring to the post-Euro-American settlement channel. In the downstream portion of the river, east of Highway 59, and in the upstream region west of the town of Wakarusa, width measurements indicate channels are narrower at present than in 1855 and 1856, but neither of the small regional changes has proven statistically significant. The amount of narrowing experienced in the downstream and upstream sections of the river, averaging 1.5 m and 13.9 m respectively, can, therefore, be construed as being within the limit of the streams' natural variability as it responds to alterations in water availability due to climatic or vegetation changes. The area that has seen statistically significant change beyond that of natural variability is that of channel widening immediately above the multipurpose level of Clinton Reservoir and below Clinton Dam, with an average width increase of 18.8 m.

Aerial photographic evidence shows that river position change from 1959 to 1991 has been minor. However, qualitative comparisons of modern channel position with the original federal land survey positions and position change illustrated in Douglas County by Dort (n.d.) indicate several channel position shifts after Euro-American settlement, but prior to 1959. Additionally, qualitative comparisons of 1941 (for Douglas County only), 1959, and 2006 aerial photographs have shown no indications of headwater extension, gully erosion, tributary incision or widening that would indicate impending mainstem channel change.

Human-induced changes to the Wakarusa River through the construction of a dam and roadways and vegetation alterations are the primary sources of channel width and position modifications. Unlike other regional river studies, such as those for the Medicine Lodge River (Martin and Johnson 1987) and the Cimarron River (VanLooy and Martin 2005), climatic fluctuations are not the primary driving force for channel change in the Wakarusa River basin. These western Kansas rivers flow in sandy alluvial channels in a semi-arid environment that, as Schumm (1977) and Knox (1983) noted, will respond more rapidly to environmental changes than will a channel of clay- and silt-rich alluvium in an environment with greater vegetation stability such as the Wakarusa River basin.

Widening in the central portion of the Wakarusa River is an effect of the construction of Clinton dam. As the reservoir filled, water backed up in the river channel to the west, increasing the low-flow width, and subsequent erosion increased bankfull widths, affecting the channel upstream from the reservoir for approximately thirteen kilometers. The reservoir itself acts as a sediment trap for over half of the drainage basin. The decreased sediment load of the water immediately downstream from the reservoir creates 'hungry water' that initiates channel degradation (bank and/or bed erosion), affecting about three kilometers of channel.

Slight channel narrowing in the lower reach and in the headwaters of the modern river, as compared to channel width of pre-Euro-American settlement, may be attributed to vegetation and land-use change. Field notes from the federal land surveys indicated the presence of a broad but discontinuous strip of riparian vegetation with sparse tree growth and prairie grass undergrowth. As early Euro-

American settlement progressed, destruction of the tree population occurred due to the construction of homes and industrial structures. As seen in Alexander Gardner's 1867 photo of post-Euro-American settlement, riparian vegetation had been decimated but some settlers had already begun cultivating orchards (Figure 26) (Charlton 2002). A viewpoint similar to that of Gardner's photograph was used by Charlton (2002) in 1994 and shows the Lawrence area covered by tree growth (Figure 27).

Today the riparian zone is narrow but contains dense tree growth and woody undergrowth along most of the channel. Aerial photographs of the Wakarusa channel south of Lawrence from 1941 (Figure 28) and 2006 (Figure 29) illustrate one of the many locations where expansion of riparian vegetation has occurred. Native prairie grass communities that were once seen in the valley bottom have been replaced with cultivated crops. The decrease in riparian vegetation after Euro-American settlement and the destruction of native prairies in favor of agricultural crops may also be responsible for the channel position changes seen prior to increased conservation practices implemented in the 1950s.

Narrowing in the downstream reach of the Wakarusa may also be occurring at present due to the affects of the reservoir impoundment on flow properties of the river. Stream discharge is now controlled and produces less variable discharges and lower peak discharges than experienced in a natural state (Figure 30). Increased channel degradation immediately below the dam supplies sediment to the water, but the regulated flow from the dam decreases the peak flows needed to carry this sediment out of the basin.

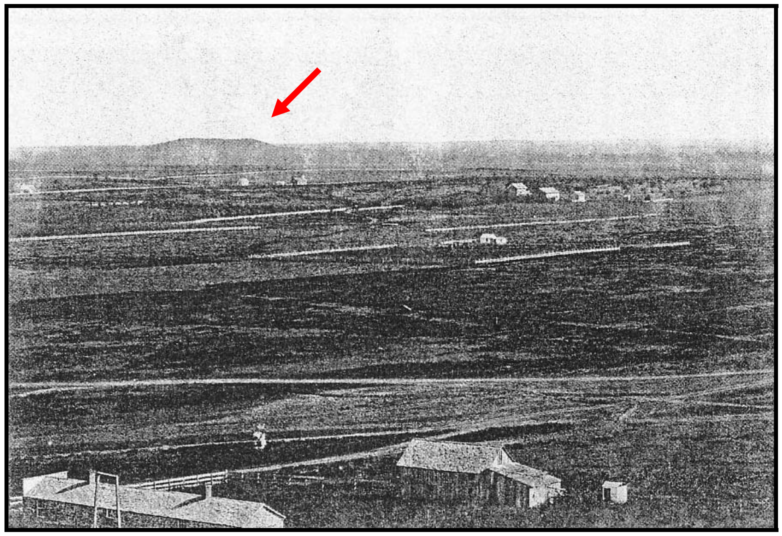


Figure 26: Alexander Gardner's 1867 photo of the Wakarusa River valley viewed south from Lawrence; Blue Mound, located on the south side of the Wakarusa River, is indicated by the red arrow (Charlton 2002)

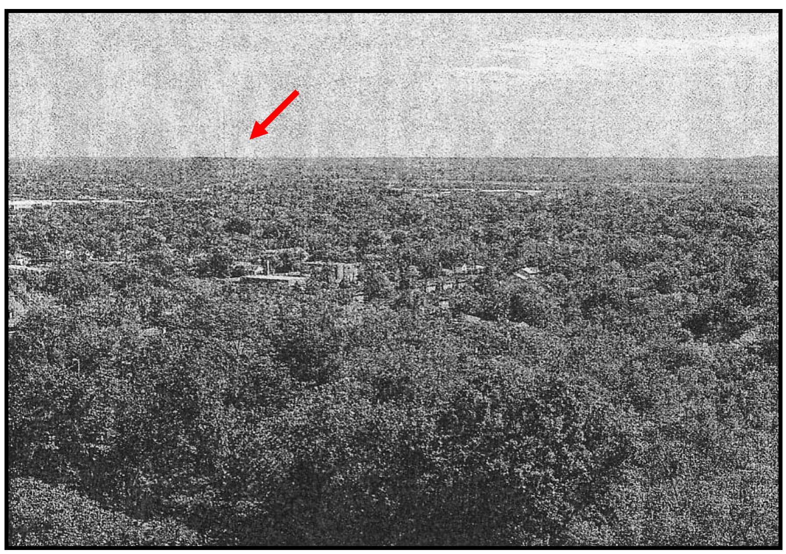


Figure 27: Repeat photography of the Wakarusa River valley south from Lawrence taken by John Charlton (2002) from the top of a building in order to have a view over the trees; Blue Mound is indicated by the red arrow

Figure 28: A 1941 aerial photograph showing the lack of trees along the Wakarusa River at a location east of Highway 59, directly south of Lawrence (KARS 1941)

Figure 29: A 2006 color infrared image of the Wakarusa River channel east of Highway 59 showing the increase of woody riparian vegetation (DASC 2007)

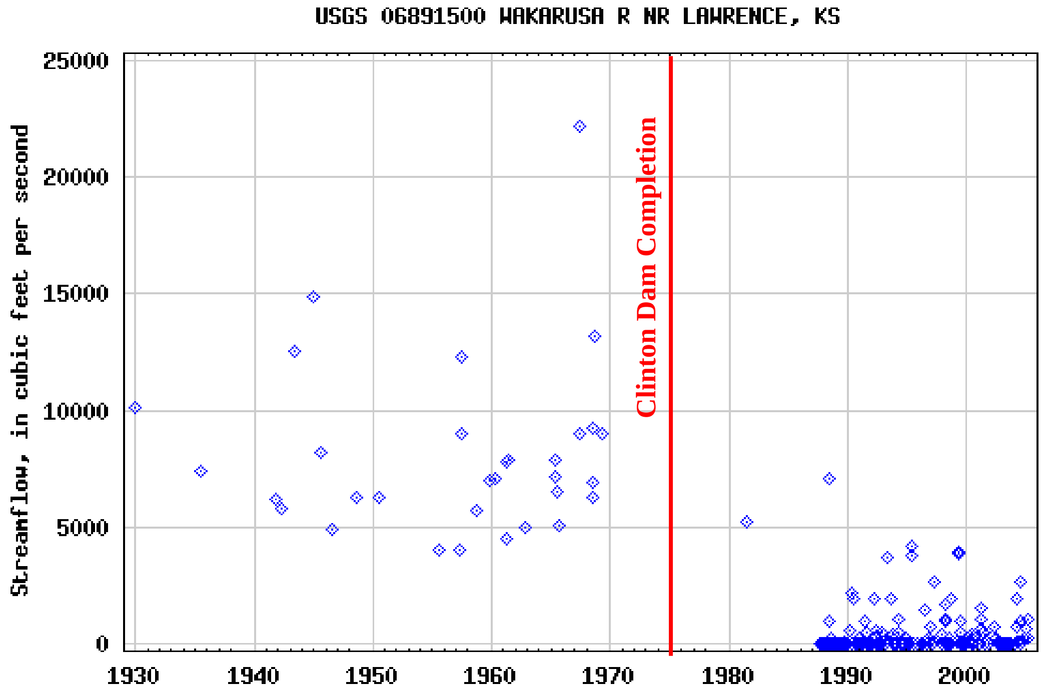


Figure 30: Streamflow measurements taken at the gaging station near Lawrence before and after dam completion in 1975. (USGS 2002)

This investigation has incorporated qualitative and quantitative measurements of width and position change, but channel depth is also an important factor when discussing channel responses to exogenic variables. Due to the lack of more than one streamflow-gaging station or any other form of previous depth measurements, modern depth measurements and comparisons were beyond the scope of this project. It has been noted, however, that in silt- and clay-rich sediments, such as in the Wakarusa River channel, there may be an alteration of channel depth, and not width, in response to water flow adjustments brought on by climate and land-use changes (Schumm 1960).

References Cited

Abmeyer, Walter, and Howard V. Campbell. 1970. *Soil Survey of Shawnee County, Kansas.* United States Department of Agriculture, Soil Conservation Service. 77 pgs.

Allen, J. R. L. 1977. Changeable Rivers: Some Aspects of their Mechanics and Sedimentation. In *River Channel Changes,* ed. K. J. Gregory, 15-46. Chichester: John Wiley & Sons.

Anonymous. 1913. Deichman's Crossing near Lawrence. http://www.ci.lawrence.ks. us/local_history/postcards/wakarusa.shtml. Accessed 3/22/2002.

Bates, J. and J. Mitchell. 1855. *Land Survey Plats*. U.S. Department of the Interior, U.S. Surveyor General of Kansas and Nebraska.

Bates, J. and J. Mitchell. 1855b. *Land Survey Field Notes*. Book 462, Part C. U.S. Department of the Interior, U.S. Surveyor General of Kansas and Nebraska.

Brinker, Russell C. and Paul R. Wolf. 1977. *Elementary Surveying*. Toronto: Fitzhenry and Whiteside, Ltd. 568 pgs.

Brockett, Walter B. 1856. *Land Survey Plats*. U.S. Department of the Interior, U.S. Surveyor General of Kansas and Nebraska.

Burt, James E. and Gerald M. Barber. 1996. *Elementary Statistics for Geographers*. New York: The Guilford Press. 640 pgs.

Burge, Clifton L. 1856. *Land Survey Plats*. U.S. Department of the Interior, U.S. Surveyor General of Kansas and Nebraska.

Card, William J. 1856. *Land Survey Plats*. U.S. Department of the Interior, U.S. Surveyor General of Kansas and Nebraska.

Charlton, John. 2002. Across the Years on Mount Oread and Around the Kaw and Wakarusa River Valleys. *Transactions of the Kansas Academy of Science* 105(1-2): 1-17.

Chorley, Richard J. 1957. Climate and Morphometry. *Journal of Geology* 65: 628-638.

Connelly, Thomas. 1856. *Land Survey Plats*. U.S. Department of the Interior, U.S. Surveyor General of Kansas and Nebraska.

Connelly, Thomas. 1856b. *Land Survey Field Notes*. Book 496, Part B. U.S. Department of the Interior, U.S. Surveyor General of Kansas and Nebraska.

Cutler, William G. 1883. *History of the State of Kansas*. Chicago: A.T. Andreas.

Data Access and Support Center (DASC). http://gisdasc.kgs.ukans.edu/. Accessed 4/15/2002.

Derrick, Henry C. 1856. *Land Survey Plats*. U.S. Department of the Interior, U.S. Surveyor General of Kansas and Nebraska.

Dickey, Harold P., Jerome L. Zimmerman, Robert O. Plinsky, and Richard D. Davis. 1977. *Soil Survey of Douglas County, Kansas*. United States Department of Agriculture, Soil Conservation Service. 73 pgs.

Dort, Wakefield, Jr. n.d. *Channel Migration Investigation: Historic Channel Change Maps.* Kansas City: U. S. Army, Corps of Engineers. 51 pgs.

Fitzgerald, Daniel. 1976. *Ghost towns of Kansas.* Topeka: Fitzgerald. 300 pgs.

Franzwa, Gregory M. 1982. *Maps of the Oregon Trail*. Gerald, MO: Patrice Press.

Grauberger, Darin T. and George F. McCleary (map developers). 1997. *Historic Trails of Douglas County, Kansas.* Lawrence, KS: Convention and Visitors Bureau.

Gregory, K. J. 1977. The Context of River Channel Changes. In *River Channel Changes*, ed. K. J. Gregory, 1-12. Chichester: John Wiley & Sons.

Harvey, A. M. 1917. *Tails and Trails of Wakarusa*. Topeka: Crane.

Johnson, William C. 1979. Historical trends in sediment movement within stream systems of the Midwestern United States. *Applied Geography Conferences* 2: 225-236.

Johnson, W.D. Jr., H.C. Wagner, and W.L. Adkison. 2001. Geologic map of Shawnee County, Kansas. Kansas Geological Survey. http://www.kgs.ku.edu 4/29/2003.

Kansas Applied Remote Sensing (KARS). 1941. Aerial photography prints.

Kansas Applied Remote Sensing (KARS). 1959. Aerial photography prints.

Knox, James C. 1972. Valley Alluviation in Southwestern Wisconsin. *Annals of the Association of American Geographers* 62(3): 401-410.

Knox, James C. 1983. Responses of River Systems to Holocene Climates. In *Late-Quaternary Environments of the United States,* ed. H.E. Wright, Jr., 2: 26-41. Minneapolis: University of Minnesota Press.

Knox, James C. 1977. Human Impacts on Wisconsin Stream Channels. *Annals of the Association of American Geographers* 67(3): 323-342.

Logan, Brad, Mary J. Adair, Steven Bozarth, Glen G. Fredlund, Rolfe D. Mandel, William Ranney, and Lauren W. Ritterbush. 1987. *Archaeological Investigation in the Clinton Lake Project Area Northeastern Kansas: National Register Evaluation of 27 Prehistoric sites*. Kansas City: U.S. Army Corps of Engineers. 326 pgs.

Martin, Charles W., and William C. Johnson. 1987. Historical Channel Narrowing and Riparian Vegetation Expansion in the Medicine Lodge River Basin, Kansas, 1871-1983. *Annals of the Association of American Geographers* 77(3): 436-449.

National Oceanic and Atmospheric Administration (NOAA). http://climvis.ncdc.noaa.gov/oa/climate/research/cag3.html 3/15/2005

Natural Resource and Conservation Service (NRCS). 1981. Color infrared (IR) aerial photography prints.

O'Connor, H.G. 1960. *Geology and Ground-water Resources of Douglas County, Kansas*. Kansas Geological Survey, Volume 148, 200 pgs.

O'Connor, H.G. 1992. Geologic map, Douglas County. Kansas Geological Survey. http://www.kgs.ku.edu 4/11/2003.

Park, C. C. 1977. Man-induced Changes in Stream Channel Capacity. In *River Channel Changes*, ed. K. J. Gregory, 121-144. Chichester: John Wiley & Sons.

Parker, Martha and Betty Laird. 1994. *Soil of Our Souls: Histories of the Clinton Lake Area Communities*. Overbrook, KS: Parker-Laird Enterprises.

Sampson, Matthew R. 2000. *Stream response to channelization: the case history of the West Nishnabotna River, Pottawattamie County, Iowa*. The University of Kansas, unpublished MA Thesis. 129 pg.

Sargent, C.S. 1884. *Report on the Forests of North America (Exclusive of Mexico).* Washington: Department of the Interior, Census Office, Government Printing Office.

Schumm, S.A. 1960. *The Shape of Alluvial Channels in Relation to Sediment Type.* Professional Paper 350-B. Washington, DC: U.S. Geological Survey.

Schumm, S.A. 1968. Speculations concerning paleohydrologic controls of terrestrial sedimentation. *GSA Bulletin* 79: 1573-1588.

Schumm, S.A. (editor). 1977. Drainage Basin Morphology. *Benchmark papers in geology* 41. Stroudsburg, PA: Dowden, Hutchinson & Ross.

Schumm, S.A. and R.W. Lichty. 1963. *Channel Widening and Flood-plain Construction Along Cimarron River in Southwestern Kansas.* Professional Paper 352-D. Washington, DC: U.S. Geological Survey. 88 pgs.

Tiffin, E. Instructions for Deputy Surveyors, 1815. In *A History of the Rectangular Survey System,* ed. C.A. White, 248. United States Department of the Interior, Bureau of Land Management: Washington, DC, 1926. 774 pgs.

Todd, J.E. 1910. History of Wakarusa Creek. *Kansas Academy of Science: Geological Papers* 211-218.

U.S. Army Corps of Engineers, Kansas City District. *Clinton Lake*. http://www.nwk.usace.army.mil/clinton/dam.htm 4/09/2002.

United States Geological Survey (USGS). National Water Information System. http://ks.waterdata.usgs.gov/nwis/ 10/29/2002.

VanLooy, Jeffrey A. and Charles W. Martin. 2005. Channel and Vegetation Change on the Cimarron River, Southwestern Kansas, 1953-2001. *Annals of the Association of American Geographers* 95(4): 727-739.

Whistler, Jerry, Mark Jakubauskas, Stephen Egbert, Edward Martinko, David Baumgartner, and Re-Yang Lee. 1991. *Kansas Land Cover Patterns*. Kansas Applied Remote Sensing Program. http://gisdasc.kgs.ukans.edu/dasc/kanviewframe.html 4/20/2003.

Williams, Garnett P. and M. Gordon Wolman. 1984. *Downstream Effects of Dams on Alluvial Rivers*. Professional Paper 1286. Washington, DC: U.S. Geological Survey. 83 pgs.

Appendix 1
Modern Field Measurements

This appendix includes plates for each site and are comprised of ground photography and cross-sectional profiles produced from field measurements at low-flow water level. Point specific data are listed in tables following the plate images. Site locations are shown in Figure 8.

