INVENTORY AND ANALYSIS OF THE BLACK VERMILLION RIVER SYSTEM RIPARIAN CORRIDORS

by

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Abstract

The purpose of the investigation was to inventory and analyze riparian corridor vegetation changes throughout the Black Vermillion watershed from approximately 1857 through 2007. Three sub-watersheds were studied; North Fork, Irish Creek and Black Vermillion Main Stem. Research questions investigated were: 1) What changes in riparian corridor width have taken place since the original territory surveys done in 1857 and why? 2) How has land cover adjacent to riparian corridors changed since the original territory surveys? 3) Has woody species composition in the riparian corridors changed? The research questions were addressed using a variety of techniques and tools including aerial photography, basic GIS, and vegetation survey techniques. Territory of Kansas survey maps and notes that were completed in 1857 were used as baseline reference conditions concerning corridor width and woody species present in the riparian corridors. Inventory and analysis of the riparian vegetation change over time and adjacent land cover will aid in understanding the present ecology of these riparian corridors and are important to stream and riparian ecosystem rehabilitation.

Woody riparian corridors increased in width throughout the watershed from 1857 until about 1956 (probably due to a decrease in prescribed burning and lack of grazing), which is the pre-channelization period for this watershed. After channelization (late 1960's & early 1970's), average corridor widths dropped significantly as the stream was shortened a total of 15.8 miles (25.4Km). Most often, the land cover changed from native, tallgrass prairie to cultivated cropland or pasture. Woody species composition has changed over time from established mature woodland to a pioneer successional stage.

The findings of this study can influence beginning stages of design for natural habitat rehabilitation purposes in this watershed. Design decisions for land rehabilitation purposes should consider reference conditions (historic), and to understand reference conditions we must study the history of land use and land change. This study provides a template for studying the history of land use and land use change of riparian corridors for Midwestern, agricultural landscapes.

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CHAPTER 1 - Introduction

Nature has given man one tongue, but two ears,
that we may hear twice as much as we speak
Epictetus, Stoic philosopher

Riparian Corridors

Healthy riparian corridors are home to many important species that facilitate important ecological functions. Riparian corridors also provide; erosion control through energy dissipation (Gurnell, 1997; Knighton, 1998), direct stream bank protection and channel stability (Gurnell, 1997; Rosgen, 1996), supply and cycling of nutrients, and sediment filters that may improve water quality (Naiman & Decamps, 1997). It is critically important that we retain healthy riparian corridors when we develop or change land use so that these habitats and ecological functions remain intact. Once riparian ecosystems are degraded, it can take decades to recover ecological function (Gordon et al. 2004).

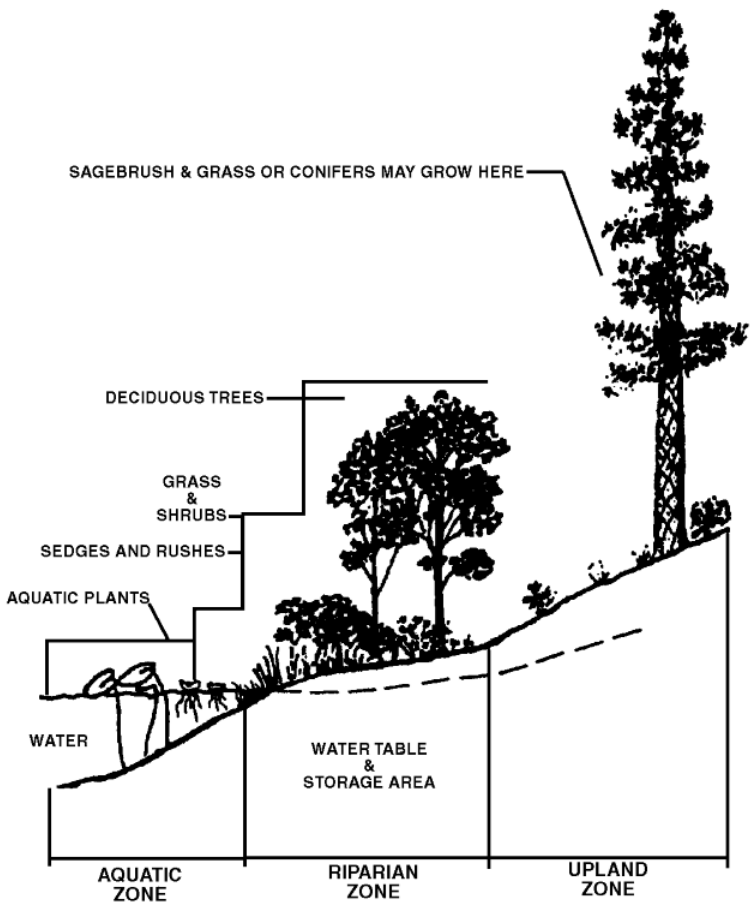
Human disturbances, such as channelization, urbanization and agriculture, are typically responsible for changing and degrading the health and integrity of riparian corridors (Rosgen, 1996). Many times riparian corridors are the last consideration in development and land use change when they should be the first. We are ruining these delicate ecosystems and their functions, which in turn may ruin our supply of fresh water and habitat for keystone riparian species.

Definition of Riparian

Riparian is defined as the zone that encompasses the stream channel between the low and high water marks and that portion of the terrestrial landscape from the high water mark toward the uplands where vegetation may be influenced by the high water table (Naiman & Decamps, 1997). Figure 1.1 illustrates a typical cross section of a riparian zone. From Figure 1.1, we can see that the water table (dotted line) and the ground surface (solid line) begin to diverge away from each other as we move upland. The

vegetation in the riparian zone is directly influenced by the water table in the riparian zone because the roots can come into direct contact with the water table. Verry (2004), suggests that the riparian zone be extended using Rosgen's floodprone width plus 30meters. Floodprone width of a stream is defined as stream width at two times the maximum depth at bankfull discharge (Rosgen, 1996).

Figure 1.1 Cross section of a typical riparian zone (Department of the Interior, 2007).



It is commonly accepted that woody riparian vegetation reduces bank erosion by slowing stream flood flow and lessening stream power by creating resistance and increasing friction (Knighton, 1998; Leopold et al. 1964). The riparian vegetation creates a soil-root matrix that increases the shear strength of the bank soil (Genet et al. 2005; Wynn et al. 2004). In addition to lessening bank erosion, vegetation decreases the

amount of precipitation and sediment runoff contributed from the adjacent land areas to the streams (Leopold et al. 1964).

Purpose of Investigation

The purpose of the investigation was to analyze riparian corridor vegetation changes throughout the Black Vermillion watershed from approximately 1857 through 2007. The Black Vermillion River and its tributaries are located in Northeastern Kansas (Figure 1.2). Frankfort and Centralia are two towns located within the watershed (Figure 1.3). The Black Vermillion Watershed is a contributor of water and sediment to Tuttle Creek Reservoir near Manhattan, Kansas. **Research questions include**: 1) What changes in riparian corridor width have taken place since the original territory surveys done in 1857 and why did those changes occur? 2) How has land cover adjacent to riparian corridors changed since the original territory surveys? 3) Has woody species composition in the riparian corridors changed?

These research questions were addressed using a variety of techniques and tools. Territory of Kansas survey maps and notes were used as baseline (1857) reference conditions for corridor width and woody species located in the corridors. These territory survey maps are not as accurate as aerial photographs, but are detailed enough to establish general corridor widths and patterns. The survey notes documented samples of the woody vegetation species and trunk diameter. Aerial photographs from 1957, 2002 and 2006 were used as comparisons of change from the baseline reference conditions. Finally, plants currently existing (summer 2007) in the riparian corridors were cataloged and compared with the reference survey notes of 1857. This analysis of the riparian vegetation change over time will help in understanding the ecology of the corridors and is important to stream and riparian ecosystem rehabilitation.

Significance of Investigation

Riparian corridor vegetation is an important factor when attempting to improve water quality, quantity and stream channel and bank stability. Healthy riparian corridors have been shown to reduce the amount of nutrient and sediment pollution entering a stream from upland areas (Naiman & Decamps, 1997). Riparian vegetation slows

surface runoff and allows infiltration of water into the soil before entering the stream. This infiltration lowers the storm hydrograph peak and dampens the flashiness of the annual hydrograph allowing the stream to work in a more sustainable way.

Research also suggests that riparian corridor vegetation lessens erosion rates though direct bank protection and by creating a soil/root matrix that strengthens the banks (Genet et al. 2005; Gordon et al. 2004; Pollen, 2007; Wynn et al. 2004). Riparian vegetation root density and root depth is a consideration when using David Rosgen's Bank Erosion Hazard Index (BEHI), which is an index that estimates the streambank's probability of failure (Rosgen, 1996). See BEHI form in Appendix A, Figure A. 1. Other bank stability assessments, such as SVAP (NRCS, 1998) and Phankuch (USDA, 2008), use riparian vegetation as a major component of the assessment. A study on how corridor vegetation has changed over time will allow for baseline measurements for stream and ecosystem assessment and rehabilitation.

Impacts of this study can be far reaching and influence design for natural habitat rehabilitation purposes in Midwestern conditions. Design decisions for land rehabilitation purposes should consider reference conditions, and to understand reference conditions we must study the history of land use and land change. This thesis provides a template for studying the history of land use and land use change of riparian corridors in Midwestern, agricultural landscapes.

Study Area

The Black Vermillion watershed is located in the eastern portion of Marshall County, Kansas, and extreme western Nemaha County, Kansas. A small portion of the watershed is located in southern Nebraska and Northern Pottawattamie County, Kansas. The river system lies in the glaciated region of Kansas and borders the Flint Hills ecoregion on the southwest side of the watershed (Figure 1.2). The watershed drains approximately 410 miles^2 (1062Km^2) at the USGS gauge near Frankfort, Kansas, before emptying into the Big Blue River west of Frankfort, Kansas. The Big Blue River then flows into Tuttle Creek Reservoir, which is northeast of Manhattan, Kansas. Three sub-drainage basins for the Black Vermillion River were selected for study: Irish Creek

(South Fork of the Black Vermillion), Main Stem of the Black Vermillion and North Fork of the Black Vermillion (Figure 1.3).

Figure 1.2 Kansas Ecoregions with Black Vermillion watershed in blue (NTS).

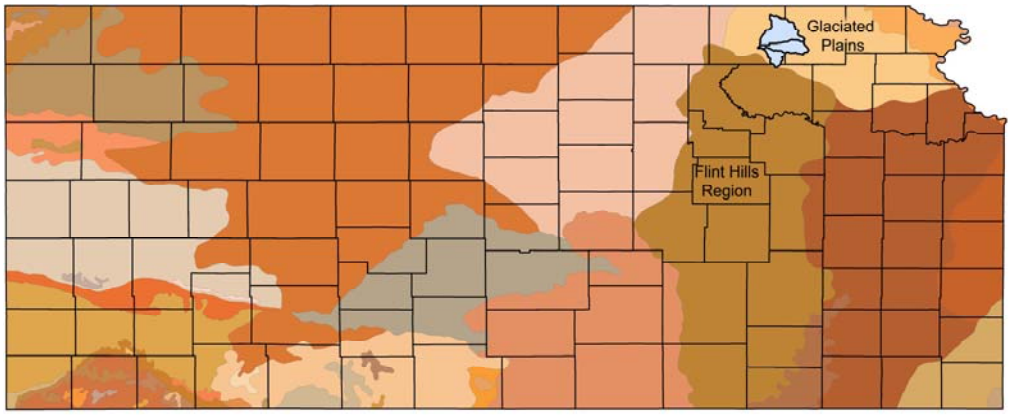
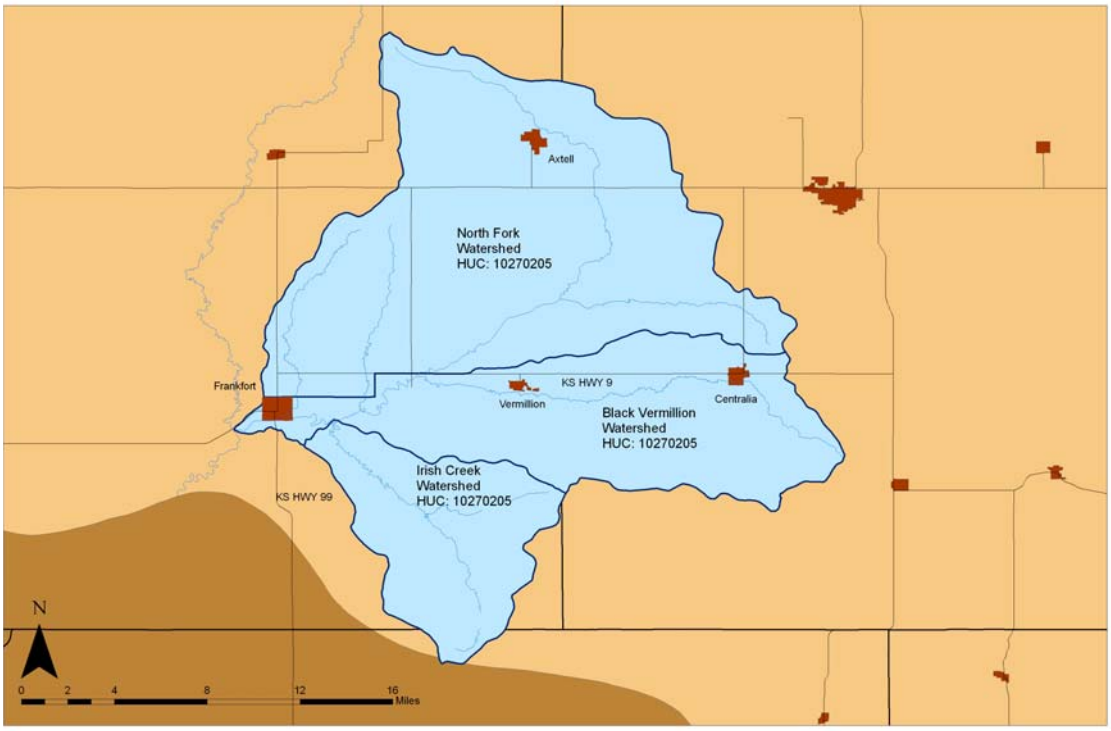


Figure 1.3 Black Vermillion watershed (detail from above).



Irish Creek Sub-watershed

Irish Creek (Black Vermillion South Fork) is a tributary located in southern Marshall County with a total drainage area of approximately 46.5 miles^2 (120.5Km^2), Figure 1.4. Irish Creek enters the Black Vermillion to the east of Frankfort, Kansas, from

the south, and flows primarily through Flint Hills uplands. Topography is typically rolling with a total fall of 290 feet (88m) in 17 miles (27.4Km) of stream (SCS, 1966). This sub-watershed lies in the tallgrass prairie region of Kansas that consisted of typical native grasses such as; big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparum*), indian grass (*Sorghastrum nutans*), sideoats grama (*Bouteloua curtindula*), and switchgrass (*Panicum virgatum*). The western banks typically resemble Flint Hills more than the east bank. The east bank typically has a deep layer of Kansan till (SCS, 1966). The Irish Creek sub-watershed contains many flow-through water impoundments changing the watershed size and stream flow characteristics from historic conditions. Representative photos of the Irish Creek sub-watershed are included as Figures 1.5, 1.6, 1.7 and 1.8. Irish Creek reach 1 has the most riparian vegetation of any site in the sub-watershed.

Figure 1.4 Irish Creek sub-watershed and sampling locations.

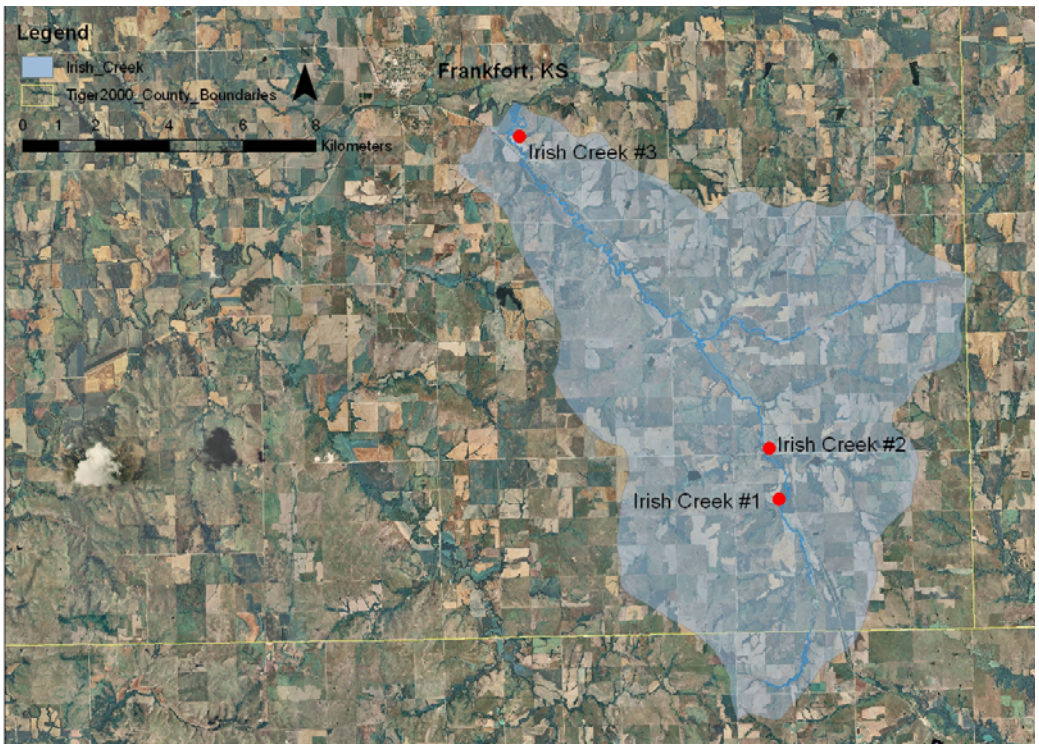


Figure 1.5 Irish Creek reach 1 (Keane, 2007).

Figure 1.6 Irish Creek reach 2 (Keane, 2007).

Figure 1.7 Irish Creek reach 2 (Keane, 2007).

Figure 1.8 Irish Creek reach 3 (Keane, 2007).

Main Stem of the Black Vermillion

The main stem of the Black Vermillion flows mostly westward and drains an area of approximately 83.8 miles^2 (217Km^2), Figure 1.9. The main stem of the Black Vermillion flows through alluvial and glacial deposits on its way into the Big Blue River and Tuttle Creek Reservoir. The predominant land use in the watershed is tillage agriculture with some pastureland. The Black Vermillion system also contains many small flow-through water impoundments with one large impoundment. Centralia Lake, completed in 1991, is an approximately 400-acre (161.9ha) impoundment and is the largest water impoundment in the entire Black Vermillion watershed (Jones, 2008). Topography is rolling with deeply dissected drainages in the system. There is approximately 260 feet (79.25m) of fall in 27 miles (43.5Km) making this the flattest sub-watershed in the system (SCS, 1966). Ridges are generally capped with thin layers of loessial soils (SCS, 1966). The Main Stem lies in the tallgrass prairie region of Kansas. Representative photos of the Main Stem sub-watershed are included as Figures 1.10, 1.11 and 1.12.

Figure 1.9 Black Vermillion Main Stem sub-watershed and sampling locations.

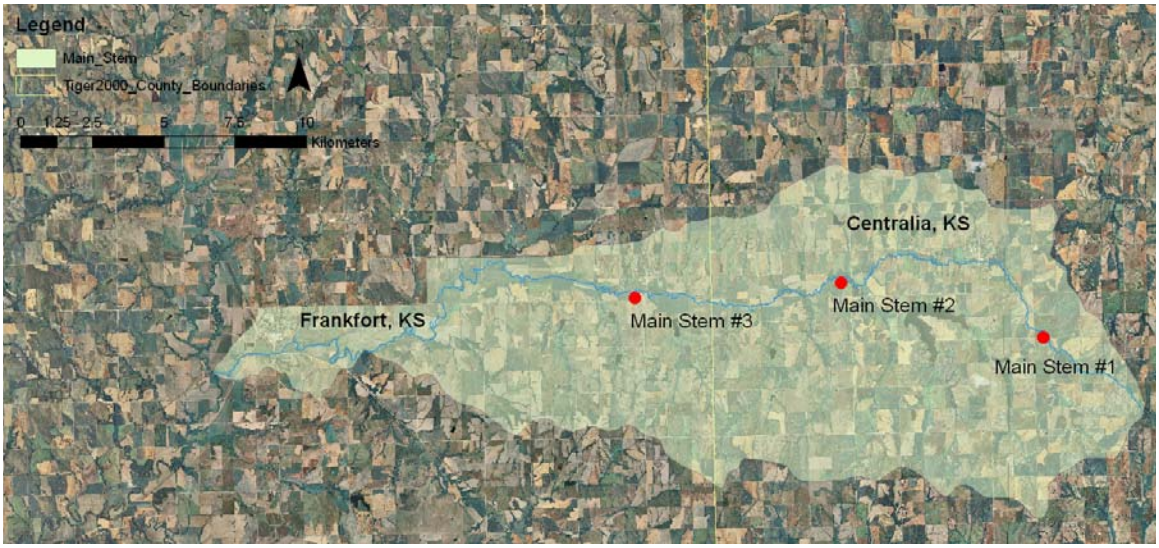


Figure 1.10 Main Stem reach 1 (Keane, 2007).

Figure 1.11 Main Stem reach 2 (Keane, 2007).

Figure 1.12 Main Stem reach 3 (Keane, 2007).

North Fork of the Black Vermillion

The North Fork of the Black Vermillion runs south and is the largest sub-watershed of the Black Vermillion watershed, containing approximately 121 miles^2 (313.4Km^2), Figure 1.13. The North Fork flows through alluvial and glacial deposits as it makes its way to the Black Vermillion River. Topography is rolling with deeply dissected and entrenched streams. Total fall in the sub-watershed is 329 feet (100.25m) in 23 miles (37Km) (SCS, 1966). Ridges and flatter tops typically are covered in thin layers of loessial soils. This sub-watershed is also located within the tallgrass prairie region of Kansas. Typically, woodlands are located in the lowlands near streams when present. Predominant land use in the watershed is tillage agriculture with minimal pasture. Representative photos of the North Fork sub-watershed are included as Figures 1.14, 1.15, and 1.16.

Figure 1.13 Black Vermillion North Fork sub-watershed and sampling locations.

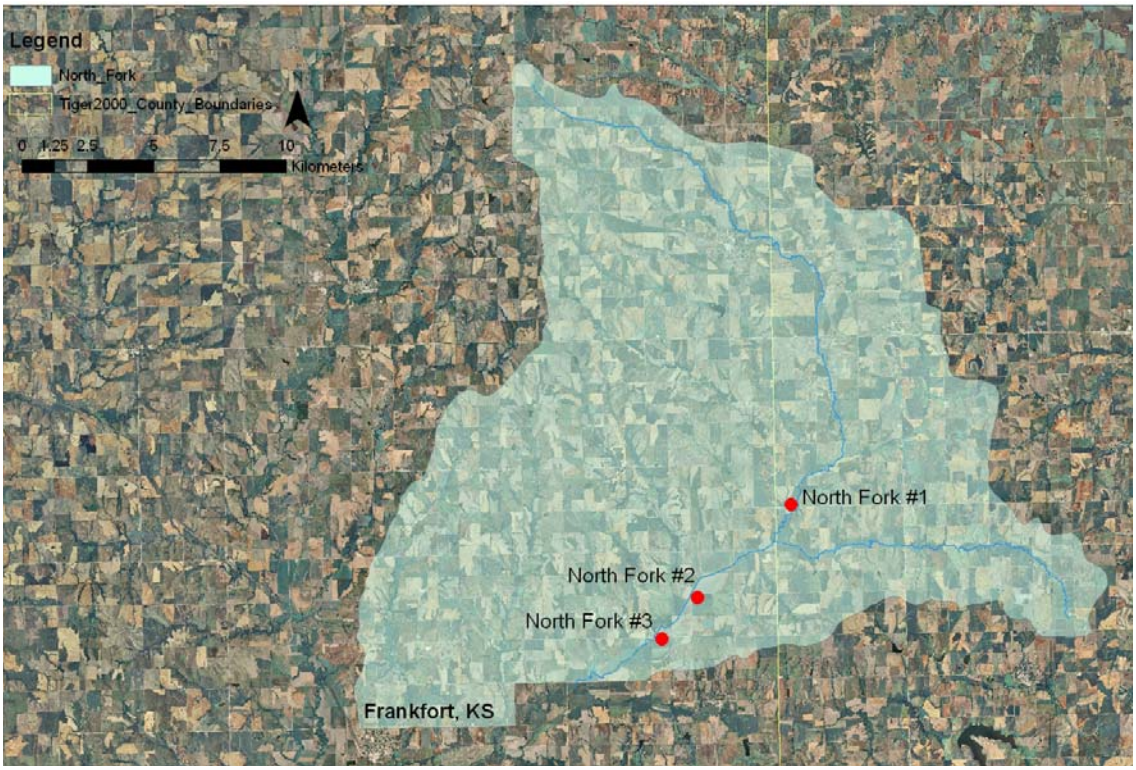


Figure 1.14 North Fork reach 1 (Keane, 2008).

Figure 1.15 North Fork reach 2 (Keane, 2008).

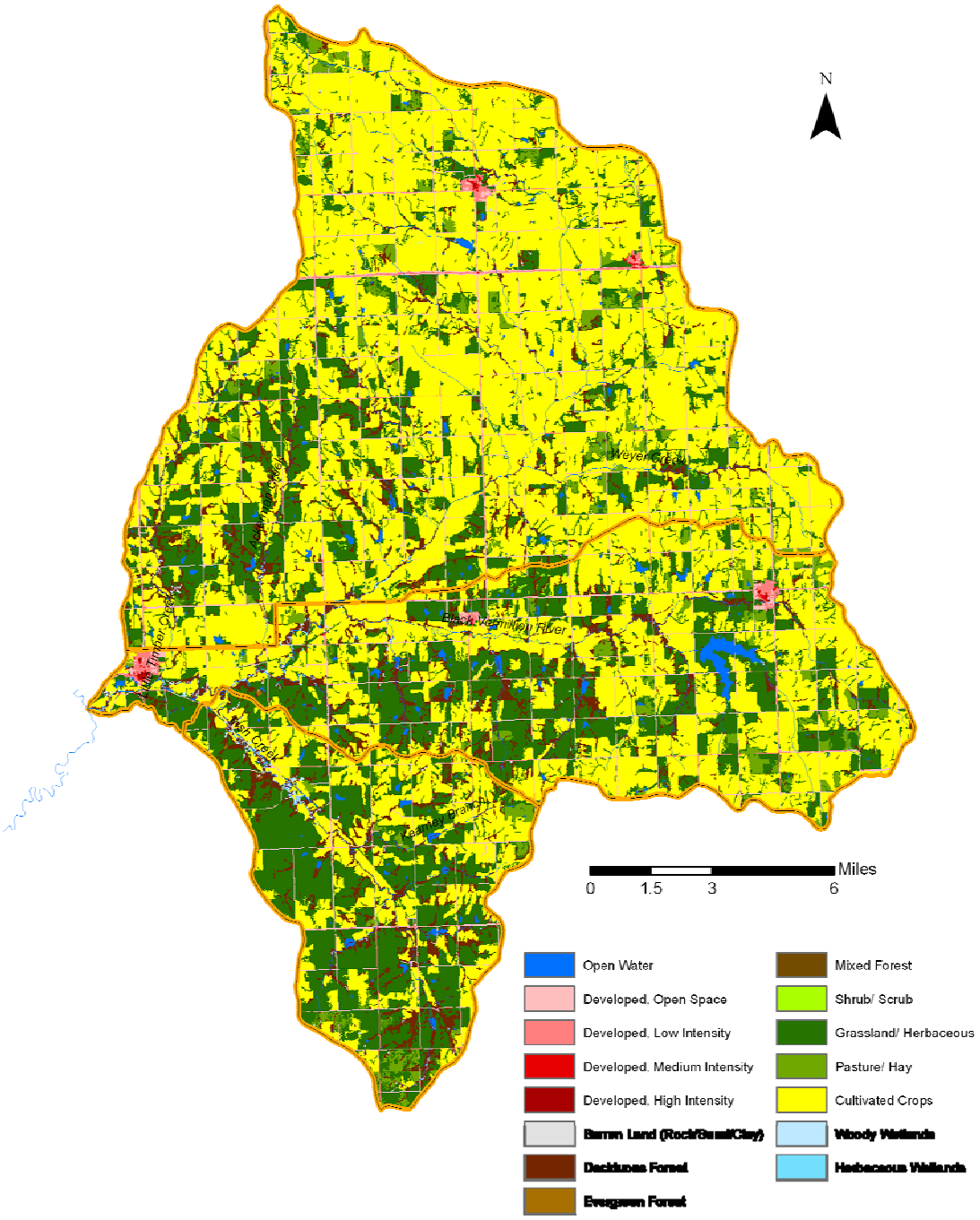
Figure 1.16 North Fork reach 3 (Keane, 2008).

Land Use

Land use and land cover vary throughout the entire watershed. Cultivated lands, pastured lands, small cities, and natural areas are included within the watershed to varying degrees. The majority of land located within the watershed is currently cultivated or pastured, Figure 1.17. The United States Army Corps of Engineers (USCOE), Soil Conservation Service (SCS), now the Natural Resources Conservation Service (NRCS), and individual landowners have modified most of the streams in the watershed in some fashion, either by straightening the channel and/or by placing levee systems between fields and the streams. The stream length in the watershed has been shortened a total of 15.8 miles (25.4Km) (USCOE, 1998). These modifications tend to decimate the riparian vegetation and lead to an increased velocity of the stream, which in turn increases erosion rates along streambed and banks while destroying riparian habitat. With no vegetation to increase bank stability and increase roughness, the stream can erode its bed and banks at a rapid rate. The watershed also contains numerous water impoundments, reservoirs or farm ponds. Many of these impoundments are "flow-through" and allow for a sustained flow of water through to the streams, which is quite different from historical flow regimes. Historically, precipitation in the watershed would infiltrate into the soil more than it does today. Infiltration of water provided more storage capacity for groundwater, lessened surface runoff and provided a non-flashy hydrograph. The historic flow regimes with groundwater flow to the streams would have provided a sustained base flow year round. (USCOE, 1998).

Figure 1.17 Land Use Map of Black Vermillion watershed.

Source: Jeff Neel via 2001 National Land Cover Data Set (For larger map, see Appendix B.1).



Key Terms

A list of key terms employed in this document is provided below:

Reference Conditions - Historic conditions at a given time in the ecosystem to which we would prefer to see restored or rehabilitated function. These conditions help to (1) establish the preferred condition; (2) determine what factors caused the degradation or change; (3) define the needs to restore the ecosystem; (4) develop criteria to measure success or failure of restoration projects. (Egan & Howell, 2001) The most important part of ecosystem rehabilitation is the selection of reference conditions "since future changes in an ecological community will always be dictated by its starting structure, the starting structure must accurately represent the reference ecosystem during the historical period.", as cited from Bonnickson, 1994, in Egan & Howell, 2001, page 10.

Watershed (catchment) - Total area above a given point on a stream that contributes water to the flow at that point (Smith & Smith, 1998).

Rehabilitation - to restore to a former capacity; reinstate; to restore to good repute; reestablish the good name of; to restore to a former state (as of efficiency, good management, or solvency); to restore or bring to a condition of health or useful and constructive activity (Misch, 1996). Rehabilitation and restoration will be used synonymously in this thesis.

Invasive Species - an introduced or native species that spreads and often causes harmful ecological effects on other species or entire ecosystems (Wright, 2005).

Soil erosion - process by which soil is washed, blown, or otherwise moved by natural agents from one place on the landscape to another (Harpstead, et al. 2001). This thesis will concentrate on soils moved by fluvial processes, or alluvium.

Species Richness - Number of different species in a given area (Smith & Smith, 1998)

Species Diversity - Measurement relating density of organisms of each type present in a habitat to the total number of species in a habitat (Smith & Smith, 1998).

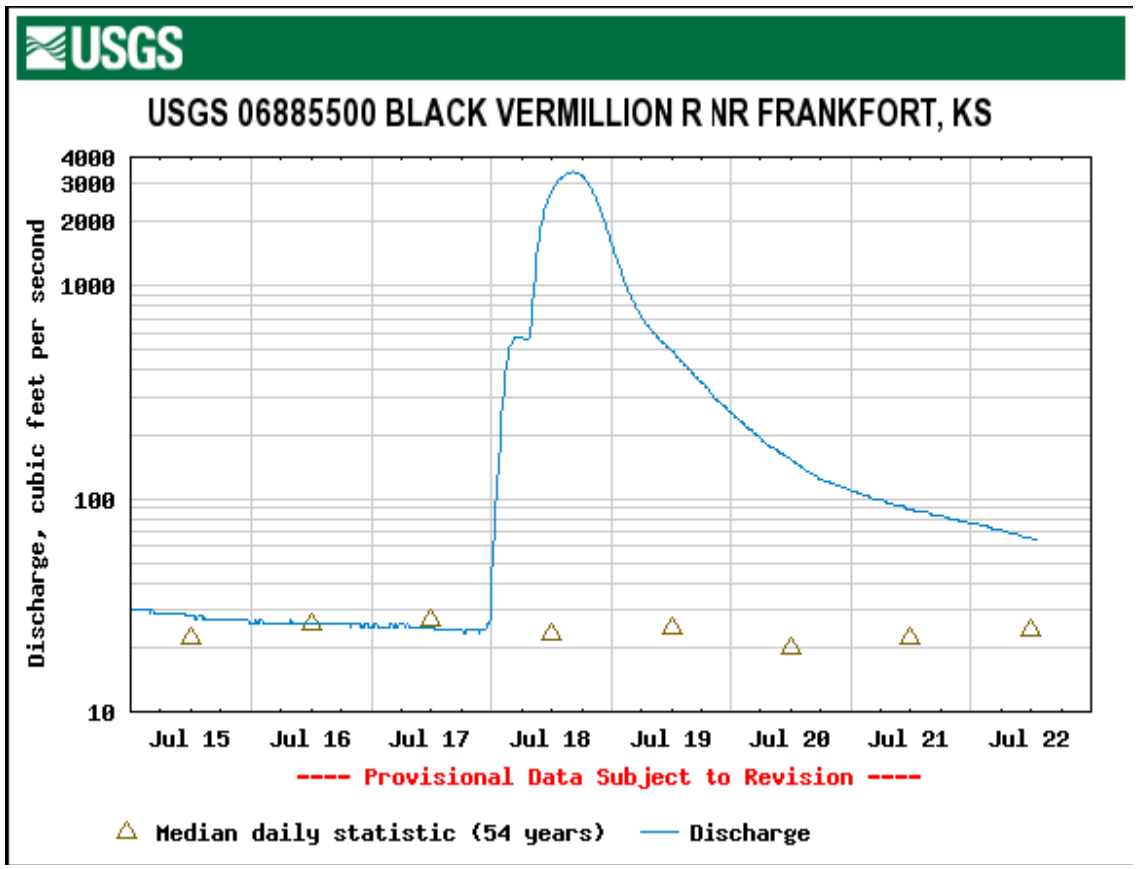
Riparian Ecotone –"contains all aquatic (channel), floodprone (flood dispersal of sediment, plants, and animals) and many upland functions (slumps, slides, subsurface water and nutrient flow) that interact strongly with the water during average, bankfull, and flood flow conditions." (Verry et al. 2004)

Bankfull Stage- Bankfull stage is the discharge at the incipient point of flow onto the floodplain. This discharge is when channel maintenance (formation) is most effective. This discharge occurs on average every two out of three years (Dunne & Leopold, 1978; Rosgen, 1996).

Disturbance- "A discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment" (Pickett & White, 1985, p7).

Hydrograph- A graph where discharge is plotted against time, Figure 1.16. It helps explain how quickly discharge rises and then falls. Historically hydrographs had lower peaks and fell at a much slower rate than they do today.

Figure 1.18 Example of a Hydrograph used by USGS at Frankfort, KS, showing a discharge change from about 25c.f.s to almost 3500c.f.s in one day after a 3" rain event. (USGS, 2008).



CHAPTER 2 - Literature Review

Northeast Kansas Climate and Geology

Climate and geology are two factors that influence plant communities of a region (Leopold et al. 1964). Northeast Kansas has a unique combination of climate and geology that contributes to its prairie setting. Two general land formations are located in the study area, the Glaciated Region of Kansas and Flint Hills Uplands (Figure 2.1). These physiographic regions present differing geology but similar climates, generating similar plant communities. Geologic formation of underlying bedrock is similar between the two regions since the area was once an inland sea, the last inland sea being approximately 270 million years ago. Shale and limestone layers that dip slightly to the northwest are prevalent under the glacial till in the glaciated region of the state (Aber, 2007). The Flint Hills have no glacial till covering the tilted shale and limestone layers, making the Flint Hills a different hydrophysiographic region.

Northeast Kansas Climate

Climate is defined as the average weather pattern over time in a given location (Smith & Smith, 1996). The climate in northeast Kansas is considered continental with an average precipitation of approximately 32”-35” (81-89cm) per year. In terms of precipitation, the area has a water surplus meaning water leaves in channels and subsurface migration (Aber, 2008). Most precipitation falls during the growing season, April through September (Oznet, 2008). Relative humidity in the area averages around 45-50%. Average annual temperatures of 55° Fahrenheit (F) (12.8° Celsius, C) characterize the climate (Aber, 2008; Oznet, 2008). Daily range in temperature is around 20°-22° F (11.1°-12.2° C). The coldest month on average is January with February usually having the coldest days. Average highs in January are 42° F (5.5° C). Eight to ten days a year temperatures can dip to 0° F (-17.8° C). July is usually the hottest month on average with temperatures reaching near 94° F (34.4° C). About ten days each summer

temperatures reach the +100° F (+37.8° C) mark. There are approximately 145 days of clear sky with winds reaching peak gust velocities of 47 mph (75.6km/hr) (Oznet, 2008).

Geology and Soils

Glaciated Region

The Pre-Illinoian Glacier terminated at the foot of the Flint Hills in Northeast Kansas approximately 600,000 years ago; see Figure 2.1 for a location of the glaciated region versus the Flint Hills region (KGS, 2007). Many glacial erratics are found throughout the glaciated area, most erratics being of Sioux quartzite, which are a reddish granitic material and came from South Dakota, Iowa and Minnesota (KGS, 2007). The underlying bedrock in the glaciated area of Northeast Kansas is Pennsylvanian and Permian limestone and shale that dip gently to the west and northwest, much like the Flint Hills. However, a layer of glacial till with silt, pebbles and boulders covers this bedrock. Figure 2.2 is a cross section of Marshall County, Kansas, the location of the Black Vermillion watershed, showing the depths of glacial deposit and alluvial deposit across the county (KGS, 2007). We can see the glacial deposit is quite deep in areas, exceeding 40'.