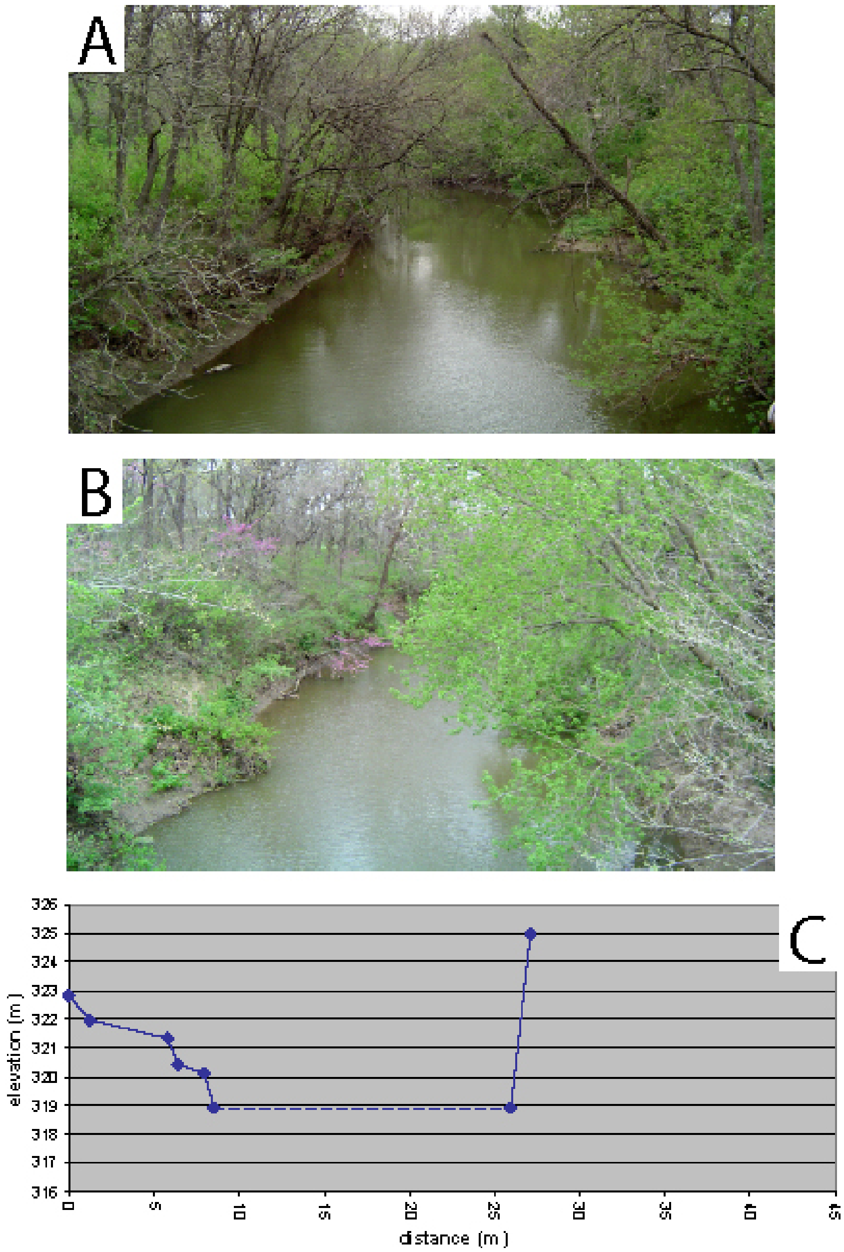


Plate 1: Site location: 38.89693° N, 95.83604° W. A) Downstream from section line, B) upstream view from bridge overlooking site 1 with thick tree growth and undergrowth, C) channel profile facing downstream

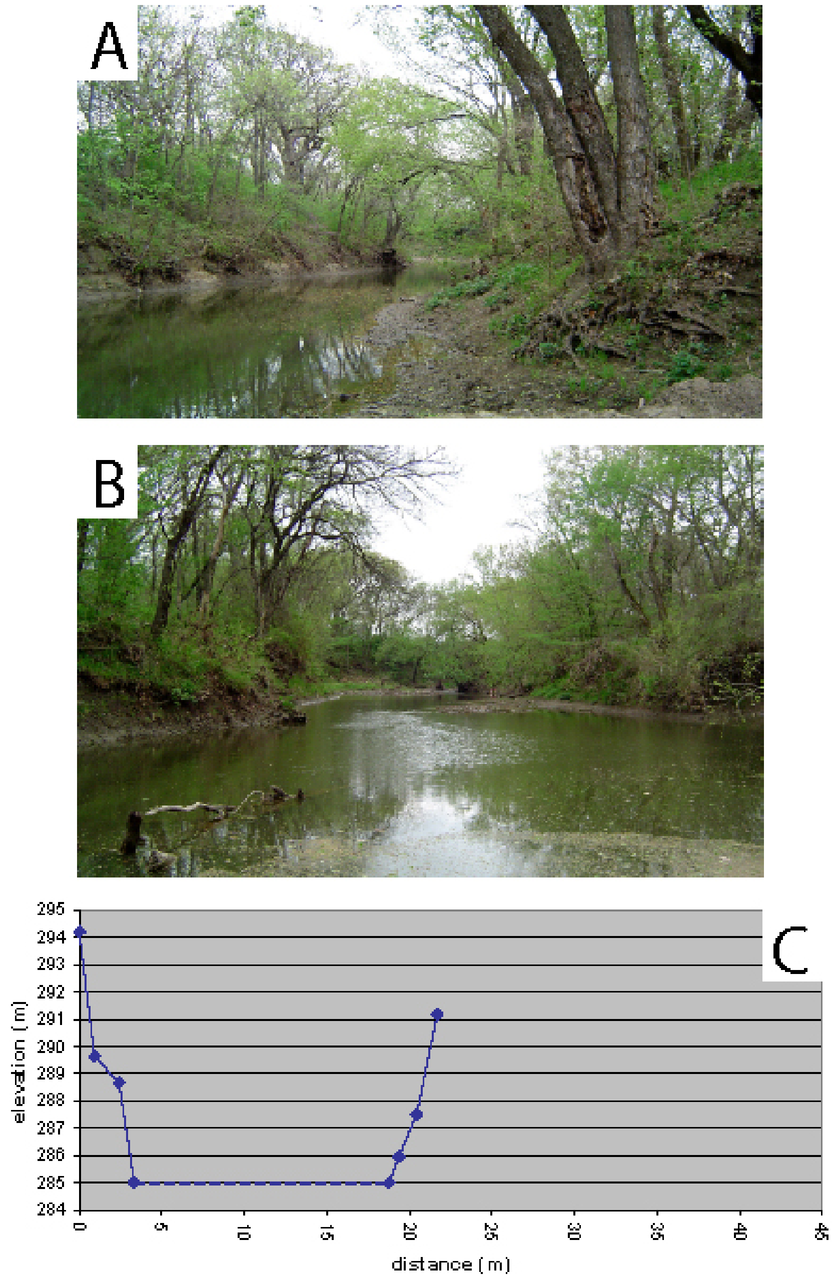


Plate 2: Site location: 38.88974° N, 95.72309° W. A) Downstream from site 2, B) upstream view, C) channel profile facing downstream

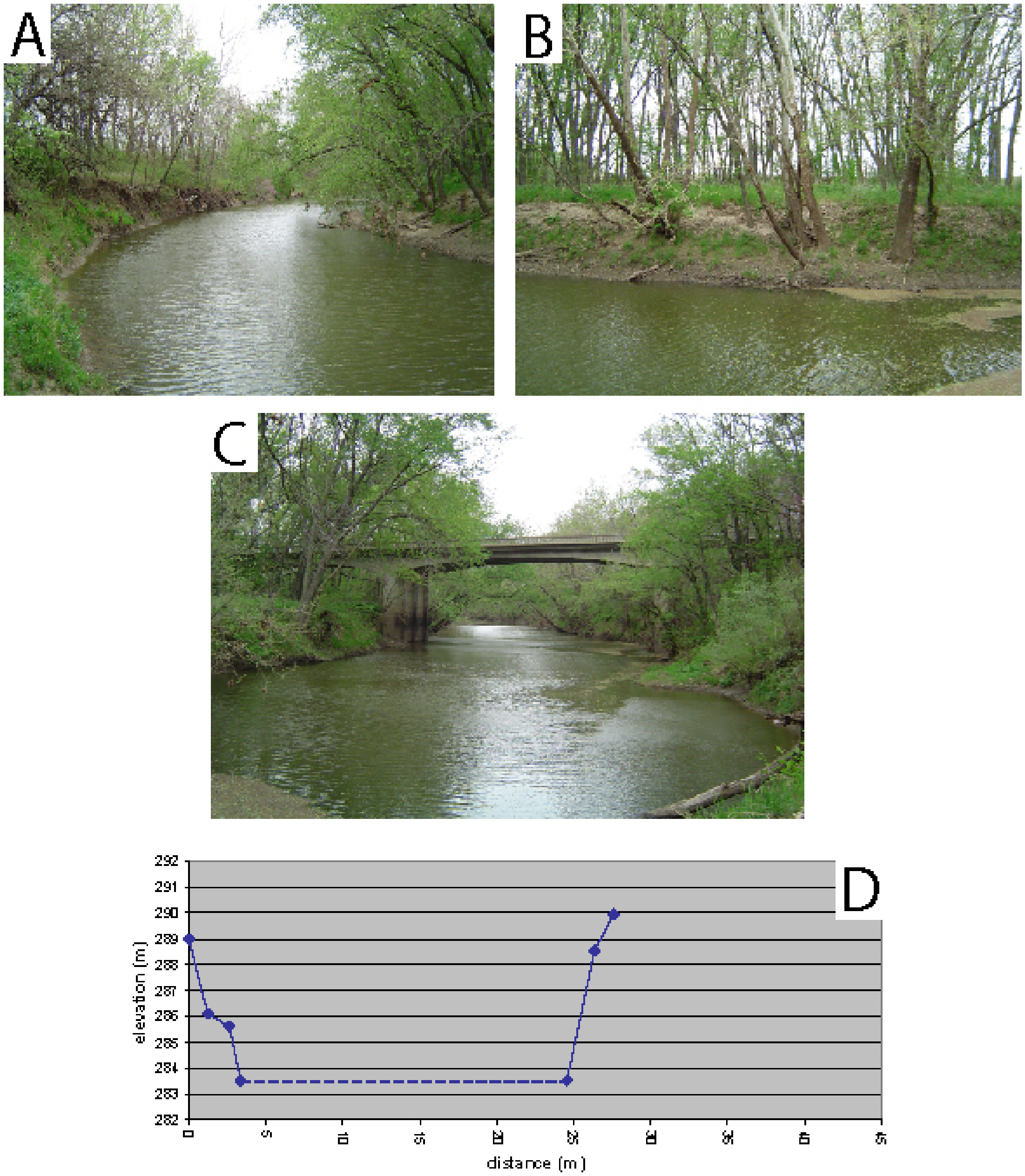


Plate 3: Site location: 38.89090° N, 95.68626° W. A) Downstream from site 3, B) south bank with tree growth at low-flow level, C) upstream view toward section line and bridge of old Highway 75, D) channel profile facing downstream

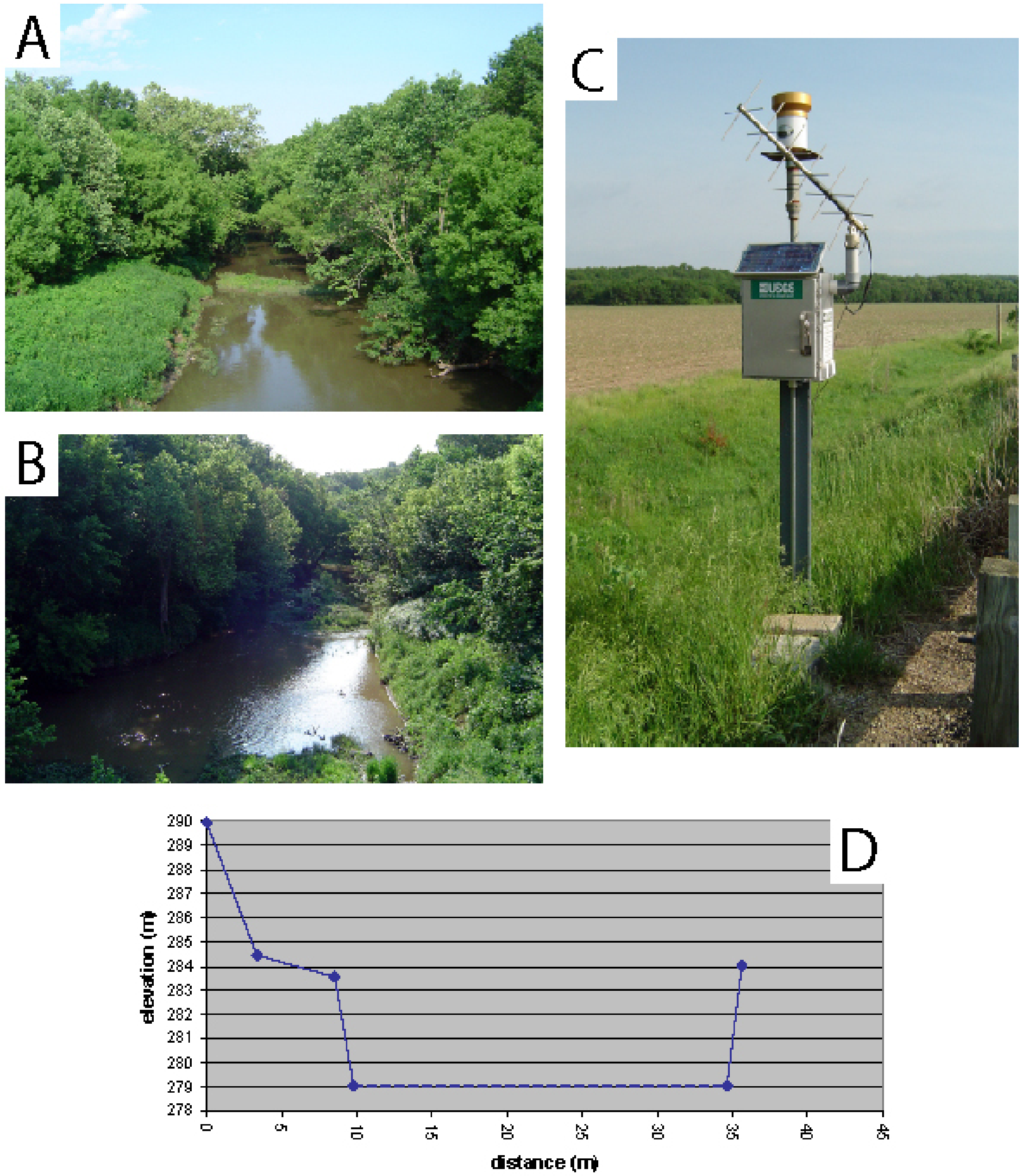


Plate 4: Site location: 38.89187° N, 95.59573° W. A) Upstream from section line bridge viewing site 4 with thick riparian vegetation, B) downstream from bridge, C) gauging station near bridge, D) channel profile facing downstream

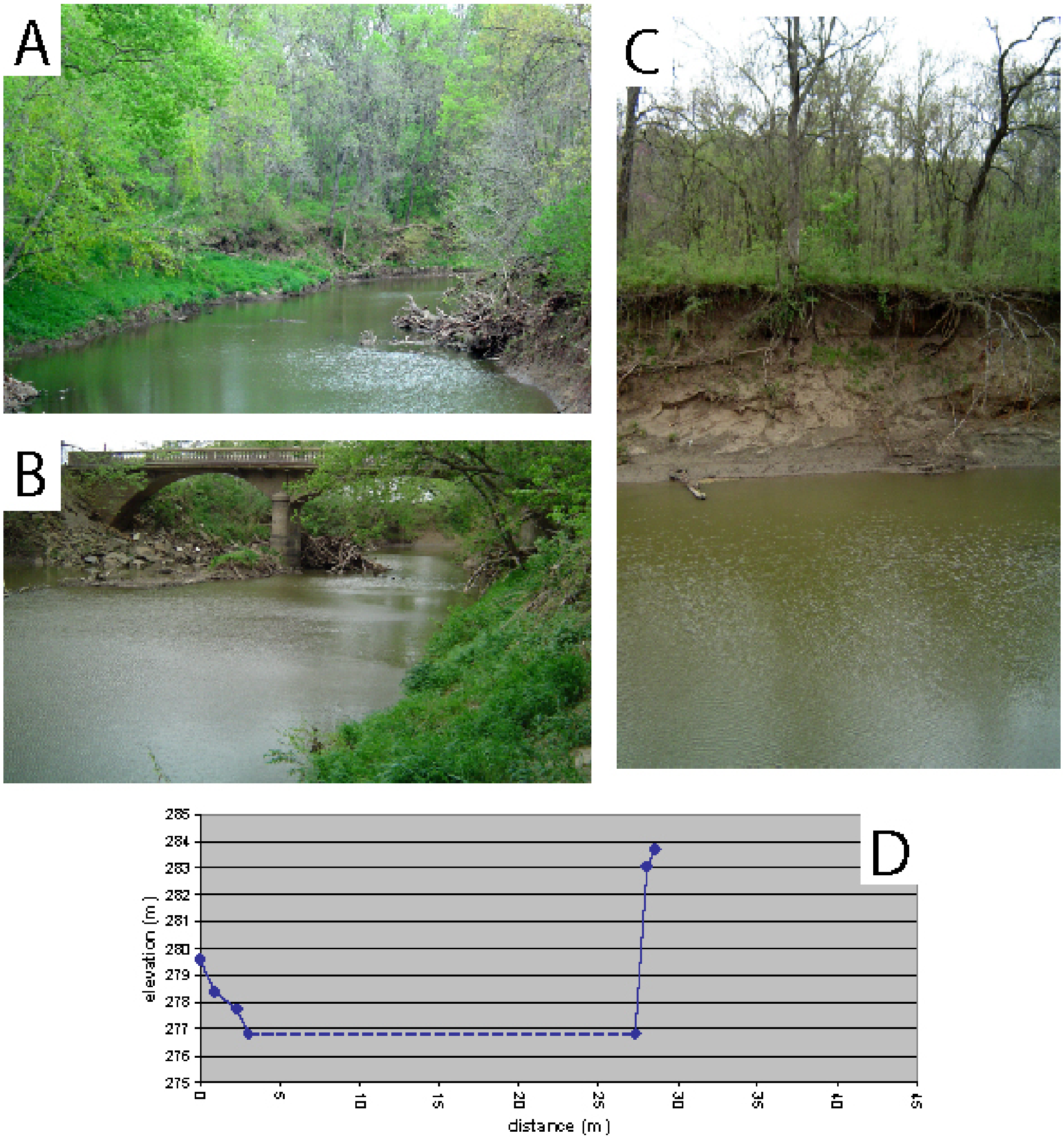


Plate 5: Site location: 38.89733° N, 95.57585° W. A) Downstream from site 5, B) upstream toward section line where debris trapped by the bridge is constricting channel width, C) bank erosion on the south bank, D) channel profile facing downstream

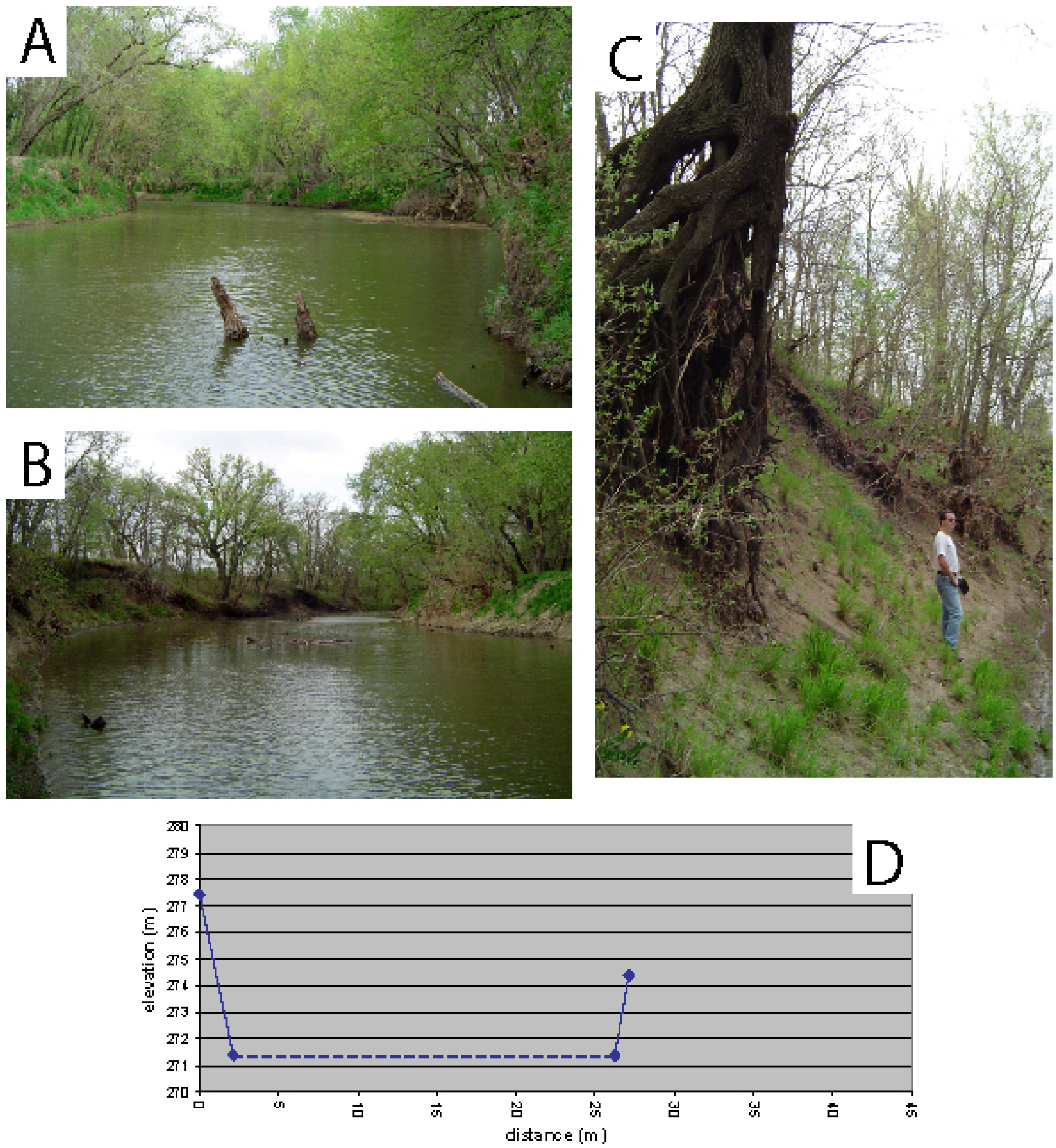


Plate 6: Site location: 38.89884° N, 95.51522° W. A) Upstream from site 6, B) downstream view, C) east bank facing downstream, D) channel profile facing downstream

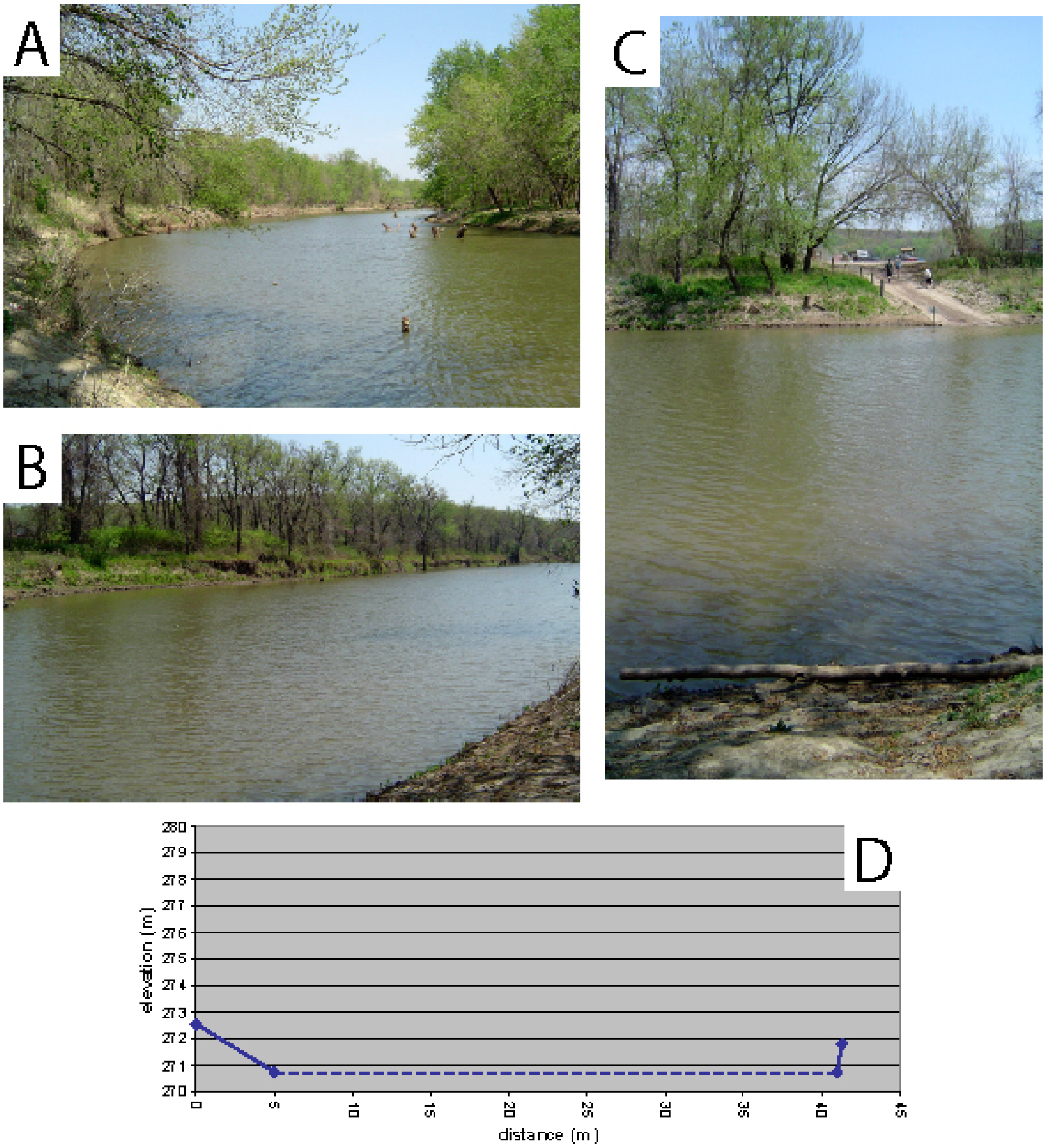


Plate 7: Site location: 38.89148° N, 95.48180° W. A) Downstream view upstream of Clinton Reservoir, B) a continuing broad channel in the upstream direction, C) boat ramp on the east bank, D) broad channel profile of site 7 facing downstream

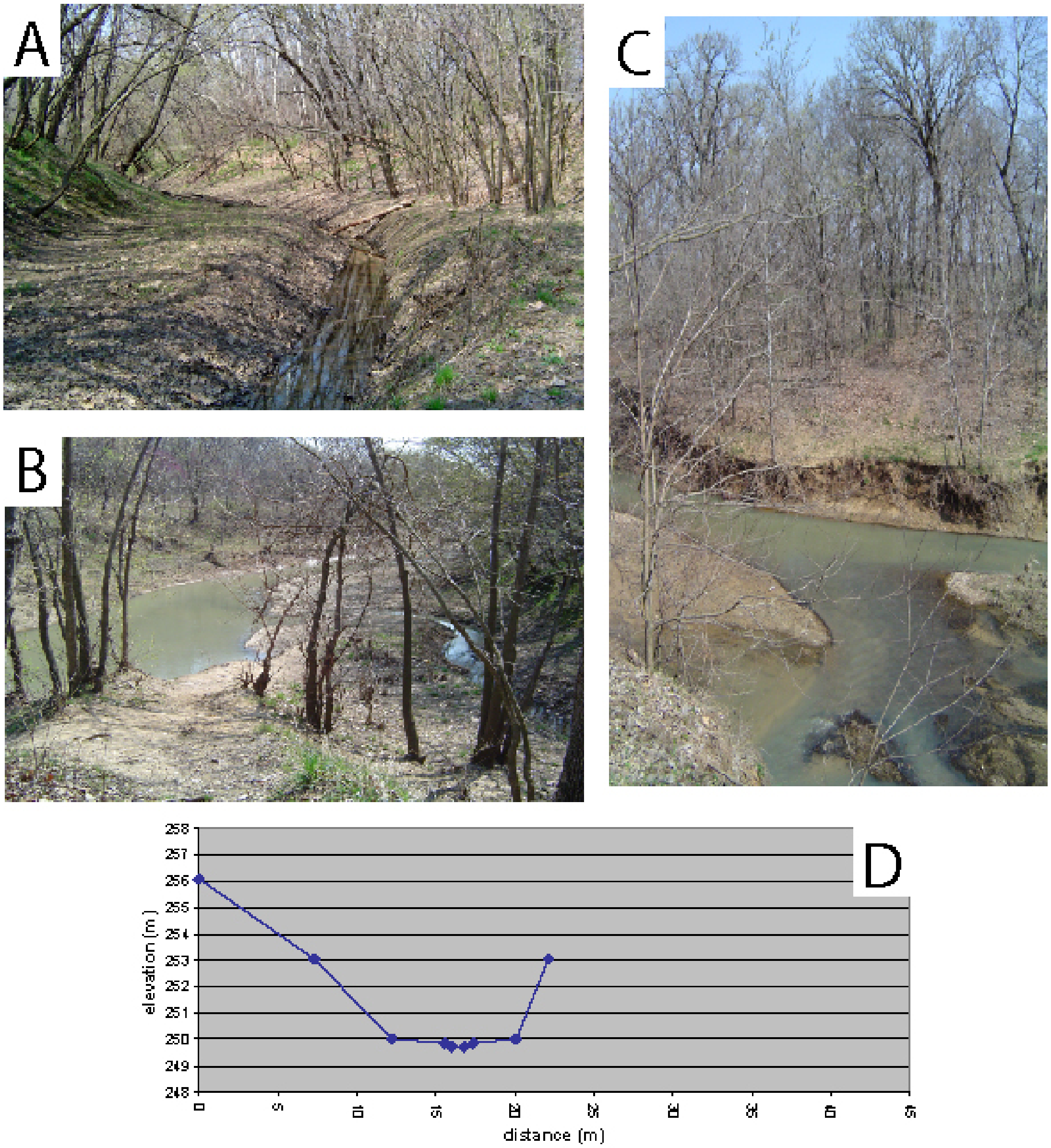


Plate 8: Site location: 38.92682° N, 95.31902° W. A) Abandoned channel below Clinton Reservoir that has been bypassed by the dam outlet channel, B) confluence of the abandoned channel and the outlet channel, C) north bank of the outlet channel, D) profile of abandoned channel facing downstream

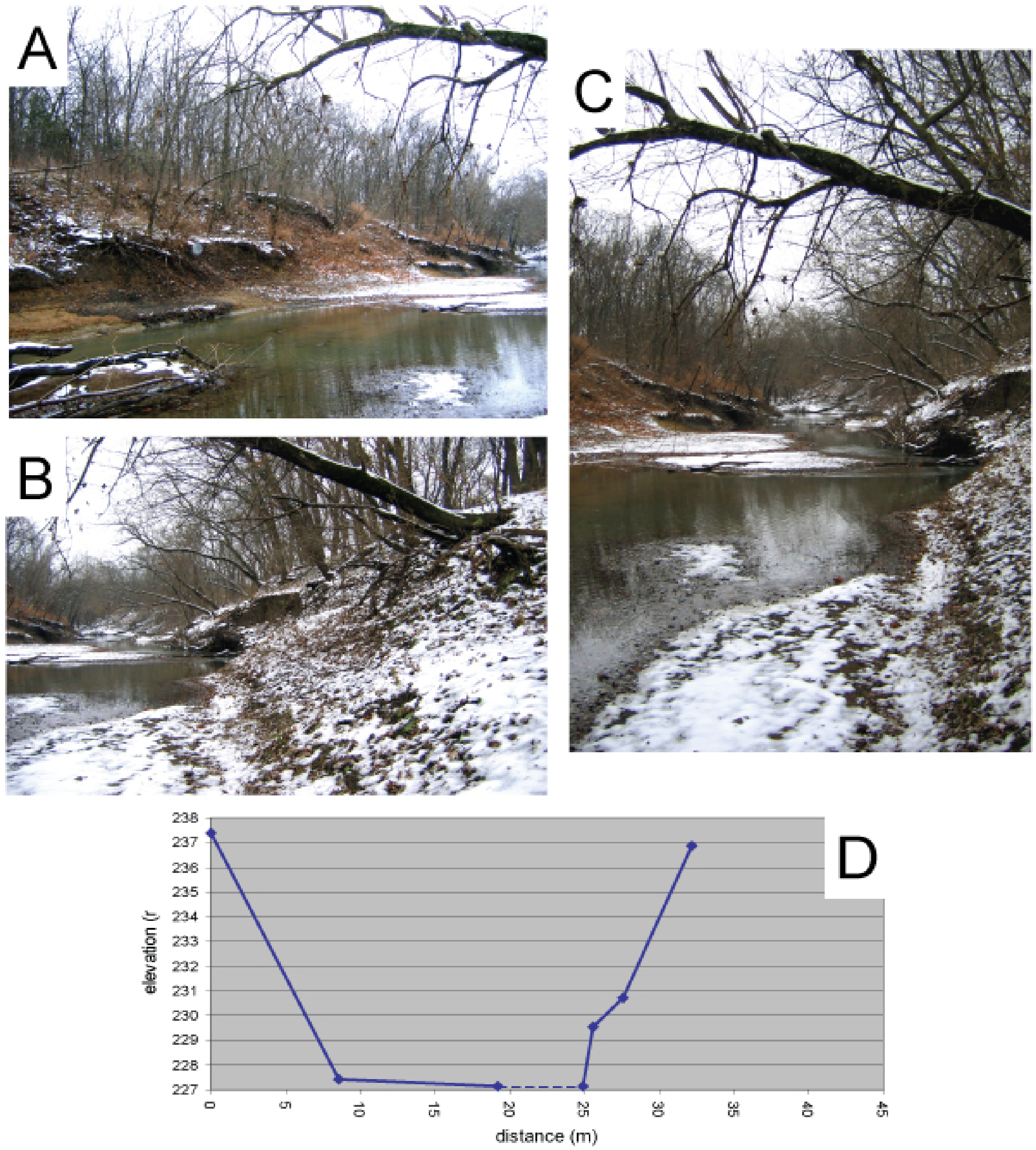


Plate 9: Site location: 38.92640° N, 95.31801° W. A) North bank showing bank erosion downstream of the dam outlet channel, B) south bank, C) downstream view showing channel sandbars, D) channel profile facing downstream

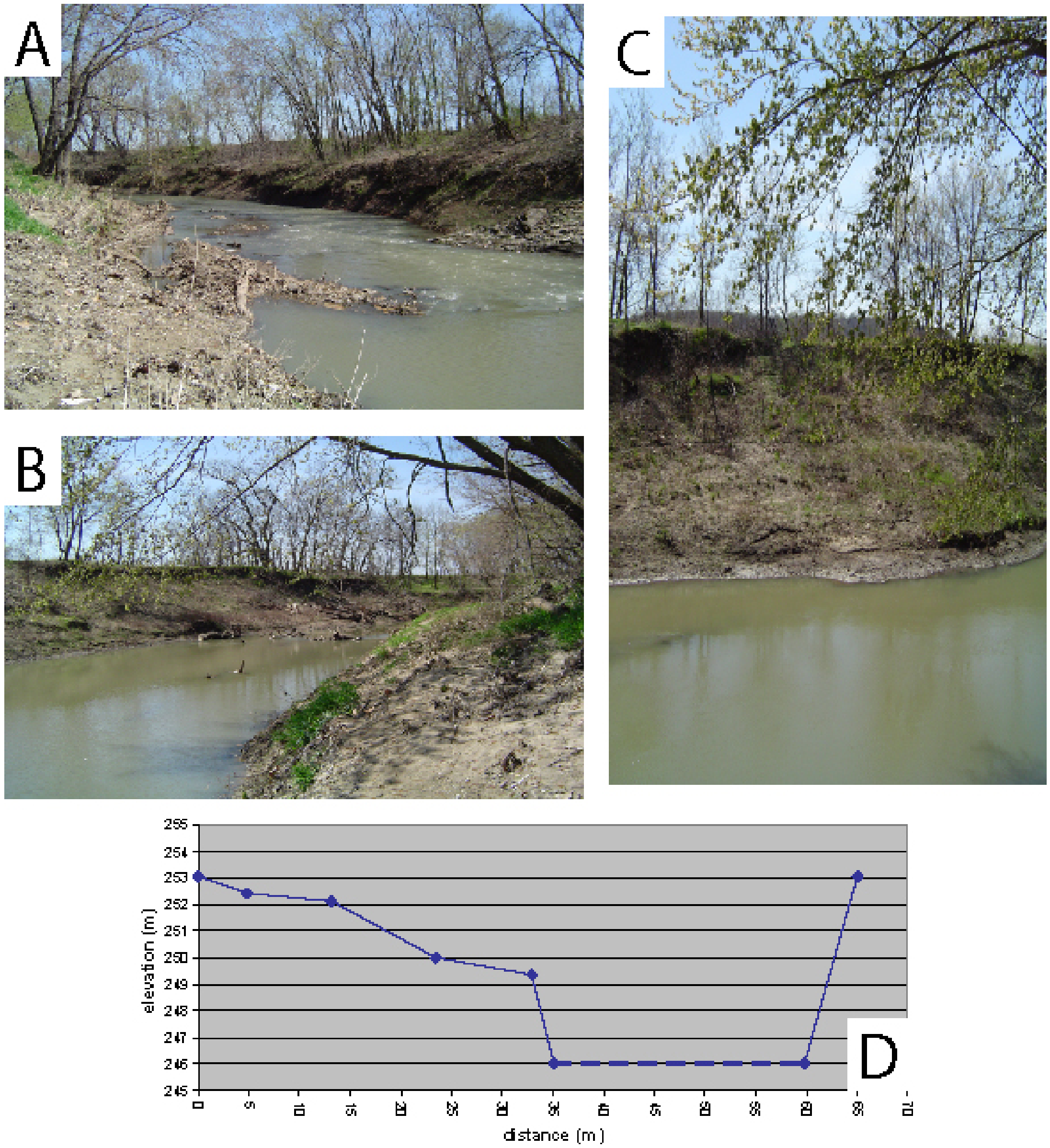


Plate 10: Site location: 38.91668° N, 95.27932° W. A) Downstream view, B) view of cutbank in the upstream direction, C) south cutbank of site 10, D) channel profile facing downstream

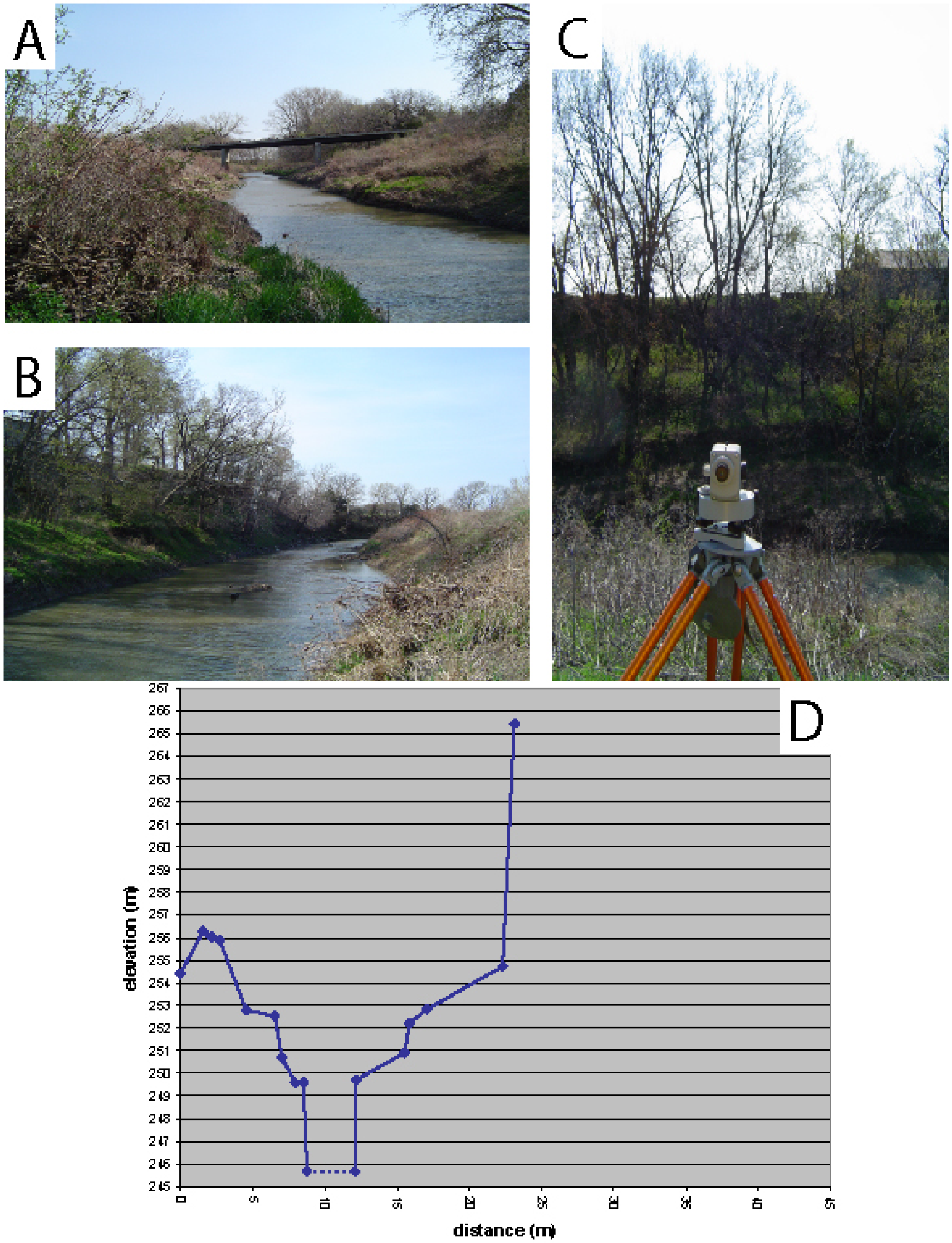


Plate 11: Site location: 38.91123° N, 95.24311° W. A) Downstream to section line and bridge on E 1400 Rd., B) upstream view, C) overlooking site 11 with the valley wall on the south side, D) the channel profile facing downstream shows the stream between the valley wall and a man-made dike

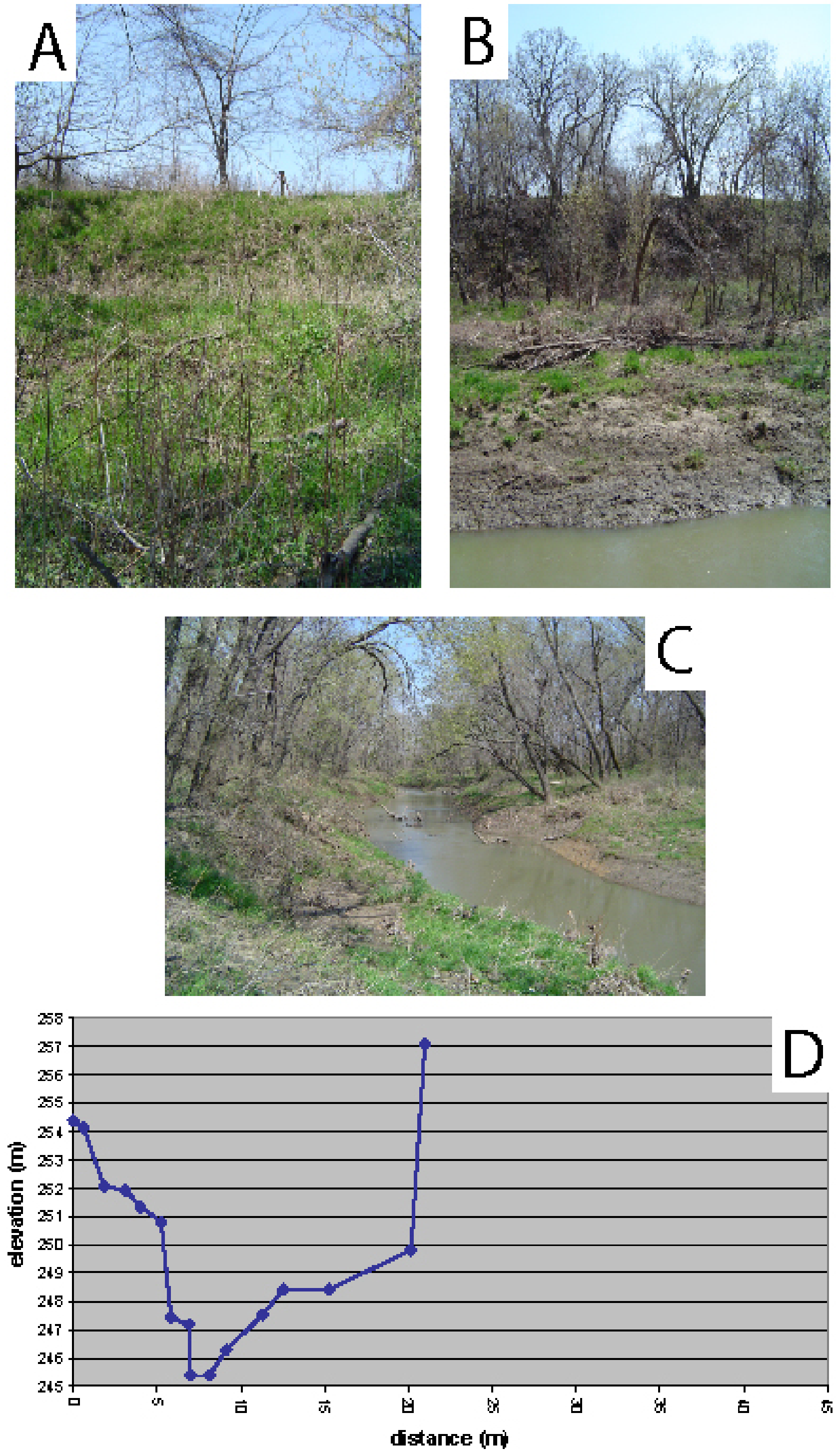


Plate 12: Site location: 38.91150° N, 95.22304° W. A) Steep southern bank, B) view of the north bank, C) downstream from site 12, D) channel profile facing downstream