Soils are an important variable when looking at vegetation community formation. Soil characteristics are determined by the interaction of five factors; these factors are parent material, biota, climate, relief, and time (NRCS, 2008; Smith & Smith, 1996). Each of these factors affects the formation of the soil type and influences the effects of the other four (Harpstead et al. 2001; NRCS, 2008). Soils in this portion of northeast Kansas are of the order Mollisol. Mollisols, or soils formed primarily by the organic contributions of grasses, have distinct horizons or layers, rich in organic matter, which take hundreds to thousands of years to form (Smith & Smith, 1996). Today's cultivated fields of row crops were once humus rich soils covered by native grasses, as they are the most agriculturally productive soils (Harpstead et al. 2001). Three modes of transportation, water, gravity and wind move soils. Soil particles moved by fluvial processes are addressed as alluvium, while dry, gravitational movement is considered colluvium.

Alluvium, or soils that are deposited by fluvial processes on floodplains, should be common in riparian corridors due to repeated flooding and deposition of sediment on the floodplain. These riparian soils are also humus rich due to the leaf litter and other detritus that accumulates in a healthy riparian zone. Humus is a major factor in soil structure and water holding capacity. More water is stored in a soil with humus and is readily available to plants (Harpstead et al. 2001).

Figure 2.1 Physiographic map of Kansas (KGS, 2007).

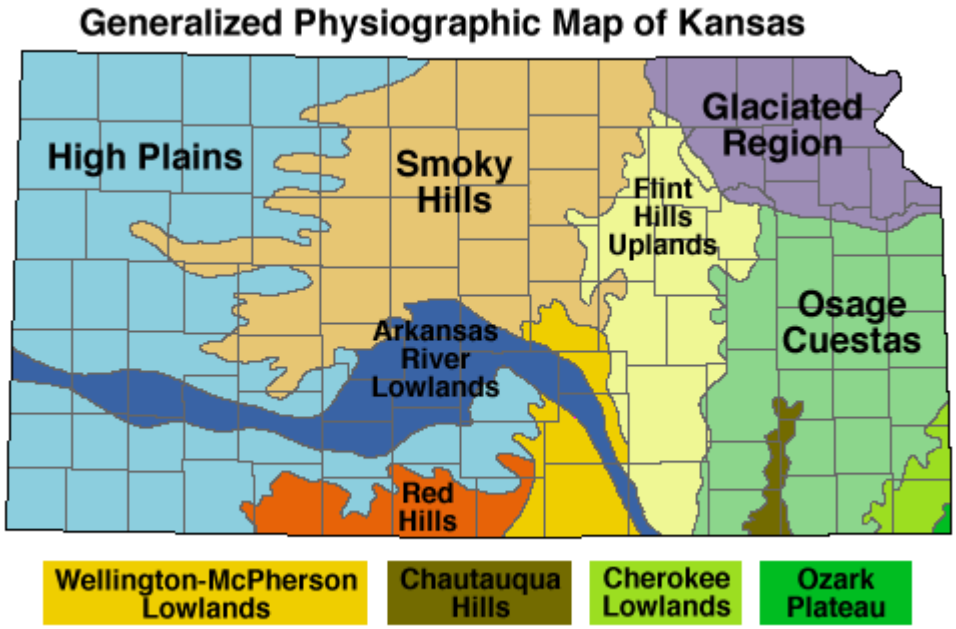
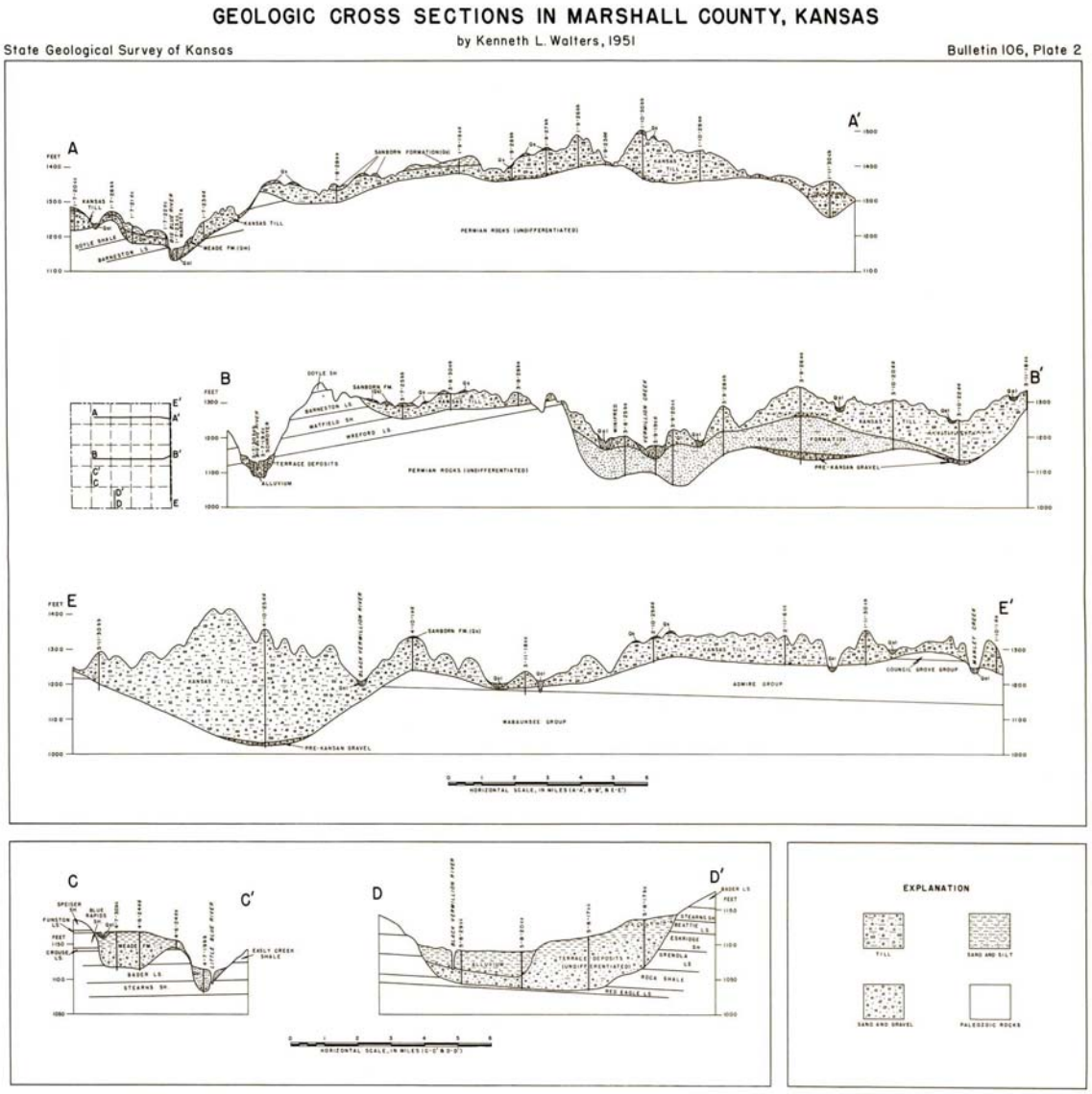


Figure 2.2 Cross sections of glaciated region (Walters, 1954) (For larger version, see Appendix Figure A.2).



Flint Hills Uplands

The Flint Hills Uplands is a unique physiographic region found in east-central Kansas; see Figure 2.1 for location. This area was formed by an inland sea that rose and fell repeatedly approximately 270-300 million years ago and was always less than 100' (30.5m) deep, as indicated by ripple marks, algal laminations and oolites found in the limestone units (Aber, 2008). The bedrock stratigraphy is consistent laterally and layers alternate between shale and limestone maintaining thickness consistency. A limestone

cap is responsible for maintaining the topographic relief due to its resistance to erosional forces. Dip is typically westward to northwestward at an angle of 4-10 degrees (Aber, 2008). The limestone contains flint nodules, from which the region received its name.

Chert, or flint, is found in nodules embedded into the limestone formations. This chert is highly resistant to weathering and when it is residual lag, it helps maintain topographic relief (Aber, 2008). Due to the chert's hardness, landform and depth to bedrock on terraces, most of the region has never been plowed. The result is the largest, contiguous region of native tallgrass prairie remaining in North America. Most of the Flint Hills region is home to cattle ranching and grazing land.

Deep valleys have been created in the Flint Hills due to stream erosion (Aber, 2008). Topographic relief in the area can be up to 100' (30.5m) and deeply entrenched streams are common, drainages tend to follow in troughs and synclines of the formations (Aber, 2008). Flash flooding is common in this region due to the semi-permeable layers of limestone and shale as well as the shallow, clay-rich soils of the areas. Valleys usually have deeper soils than ridge tops due to the steep slopes typically found on the formations. Surface runoff occurs mostly during storm events which happen in the spring and early summer and then again in fall (Aber, 2008). In Figure 2.2, we can see a typical Flint Hill formation in eastern Marshall County in Section B-B[1].

Northeast Kansas Vegetaion

Historic Composition

Approximately 42% of the earth's terrestrial surface was once covered by grasslands. Grasslands, or prairies, typically receive precipitation between 10"-32" (25.4-81.28cm) and require periodic fires and grazing for maintenance, renewal, and elimination of woody growth (Smith & Smith, 1998). Northeast Kansas historically supported a tallgrass prairie ecosystem (Briggs et al. 2005; Haddock, 2005). Typical grasses in the tallgrass prairie ecosystem include big bluestem (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*) and switchgrass (*Panicum virgatum*) (Haddock, 2005). Northeast Kansas received sufficient precipitation amounts to support deciduous forests, but with fire and grazing as disturbance regimes, woody species were confined to riparian corridors. Northeast Kansas did support a wide-open expanse of tallgrass prairie

along with scattered trees, such as bur oak (*Quercus macrocarpa*) and narrow riparian corridors with mixed woody species such as black walnut (*Juglans nigra*), sycamore (*Platanus occidentalis*) and cottonwood (*Populus deltoides*) (KSLS, 2005).

Riparian vegetation once covered approximately 2% of North America with more than 89% of the 2% being lost over the last 200 years (Popotnik & Giuliano, 2000). North America is approximately 9.45 million miles^2 (24.4 million Km^2), which means we have approximately 21,000 miles^2 (54,390 Km^2) of riparian vegetation left in North America. These corridors have been victim to logging, agricultural practices and urban development (Popotnik & Giuliano, 2000).

Riparian forests located within the prairie were found only on floodplains of streams and were generally not extensive from the centerline of the creek (KSLS, 2005). Headwater streams generally flowed through native prairie grasses, sedges, rushes and forbs as opposed to woody riparian vegetation corridors (KSLS, 2005). This set of circumstances is due to the unfavorable conditions for the growth of woody species; the typical burning and grazing of the prairie (Knight et al. 1994; Richardson et al. 2007). Historically, wooded riparian corridors located within prairie settings were narrow and linear in form (gallery forest) with a few areas that increased in width, usually at a tributary confluence. Riparian forests contained understory shrubs and forbs along with scattered canopy trees (Knight et al. 1994; KSLS, 2005). Historic species diversity and richness in the riparian corridors should have been greater in 1857 than current due to the regular disturbance of flooding, fire, and native grazing versus the current practice of cultivation that creates a monoculture (Haddock, 2005).

Current Land Cover

Land cover in northeast Kansas has changed dramatically since 1857 from tallgrass prairies with typically narrow woody riparian corridors to a sea of row crops containing corn, soy beans and winter wheat with narrow to non-existent woody riparian corridors. Exotic species that are now dominant within the watersheds include; smooth brome (*Bromus* sp.), bluegrass (*Poa* sp.), grain sorghum (*Sorghum* sp.), and alfalfa (*Medicago sativa*). New dominant fauna inhabit the ecosystem as well. Cattle and horses currently roam and graze pastures in northeast Kansas. White-tail deer

populations have exploded and are a cause for concern due to their grazing habits. Precipitation runoff is increased in agricultural fields and grazed pastures due to bare and compacted soils acting as a semi-impervious surface. Concerns of ecologists include loss of flora and fauna, loss of diverse and important habitat, and reduced water quality with increased sediment in streams from stream bed and bank erosion (Popotnik & Giuliano, 2000).

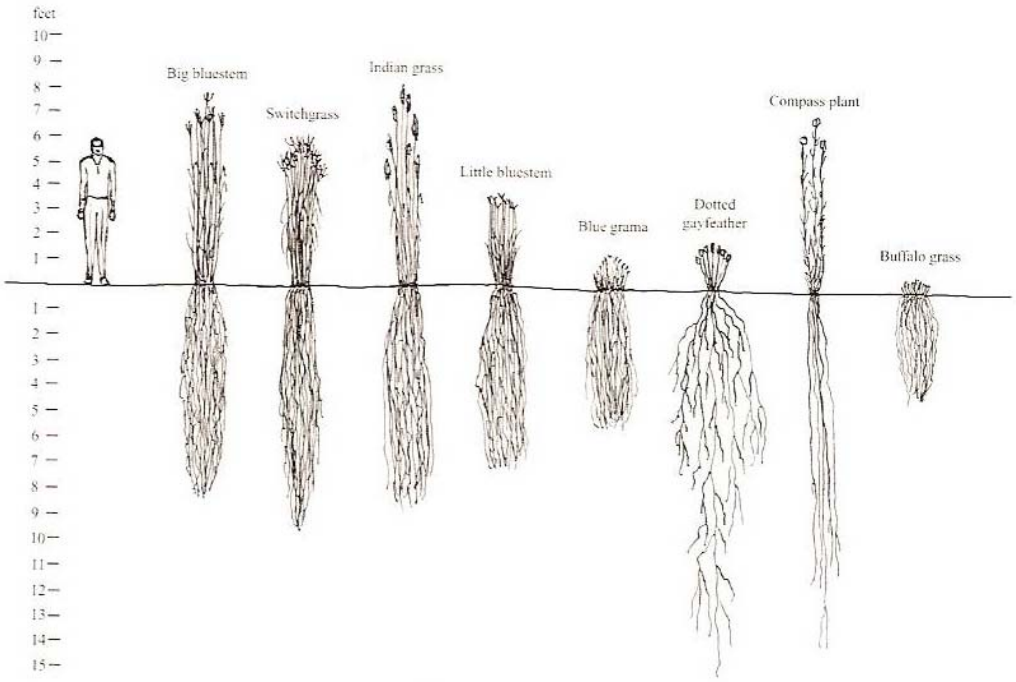
Vegetation Root Systems

Root systems between herbaceous and woody plants differ in their structure. In general, woody root structure is thicker and less fibrous versus the more fibrous and deep root systems of native grasses and forbs. Figure 2.3 is an example of native prairie grasses and forbs rooting depth. Row crops and non-native cool season grasses have a much shallower and less fibrous root system than native prairie vegetation allowing for less infiltration of water into the soil (Harpstead et al. 2001). A shallow root system of about 6" (15.24cm) is typical in cool season grasses such as Brome (*Bromus* sp.) and annual crop species such as corn (*Zea mays*). In addition to infiltration differences, sediment yield from agricultural row crops is higher than the native grassland (Leopold et al, 1964). Forbs, such as compass plant (*Silphium laciniatum*), can reach a rooting depth of 15' (4.6m) while the fibrous root systems of grasses such as big bluestem (*Andropogon gerardii*) can delve to a depth of 8'-10' (2.4-3m). These native fibrous root systems were adequate to hold streambanks together under the historic hydrograph.

Woody vegetation has a slightly different root architecture compared to herbaceous plants. Depending on the species and growing conditions, roots for a woody plant may be shallow, such as willow (*Salix* sp.), to deep, penetrating lateral root structure, such as boxelder (*Acer negundo*). Some woody species even have a taproot system plus a deep lateral root structure. When exposed to the open air, woody roots become more like stems or branches, including annual growth rings and bark. We can date these new "branches" and find out when they became exposed, or when the streambank retreated. Woody roots are also stronger at providing tensile strength in the soil-root matirx than herbaceous roots, making them a better bank stabilizer than herbaceous species roots. Tensile strength is how much tension a root can bear before it

is pulled apart. It is tensile strength of the soil- root matrix that helps streambanks resist shear stress and thus bank failure.

Figure 2.3 Example of native prairie plant rooting depth (Haddock, 2005).



Importance of Riparian Corridors

Riparian corridors serve many ecological functions such as stopping points for migrating species, cover for local species and thermal regulation of the stream itself (Gurnell, 1997; Naiman & Decamps, 1997; Popotnik & Giuliano, 2000). Riparius is Latin for of, or belonging to the bank of a river (Naiman & Decamps, 1997). Most conservationist and wildlife biologist believe that corridors are essential connectors between habitats and are needed to thwart local extinctions and lowered biological diversity (Rosenberg et al. 1997). Unfortunately, riparian corridors are the few remaining natural corridors left. Streamside riparian areas support a wealth of diversity and are ecologically important regardless of their role as corridors (Rosenberg et al. 1997). These systems are the most diverse, dynamic and complex ecosystems on the terrestrial portion of the earth (Naiman et al. 1993). Due to the dynamic nature of riparian areas, they are highly prone to invasive, alien species invasion (Richardson et al. 2007).

Healthy riparian areas include a diversity of habitat and maintain the integrity of aquatic ecosystem by providing shade, nutrients and structure while reducing sedimentation and pollution (Rosenberg et al. 1997).

Riparian Ecotone and Edge

Ecotones are integrations between two vegetation communities (Smith & Smith, 1998). Riparian corridors can be considered an ecotone in their own right, being the transition and integration between the aquatic and terrestrial vegetation, then from riparian forest to grassland. Ecotones possess specific physical and chemical attributes, biotic properties, and energy and material flow processes (Naiman & Decamps, 1997). The biotic properties and chemical attributes are in specific balance and when one variable is changed in the system, the entire system must adjust to attempt a new balance. This new balance may exclude species that were already in the ecotone, but now are unable to survive in the new environ. Riparian corridors are potentially sensitive sites for interactions between biological populations and their controlling variables, have relatively high biodiversity, maintain critical habitat for rare or threatened species, and are refuge and source areas for pests and predators (Naiman & Decamps, 1997). The interfaces between freshwater ecosystems and terrestrial ecosystems are particularly sensitive to change (Naiman & Decamps, 1997).

Edge condition is quite different from the ecotone condition. An edge is the abrupt change in vegetation communities with little to no integration of communities (Smith & Smith, 1998). We can see this condition when we look at agricultural fields against the banks of the streams or forested corridors and agricultural fields. There is no transition or integration of vegetation, just abrupt change. Edge condition happens naturally in some locations; however, species that have not evolved with edge conditions are affected by abrupt changes and are slow to adapt or survive the new ecosystem condition. Changes to ecotones and edges can be, and often are, human induced.