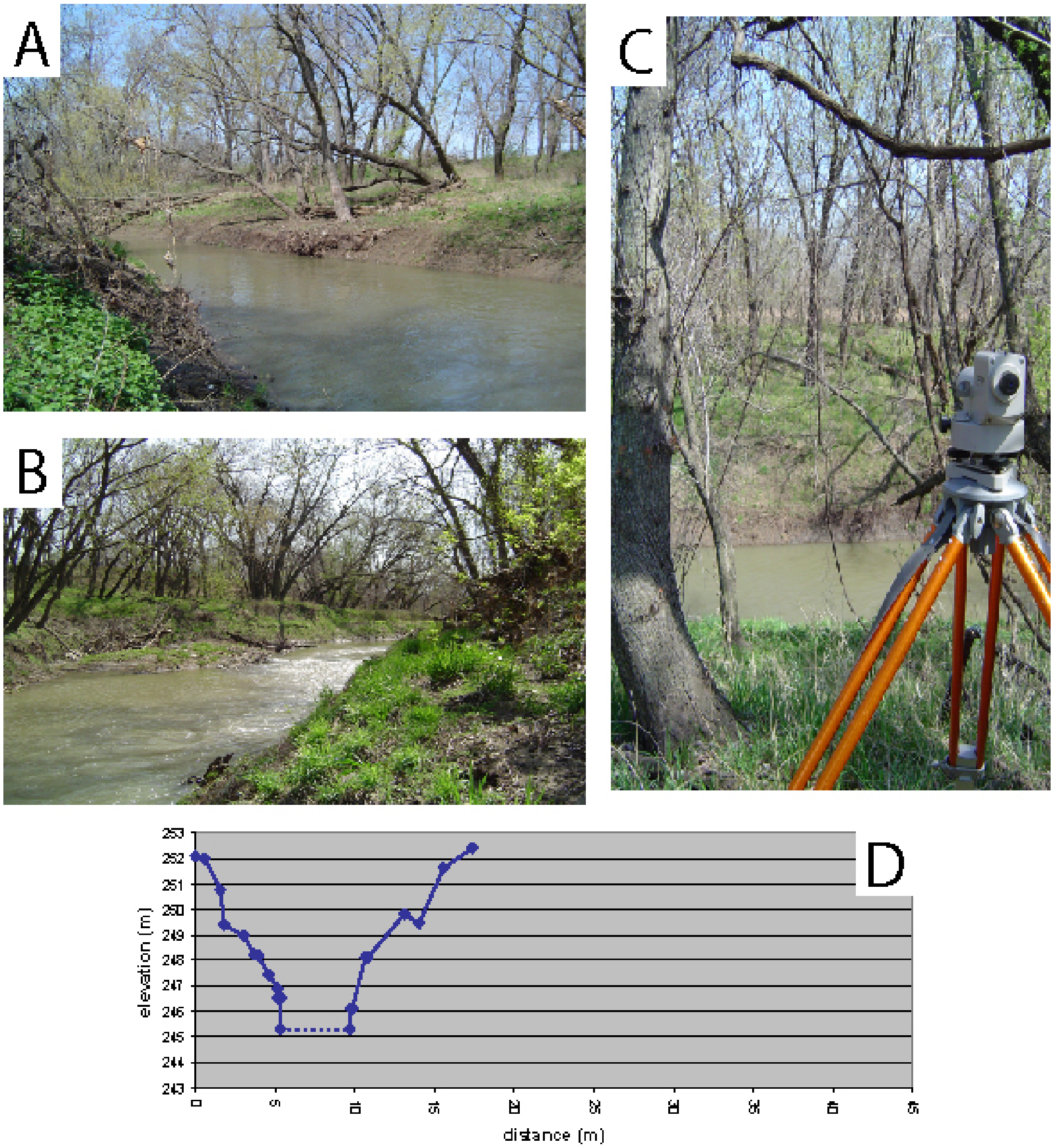


Plate 13: Site location: 38.91295° N, 95.22207° W. A) Downstream channel, B) upstream view with tree growth near the low-flow water level, C) view to the east bank, D) channel profile facing downstream

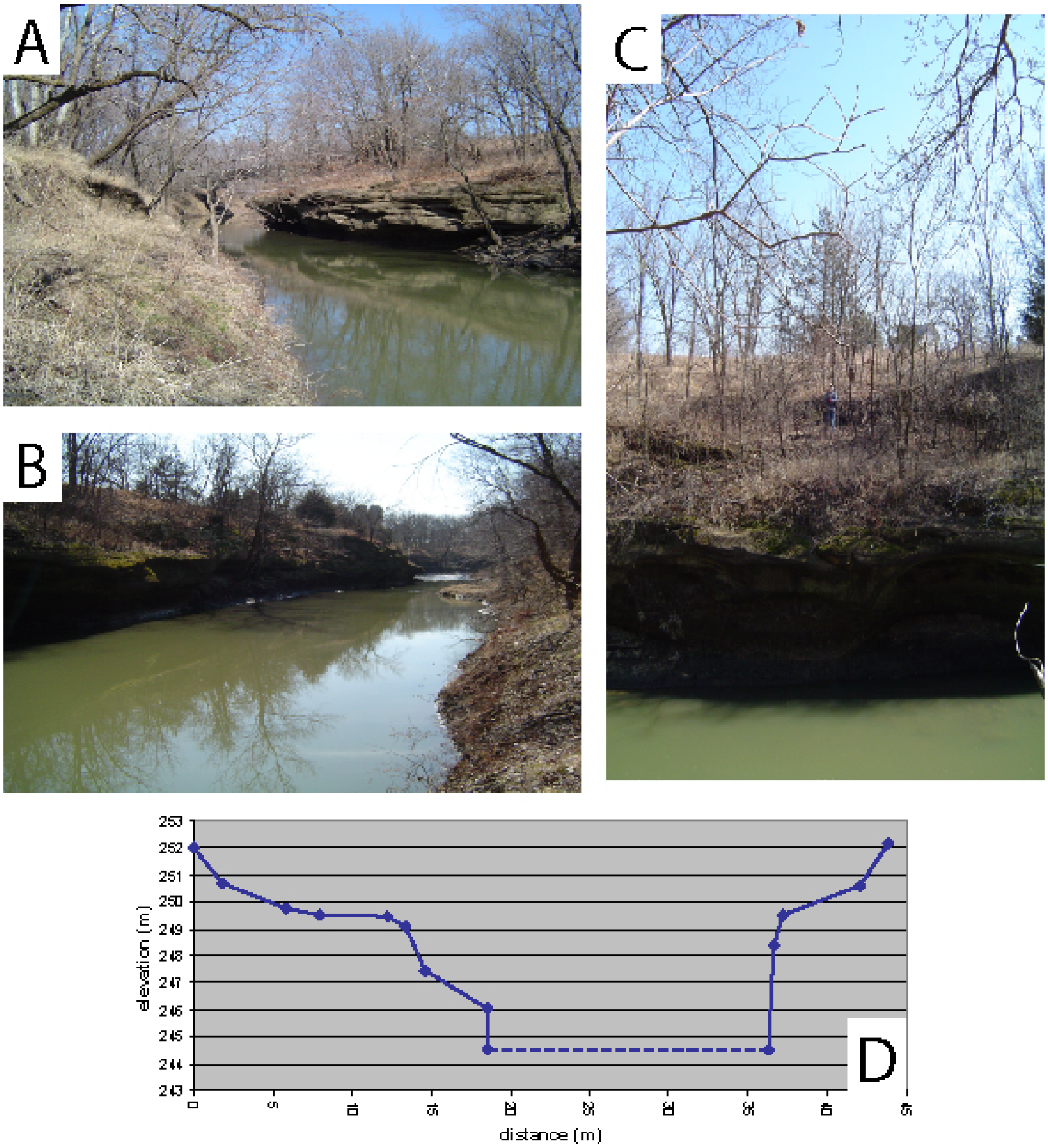


Plate 14: Site location: 38.92607°N 95.1495°W. A) Downstream toward section line, B) upstream view, C) sandstone outcrop on the south bank, and D) cross section profile facing downstream

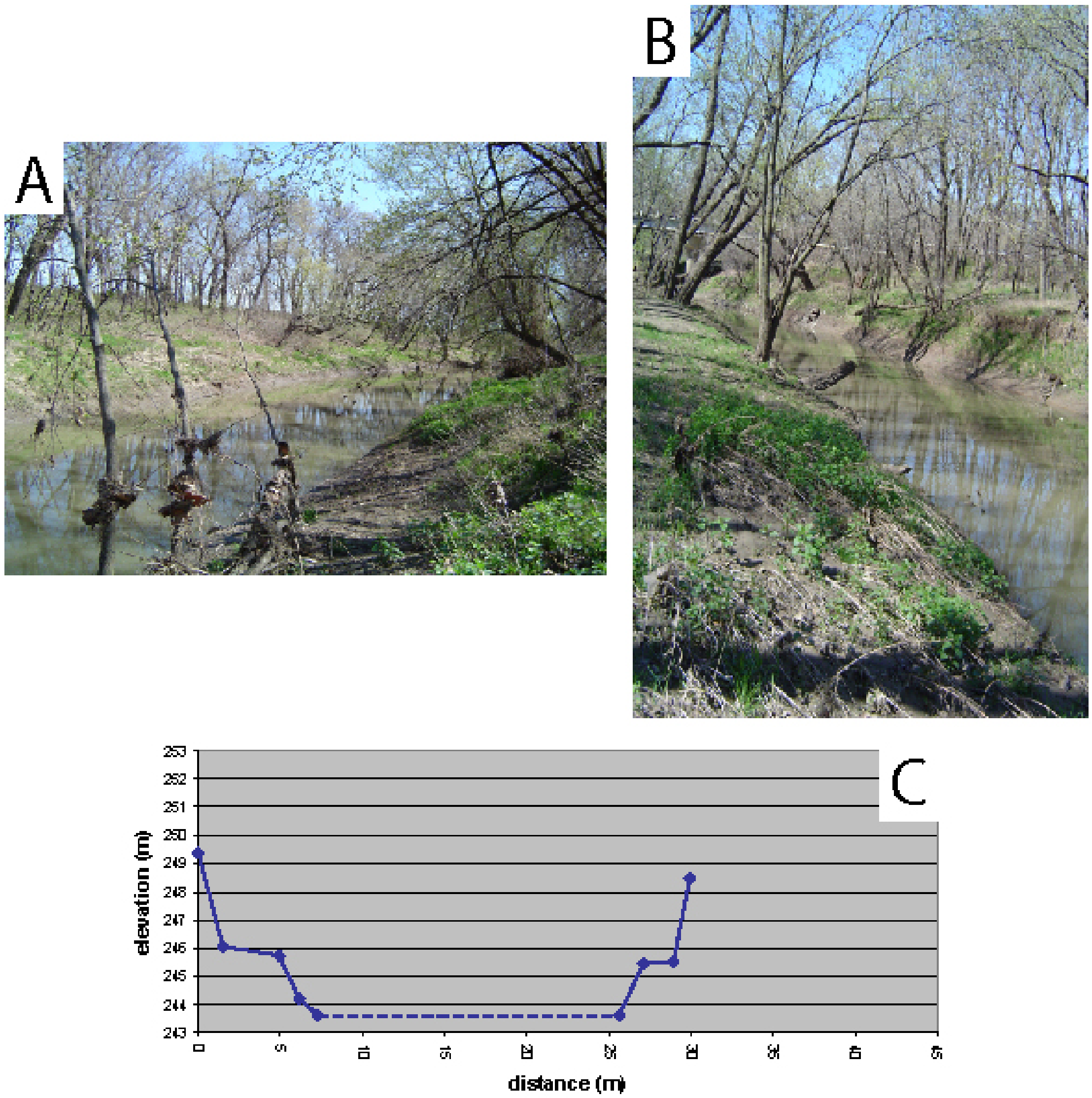


Plate 15: Site location: 38.92785° N, 95.14835° W. A) Channel downstream from site 15, B) upstream toward section line bridge on Hwy. 1057, C) channel profile facing downstream

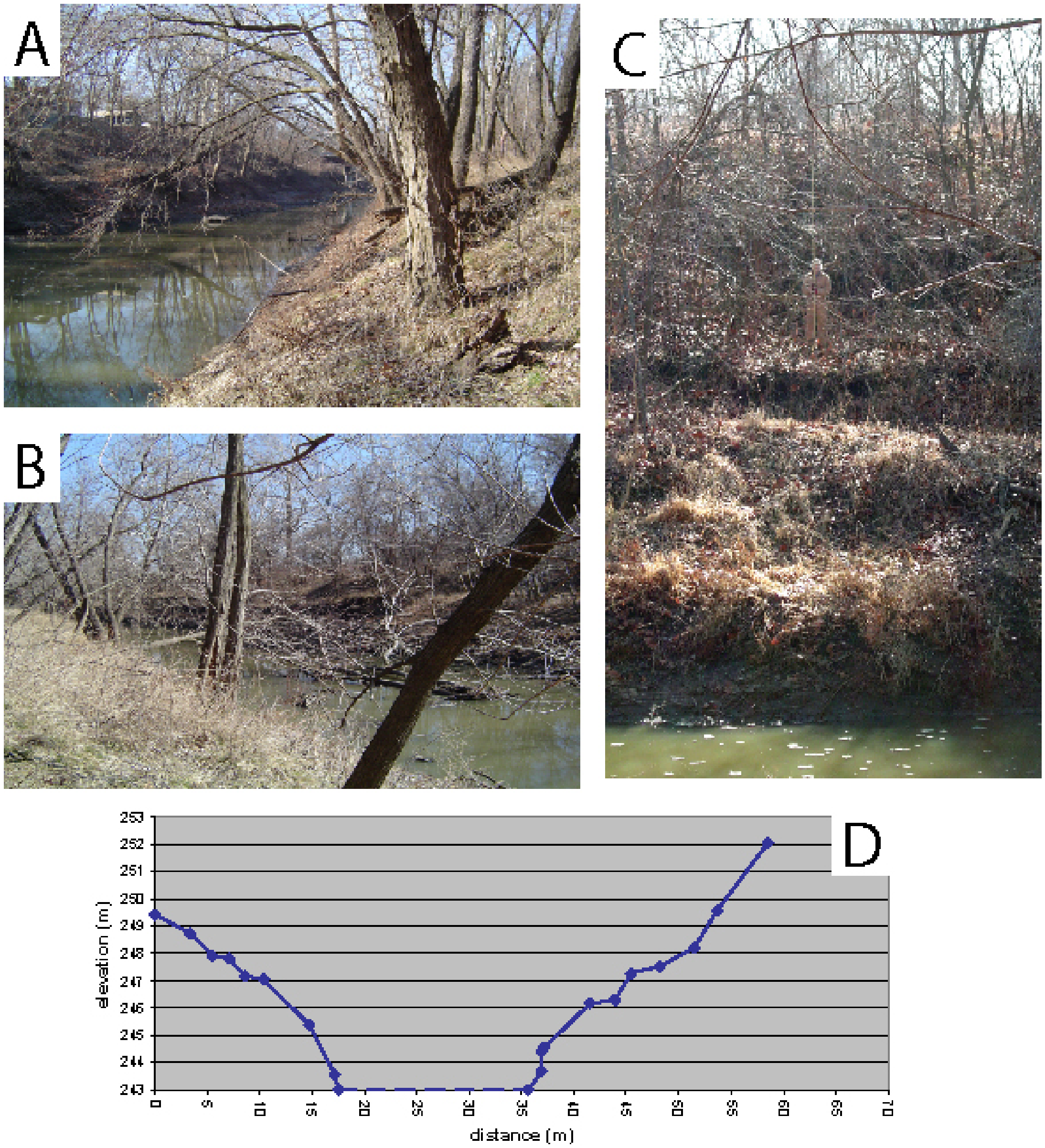


Plate 16: Site location: 38.94361° N, 95.11133° W. A) Upstream view with tree growth and grass covering the banks down to low-flow water level, B) downstream, C) steep bank of the east side, D) channel profile facing downstream

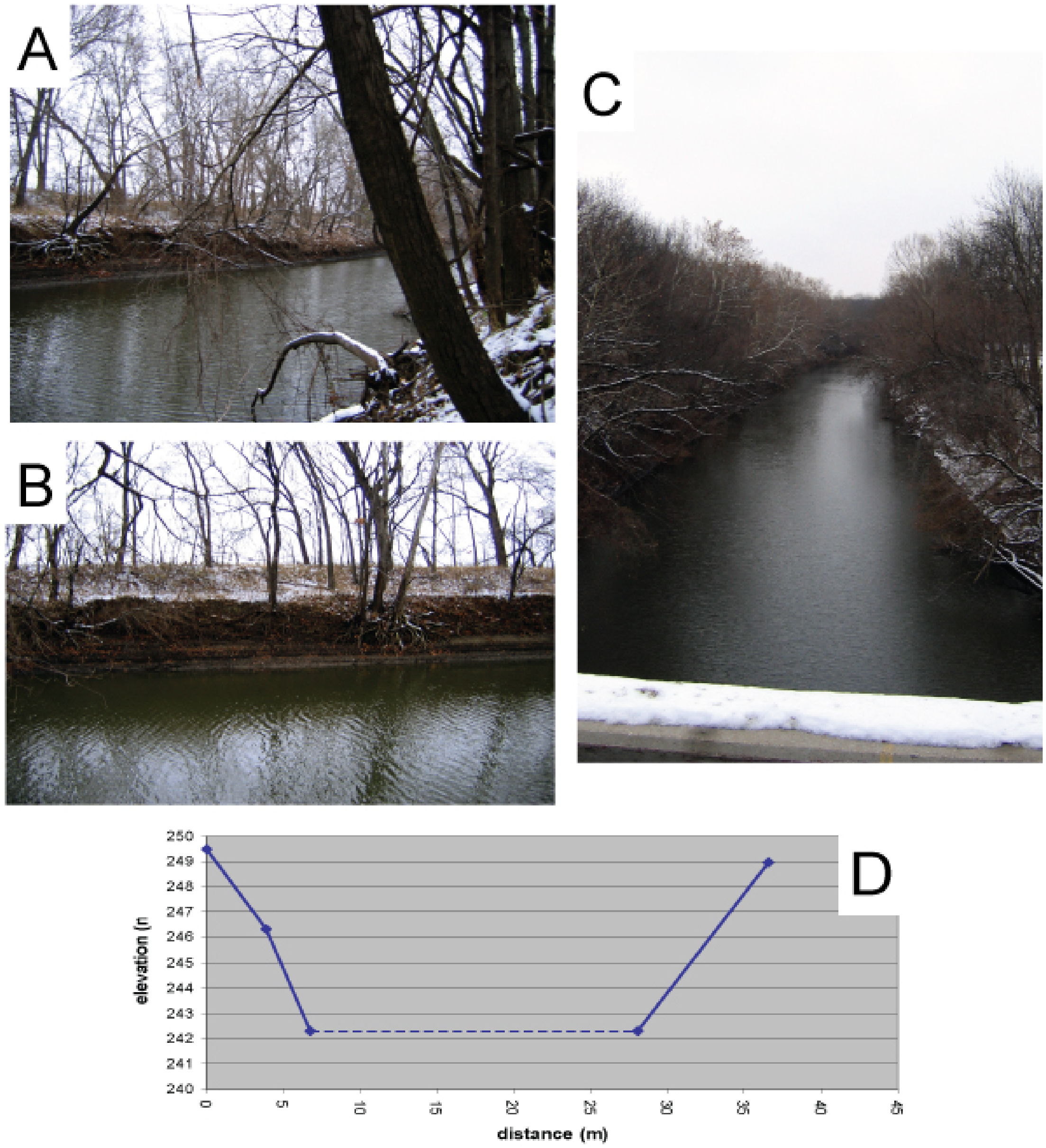


Plate 17: Site location: 38.95092° N, 95.09603° W. A) Downstream from site 17, B) north bank with erosion exposing tree root systems, C) downstream view from bridge upstream of site 17, D) channel profile facing downstream

Field Data from Stadia Level and GPS Readings

#1

Station	distance (m)	elevation (m)	distance (ft)	elev. (ft)
A	0.00	322.87	0	1059
1	1.22	321.95	4	1056
2	5.79	321.34	19	1054
3	6.40	320.43	21	1051
4	7.93	320.12	26	1050
5	8.54	318.90	28	1046
6	25.91	318.90	85	1046
7	27.13	325.00	89	1066

#2

Station	distance (m)	elevation (m)	distance (ft)	elev. (ft)
A	0.00	294.21	0	965
1	0.91	289.63	3	950
2	2.44	288.66	8	946.8
3	3.35	285.00	11	934.8
4	18.75	285.00	61.5	934.8
5	19.36	285.98	63.5	938
6	20.43	287.50	67	943
7	21.65	291.16	71	955

#3

Station	distance (m)	elevation (m)	distance (ft)	elev. (ft)
A	0.00	288.99	0	947.88
1	1.22	286.09	4	938.38
2	2.59	285.63	8.5	936.88
3	3.35	283.50	11	929.88
4	24.54	283.50	80.5	929.88
5	26.35	288.53	86.42	946.38
6	27.59	289.94	90.5	951

#4

Station	distance (m)	elevation (m)	distance (ft)	elev. (ft)
A	0.00	289.94	0	951
1	3.35	284.45	11	933
2	8.54	283.54	28	930
3	9.76	279.04	32	915.25
4	34.60	279.04	113.5	915.25
5	35.67	284.04	117	931.65

#5

Station	distance (m)	elevation (m)	distance (ft)	elev. (ft)
A	0.00	279.57	0	917
1	0.91	278.35	3	913
2	2.29	277.71	7.5	910.9
3	3.05	276.80	10	907.9
4	27.29	276.80	89.5	907.9
5	28.05	283.05	92	928.4
6	28.51	283.69	93.5	930.5

#6

Station	distance (m)	elevation (m)	distance (ft)	elev. (ft)
A	0.00	277.44	0	910
1	2.13	271.34	7	890
2	26.22	271.34	86	890
3	27.13	274.39	89	900

#7

Station	distance (m)	elevation (m)	distance (ft)	elev. (ft)
A	0.00	272.56	0	894
1	5.00	270.73	4	888
2	41.01	270.73	134.5	888
3	41.31	271.80	135.5	891.5

#8

Station	distance (m)	elevation (m)	distance (ft)	elev. (ft)
A	0.00	256.10	0	840
1	7.32	253.05	24	830
2	12.20	250.00	40	820
3	15.55	249.85	51	819.5
4	16.01	249.70	52.5	819
5	16.77	249.70	55	819
6	17.38	249.85	57	819.5
7	20.12	250.00	66	820
8	22.10	253.05	72.5	830

#9

Station		distance (m)	elevation (m)	elev. (ft)
A		0	237.39	
	1	8.56	227.41	
	2	19.21	227.15	
	3	24.87	227.15	
	4	25.60	229.55	
	5	27.53	230.71	
	6	32.20	236.89	777

#10

Station	distance (m)	elev. (m)	distance (ft)	elevation (ft)
A	0	253.05	0.00	830.00
1	4.88	252.44	16.00	828.00
2	13.11	252.13	43.00	827.00
3	23.48	250.00	77.00	820.00
4	32.93	249.39	106.25	818.00
5	35.00	246.04	108.00	807.00
6	59.76	246.04	196.00	807.00
7	65.00	253.05	201.00	830.00

#11

Station	distance (m)	elevation (m)
14	0	254.4
13	1.53	256.29
A	2.14	256.05
1	2.75	255.85
2	4.58	252.77
3	6.52	252.50
4	7.02	250.72
	7.89	249.60
5	8.49	249.58
6	8.75	245.70
12	12.07	245.70
11	12.14	249.70
7	15.50	250.92
	15.87	252.20
8	17.09	252.82
9	22.27	254.74
10	23.14	265.44

#12

Station	distance (m)	elevation (m)	elev. (feet)
A	0.00	254.36	807
1	0.61	254.11	
2	1.83	252.03	
3	3.05	251.94	
4	3.97	251.34	
5	5.19	250.83	
7	5.80	247.44	
8	6.85	247.20	
6	6.95	245.40	
10	8.10	245.40	
9	9.15	246.30	
11	11.29	247.53	
12	12.51	248.43	
13	15.25	248.44	
14	20.13	249.83	
15	21.00	257.13	

#13

Station	distance (m)	elevation (m)
A	0.00	252.10
8	0.61	252.02
6	1.53	250.77
10	1.83	249.38
9	3.05	248.97
11	3.66	248.26
12	3.97	248.21
13	4.58	247.44
14	5.19	246.94
	5.19	246.52
15	5.30	246.52
16	5.30	245.32
	9.68	245.32
1	9.76	246.12
	9.82	246.12
2	10.68	248.15
	10.85	248.15
3	13.12	249.80
4	14.03	249.44
5	15.56	251.61
7	17.39	252.41

#14

Station	distance (m)	elevation (m)	dist. (ft)	elev. (ft)
B	0	252.04	0	826.7
1	1.83	250.70	6	822.3
Tpb	5.79	249.79	19	819.3
Tpa	5.79	249.79	19	819.3
A	7.93	249.51	26	818.4
1	12.20	249.45	40	818.2
2	13.41	249.05	44	816.9
3	14.63	247.44	48	811.6
4	18.60	246.04	61	807
5	18.60	244.51	61	802
7	36.28	244.51	119	802
8	36.59	248.38	120	814.7
6	37.20	249.51	122	818.4
9	42.07	250.61	138	822
10	43.87	252.16	143.9	827.1

#15

Station	distance (m)	elevation (m)	distance (ft)	elev. (ft)
A	0.00	249.39	0	818
1	1.52	246.04	5	807
2	4.88	245.73	16	806
3	6.10	244.21	20	801
4	7.32	243.60	24	799
5	25.61	243.60	84	799
6	27.13	245.43	89	805
7	28.96	245.49	95	805.2
8	29.88	248.48	98	815

#16

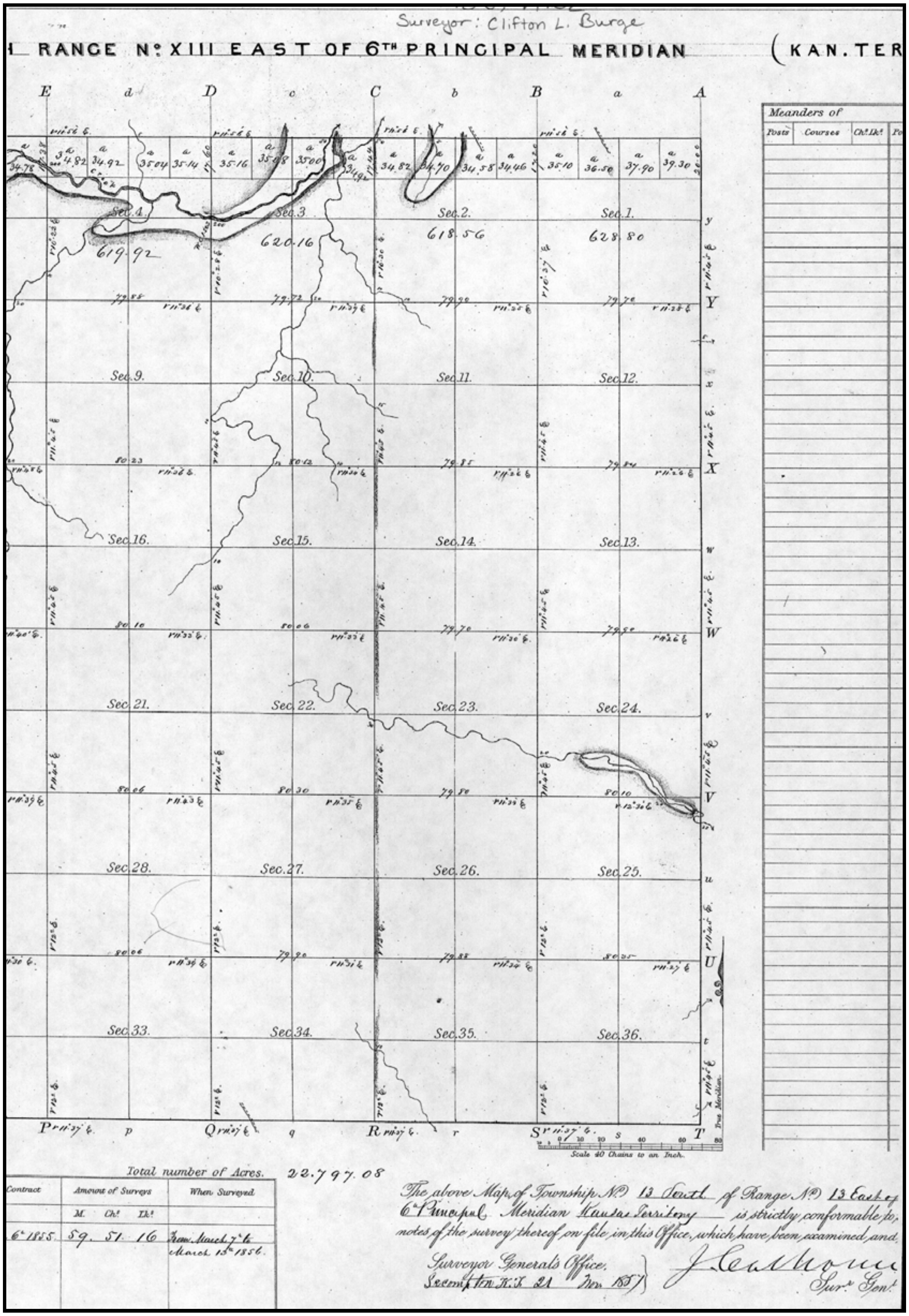
Station	distance (m)	elevation (m)	dist.(ft)	elev. (ft)
A	0.00	249.39	0	818
1	3.35	248.72	11	815.8
2	5.49	247.90	18	813.1
3	7.01	247.80	23	812.8
4	8.54	247.20	28	810.8
5	10.37	247.01	34	810.2
6	14.63	245.40	48	804.9
7	17.07	243.60	56	799
8	17.55	243.02	57.55	797.1
16	35.70	243.02	117.1	797.1
15	36.89	243.69	121	799.3
14	36.89	244.39	121	801.6
13	37.20	244.57	122	802.2
12	41.46	246.16	136	807.4
11	43.90	246.31	144	807.9
10	45.43	247.26	149	811
9	48.17	247.50	158	811.8
17	51.52	248.20	169	814.1
18	53.66	249.57	176	818.6
19	58.45	252.04	191.7	826.7

#17

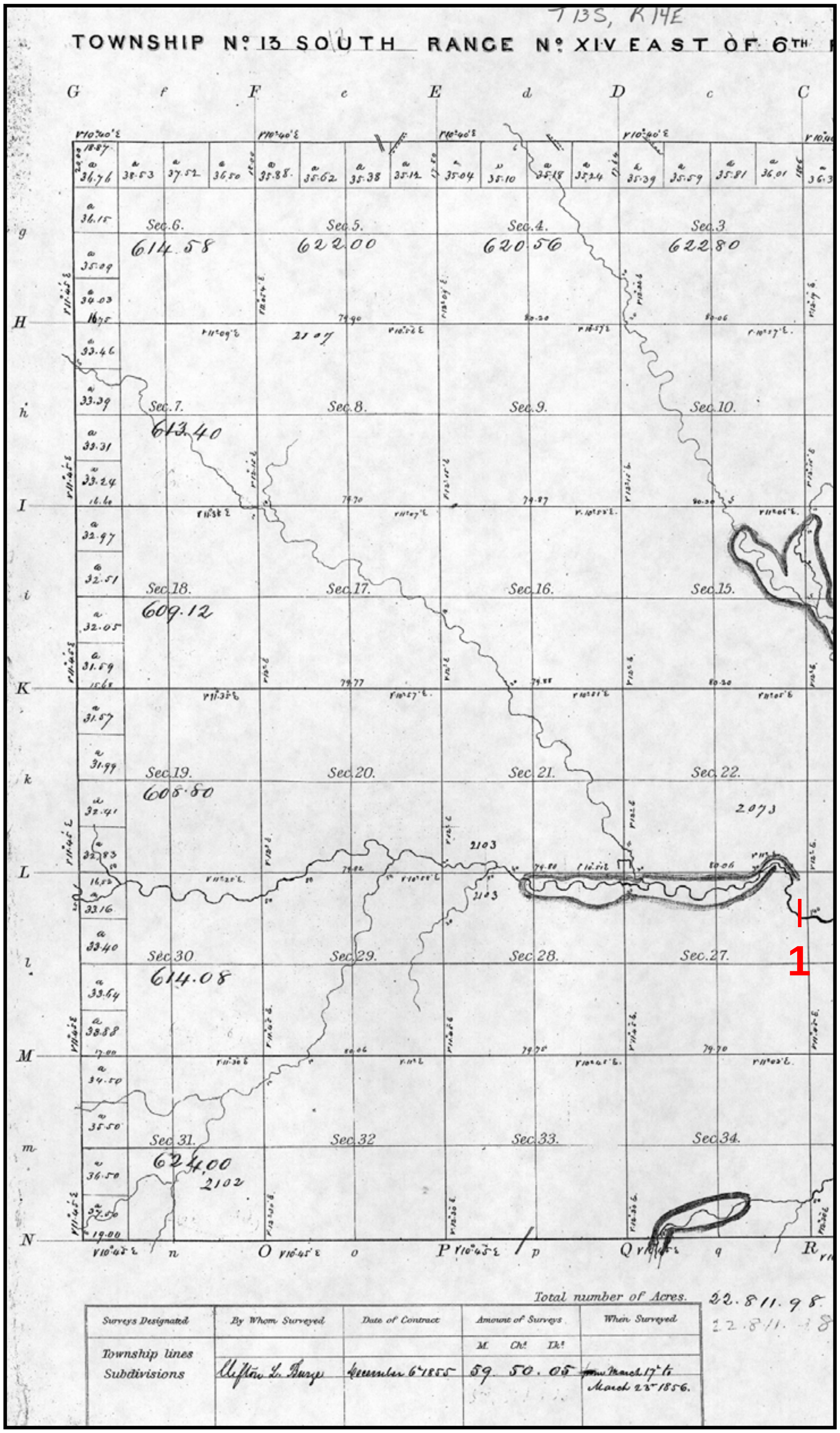
Station		distance (m)	elevation (m)
	1	0	249.49
A		3.85	246.34
	2	6.77	242.28
	3	28.03	242.28
	4	36.54	248.98

Appendix 2
Land Survey Plat Maps

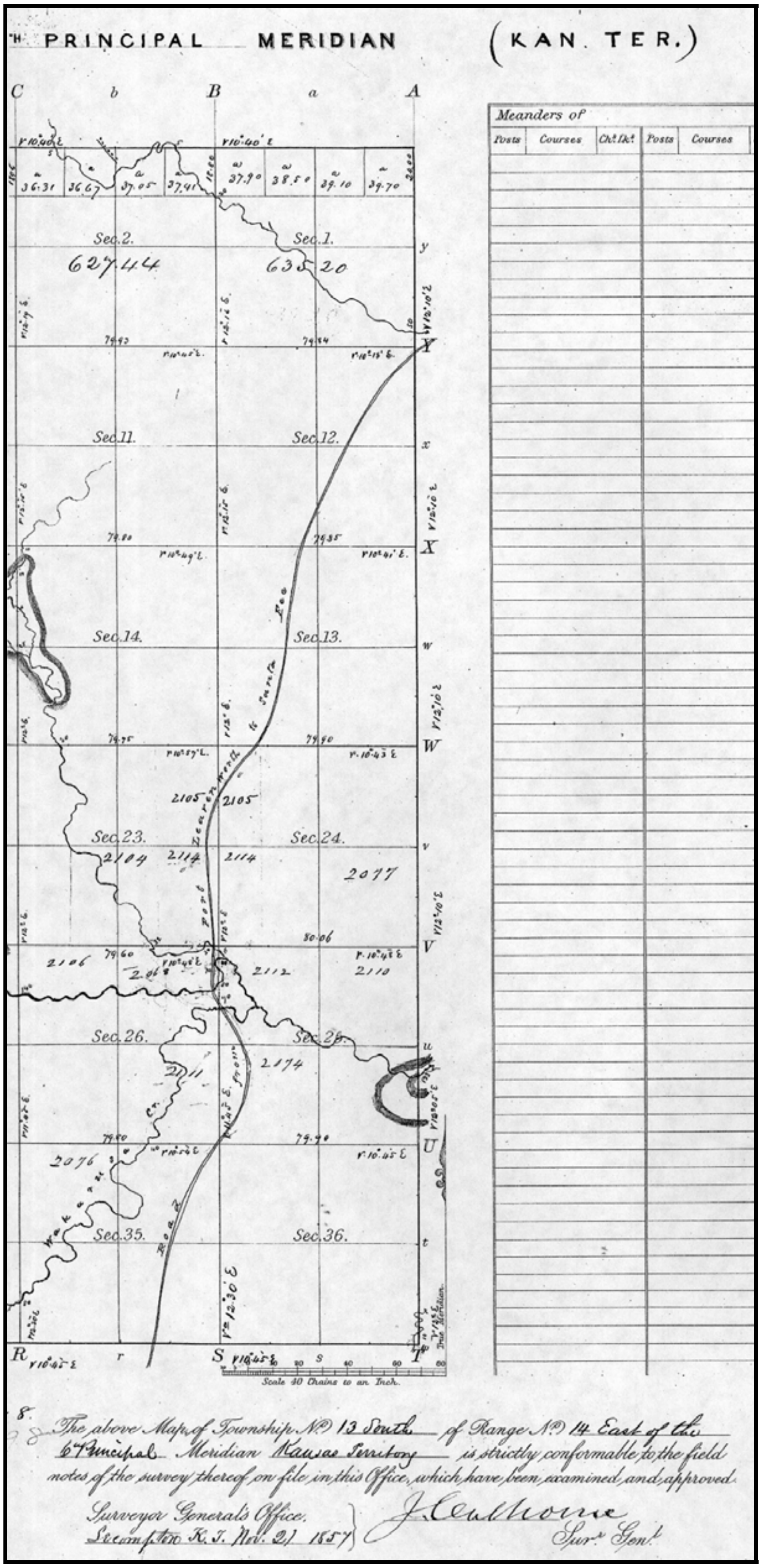
Following are copies of the original federal land survey plat maps at a reduced size. The maps are in order, beginning at the headwater region in the west and continuing downstream to the confluence with the Kansas River. Modern site locations are indicated with a cross-section line and site number. Channel width measurements taken from these maps are also presented in tabular format on following pages.



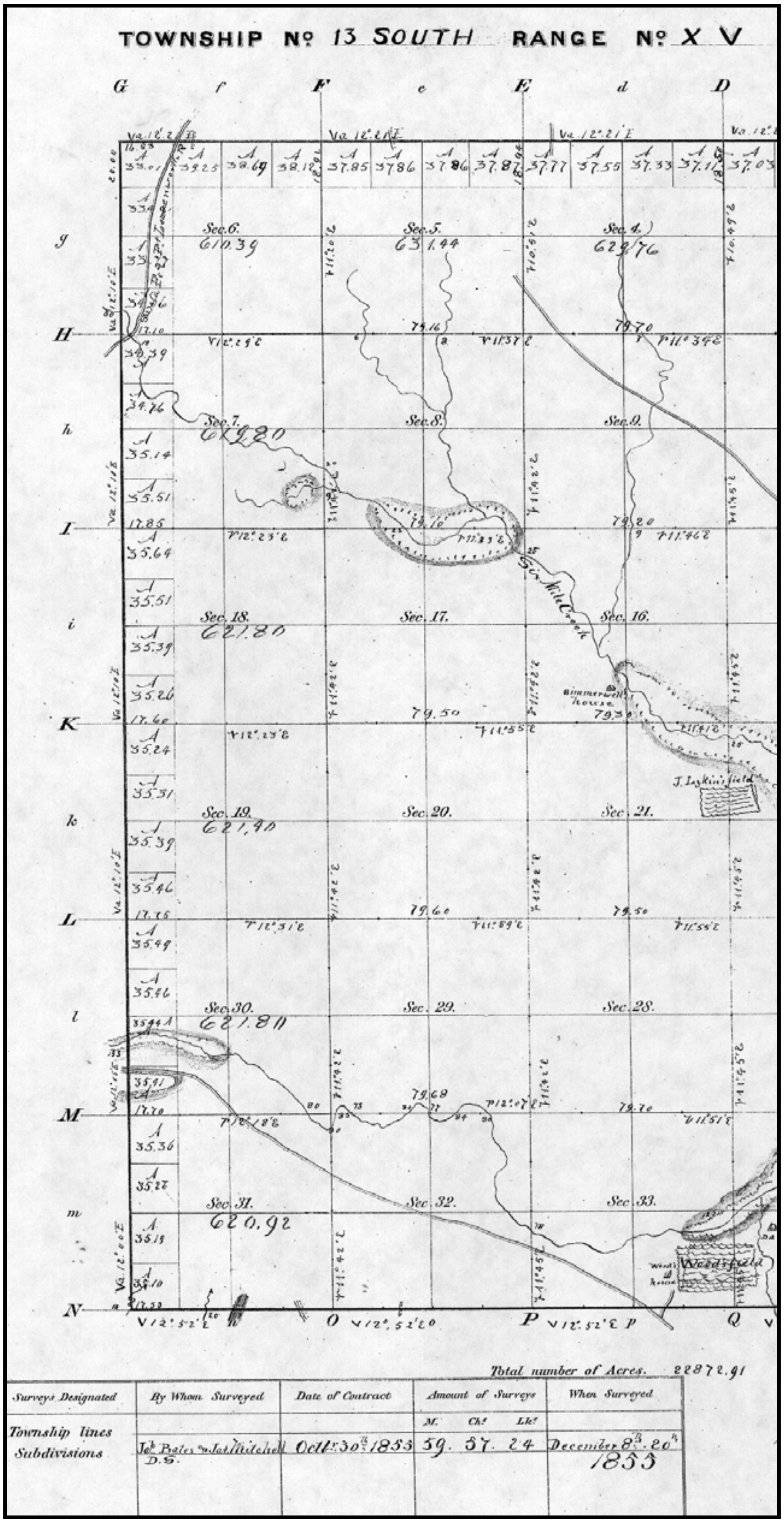
Headwater region in Township 13 South, Range 13 East (Burge 1856)