Ecological Functions

Riparian corridors provide important ecological functions. Riparian vegetation creates habitat and forage for migratory birds, other year round fauna such as white-tail deer (*Odocoileus virginianus*) and badger (*Taxidea taxus*), as well as movement corridors

between habitat patches (Naiman & Decamps, 1997; Popotnik & Giuliano, 2000). It has been suggested riparian corridors are a refuge for mesic flora during times of drought (Naiman & Decamps, 1997). Fauna use riparian corridors as breeding, rearing, feeding and drinking habitat. Local species which are intricately tied to riparian zones include; white-tail deer (*Odocoileus virginianus*), yellow warbler (*Dendroica petechia*), and gray catbird (*Dumetella carolinensis*). Topeka shiner (*Notropis topeka*), a threatened species in Kansas, depends on the thermal regulation provided by riparian corridors and the detritus from the corridor as a food source.

Vegetation in riparian corridors has been shown to uptake nutrients that are filtered out of overland flow (Naiman & Decamps, 1997; NRCS, 2008). Short-term accumulation of nutrients results in non-woody uptake of nutrients into biomass while long-term accumulation results in woody biomass (Naiman & Decamps, 1997). Vegetation in riparian corridors remove 80-90% of all sediment and nutrients moving toward the stream in overland flow. Coarse sediments drop out within a few meters of entering the riparian corridor and finer sediments drop out as they move toward the stream mixing with overbank deposition (Naiman & Decamps, 1997).

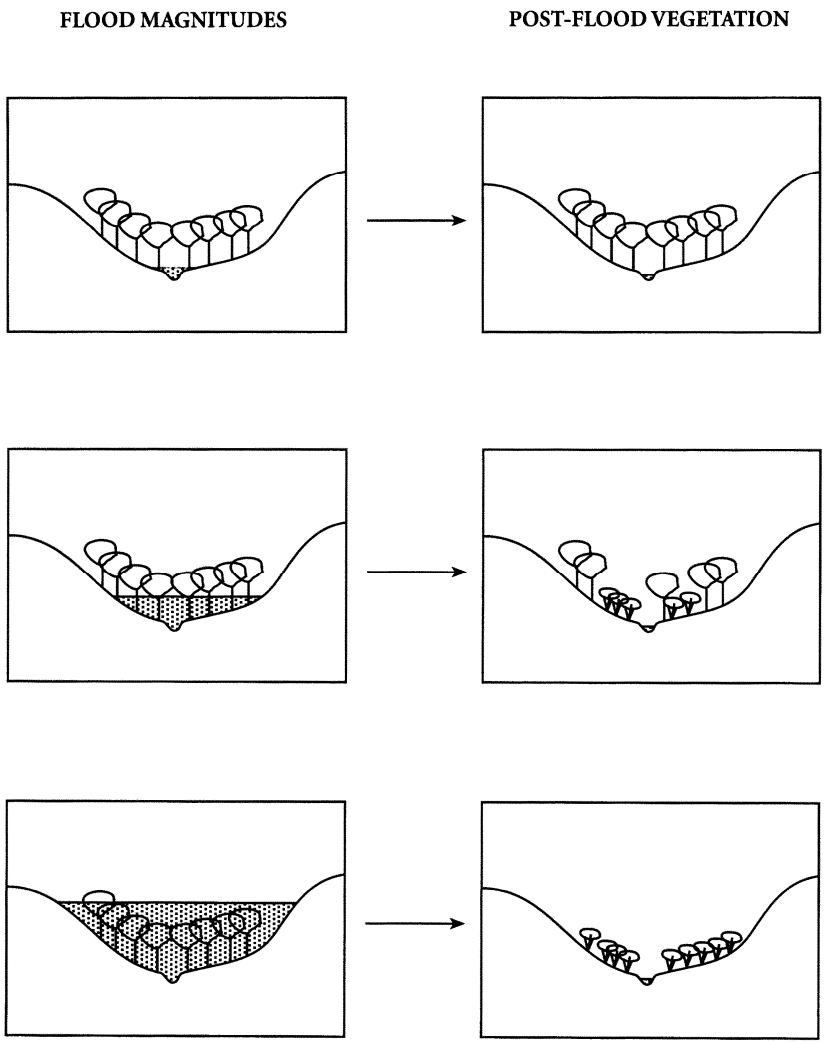
Riparian corridors facilitate many functions of the stream and adjacent ecosystems. One function of a riparian corridor is the regulation of the stream water temperature as stream water temperature has been directly linked to riparian corridor temperature (Naiman & Decamps, 1997; NRCS, 2008). The riparian vegetation attenuates water temperature in two ways: first, the vegetation allows for slower seepage of groundwater flow through the soil allowing the infiltrated water to cool to soil temperature before leaving the ground and moving into the stream. Second, the vegetation, if tall enough, directly shades the stream or sides of the steam while allowing dappled sunlight into the stream.

Riparian systems are harsh environments that are prone to flooding, droughts and human interference. Streams seem to be in a constant state of non-equilibrium (Knighton, 1998) that has strong effects on biota of the riparian zone (Naiman & Decamps, 1997). This harsh riparian system has lead to the adaptation of the life histories of the flora and fauna that live in riparian corridors. An example of life history adaptation of flora in the riparian corridor is quick growing, spring seeding species,

where floods are more prevalent. Spring floods can uproot trees and other vegetation during high flows allowing opportunities for new vegetation in cleared areas, giving the spring seeders an advantage in establishing the newly cleared site. One such species is Cottonwood (*Populus deltoides*), a common resident in riparian systems. Riparian systems encourage high species diversity due to the disturbance of flooding, especially in the middle reaches of stream systems, which may be prone to exotic species invasion (Bendix, 1997; Larson et al. 2001). Channelization and other channel modifications can increase the chance of exotic or invasive species through the clearing of the landscape's native vegetation. This clearing of native vegetation increases the available area for exotic or invasive species establishment.

Riparian vegetation should be ever-changing in age and composition due to the disturbance of flooding, see Figure 2.4 (Bendix, 1997). We can imagine, looking at Figure 2.4 that the first scenario would represent a channel that has been modified in a way that no longer allows contact with the floodplain. This disconnect from the floodplain lowers species diversity and age diversity in vegetation. The second scenario would represent a healthy riparian zone that has a connected floodplain and allows for changes in the riparian vegetation and age diversity of the vegetation. Scenario three might represent high stream discharge due to land use change. The land use change would be responsible for an increase in impervious surfaces increasing the runoff to the stream. This increase in discharge would cause flooding at a greater depth than before, destroying vegetation higher on the banks that was not affected before the land use change. Such an increase in discharge would lead to increased erosion from the banks due to the removal of vegetation and not allowing the vegetation time to re-establish.

Figure 2.4 Example of Intermediate Disturbance Hypothesis (Bendix, 1997).



Riparian corridors tend to be vulnerable to alien plant species invasion and outside disturbances (Richardson et al. 2007; Popotnik & Giuliano, 2000). Popotnik and Giuliano (2000), found that bird species diversity in ungrazed riparian areas was 1.6 times greater than grazed corridors. Nest density was 1.9 times higher in the ungrazed stream corridors in the same study due to the increased shrub cover available for nesting. Riparian corridor vegetation provide nourishment to both aquatic and terrestrial species, regulates overland water and nutrient flow from the uplands and provides an unusually diverse array of habitat and ecological services (Naiman et al. 1993). Even though riparian systems are unforgiving environments, they are very important areas housing many different species and providing varied habitat for those many different species.

Naiman et al. (1993), state that natural riparian corridors are the most species diverse, dynamic and complex biophysical terrestrial habitats on earth.

Riparian Corridor Hydrological Functions

Riparian corridor vegetation plays a role in three important hydrologic functions. First is to slow water and dissipate energy during flood events (Knighton, 1998, Naiman & Decamps, 1997). When water is flowing over the floodplain, riparian vegetation creates increased friction through increased surface roughness and makes the flow more turbulent, thus dissipating energy. Water with reduced energy drops sediment and can no longer pick up additional sediment, meaning that little to no erosion can take place on the floodplain, only deposition.

Second, riparian corridors filter sediment and nutrients from overland flow originating in the uplands and provide temporary to long-term sediment storage. Riparian corridors have been found to reduce sediment, agricultural waste products and nutrients moving to the stream by 80-90% (Naiman & Decamps, 1997; Rosgen, 1996). This is a significant amount of nonpoint source pollution that is captured by riparian vegetation, stored and recycled. The riparian corridors located on associated connected floodplains are a place of long to short-term sediment storage. Vegetation in general is the primary control of sediment supply and watershed hydrology. It is also the most susceptible entity to human disturbance (Knighton, 1998).

Lastly, the vegetation allows a soil-root matrix, increasing bank shear strength that keeps the soil from eroding easily from the streambanks (Gurnell, 1997; Wynn et al. 2004). The soil-root matrix is much like reinforcing concrete with steel rebar. Roots have a high tensile strength but low compressive strength, soil is the opposite, just like concrete (Pollen, 2007). Roots in the soil matrix tend to adhere to soil much tighter in drier conditions than in wet conditions (Pollen, 2007), which allows roots to pull out of banks and break easier during times of excessive moisture providing the possibility of more erosion. Pollen (2007) found that river birch (*Betula nigra*) roots provided the most shear strength to the stream bank. In addition to increasing shear strength by forming a soil-root matrix, roots provide a drainage system for groundwater lessening weight of the bank decreasing shear stress (Gurnell, 1997). Banks are more easily eroded if they are

not vegetated, up to 30 times easier (Naiman & Decamps, 1997) Rosgen (1996) states that for his "C" type stream, vegetation is an important controlling influence in stream morphology and stability. One of the stable stream types in the Midwestern region is a "C" type stream, which is a slightly entrenched, moderate width/depth ratio channel with moderate to high sinuosity. The "C" type stream's bank stability is highly dependant upon woody vegetation root systems, as these root systems form the necessary root-soil matrix.

Stream stability assessments often include bank stability measures. Commonly used bank stability ratings, such as the United States Forest Service's Pfankuch (USDA, 2008) and Rosgen's Bank Erosion Hazard Index (BEHI) (Rosgen, 1996), have vegetation and root density as important rating variables for bank stability (Forms located in Appendix A, Figures A.1 & A.2, respectfully). Vegetation tends to protect the bank surface while roots tend to hold the soils together in a soil-root matrix. If no vegetation exists on a bank to protect it, then a bank will erode at a faster rate than a vegetated bank.

Stream Power

Stream power is an index for describing the erosive capacity of a stream and is related to channel profile, pattern, and sediment supply. When channel slope or discharge is increased, the stream power is also increased (Gordon et al. 2004). The higher the stream power, the more sediment (or larger sediment size) is needed to satisfy the stream's sediment transport capacity. The reason for this is that sediment helps dissipate stream energy, and if there is more power then more sediment is needed to dissipate energy. Many have attempted to define stream power as an equation, but the many assumptions that are made do not make the equation realistic. However, local stream power can be estimated through near bank stress. In general, human disturbance typically increases stream power. This increase in stream power is generated by channelization, increased runoff and development, whether it is agricultural or urban.

Summary

Human development and improvements have played havoc with natural systems throughout the United States, and the Black Vermillion watershed is no exception. Changes in land cover have reduced species richness through the conversion of native

prairie to monocultures of tillage agriculture. Riparian areas have been decimated through channelization and conversion to tillage agriculture. Riparian corridors are important both ecologically and hydrologically and must be preserved and restored. We currently have approximately 21,000 square miles (54,390 square Km) out of the historic 189,000 square miles (489,500 square Km) of riparian corridors left in the United States and we are losing more each year. This study will aid in understanding the timing and extent of riparian corridor area lost over 150 years in the Black Vermillion watershed.

CHAPTER 3 - Methods

Site Selection

Black Vermillion Watershed

The Black Vermillion River and its watershed (watershed map, Figure 1.3) were selected for study for several reasons. First, the watershed is in close proximity to Kansas State University. Second, the watershed has experienced varying levels of channel modification and there are known problems of soil erosion throughout the watershed. Third, a USDA-CSREES integrated grant was awarded to study sedimentation and erosion in the watershed, which ultimately empties into Tuttle Creek Reservoir. Fourth, there are varying land uses throughout the watershed that may enhance or limit erosion of the land surface or streambed and banks (land use map, Figure 1.17). Fifth, historic data of the river and watershed exists and are easily accessible.

Riparian Corridor Measurements

Riparian Corridor Width Changes

Two different measures of the riparian corridors were taken to discern if a change in corridor width had taken place. First, an average of riparian corridors was established for the three sub-watersheds; Irish Creek, Black Vermillion Main Stem and North Fork of the Black Vermillion. Next, eighteen transects were established in the three sub-watersheds to establish a direct comparison of riparian corridor widths.

Average Corridor Measures

An average measure of the riparian corridors in each sub-watershed was established by measuring the corridor widths in the sub-watersheds. These measures were random for each corridor in each available year allowing an objective average riparian corridor width to be calculated for each sub-watershed. The riparian corridors of

the survey maps from 1857 were measured directly from the survey maps and notes for baseline conditions. Riparian corridor widths from 1956, 2002 and 2006 aerial photographs were measured as comparisons to the baseline conditions recorded from the 1857 Kansas Territory Land Survey.

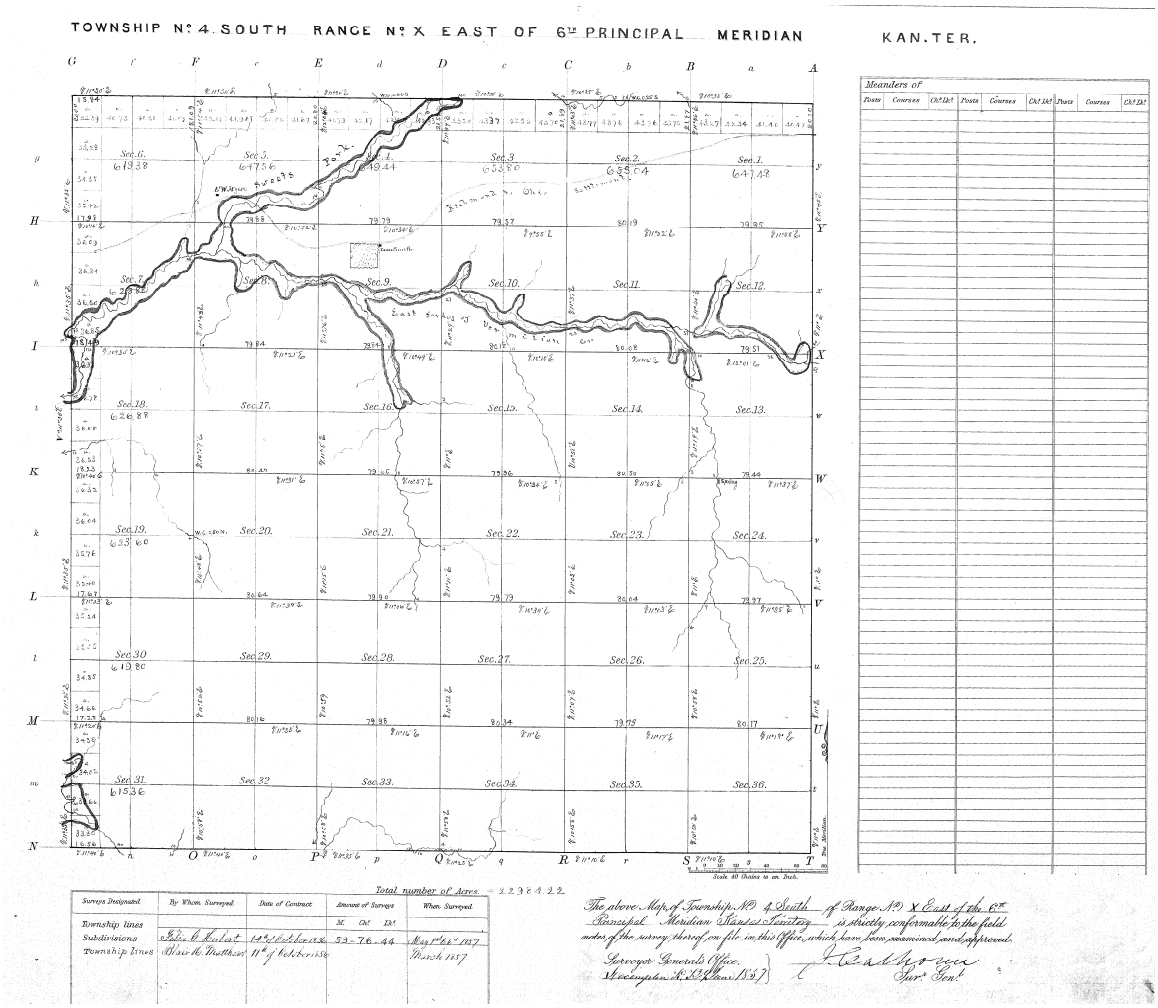
1857 Kansas Territory Survey and Notes

The original Kansas Territory Survey maps and notes were used here as a baseline for understanding historic riparian corridor width, species composition and trunk size or age class of woody species. The survey notes also provide land cover information that was adjacent to the riparian corridors, which was described as tall grasses and prairie forbs with scattered trees. Surveyors of the time were versed in vegetation recognition, especially woody vegetation that had cultural or economic value. The surveyors measured representative tree-trunk diameters used in marking sections or quarter sections during the 1857 survey and noted them in the original field notes. Historic diameters were compared to current tree-trunk diameters at breast height (DBH) of the same species to see if there was a difference in average diameters (age) of the woody vegetation.

Survey Maps

The originals of the 1857 survey maps and notes are available at the Kansas State Historical Society in Topeka, Kansas. These surveys were conducted as a part of the Public Land Survey System (PLSS) to subdivide and describe the land of the United States and were completed between the months of March and October of 1857 for the Black Vermillion Watershed areas. The survey records are arranged according to township and range, which are approximately 6-miles by 6-miles. Each township is subdivided into 36 sections, which are approximately 1-mile-by-1-mile. The maps were scanned at the Historical Society at a medium resolution and saved to a disc. The scanned maps were then used to measure riparian corridor widths, Figure 3.1. These maps were also available in digital format through the Kansas Society of Land Surveyors & Kansas Historical Society (http://www.ksls.com/).

Figure 3.1 Map of Kansas Territory Survey 1857 (KSLS, 2005)(See Appendix for larger map).