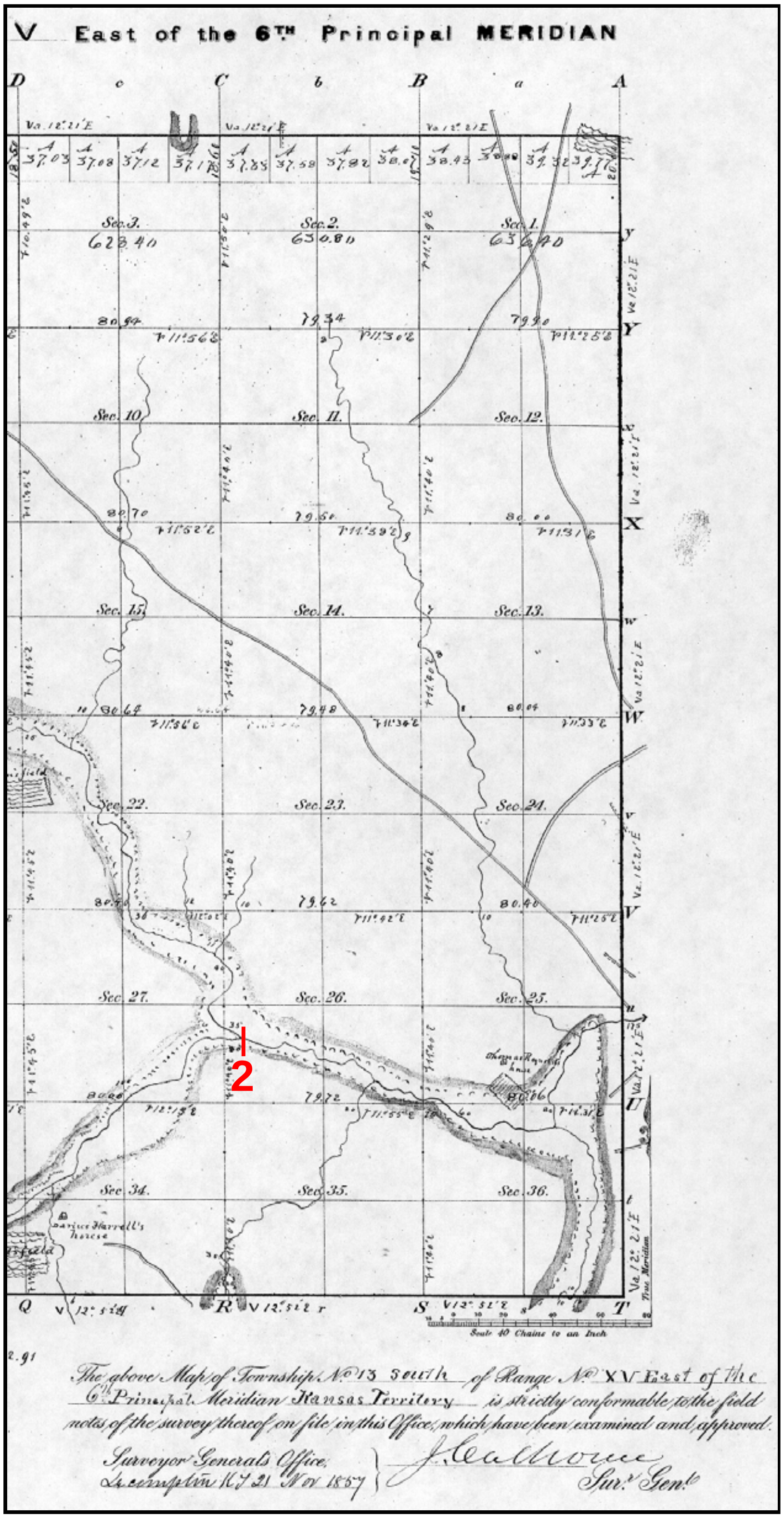
Township 13 South, Range 14 East (a) (Burge 1856)



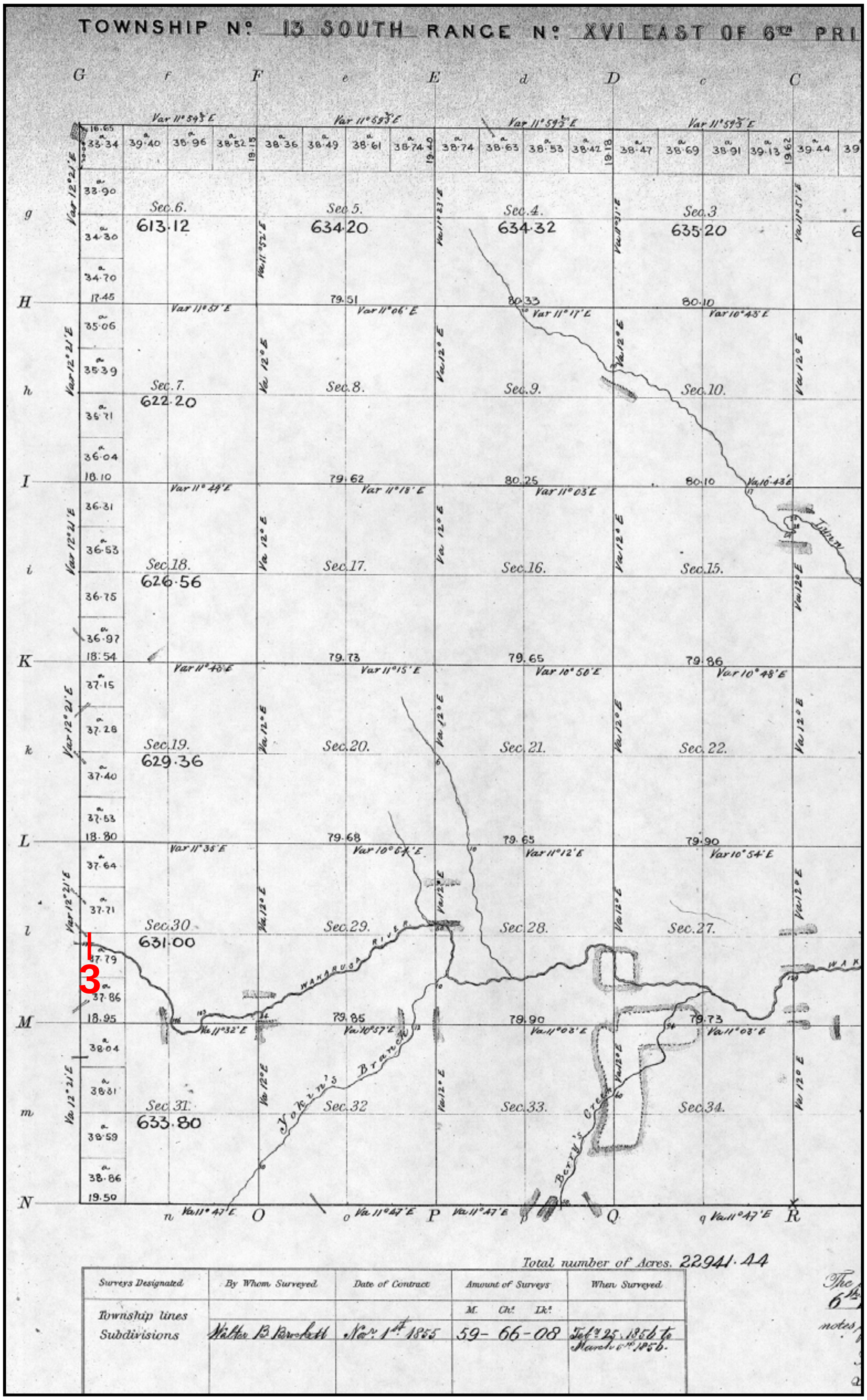
Township 13 South, Range 14 East (b) (Burge 1856)



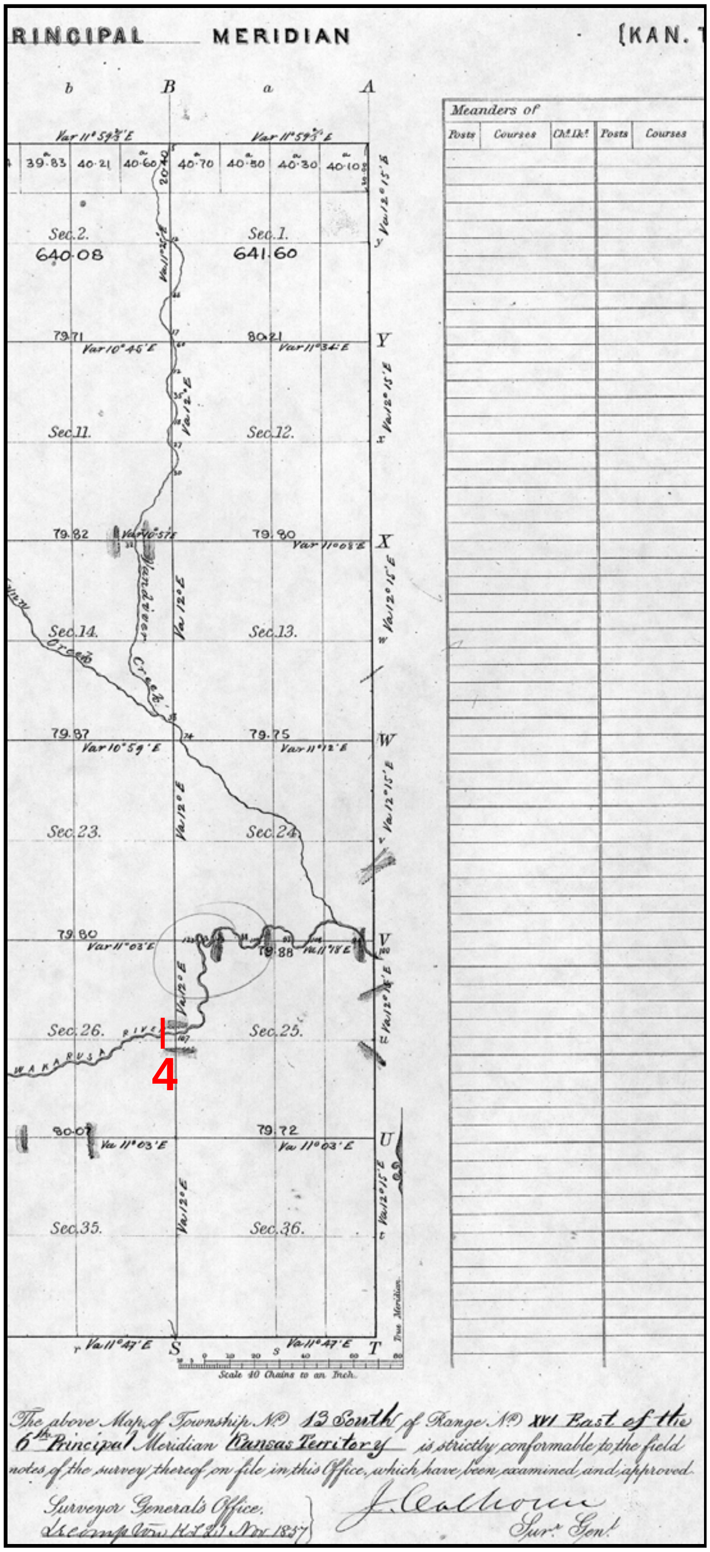
Township 13 South, Range 15 East (a) (Bates and Mitchell 1855)



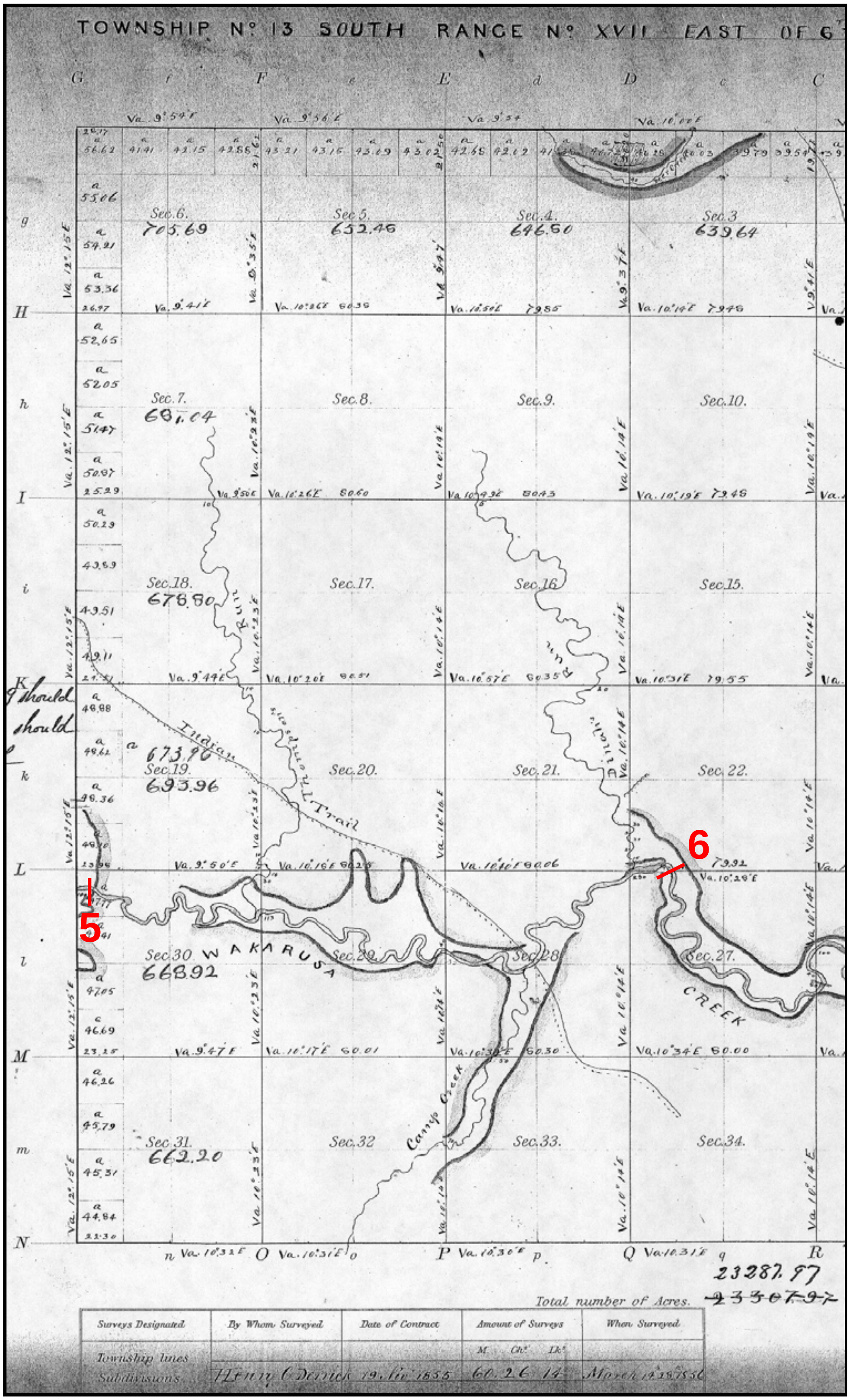
Township 13 South, Range 15 East (b) (Bates and Mitchell 1855)



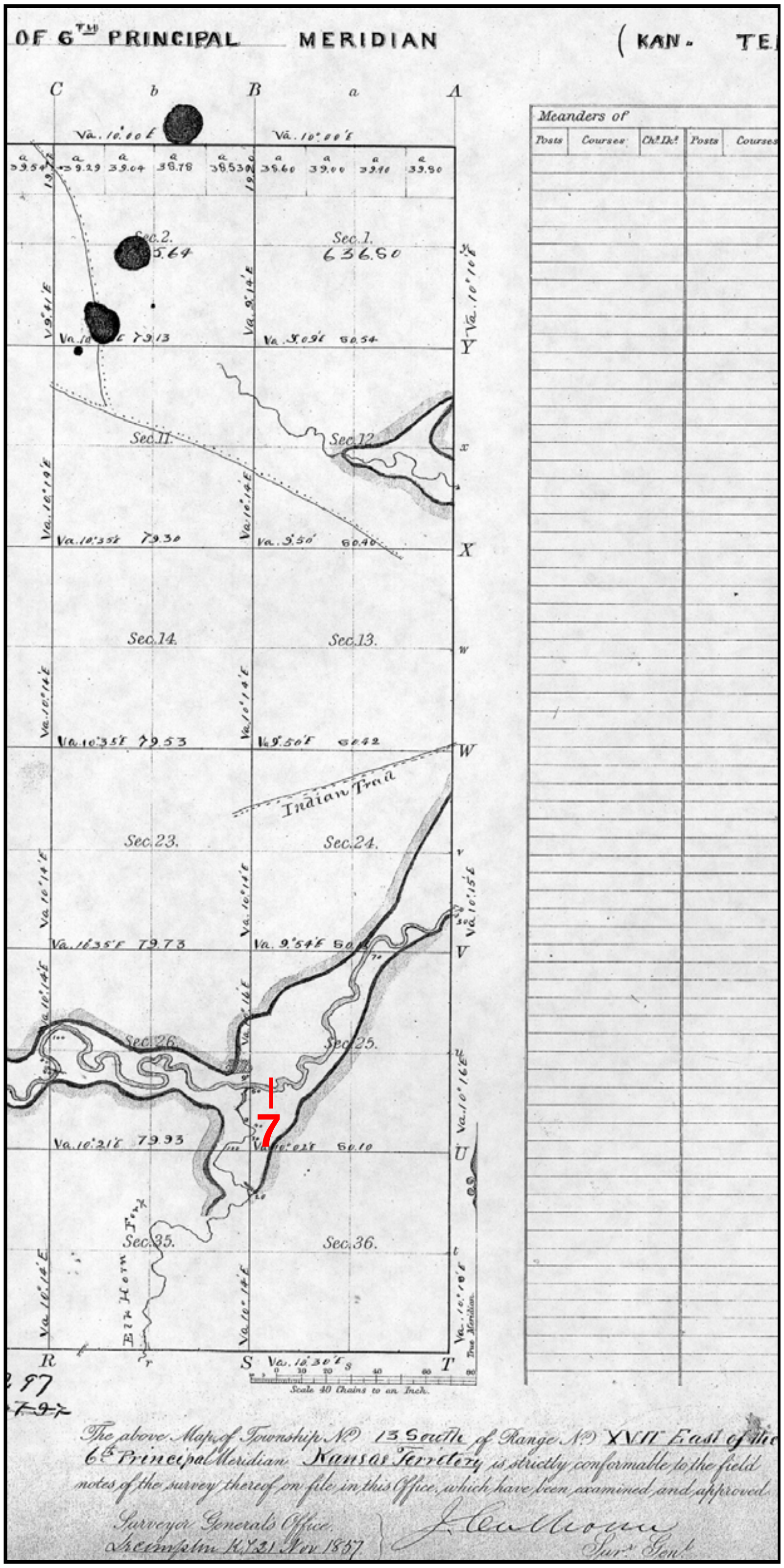
Township 13 South, Range 16 East (a) (Brockett 1856)



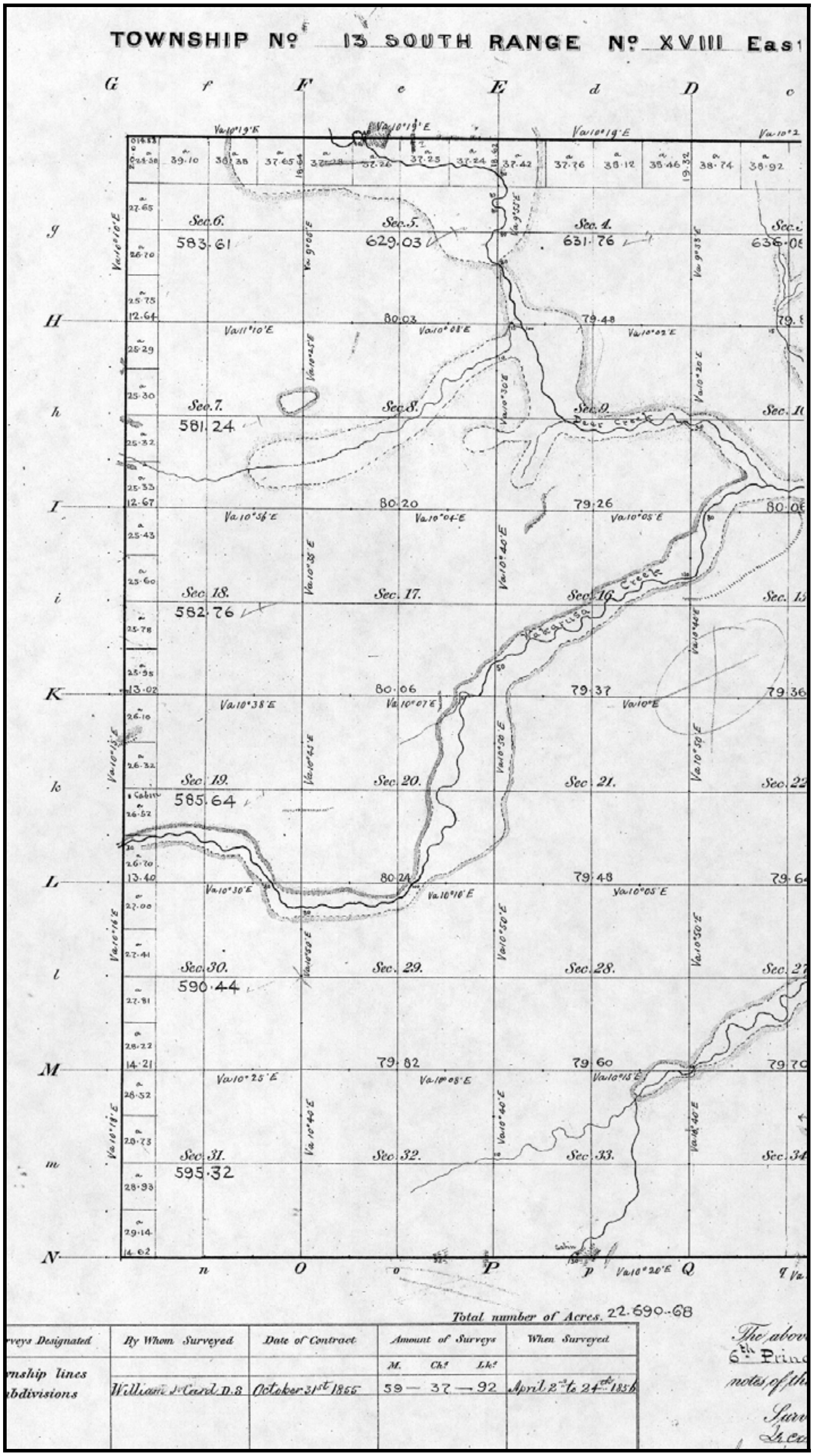
Township 13 South, Range 16 East (b) (Brockett 1856)