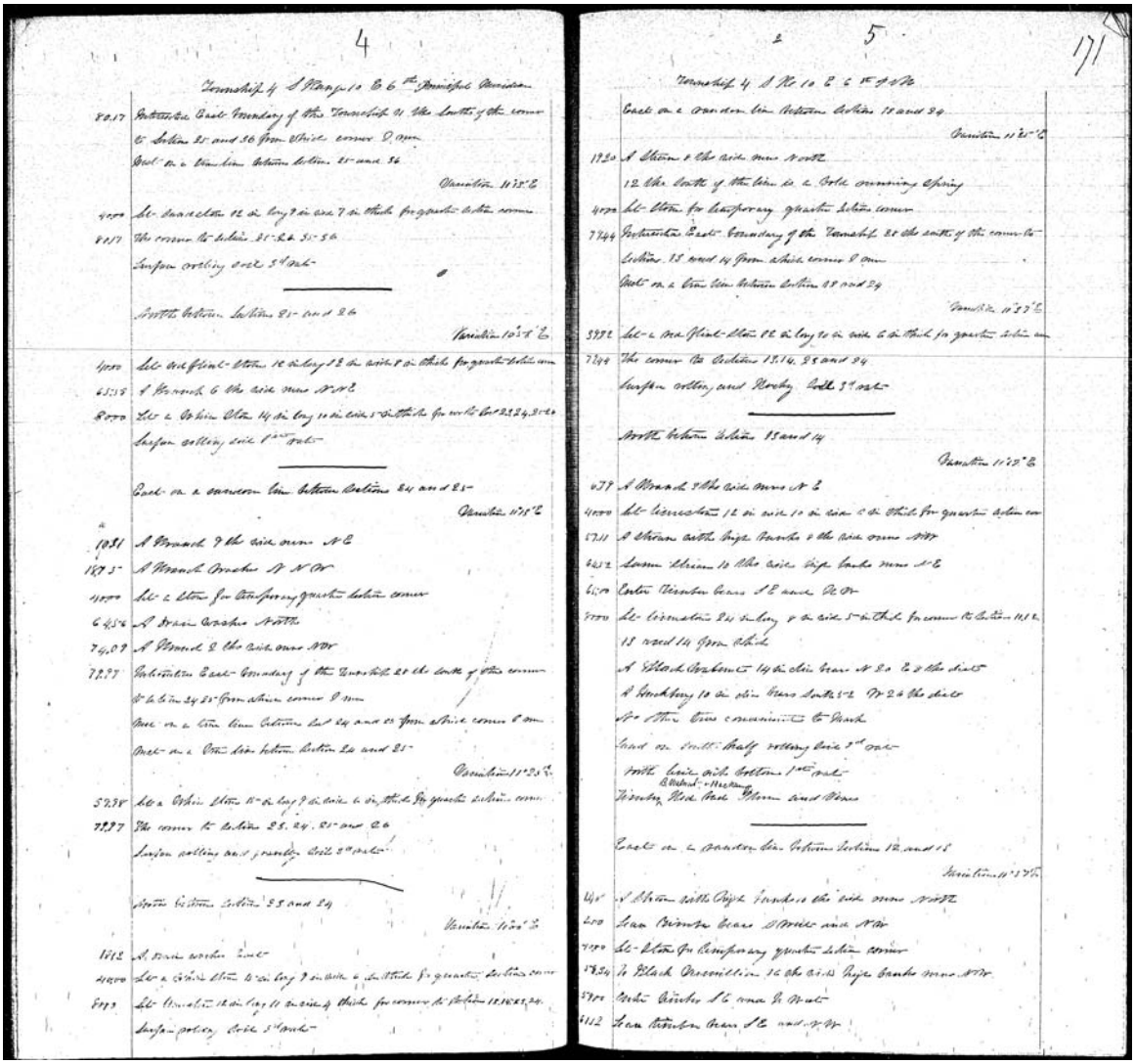


Survey Notes

The original notes from the survey were available and retrieved at the Kansas State Historical Society. These notes were still in the original surveyor's notebooks. I read the notebooks of the townships that contained the Black Vermillion watershed and copied the passages that contained information about the riparian area and any vegetation notes made. This included tree-trunk diameter, entry and exit of riparian corridors, land cover of the adjacent ecosystems and stream width. However, I cannot say with certainty how stream width was measured, if it was from bank to bank or edge of water to edge of water. These notes were also available in digital format through the Kansas Society of Land Surveyors & Kansas Historical Society (http://www.ksls.com/).

The 1857 survey notes proved useful in that they described the land cover and stream condition and a digital copy of the original survey notes was available for further review, Figure 3.2. The notes allowed me to discern the general conditions of the watershed at the time of the survey. I compared the noted species in the survey to species currently in the riparian corridor and compared the difference in stream corridor widths between 1857 and 2006.

Figure 3.2 Notes from Kansas Territory Survey 1857 (KSLS, 2005)(See Appendix for larger image).



Riparian Corridor Measurement of the 1857 Territory Surveys

Riparian corridors on the 1857 survey maps were delineated by cartographers and could be measured directly. The maps were at a scale of 1in = 40-chains. A conversion of 1-chain = 66ft was used to convert chains into feet, allowing one-inch to equal 2640ft, or one-half mile. I measured the riparian corridor widths using a 40-scale engineering scale so that each denomination equaled 1-chain. For example, a corridor might measure 36 denominations (36-chains) meaning that the corridor is approximately 2376ft in width (36-chains x 66ft/chain = 2376ft). The accuracy of the delineated corridors is an issue, as it depended on the surveyor and cartographer. One way to resolve this issue is to use the notes that indicate when the survey crew entered and exited the wooded riparian corridors as a check for the map scale and accuracy. If the measures were significantly different between the notes and maps, the notes from the book would have been used to establish riparian corridor widths because of the accuracy in the actual survey.

An example of how the surveyor's notes would have been used in this study is illustrated below:

From Township 4S Range 9E Between sections 25 & 26 (Irish Creek)

Station 22.10 – Entered bottomland

Station 38.04 – Creek 85 links wide, gentle current, timber on banks

Station 48.00 – Leave timber

The measure at this point would be 48.00-22.10= 25.90 chains, or about 1709.4'. When the same corridor is measured on the plan, it measures to be approximately 23.5 chains, or about 1551' for an approximate difference of 160' or 10%. This difference may be attributed to the term "bottomland" instead of "entered timber", as was the more common verbiage, my measurement error, not being a straight-line measure during the survey or the drawing of the riparian corridor on the map. As we can see, these numbers may not be as precise as we would like, but do provide a suggestion of the width of the riparian corridors and stream channels at the time of the 1857 Territory Survey.

The average corridor measurements were taken in a random nature throughout each sub-watershed, added together, and then divided by the total number of measures. This provided an average corridor width for each sub-watershed. A minimum of ten to twenty measurements per township map were taken depending on the riparian and stream

network in the township. If a township map contained a large amount of stream network, more riparian corridor width measures needed to be taken. A similar process to gain an average corridor width was conducted for the aerial photographs for the years available.

Aerial Photographs

1956 Marshall County and 1957 Nemaha County

Black and white aerial photographs from 1956 (Marshall County) and 1957 (Nemaha County) of the watershed area were available in hard copy format. The aerial photographs were at a scale of 1:20,000, meaning that one inch on the photograph equaled 20,000 inches on the ground. Corridor widths were measured using a 40-scale engineering scale making each denomination on the scale worth 41.67' (1/40"=.025" x 20000"= 500"/12"= 41.67' per denomination). These photographs were scanned and saved onto a disc for later measurements and geo-rectification.

Aerial photographs showing the Black Vermillion watershed in 1956 were used to compare the riparian corridors to other years averages. The year 1956 was chosen because the aerial photographs were available and the timing was before channelization by the SCS (NRCS) had taken place in the watershed. The riparian corridors in the photographs were measured by hand and that measure was recorded on a data sheet. Figure 3.3 is an example of the photographs from 1956.

Figure 3.3 1956 Marshall County aerial photograph example.

2002 and 2006 Marshall and Nemaha Counties

I accessed and downloaded the 2002 and 2006 Marshall and Nemaha County aerial photographs through the Kansas GIS geospatial community commons (DASC) website (http://www.kansasgis.org/). These aerial photographs were projected in the NAD North 27 projection. I also obtained hydrologic unit code (HUC) 11 boundaries for watershed delineation on the aerial photographs in ArcMap. Stream flow lines, county boundaries and city boundaries were also obtained at this website. The riparian corridor widths were measured using ArcMap utilities and are described in more detail below.

I utilized ArcMap utilities to measure the riparian corridor widths in the Black Vermillion watershed. ArcMap allowed me to measure riparian corridor widths from the aerial photos dated 2002 and 2006 using the standard measure tool. Figure 3.4 is an example of the photographs from 2002. These photographs were taken post-channel modification era. I could make a direct comparison of changes in riparian corridor widths over the four-year time span while the aerial photographs were overlaid. The riparian corridors representing the 2006 year were also measured using ArcMap measure tool. Figure 3.5 is and example of the photographs from 2006. All measures for all years were recorded in feet to match the 1857 survey data measures and later converted to SI units.

Figure 3.4 2002 aerial photograph example.

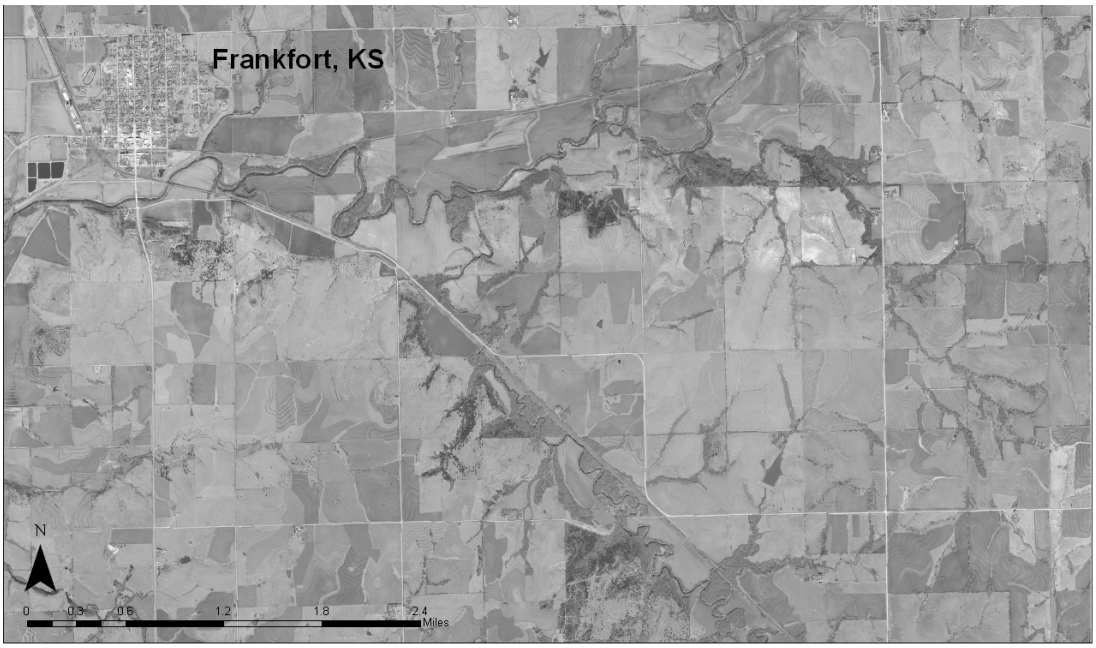


Figure 3.5 2006 aerial photograph example.

I measured the corridor widths at random points along the stream, just as I did the Territory Survey and 1957 aerial photographs. No points were intentionally the same as on other aerial photographs or map points. Random measures helped provide an average corridor width along the streams in each sub-watershed. For streams that contained no woody vegetation at the random location in the corridor, I measured the distance between woody vegetation corridors and then recorded a zero (0) vegetation corridor width for that distance.

Representative Reach Selection & Transect Measures

Representative Reach Selection

Nine reaches, three each in Irish Creek, North Fork of the Black Vermillion and Main Stem Black Vermillion sub-watersheds were selected as representative reaches in the system. We chose an upper, middle and lower reach on each stream that represented the different stream conditions in the sub-watersheds (Figures 3.6, 3.7 and 3.8). All reaches have experienced different levels of channel modification since the date of the Territory Survey of 1857, including but not limited to; water impoundments, channelization, vegetation removal, stabilization structures and levees. Groups

responsible for channel modification in the watershed include the United States Army Corps of Engineers (USCOE), United States Soil Conservation Service (SCS, now known as the Natural Resources Conservation Service, NRCS) and individual landowners / private citizens. These nine sites are part of a larger study in the watershed that is studying sediment contributions from streambeds and banks. They were used in this study due to the easy accessibility and overall corridor representation of the watershed.

Figure 3.6 North Fork Black Vermillion study reach locations.

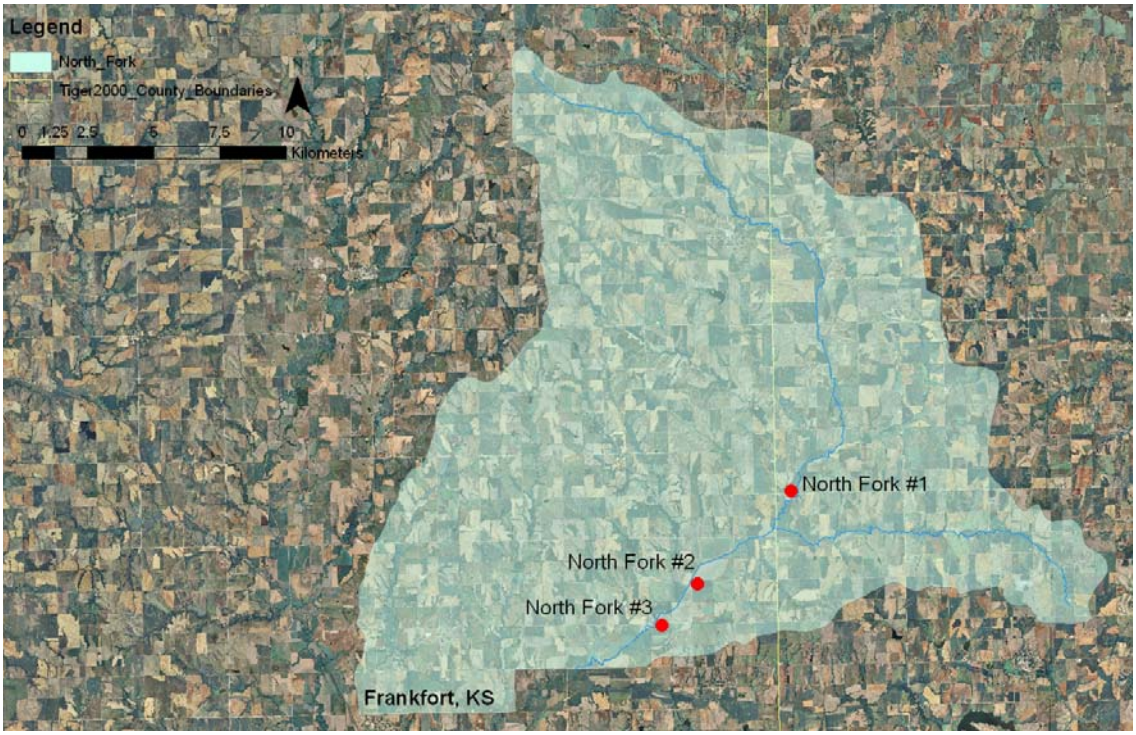


Figure 3.7 Black Vermillion Main Stem study reach locations.

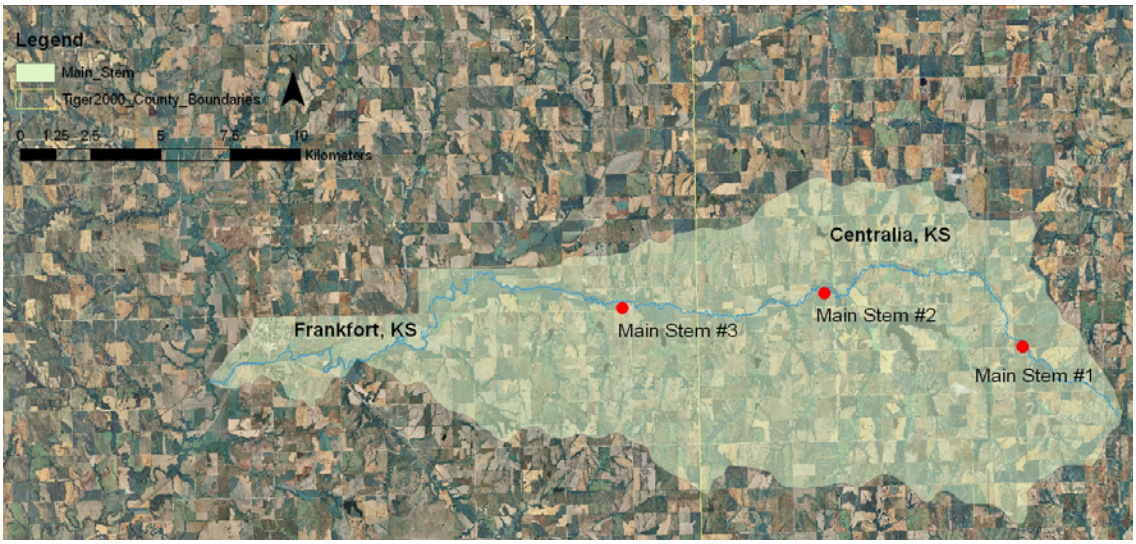
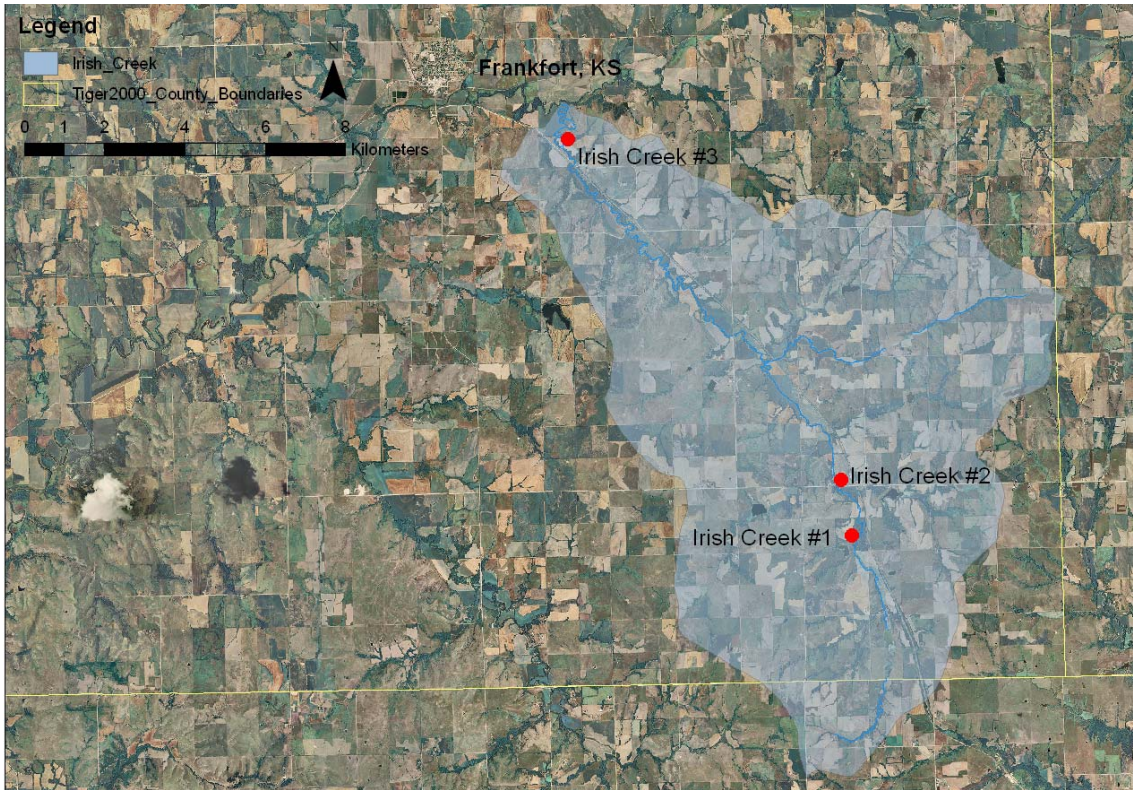


Figure 3.8 Irish Creek study reach locations.



The nine sites were chosen to include varied geology, geomorphology, differing adjacent land cover / land uses within the sub-watersheds, and availability of landowner permission providing access to the stream. Land cover and use includes; riparian areas, native tallgrass prairie, cultivated cool-season grass pastures, and tillage agriculture such as corn and wheat. Native tallgrass prairie and cool season grass pastures are combined

in this study as pastureland. Changes in land cover and land use from the historical conditions may contribute to a flashier hydrograph by producing more and quicker runoff than pre-settlement conditions, thus increasing erosion potential.

The nine research sites have differing amounts and types of riparian vegetation. Some reaches have a relatively wide belt (at least 60' (18m) or more per side) of mature woody growth, while other riparian corridors are composed of tillage agriculture, or 0' (0m) of woody vegetation. Most of the riparian corridors fall somewhere between these measures with one or two row of trees that may be sloughing off into the streams. Some streams are beginning to re-vegetate closer to the channel at a lower elevation with small willows (*Salix* sp.) and cottonwood (*Populus deltoides*), typically a sign that the stream is beginning to re-establish a floodplain and new riparian vegetation while adjusting to the new hydrologic regime. Streams naturally adjust their dimensions (width, depth and slope) according to the amount of sediment and runoff the stream is given by the watershed (Leopold et al. 1964). The channel must change its geometry to accommodate the new bankfull discharge resulting from runoff or sediment load changes. Rosgen (1996) notes that channel widths can be modified in several ways, one being changes in streamflow regime due to watershed changes, such as urban or agricultural development.

Adjacent land use and change in land cover contribute to changes in runoff to the stream (Leopold et al. 1964; Rosgen, 1996). Non-native grazing ungulates, such as cattle, and tillage practices typically compact soil decreasing infiltration of precipitation and increasing runoff to the stream (Harpstead et al. 2001; Rosgen, 1996). Tillage compacts the soil when it is tilled at a constant depth over time, creating what is called a dense plow pan (Harpstead et al. 2001). The soil compaction from cattle and dense plow pan lessens soil water storage, lessens water infiltration into deeper soils and increases overland flow, which departs from historical hydrology of the area. In addition, agricultural crop cover is less dense during the wet season than the pre-settlement prairie cover, providing less vegetation interception, less stem flow and more runoff. Early land cover in the watershed (native prairie) rarely left bare soil exposed to precipitation lessening splash erosion. Typically, a detritus layer of grass stems, old forb foliage, and emerging plant growth would intercept incoming precipitation. Now, fields are planted

in early spring when we get most of our precipitation allowing for more erosion potential of the bare soil due to the nature of current agricultural practices.

Eighteen Transects

Within the nine study site reaches, 18 transects were established (two per study site reach) to measure riparian corridor widths at those transects. Transect number one was always located upstream from transect number two at each reach. All measures of riparian corridors were taken perpendicular to the stream channel. These transects were measured using the 1857 survey maps and 1956, 2002, and 2006 aerial photographs (Figure 3.9 is an example of the transects at Irish Creek reach #2 from 2006). These 18 transects were located in approximately at the same location for all riparian corridors for all years measured. The 18 transect width measures were compared allowing for direct comparison in riparian widths in specific riparian corridor locations. Transect measures were taken as closely as possible to the 1857 baseline measure transects of the original survey map for the aerial photograph transects dating from 1956 / 1957, 2002 and 2006. Stream channel meanders were straightened during channel and watershed modification that began in the 1950s, making exact replication of all transects from the 1857 survey impossible.

Again, the 1857 survey maps were used as baseline measures for corridor widths at the transect lines. I measured the 18 control points (same on all aerial photos and maps) from the 1857, 1957 / 1956, 2002 and 2006 aerial photographs for the direct comparison of corridor widths over time. Transects from 1857 and 1956 / 1957 were measured using similar techniques as the average widths measures, just at transect locations. Transects from 2002 and 2006 were measured using the standard measure tool in ArcMap. Some transects from the 1956 / 1957 aerial photographs were not available due to missing aerial photographs. These measures were compared over the 150 year span.

Figure 3.9 Transect example of Irish Creek #2.

Note: The stream once meandered to the west side of the current stream between the house and current stream. It then crossed back to the east where riparian vegetation and woodland meet on the north side.

Land Cover and Vegetation Changes

Vegetation Sampling

Vegetation sampling was done adjacent to the stream channel on each of the nine study stream reaches in the Black Vermillion Watershed (Figures 3.6, 3.7 and 3.8). I used the data collected to compare species and tree diameter at breast height (dbh) sizes with the 1857 Territory Survey notes. The comparison should begin to provide a measure of departure from historical conditions as far as age diversity and species richness and answer the question of what changes occurred in land cover and land use.

Sampling Method

I completed a vegetative assessment on all nine previously described sites. This assessment included woody species identification, diameter at breast height (dbh) measurement of selected trees in centimeters, and herbaceous species identification. All notes and species were recorded on a vegetation recording form at each site. I also noted whether the woody vegetation was located on a connected floodplain. A connected floodplain is defined as land adjacent to the stream at an elevation near bankfull. I felt this was important because if the vegetation was not located on a connected floodplain, then it does not provide as much bank protection against erosion (Knighton, 1998; Leopold et al. 1964; Rosgen, 1996). Notes were then synthesized and compared with the 1857 Territory Survey notes to ascertain vegetation change over time, both in size and species composition.

The nine sites selected for woody vegetation sampling were chosen due to the accessibility to the sites. Permission to enter the sites had already been obtained for a larger study (a USDA-CSREES funded study of stream sediment and stream morphology). These nine sites are also representative of how the watershed riparian corridors are managed and established regarding vegetation composition.

The method of vegetation surveying was a plot sample technique. Four plots were surveyed at each stream reach, two per stream side. These plots were located at cross-section sites used for the larger river morphology study mentioned previously. Plots were 10m in radius (20m diameter), which was delineated with a 10m rope tied to a stake. Measures of tree trunk dbh was taken at approximately 4’ (1.37m) above the

ground on the uphill side. Measures were taken with a dbh tape measure in centimeters. If no trees existed in a plot, notes were taken as to what type of land cover existed. All vegetation surveys were completed in July and early August of 2007.

SCS Watershed Work Plans

The watershed work plans written by the SCS dated January 1966 were used to gain a fundamental understanding of what types of channel modifications were planned and when they were built. There were three work plans available through the NRCS; Irish Creek, North Black Vermillion (North Fork) and the Upper Black Vermillion (Main Stem). These work plans were comprehensive guides as to why the SCS did what they did in each watershed. All structures that were to be built were listed both in table form and on a map of the sub-watersheds. Modifications to the original plans were also documented. All work plans include economic and physical descriptions of the watershed, watershed problems, goals of the structures, expected costs, expected effects of improvements, maintenance and project maps. These watershed work plans begin to shed light on land cover change in each sub-watershed as far as riparian vegetation and adjacent land cover modifications.

Land Cover Comparison

The survey notes of 1857 provided a baseline of pre-settlement land cover conditions. The notes were compared with current conditions via the 2001 land cover data set (Figure 1.17) and the 1966 SCS work plan report of land cover. Current conditions were verified in the field. Results of the above analyses are discussed in the following chapter.

CHAPTER 4 - Results

This study measured and assessed change in riparian corridors, both in width and species composition, spanning a 150-year period from 1857 to 2007. The study was guided by three questions; 1) What changes in riparian corridor width have taken place since the original territory surveys done in 1857 and why did those changes occur? 2) How has land cover adjacent to riparian corridors changed since the original territory surveys? 3) Has woody species composition in the riparian corridors changed? These questions were answered using the sources and techniques described in the methods.

Riparian corridor width data was collected using survey maps and notes from 1857, aerial photography (from 1956, 2002 and 2006), ArcMap G.I.S. capabilities, and 1966 SCS watershed work plans. Land cover data was compared using 1857 survey notes, 1966 SCS watershed work plans land cover estimates, and 2001 land cover data map of Kansas. Species data concerning vegetation was collected using survey notes from 1857 and a field survey of the current vegetation during the summer of 2007.

Riparian Corridor Widths

Average Corridor Widths Summary

A summary of findings for average corridor widths for each year is shown in Table 1. Table 2 illustrates average riparian corridor area lost in square miles. General trends in the findings show an 80-85% decrease in average corridor widths between 1956 and 2002, which coincides with the NRCS and landowner channel modification timetable. Irish Creek sub-watershed corridor width decreased the most, decreasing by almost 50% between 1857 and 1956, then again by 85% from 1956 until 2002. The corridor average width in the North Fork sub-watershed actually increased in width from 1857 until 1956 by about 38%, but after 1956, the average dropped to the smallest average width of the three sub-watersheds. As is common with channel modification, riparian vegetation is destroyed to allow necessary equipment access to the stream for modification purposes, thus the change in riparian corridor widths from 1956 through

2002. In addition to clearing of woody vegetation during channel modification, the newly constructed channel usually cuts off meander bends through fields that have no riparian vegetation established, thus no vegetation to hold the banks together. The NRCS scheduled to have all planned and approved channel modifications outlined in the 1966 SCS work plans started by the late 1960's and finished by the late 1970's. It has been suggested farmers were encouraged by the SCS to plant crops bank to bank and leave no riparian areas intact. The NRCS, (2008), now encourages the inclusion of a buffer zone between the agricultural field and stream system.

Table 1 Average riparian corridor widths in feet (meters) for Irish Creek (IC), Black Vermillion Main Stem (BV) and the North Fork Black Vermillion (NF).

(↓)- Decrease (↑)- Increase (-) - No Change

Site	Year			
	1857	**1956**	**2002**	**2006**
IC	1218 (371)	**(↓)** 691 (211)	**(↓)** 104 (32)	**(-)** 140 (43)
BV	748 (228)	**(↓)** 608 (185)	**(↓)** 130 (40)	**(-)** 149 (45)
NF	409 (125)	**(↑)** 568 (173)	**(↓)** 83 (25)	**(-)** 93 (28)

Table 2 Average area of riparian corridor in miles^2 (Km^2) for Irish Creek (IC), Black Vermillion Main Stem (BV), and North Fork Black Vermillion (NF).

Site	Year			
	1857	**1956**	**2002**	**2006**
IC	3.92 (10.2)	2.22 (5.7)	0.33 (0.85)	0.45 (1.2)
BV	3.82 (9.9)	3.10 (8.0)	0.66 (1.7)	0.76 (2.0)
NF	1.78 (4.6)	2.47 (5.4)	0.36 (0.93)	0.41 (1.1)
Totals	9.52 (24.7)	7.79 (19.1)	1.35 (3.48)	1.62 (4.3)
Total riparian area lost (9.52 – 1.35)				**8.17 miles^2 (21.2Km^2)**

Eighteen Transects Summary

As described in Chapter 3, 18 transects were used to gage how riparian corridor widths changed at specific points over time. The results for Transect 1 measurements for

all nine reaches are summarized in Table 4, while Transect 2 measurements are summarized in Table 5. Transects without a photograph are denoted with an (*). General trends of transects after 1956 are similar to the average corridor width trends, however the trend from 1857 until 1956 is slightly different. An increase in widths from 1857 until 1956 is typical in the 18 transects, while the average widths decreased. Increases in corridor widths may be attributed to an individual owner's land ethic, fire control, plantings encouraged by the SCS, stream channel changes (widening) due to increased discharge because of land cover change, or a combination of the above. After 1956, the averages and transects are very similar in that there was a significant decrease in stream corridor width from 1956 until 2002 and then virtually no change from 2002 until 2006. A decrease in average corridor width may be explained through the private channelization that took place pre-1966 and the SCS watershed work plans. The 1857 survey maps contained many places in downstream areas that had no woody vegetation delineated on the maps, as discontinuous riparian corridors were common in the prairie ecosystem. Zeros recorded in a transect represented no woody vegetation located at that transect.

Table 3 Transect 1 - Corridor widths in feet (meters) for all nine reaches.

***-indicates no photo available for this reach**

(↓)- Decrease (↑)- Increase (-) - No Change

Site	**1857**	**1956**	**2002**	**2006**
	Transect 1	Transect 1	Transect 1	Transect 1
IC-1	924 (282)	**(↑)** 1250 (381)	**(↓)** 285 (87)	**(↓)** 224 (68)
IC-2	2376 (724)	**(↓)** 0	**(↑)** 64 (20)	**(-)** 88 (27)
IC-3	528 (161)	**(↑)** 750 (229)	**(↓)** 180 (55)	**(↑)** 234 (71)
BV-1	660 (201)	*	**(↓)** 0	**(-)** 0
BV-2	1056 (322)	**(↓)** 833 (254)	**(↓)** 50 (15)	**(↑)** 106 (32)
BV-3	0	0	**(↑)** 134 (41)	**(-)** 143 (44)
NF-1	0	**(↑)** 1250 (381)	**(↓)** 58 (18)	**(-)** 85 (26)
NF-2	396 (121)	**(↑)** 625 (191)	**(↓)** 104 (32)	**(-)** 94 (29)
NF-3	660 (201)	*	**(↓)** 0	**(↑)** 112 (34)

Table 4 Transect 2 - Corridor widths in feet for all nine reaches.

***-indicates no photo available for this reach**

(↓)- Decrease (↑)- Increase (-) - No Change

Site	1857	1956	2002	2006
	Transect 2	Transect 2	Transect 2	Transect 2
IC-1	792 (241)	**(↑)** 2500 (762)	**(↓)** 280 (85)	**(↑)** 408 (124)
IC-2	1056 (322)	**(↓)** 0	**(-)** 0	**(↑)** 80 (24)
IC-3	792 (241)	**(↓)** 416 (127)	**(↓)** 60 (18)	**(↑)** 106 (32)
BV-1	792 (241)	*	**(↓)** 0	**(-)** 0
BV-2	924 (282)	**(↑)**4167 (1270)	**(↓)** 750 (229)	**(↑)**806 (246)
BV-3	0	**(-)** 0	**(↑)** 83 (25)	**(-)** 86 (26)
NF-1	0	**(↑)** 1416 (432)	**(↓)** 76 (23)	**(-)** 77 (23)
NF-2	528 (161)	**(↑)** 583 (178)	**(↓)** 90 (27)	**(↑)** 288 (88)
NF-3	924 (282)	*	**(↓)** 97 (30)	**(-)** 109 (33)

Land-Cover & Vegetation Changes

1857 Land Cover According to Survey Notes

Notes from the 1857 Kansas Territory Survey provide an idea of land cover throughout the watershed. Generally, the land was described as rolling, or as a gently rolling surface abounding with native prairie vegetation. Soils were rated from 1st rate through 3rd rate, where 1st rate soils were best for tillage agriculture. Third-rate soils often were described as gravelly and hard to till. This passage is taken from Township 3 south Range 10 east on page 4 of the original survey notes; surveyors moved north between sections 25 and 26, which is located in the North Fork system above the confluence (Figure 4.1 and 4.2, 1857 and 2006 area location described):

Land rolling prairie 2nd rate.

61.00 A creek 6 links wide runs SW & enter timber.

65.00 Leave timber & enter level prairie.

Land south part high prairie 2nd rate.

North part level bottom 1st rate.

Timber Walnut & Elm.

Figure 4.1 1857 map of above description (North Fork, between sections 25 & 26).

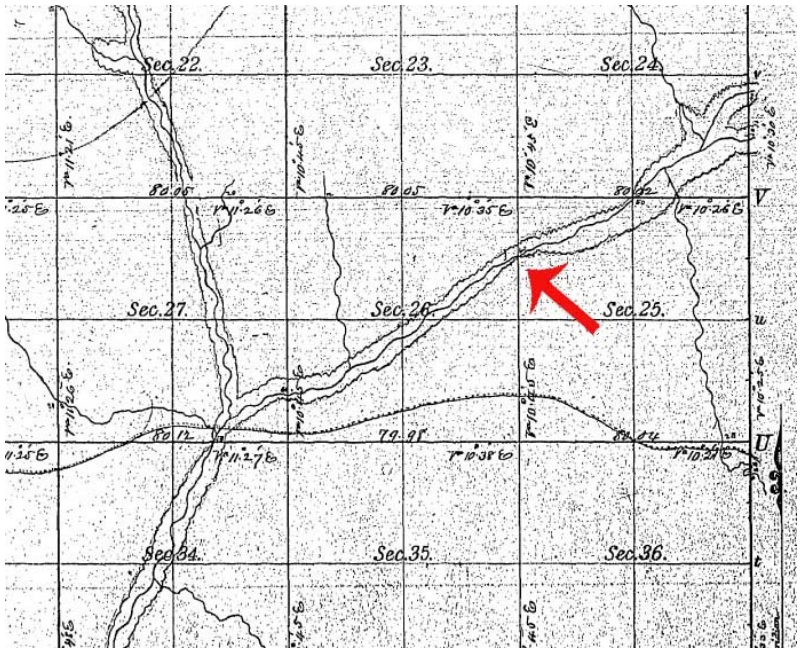


Figure 4.2 2006 aerial photograph of same area as in Figure 4.1 (red box).

The streams of the watershed were often narrow and deep with "muddy banks" and contained woody riparian vegetation. As noted by the surveyors, a measurement of the Black Vermillion lower in the watershed (approximately where Reach 3 of the Main

Stem Black Vermillion is located, Figure 3.7) was only 27 links wide or about 18-feet (5.5m) in width. I am not sure where the measure was taken, it could have been top of one bank to the top of the opposite bank or from water's edge to water's edge, the assumption is the former. Currently, top of bank to top of bank at our Reach 3 of the Main Stem is about 84' (25.6m), with a depth of 19.7' (6m) to the thalweg, or deepest portion of the stream. This is quite the departure from historical conditions of the stream.

Headwaters of the prairie streams often lacked woody vegetation as riparian corridors and instead were flanked by native forbs, grasses and sedges (deep, fibrous rooted plants). The Black Vermillion headwaters historically measured around five to fifteen links in width (3-feet to 10-feet). Bottoms of the streams were noted as having gravel or mud depending on where the reach was in the watershed. Most of the streams were noted as having clear, running water.

Current Land Cover Adjacent to Streams & Corridors

Today, land cover in the Black Vermillion watershed is comprised of gently rolling agricultural fields dotted with native or cool-season grass pastures. North Fork of the Black Vermillion has more acreage in cultivation than the other two sub-watersheds, as illustrated in Figure 1.17 and Tables 5 and 6. Moving south through the watershed, we see more pasture (includes native grasslands) due to steeper topography and gravelly soils. The southern portion of the entire watershed, especially Irish Creek sub-watershed, has more pasture than the other two northern sub-watersheds (Figure 1.17, Tables 5 and 6). The totals of differing land cover in the watershed have not changed tremendously from 1966 through 2001, Table 5 compared to Table 6. The changes in percentages that have occurred may be due to registering land into conservation reserve program (CRP) land since program inception in 1985.

Table 5 Approximate percentages (%) of land cover by watershed (USDA-SCS, 1966).

	Cropland	Pasture	Woodland	Misc.
IC	78	17	2	3
NF	83	12	2	3
BV	85	9	2	4

Table 6 Approximate percentages (%) of land cover by watershed (National Land Cover Data Set, 2001).