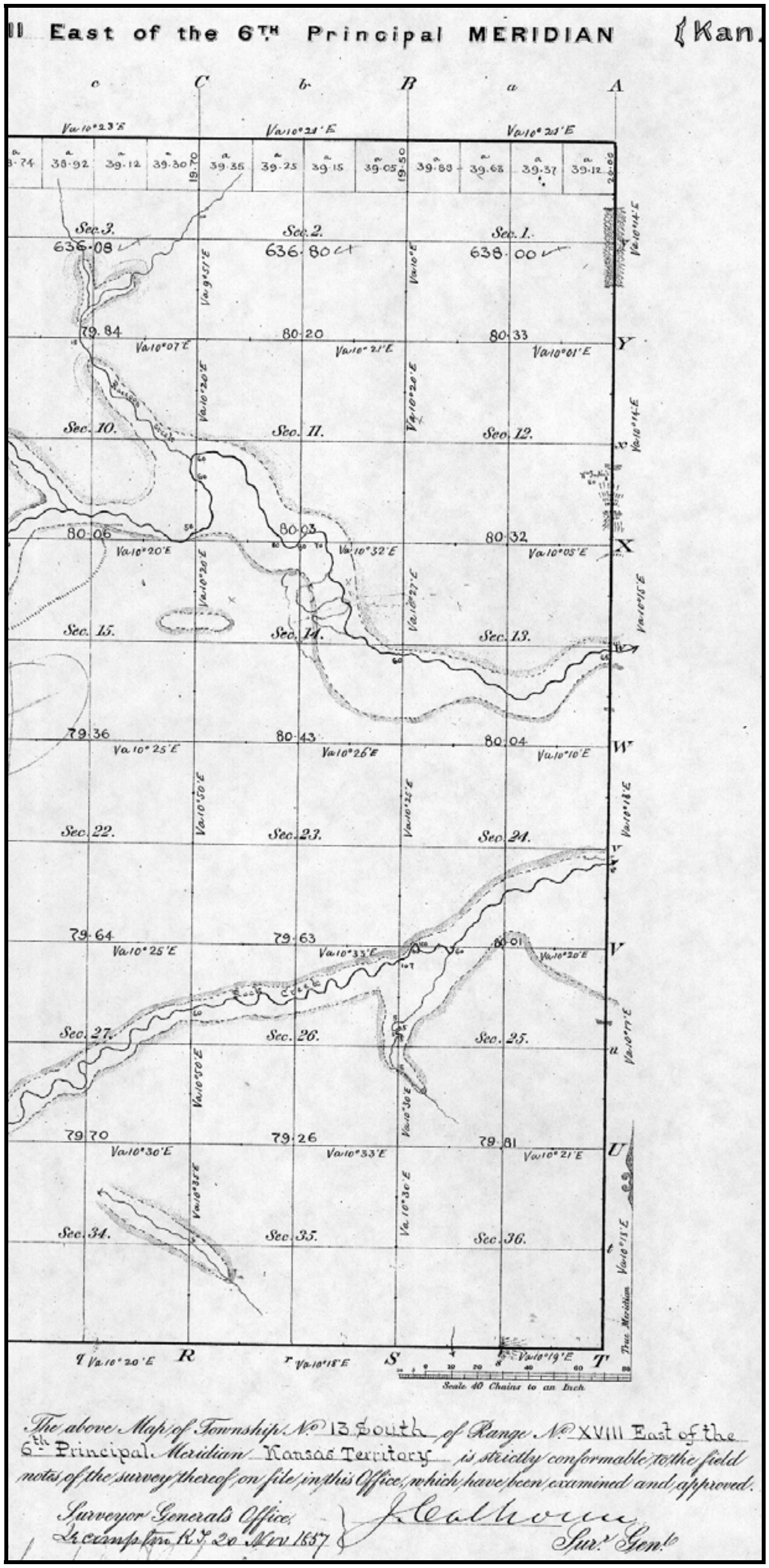
Township 13 South, Range 17 East (a) (Derrick 1856)



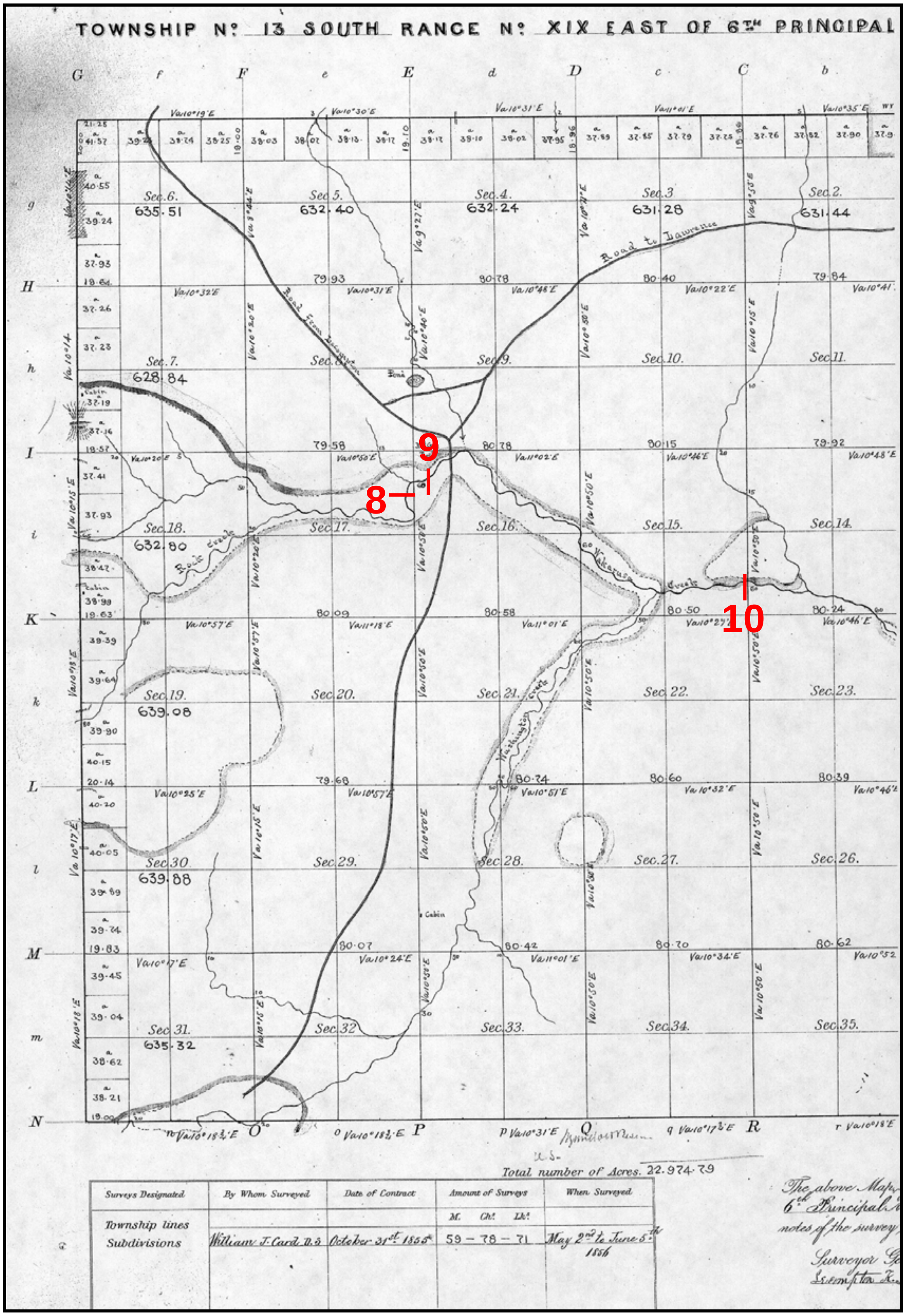
Township 13 South, Range 17 East (b) (Derrick 1856)



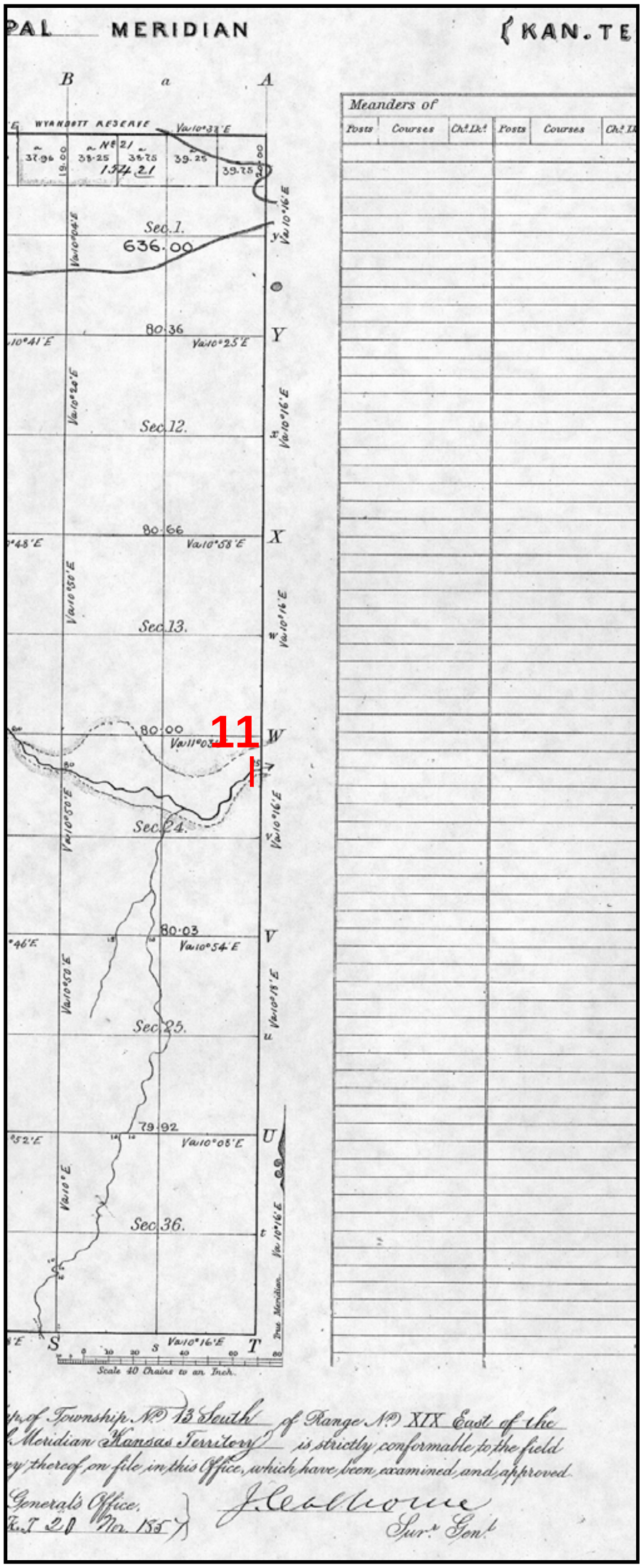
Township 13 South, Range 18 East (a) (Card 1856)



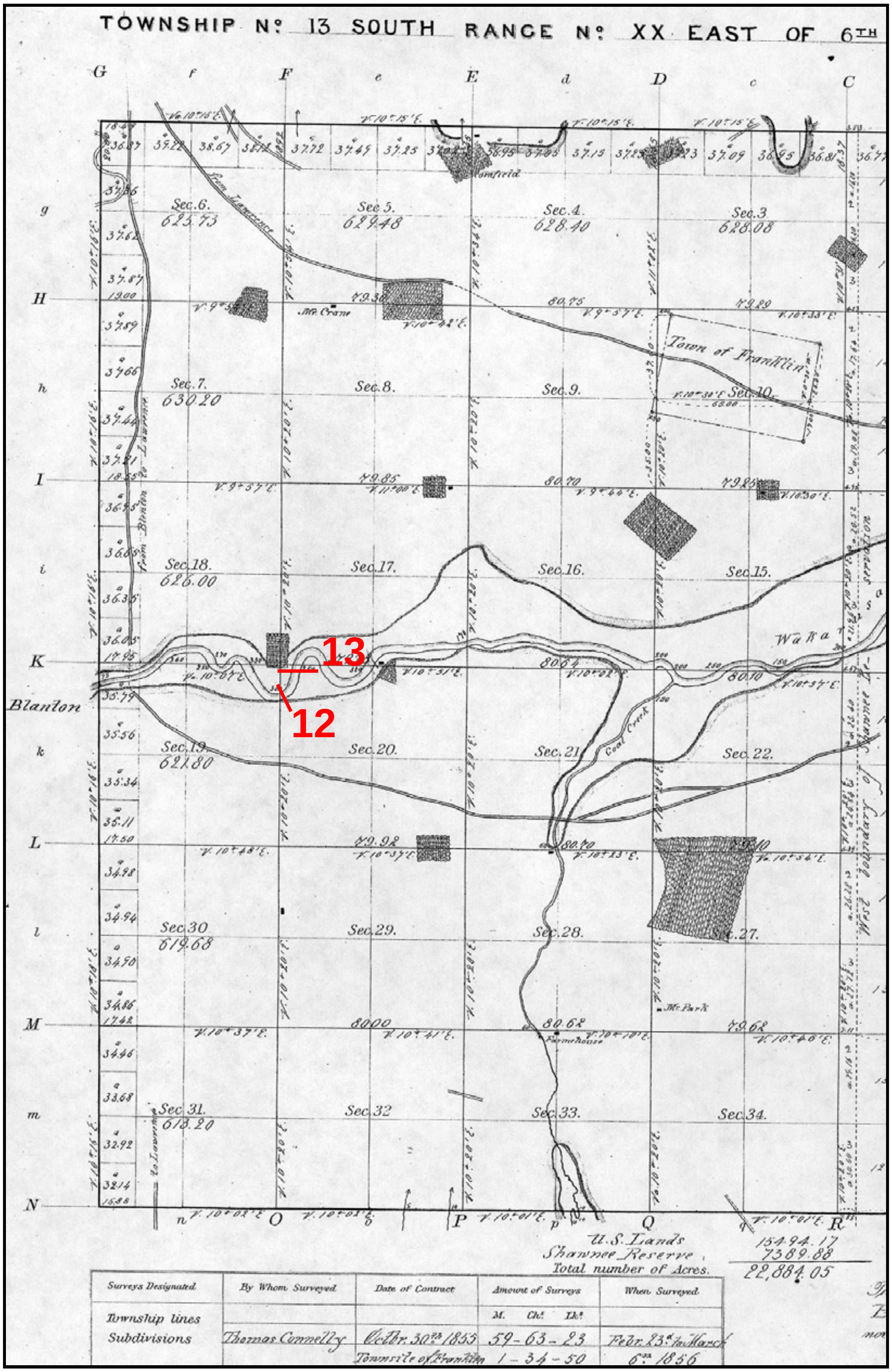
Township 13 South, Range 18 East (b) (Card 1856)



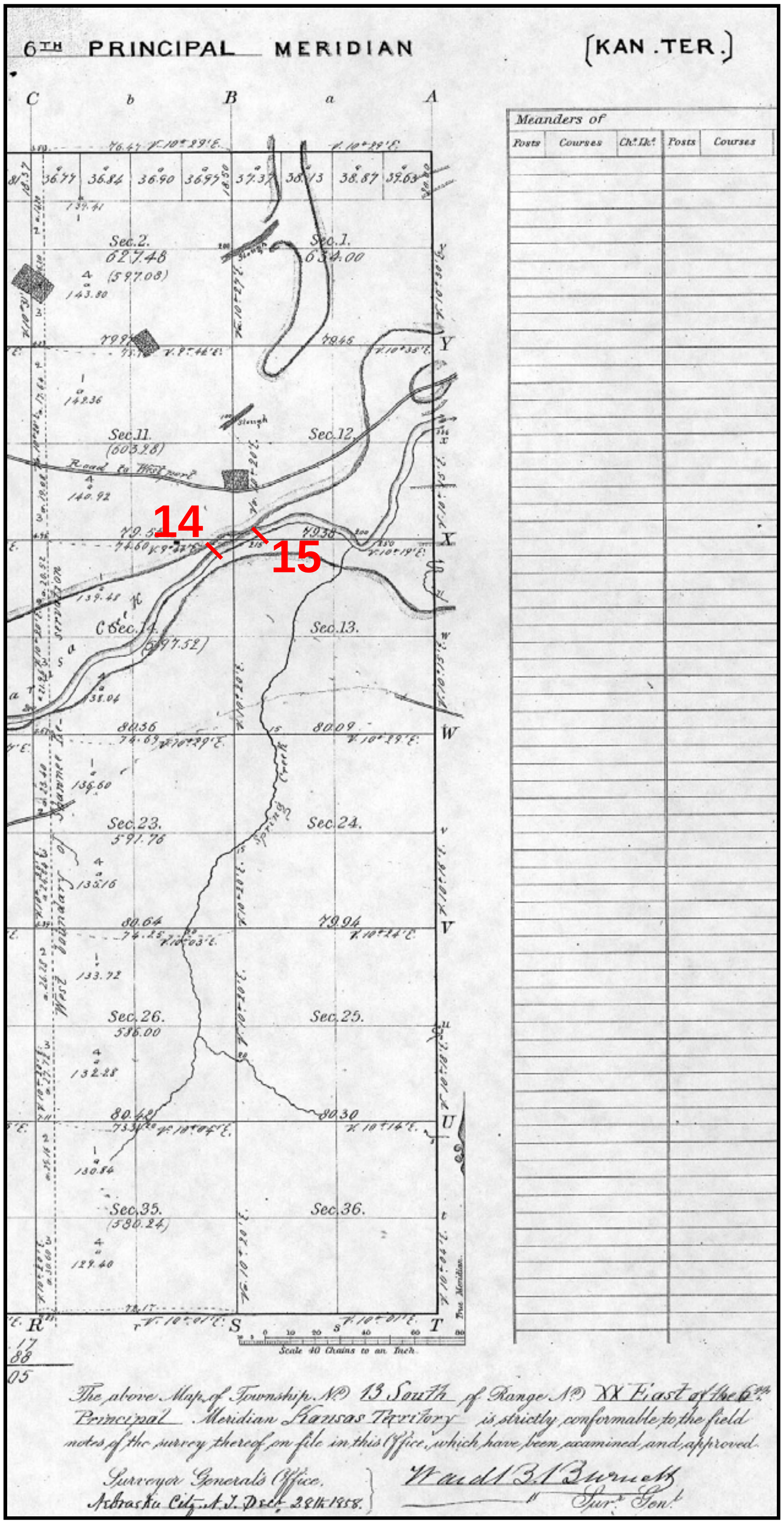
Township 13 South, Range 19 East (a) (Card 1856)



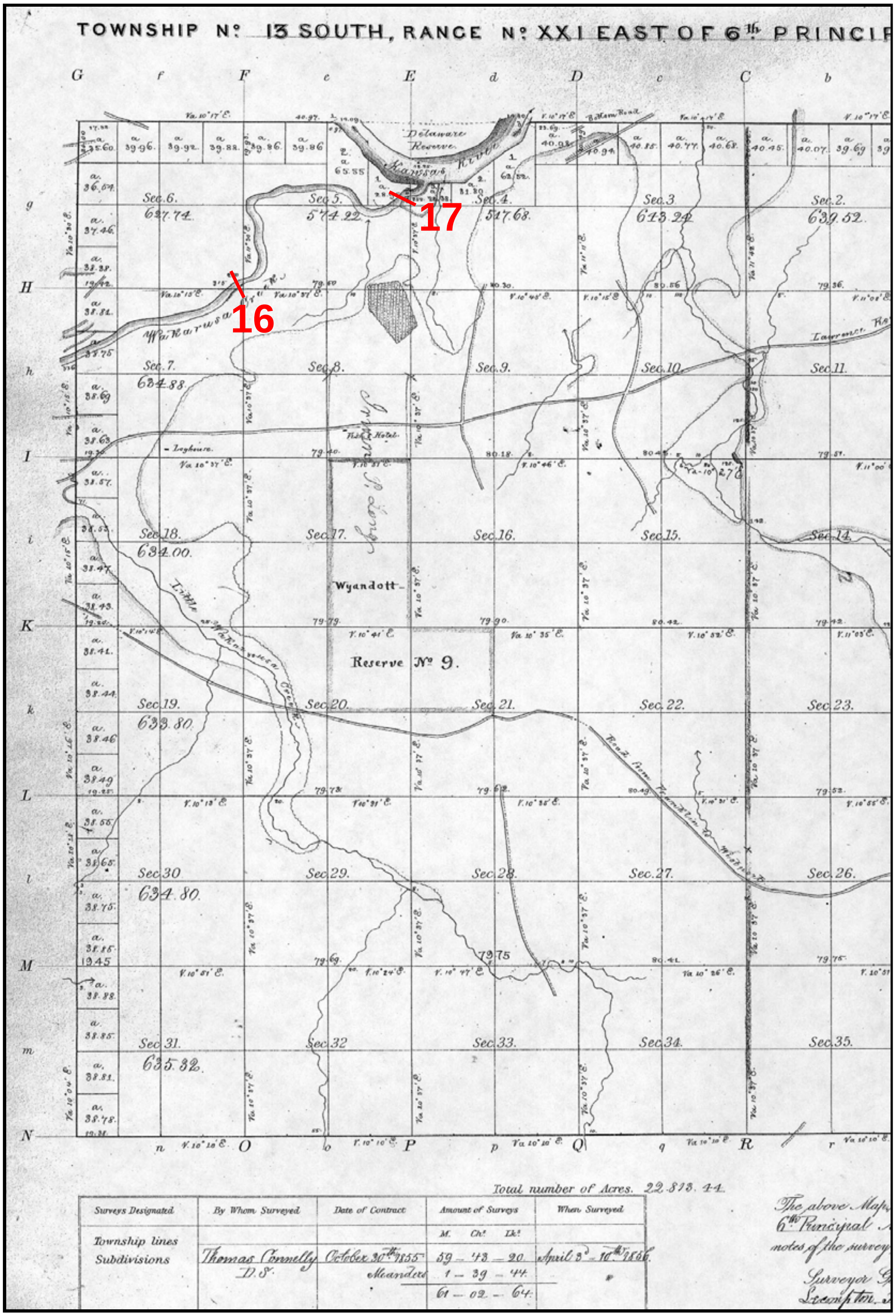
Township 13 South, Range 19 East (b) (Card 1856)