	Cropland	Pasture	Woodland	Misc.
IC	65	30	2	3
NF	79	15	2	4
BV	75	20	2	3

Black Vermillion Watershed Work Plans & Land Change

In January of 1966, three work plans were set forth by the USDA-SCS. These work plans were created in conjunction with the Upper Black Vermillion Watershed Joint District No. 37, Marshall County Soil Conservation District, Pottawatomie County Soil Conservation District and the Nemaha County Soil Conservation District for Irish Creek Watershed, North Black Vermillion Watershed (North Fork) and the Upper Black Vermillion Watershed (Main Stem). All three watershed work plan goals were to minimize flooding and erosion in the watershed using structural control methods such as flood control dams, combination grade stabilization-flood water retarding structures, multipurpose retention development (Centralia Lake), and channelization (Figures 4.3, 4.4 and 4.5). Since the watersheds are predominately agricultural, the goals of the work plans were based on agricultural needs. The major problems listed were upland erosion; gully erosion; floodwater damage to crops, land, other agricultural property, roads, railways and bridges; and sedimentation of streams and reservoirs. The work plans called for early best management practices in conjunction with stream improvements to thwart the noted problems. These practices included planting vegetation along the stream, fire control, channel improvement and grazing control.

Figure 4.3 Floodwater retarding structure (SCS, 1966).

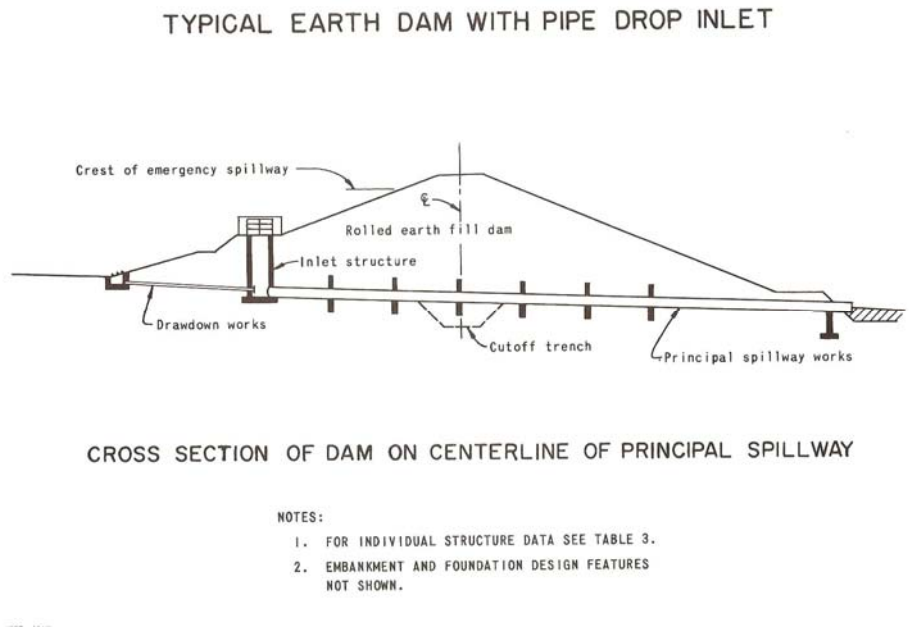


Figure 4.4 Grade control structure (SCS, 1966).

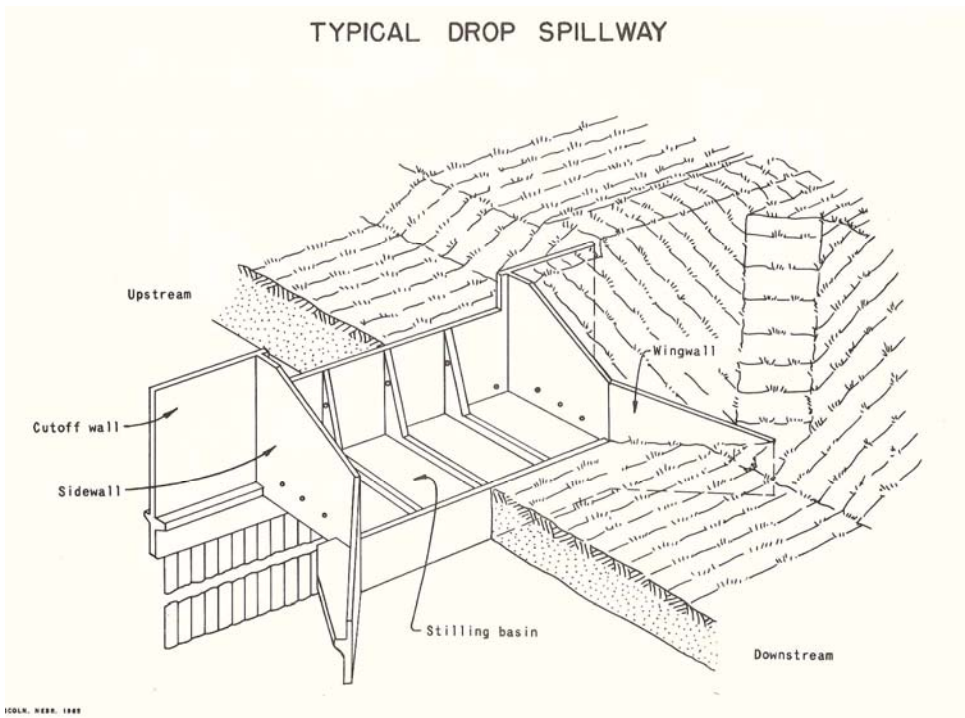
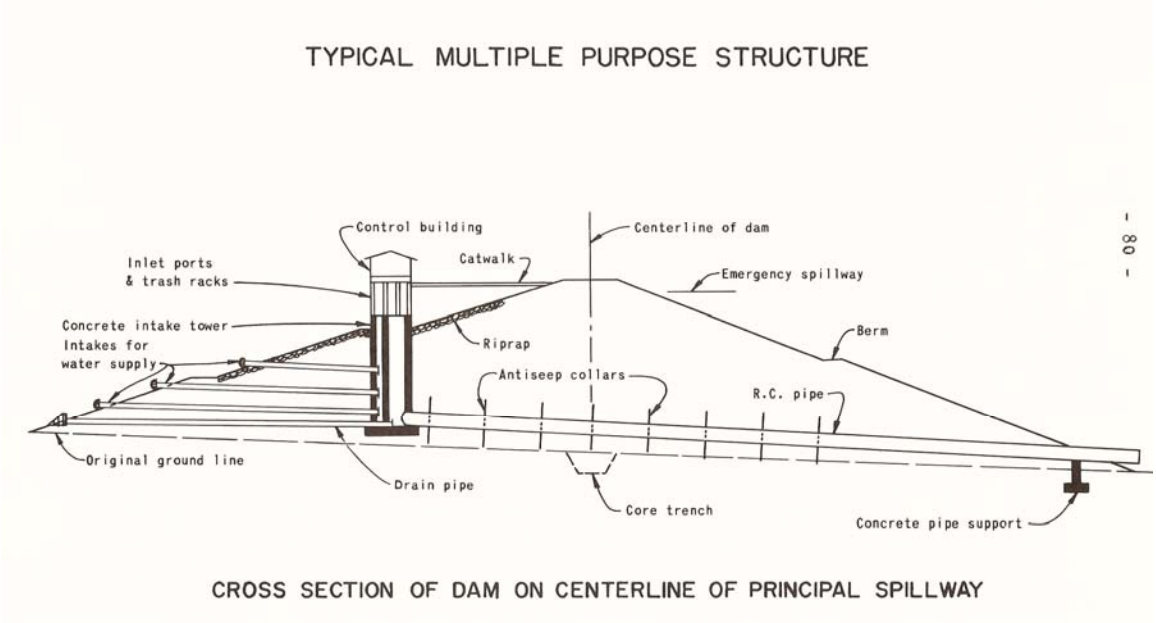


Figure 4.5 Multipurpose structure, Centralia Lake Dam (SCS, 1966).



Irish Creek Work Plan

Irish Creek was to be the least controlled sub-watershed of the three watersheds regarding the number of structures and lack of channel improvement (channelization). A comprehensive plan for the sub-watershed is illustrated in Figure 4.6. Primary goals of the work plan were to decrease floodwater damage to the land, crops and other valuable property "within" the floodplain, create a system of structural measures that would stabilize the stream so other land treatments could be established and to protect the soil against excessive erosion. A total of 16 structures were to be placed in the watershed and were to be finished in 10 years. The major structures planned were 8 floodwater retarding structures and 8 combination grade stabilization-floodwater retarding structures each. Minor structures included building 27 minor grade stabilization structures and 474 acres (192ha) of grassed waterways. There were no plans for channelization anywhere in the watershed, however it is evident that channelization has occurred along portions of the stream.

Channelization is evident along reaches of the stream through both aerial photography and field observation. At study reach Irish Creek 1 (Figure 3.8), there is spoil along both sides of the incised channel with old streambeds weaving through the forested areas on both sides of the stream channel. Aerial photography shows channels

that once meandered are now unnaturally straight and then return to a meandering form see Figure 4.7.

Figure 4.6 Irish Creek Work Plan (See Appendix for larger version), (SCS, 1966).

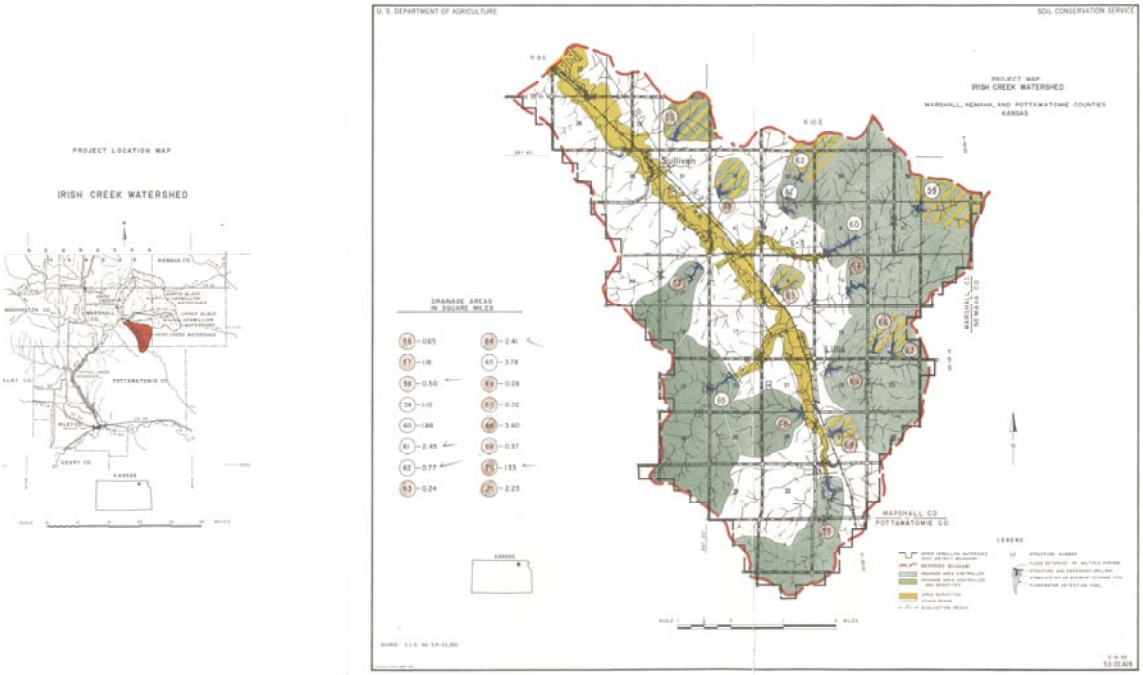
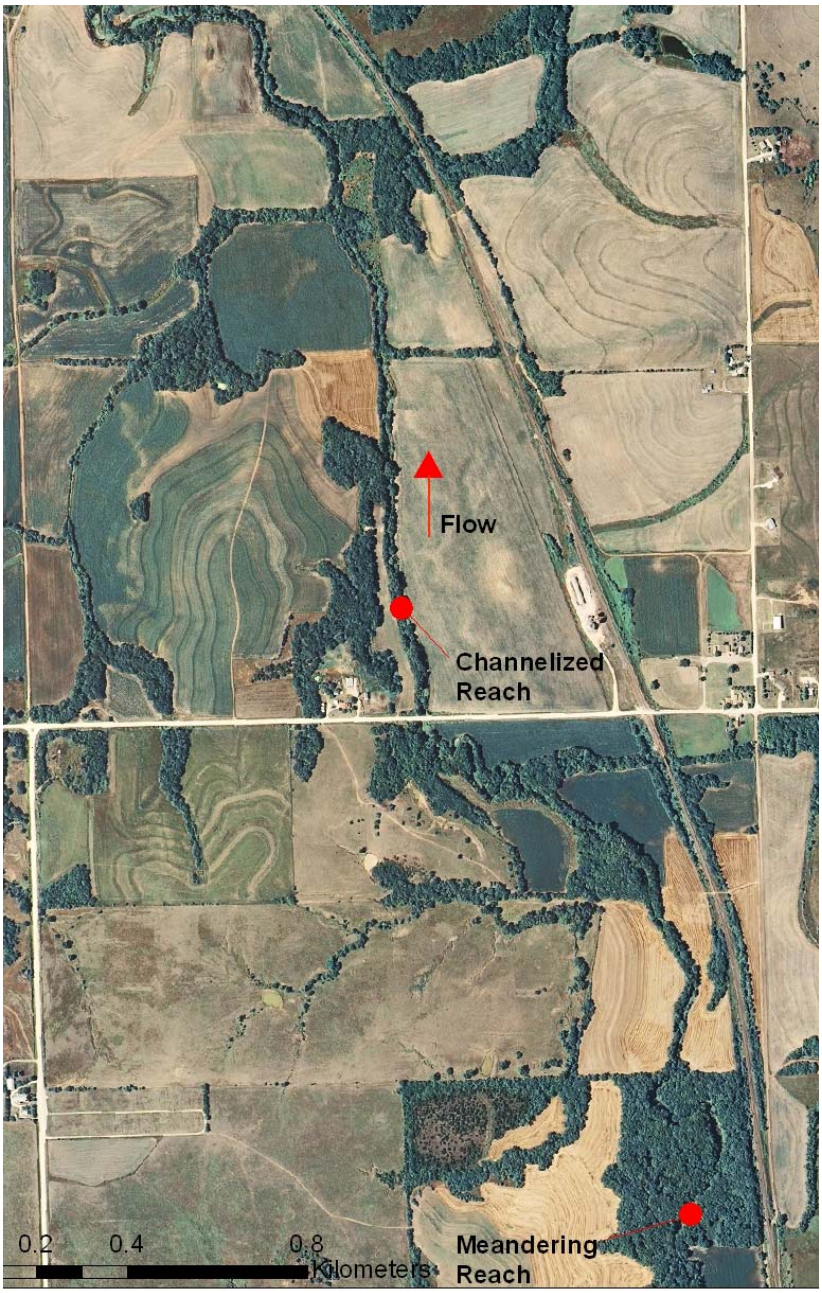


Figure 4.7 Example of channelization and natural meander bends in Irish Creek.



Upper Black Vermillion Work Plan

The Upper Black Vermillion, also known as the Main Stem, work plan contained the most extensive channelization of the three sub-watersheds (Figure 4.8). The primary goals of the work plan were to decrease the floodwater damage to the land, crops and other valuable property "within" the floodplain, create a system of structural measures that would stabilize the stream so that other land treatments could be established and to

protect the soil against excessive erosion. Thirty-eight structures and 11.87 miles (19.1Km) of channel improvement (channelization) were to be built in the watershed. Overall, a system of 12 floodwater retarding structures, 25 combination grade stabilization-floodwater retarding structures and one multi-purpose structure (Centralia Lake, Figure 4.9), Figure 4.5, were to be installed in the watershed. All channelization was located in the lower portion of the watershed moving upstream from Frankfort, KS, where the USCOE had stopped their channelization in 1963.

Channel modification other than what was planned is evident in this watershed. Many channels in aerial photographs go from meandering to straight just after a section line or property line. Then the channel may return to a meandering stream once again after it crosses another section line or property line, Figure 4.10. There are stretches of stream where riparian vegetation has been removed and the stream appears to be unnaturally straight. All of this is outside or upstream of the original approved work plan set forth by the SCS.

Figure 4.8 Black Vermillion Main Stem Work Plan (See Appendix for larger version), (SCS, 1966).

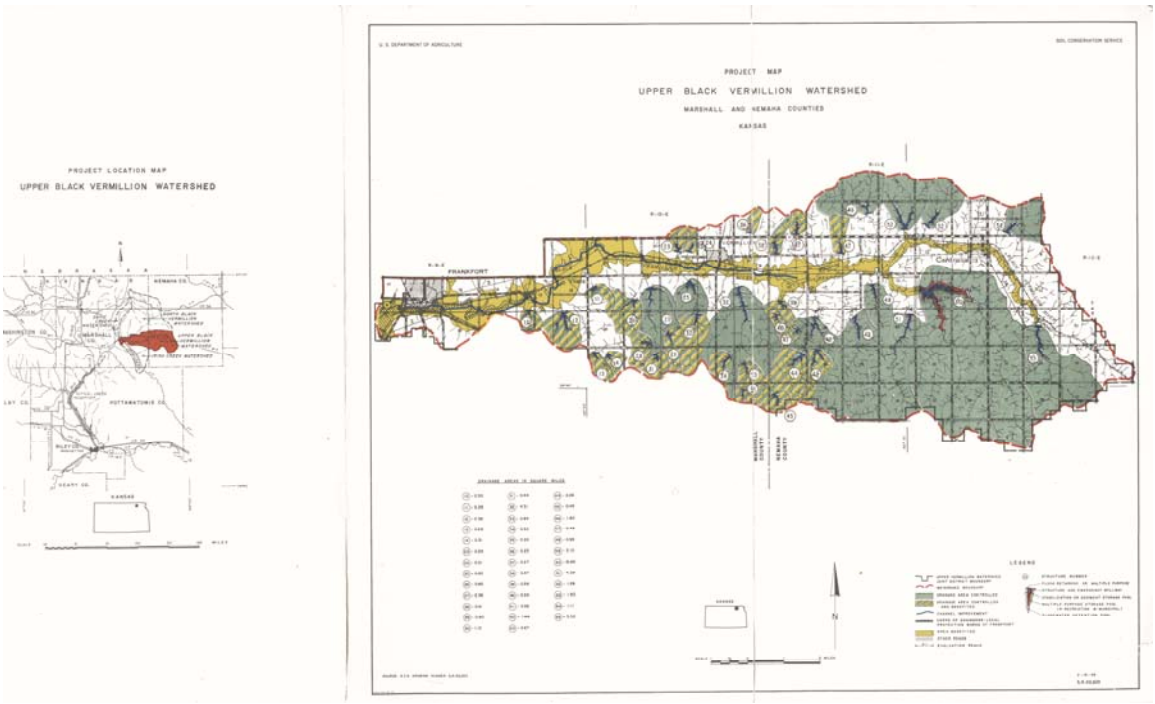


Figure 4.9 Centralia Lake Work Plan (See Appendix for larger version), (SCS, 1966).