Township 13 South, Range 20 East (a) (Connelly 1856)



Township 13 South, Range 20 East (b) (Connelly 1856)



Confluence of the Wakarusa River and the Kansas River, Township 13 South, Range 21 East (Connelly 1856)

Original Federal Land Survey Width Measurements

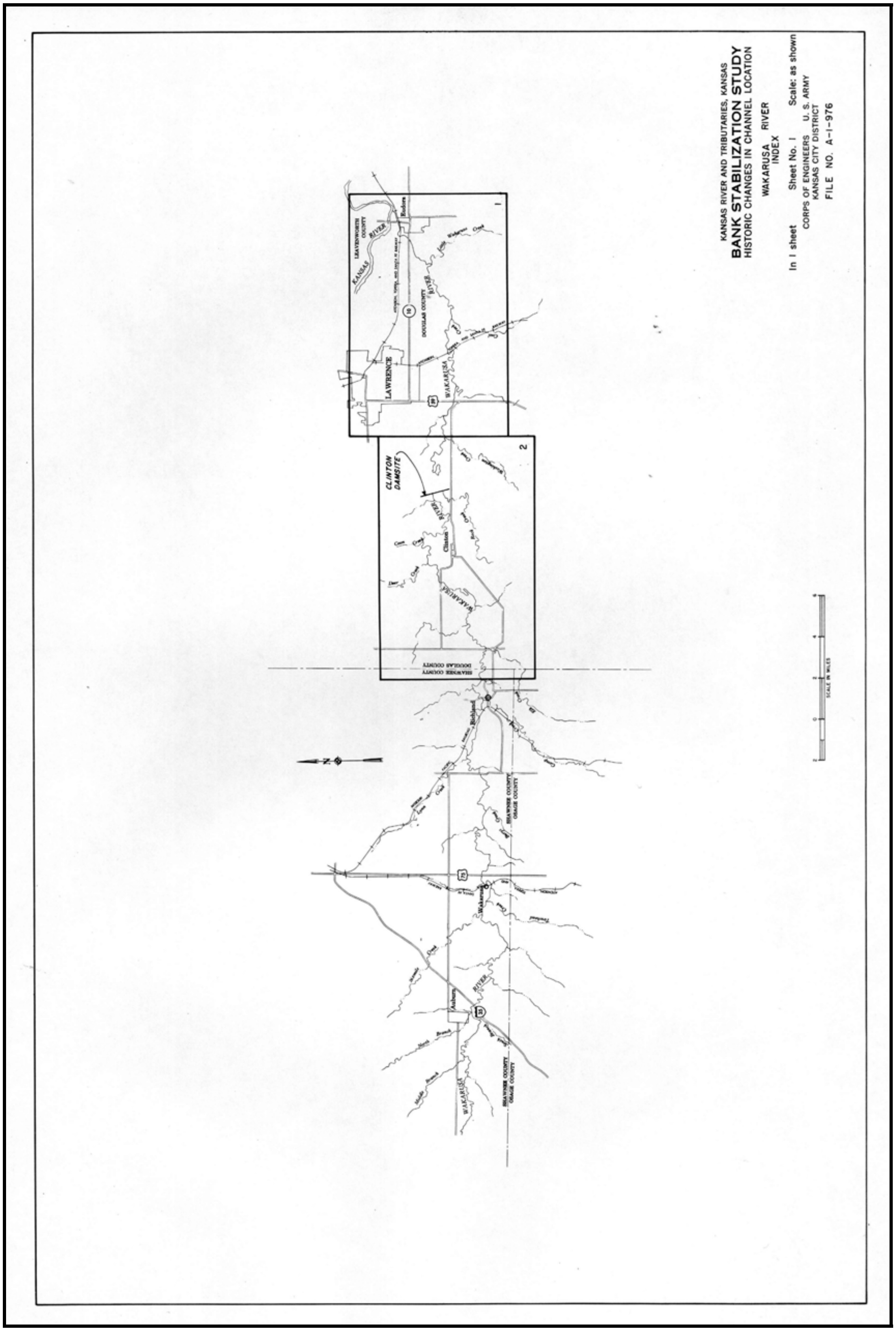
Location	width in chains	width in meters	bank height (m)	site #
Sec. 23/22, T13S, R13E	0.30	6.04		
Sec. 24/23, T13S, R13E	0.20	4.03		
Sec. 25/24, T13S, R13E	0.20	4.03		
Sec. 30/25, T13S, R14E	0.25	5.03		
Sec. 29/30, T13S, R14E	0.50	10.07		
Sec. 20/29, T13S, R14E	0.50	10.07		
Sec. 21/20, T13S, R14E	0.20	4.03		
Sec. 28/21, T13S, R14E	0.60	12.08		
Sec. 27/28, T13S, R14E	0.70	14.09		
Sec. 22/27, T13S, R14E	0.70	14.09		
Sec. 27/22, T13S, R14E	0.60	12.08		
Sec. 26/27, T13S, R14E	1.40	28.18		1
Sec. 25/26, T13S, R14E	0.50	10.07		
Sec. 26/25, T13S, R14E	0.70	14.09		
Sec. 25/26, T13S, R14E	0.60	12.08		
Sec. 30/25, T13S, R15E	1.33	26.77		
Sec. 31/30, T13S, R15E	0.80	16.10		
Sec. 32/31, T13S, R15E	0.80	16.10		
Sec. 29/32, T13S, R15E	0.85	17.11		
Sec. 32/29, T13S, R15E	0.78	15.70		
Sec. 29/32, T13S, R15E	0.80	16.10		
Sec. 32/29, T13S, R15E	0.77	15.50		
Sec. 29/32, T13S, R15E	0.84	16.91		
Sec. 32/29, T13S, R15E	0.80	16.10		
Sec. 33/32, T13S, R15E	0.78	15.70		
Sec. 34/33, T13S, R15E	1.25	25.16		
Sec. 27/34, T13S, R15E	1.00	20.13		
Sec. 26/27, T13S, R15E	0.80	16.10		2
Sec. 25/26, T13S, R15E	0.75	15.10		
Sec. 36/25, T13S, R15E	0.60	12.08	4.88 to 6.1	
Sec. 25/36, T13S, R15E	0.80	16.10		
Sec. 30/25, T13S, R16E	1.75	35.23		3
Sec. 31/30, T13S, R16E	1.96	39.46		
Sec. 30/31, T13S, R16E	1.03	20.73		
Sec. 29/30, T13S, R16E	0.84	16.91		
Sec. 28/29, T13S, R16E	0.60	12.08		
Sec. 27/28, T13S, R16E	-----	------		
Sec. 26/27, T13S, R16E	1.29	25.97		
Sec. 25/26, T13S, R16E	1.07	21.54		4

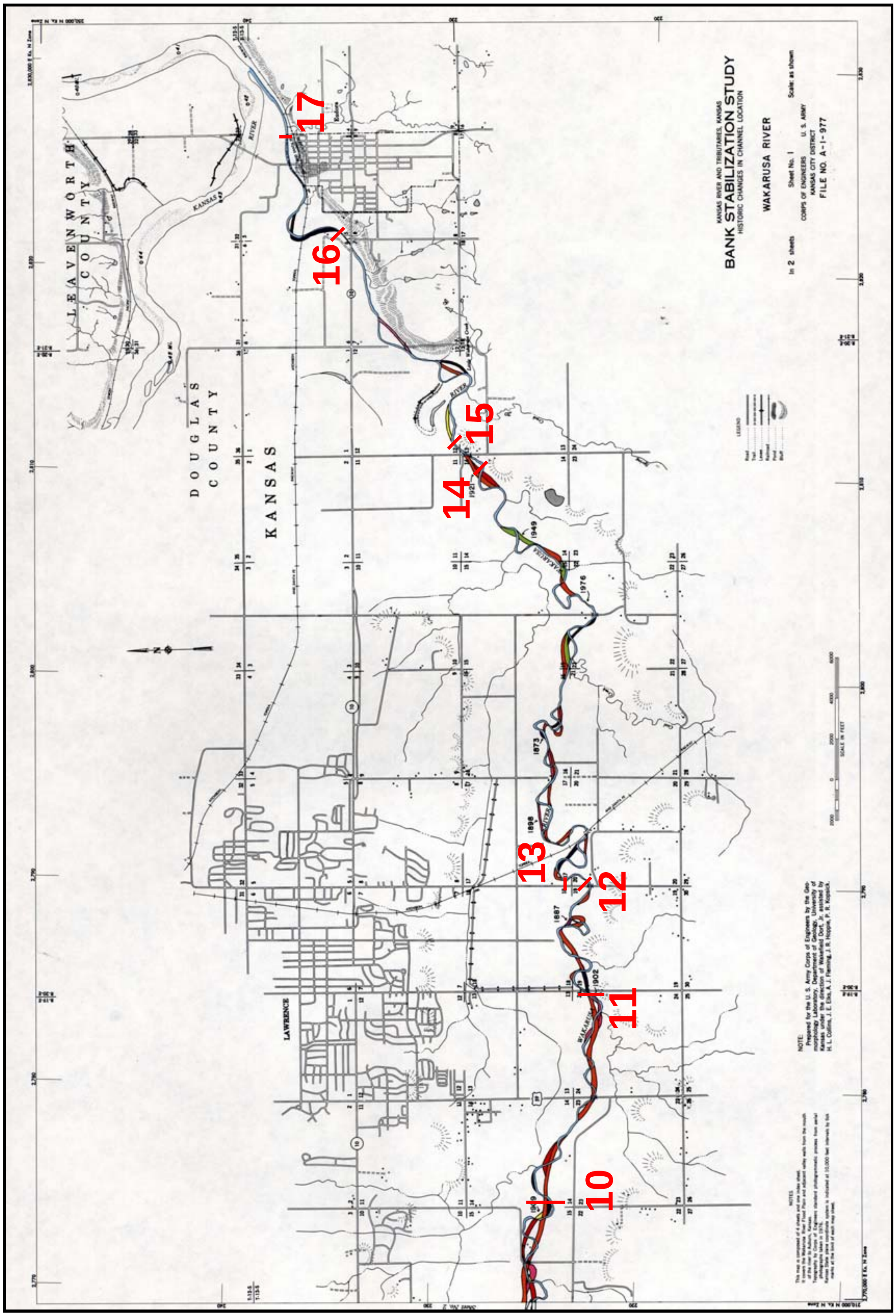
Location	width in chains	width in meters	bank height (m)	Site #
Sec. 24/25, T13S, R16E	1.23	24.76		
Sec. 25/24, T13S, R16E	1.53	30.8		
Sec. 24/25, T13S, R16E	1.09	21.94		
Sec. 25/24, T13S, R16E	0.88	17.71		
Sec. 24/25, T13S, R16E	1.10	22.14		
Sec. 25/24, T13S, R16E	0.93	18.72		
Sec. 24/25, T13S, R16E	1.08	21.74		
Sec. 25/24, T13S, R16E	0.94	18.92		
Sec. 30/25, T13S, R17E	1.00	20.13		5
Sec. 29/30, T13S, R17E	1.13	22.75		
Sec. 28/29, T13S, R17E	0.40	8.05		
Sec. 22/27/28, T13S, R17E	2.90	58.38		
Sec. 27/22, T13S, R17E	1.00	20.13		6
Sec. 26/27, T13S, R17E	0.50	10.07		
Sec. 27/26, T13S, R17E	0.40	8.05		
Sec. 26/27, T13S, R17E	1.00	20.13		
Sec. 25/26, T13S, R17E	0.50	10.07		7
Sec. 24/25, T13S, R17E	0.70	14.09		
Sec. 19/24, T13S, R18E	0.30	6.04		
Sec. 30/19, T13S, R18E	0.80	16.10		
Sec. 29/30, T13S, R18E	0.80	16.10		
Sec. 20/29, T13S, R18E	1.00	20.13		
Sec. 17/20, T13S, R18E	-----	------		
Sec. 16/17, T13S, R18E	0.50	10.07		
Sec. 15/16, T13S, R18E	1.20	24.16		
Sec. 10/15, T13S, R18E	0.80	16.10		
Sec. 11/10, T13S, R18E	0.50	10.07		
Sec. 10/11, T13S, R18E	0.60	12.08		
Sec. 11/10, T13S, R18E	0.60	12.08		
Sec. 14/11, T13S, R18E	0.80	16.10		
Sec. 11/14, T13S, R18E	0.80	16.10		
Sec. 14/11, T13S, R18E	0.70	14.09		
Sec. 13/14, T13S, R18E	0.60	12.08		
Sec. 18/13, T13S, R19E	0.65	13.08		
Sec. 17/18, T13S, R19E	0.50	10.07		
Sec. 16/17, T13S, R19E	0.60	12.08		8,9
Sec. 15/16, T13S, R19E	0.60	12.08		
Sec. 14/15, T13S, R19E	0.60	12.08		10
Sec. 23/14, T13S, R19E	0.60	12.08		
Sec. 24/23, T13S, R19E	0.80	16.10		

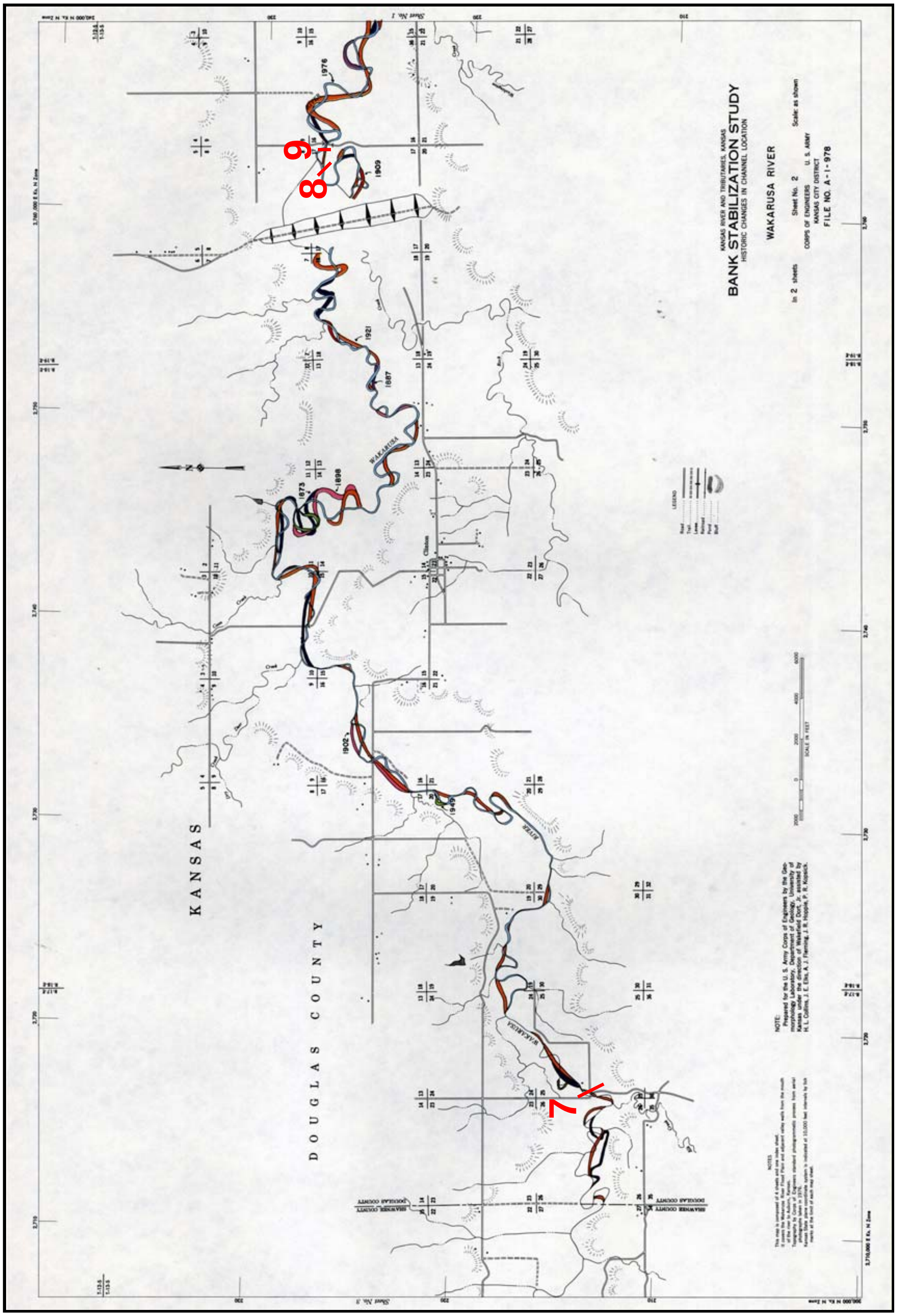
Location	width in chains	width in meters	bank height (m)	Site #
Sec. 19/24, T13S, R20E	0.75	15.1	12.2	11
Sec. 18/19, T13S, R20E	3.40	68.44		
Sec. 19/18, T13S, R20E	2.50	50.33		
Sec. 18/19, T13S, R20E	2.70	54.35		
Sec. 19/18, T13S, R20E	3.30	66.43		
Sec. 20/19, T13S, R20E	3.00	60.39		12
Sec. 17/20, T13S, R20E	2.50	50.33		
Sec. 20/17, T13S, R20E	3.00	60.39		
Sec. 17/20, T13S, R20E	3.20	64.42		13
Sec. 16/17, T13S, R20E	1.70	34.22		
Sec. 15/16, T13S, R20E	2.00	40.26		
Sec. 22/15, T13S, R20E	2.00	40.26		
Sec. 15/22, T13S, R20E	2.50	50.33		
Sec. 15/22, T13S, R20E	1.50	30.20		
Sec. 14/15, T13S, R20E	2.00	40.26		
Sec. 12/13/14, T13S, R20E	2.15	43.28		14,15
Sec. 13/12, T13S, R20E	2.00	40.26		
Sec. 12/13, T13S, R20E	2.50	50.33		
Sec. 7/12, T13S, R21E	3.36	67.64	3.66	
Sec. 6/7, T13S, R21E	3.15	63.41	30.49	
Sec. 5/6, T13S, R21E	2.50	50.33		16
Sec. 4/5, T13S, R21E	2.50	50.33		17

Appendix 3
Historical Changes of Wakarusa Channel in Douglas County

The maps of Dort (n.d.) from a Kansas River study show fairly continuous channel position change in the Douglas County region of the Wakarusa River since Euro-American settlement. Modern site locations are indicated with cross section lines and site numbers.


KANSAS RIVER AND TRIBUTARIES, KANSAS
BANK STABILIZATION STUDY
HISTORIC CHANGES IN CHANNEL LOCATION
WAKARUSA RIVER
INDEX
In 1 sheet
Sheet No. 1
Scale: as shown
CORPS OF ENGINEERS U. S. ARMY
KANSAS CITY DISTRICT
FILE NO. A-1-976
CLINTON DAMSITE
LAWRENCE
KANSAS RIVER
WAKARUSA
DOUGLAS COUNTY
SHAWNEE COUNTY
OSAGE COUNTY


KANSAS RIVER AND TRIBUTARIES, KANSAS
BANK STABILIZATION STUDY
HISTORIC CHANGES IN CHANNEL LOCATION
WAKARUSA RIVER
In 2 sheets
Sheet No. 1
Scale as shown
CORPS OF ENGINEERS
U. S. ARMY
KANSAS CITY DISTRICT
FILE NO. A-1-977
LEAVENWORTH COUNTY
DOUGLAS COUNTY
KANSAS
LAWRENCE
KANSAS RIVER
WAKARUSA
1949
1976
1873
1898
1887
1902
10
11
12
13
14
15
16
17


KANSAS RIVER AND TRIBUTARIES, KANSAS
BANK STABILIZATION STUDY
HISTORIC CHANGES IN CHANNEL LOCATION
WAKARUSA RIVER
Sheet No. 2
In 2 sheets
Scale: as shown
CORPS OF ENGINEERS
U. S. ARMY
KANSAS CITY DISTRICT
FILE NO. A-1-978
KANSAS
DOUGLAS COUNTY
WAKARUSA
RIVER
1976
1909
1921
1887
1873
1898
1902
1949
7
8
9