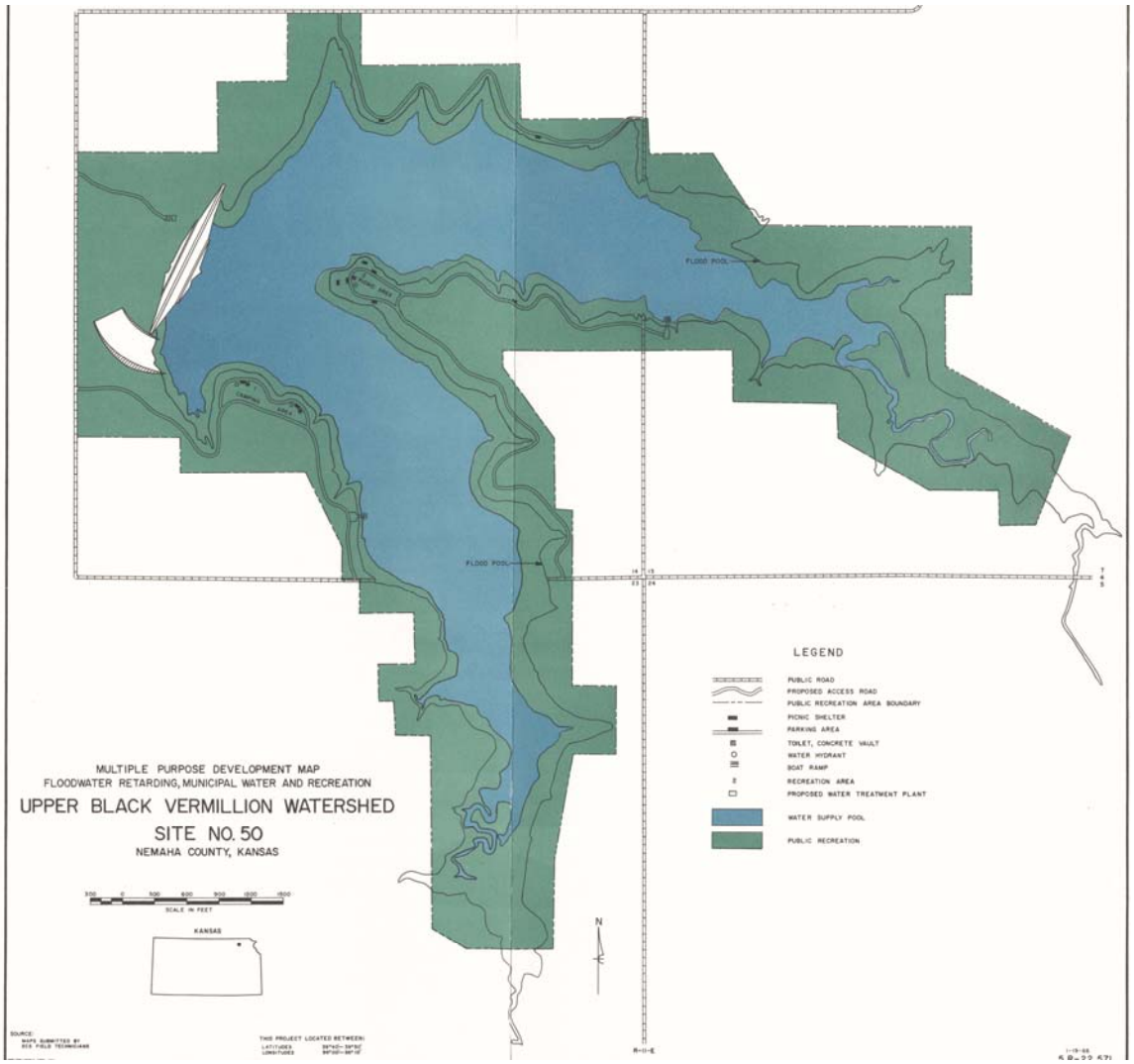
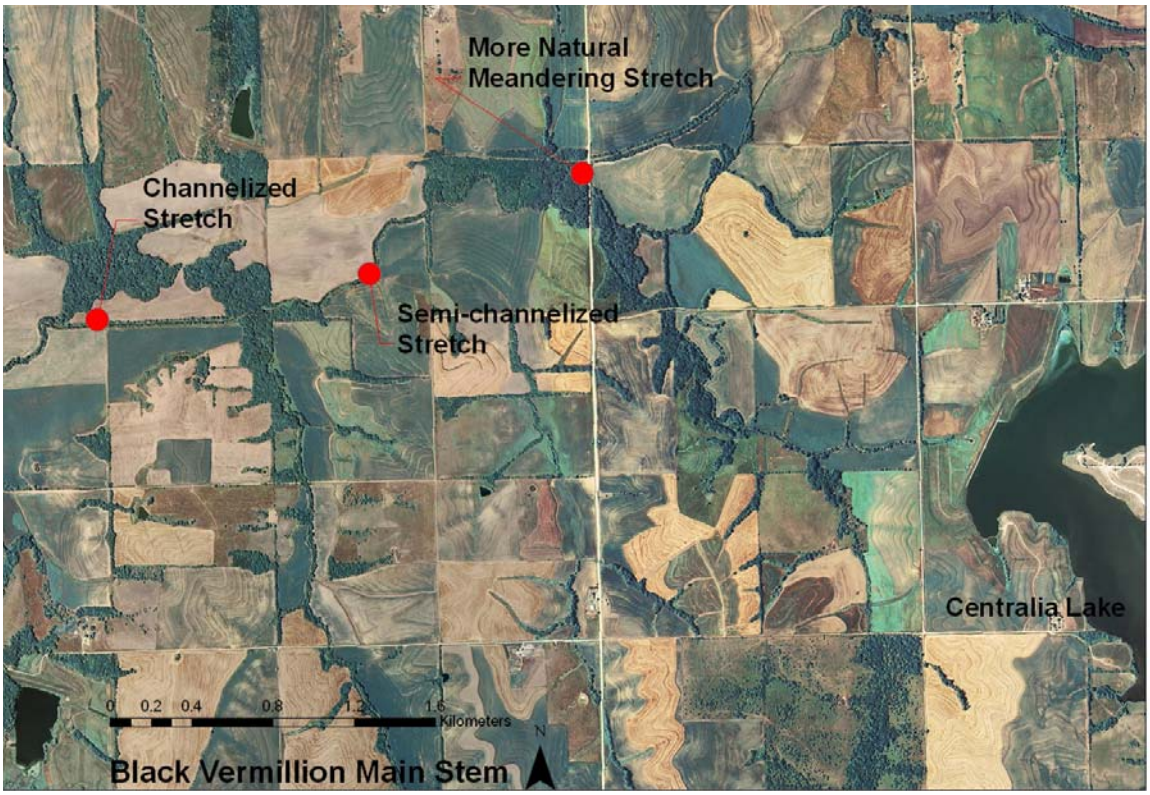


Figure 4.10 Natural meanders to channelized reaches on Main Stem 2006 aerial.



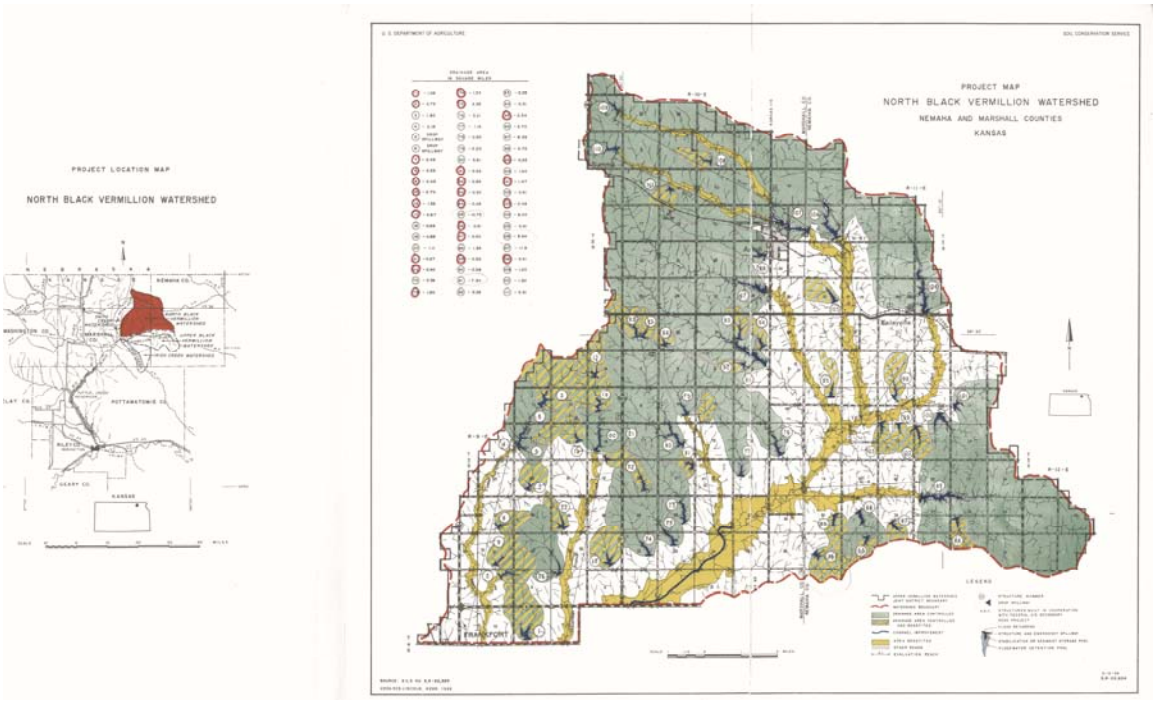
North Black Vermillion Work Plan

The North Black Vermillion, or the North Fork, work plan was to be the most extensive plan of the three regarding structures (Figure 4.11). The primary goals of the work plan were to decrease the floodwater damage to the land, crops and other valuable property "within" the floodplain, create a system of structural measures that would stabilize the stream so that other land treatments could be established and to protect the soil against excessive erosion. A total of 57 structures and 4.28 miles (6.9Km) of channel improvement were called for in the original plan. Overall, 22 floodwater retarding structures, 33 combination grade stabilization-floodwater retarding structures, 2 grade stabilization structures, and 4.28 miles (6.9Km) of channel improvement was to be completed within 10 years. This original work plan was modified twice, once in 1971 and then in 1983. Sixteen structures were deleted along with the channel improvement in 1983 while 22 structures were added in different places. All improvements deleted were considered "no longer feasible due to land rights problems, economics, and

environmental considerations"(page 1, Supplemental Watershed Plan No. 2 of the North Black Vermillion Watershed Work Plan).

Again, channel modification is evident in this watershed. Looking at the 1956 aerial photographs, channel re-alignment is obvious throughout the sub-watershed, including our study reaches number two and just downstream of reach three (Figure 3.6). There are old meander scrolls and riparian vegetation still standing in the agricultural fields. In talking with landowners casually, their grandparents or parents channelized the streams themselves in the 1950's or 1960's. One landowner talked about bulldozing trees into the channel. The same channel (North Fork Site 1) used to have two large meanders through the field and is now straight. This same landowner has since kept trees out of and away from the channel, actually not knowing he was increasing bank erosion in the area. Another landowner talked about blowing tree stumps out of the way with dynamite. He said they had enough fish from the blast to feed quite a few people at a fish fry. He noted several types of catfish, bass and crappie as common in the stream. Today, fisheries of the system include only gar and small minnow. Private, non-permitted channel work seems to have been common throughout the watershed. However, as mentioned above, channel improvement was taken out of the SCS work plan in this sub-watershed.

Figure 4.11 Black Vermillion North Fork Work Plan (See Appendix for larger version), (SCS, 1966).



Land Cover Changes Summary

Land cover changes throughout the watershed have been drastic over the past 150 years. One difference is there is little to no native vegetation on the uplands to intercept and infiltrate precipitation. Most of the prairies of the 1857 survey have been converted in the North Fork and Main Stem sub-watersheds to tillage agriculture. This change in land cover has decreased the number of deep-rooted, densely vegetated prairie to shallow-rooted, less dense tillage crops. The change in land use and cover has increased the direct runoff to the stream system creating a change in the hydrologic regime. Irish Creek sub-watershed, in low-lying areas (floodplains and bottomlands), has been converted to tillage agriculture while the uplands are mostly upland pasture composed of prairie grasses or brome. We know from the surveyor's notes in 1857 that the land cover was prairie or gallery (riparian) forest, and the forests were sparse and at times discontinuous.

Riparian Vegetation in the Corridors

Riparian Species Noted in 1857 & 2007

A list of species from the 1857 survey notes and the 2007 inventory was compiled to illustrate species richness in the corridors. Tables 7 and 8 list overstory woody species noted in the riparian corridors from 1857 and 2007, respectively. Tables 9 and 10 list understory woody species noted in the riparian corridors from 1857 and 2007, respectively. The surveyors probably would have noted species that had cultural value, such as good timber or a food source. I have attempted to note all woody species found in the corridors during the summer of 2007. Some species may be present in the riparian corridors in the watersheds that are not included here in the 2007 list due to limitations in sampling the sites visited.

Table 7 Overstory woody species list from 1857 surveys.

***- indicates specific species not known or not known to exist in the area**

Overstory Woody Species	
1857	
Common Name	**Species**
Hickory*	*Carya* spp.
Elm	*Ulmus americana*
Cottonwood (Aspen*)	*Populus detoides*
Mulberry	*Morus rubra*
Boxelder	*Acer negundo*
Willow*	*Salix* spp.
Black Walnut	*Juglans nigra*
Hackberry	*Celtis occidentalis*
Bur Oak	*Quercus macrocarpa*
White Oak *	*Quercus* sp
Post Oak*	*Quercus stellata*
Silver Maple	*Acer saccharinum*

Table 8 Overstory woody species list from 2007 vegetation survey.

Overstory Woody Species	
2007	
Common Name	**Species**
Bitternut Hickory	*Carya cordiformis*
Red Elm	*Ulmus rubrum*
Cottonwood	*Populus deltoides*
Mulberry	*Morus rubra*
Boxelder	*Acer negundo*
Black Willow	*Salix nigra*
Sandbar Willow	*Salix interior*
Black Walnut	*Juglans nigra*
Hackberry	*Celtis occidentalis*
Bur Oak	*Quercus macrocarpa*
Chinkapin Oak	*Quercus muhlenbergi*
Ohio Buckeye	*Aesculus glabra*
Green Ash	*Fraxinus pennsylvanica*
Honey Locust	*Gleditsia triacanthos*
Silver Maple	*Acer saccharinum*
Linden	*Tilia americana*
Black Locust	*Robinia pseudoacacia*
Kentucky Coffeetree	*Gymnocladus dioicus*

Table 9 Understory woody species list from 1857 surveys.
***- indicates specific species not known**

Understory Woody Species	
1857	
Hazel(nut)	*Corylus americana*
Wild Plum	*Prunus americana*
Grape	*Vitis riparia*
Briers *	*Smilax tamnoides*
Vines & Ivy *	*Toxicodendron radicans*
Virginia Creeper	*Parthanosissus quinquefolia*
Prickly Ash	*Zanthoxylum americanum*
Dogwood	*Cornus drumundii*

Table 10 Understory woody species list from 2007 vegetation survey.

Understory Woody Species	
2007	
Gooseberry	*Ribes missouriense*
Wild Plum	*Prunus americana*
Riverbank Grape	*Vitis riparia*
Greenbriar	*Smilax tamnoides*
Poison Ivy	*Toxicodendron radicans*
Virginia Creeper	*Parthanosissus quinquefolia*
Buck Brush	*Symphoricarpos orbiculatus*
Leadplant Amorpha	*Amorpha canescens*

Root Structure Comparison

Woody vegetation has different root structures and thus differing soil holding capacities. Table 11 compares root structure of many of the woody species located in the riparian corridors of the Black Vermillion Watershed. We can see a diverse array of root architecture among all of the species. Root structure can be variable according to soil condition and type. For example, a taproot may be stunted due to the presence of a water table or bedrock not allowing the taproot to penetrate. These scenarios may produce a fibrous or lateral root structure. Most woody vegetation associated with floodplains, or hydrophilic species, seem to have a more shallow, fibrous root structure compared to species adapted to upland conditions in the landscape. A more fibrous root structure is typically better in preventing erosion of bank soils.

Table 11 Root structure comparison chart. (Adapted from Hightshoe, 1988).

Root Structure		
Common Name	Species	Root Structure
Bitternut Hickory	*Carya cordifomis*	Taproot
Red Elm	*Ulmus rubrum*	Shallow to deep laterals
Cottonwood	*Populus deltoides*	Shallow fibrous
Mulberry	*Morus rubra*	Taproot w/deep laterals
Boxelder	*Acer negundo*	Deep spreading laterals
Black Willow	*Salix nigra*	Shallow
Sandbar Willow	*Salix interior*	Shallow
Black Walnut	*Juglans nigra*	Taproot
Hackberry	*Celtis occidentalis*	Deep spreading laterals
Bur Oak	*Quercus macrocarpa*	Taproot
Ohio Buckeye	*Aesculus glabra*	Taproot
Green Ash	*Fraxinus pennsylvanica*	Shallow fibrous
Honey Locust	*Gleditsia triacanthos*	Variable
Silver Maple	*Acer saccharinum*	Shallow fibrous
Linden	*Tilia americana*	Deep laterals
Black Locust	*Robinia pseudoacacia*	Shallow fibrous
American Elm	*Ulmus americana*	Shallow to deep laterals
Kentucky Coffeetree	*Gymnocladus dioicus*	Deep, course laterals
Leadplant Amorpha	*Amorpha canescens*	Shallow fibrous

Riparian Tree Diameter Comparison

Tree diameter at breast height can indicate age classes of a community of trees, as well as give insight to successional stage. Woody riparian vegetation diameters were noted in the survey of 1857 and these measures were recorded to compare with dbh's of 2007. I measured tree trunk diameter during the summer of 2007 where woody riparian vegetation existed. Table 12 lists average diameters in centimeters noted for species from 2007 and 1857 that were noted in the survey notes. Typically, surveyors noted diameters of trees they used for section corners or quarter section corners. Therefore, there were

not enough 1857 tree diameters for each species to calculate a true average and so a range of size is given as well as an "average" for each species for 1857.

Table 12 Tree trunk diameter averages and ranges in centimeters.

2007	Average	Range	1857	Average	Range
Cottonwood	37.9	140.2-3.2		43.2	61.0-25.4
Bur Oak	38.8	82.3-10.8		43.5	66.0-20.3
Hackberry	30.1	67.3-6		26.7	27.9-25.4
Mulberry	14.8	16-12.5		N/A	N/A
Silver Maple	20.9	38.6-10.2		N/A	N/A
Green Ash	7.2	9.5-4.8		N/A	N/A
Elm	16.2	21.8-8.5		32.6	38.1-20.3
Honey Locust	24.9	70.6-4.3		N/A	N/A
Boxelder	26.9	46.8-11.5		16.5	17.8-15.2
Ohio Buckeye	8.5	12.9-2.8		N/A	N/A
Kentucky Coffee Tree	8.2	N/A		N/A	N/A
Walnut	45.3	58.8-31.8		35.6	N/A
Hickory *	14.7	18.7-10.6		25.4	N/A
Linden	18.8	21.6-16		N/A	N/A
Willow sp.	N/A	N/A		22.9	25.4-20.3
Post Oak**	N/A	N/A		33.0	38.1-27.9

*Assumed to be Bitternut Hickory

** Assumed as a mis-identification

CHAPTER 5 - Conclusions & Discussion

Studying changes in land cover allows one to uncover variables that may have affected how the landscape was transformed from its native state to its current state and how the landscape, especially riparian corridors, changed under a given set of conditions. Considering and appreciating the ecological and social processes, along with the social context of how the landscape has changed, a designer may then take appropriate steps toward ecosystem restoration or rehabilitation while still anticipating changes that may take place in the future landscape. Designers working on large-scale projects can begin to predict what might happen to riparian areas if adjacent land-cover changes occur in a given area. Most often, leaving riparian corridors intact have shown not only improved aesthetic and monetary value of the site, but also improved overall health of the immediate environment, ecosystem and stream system stability (Riley, 1998, 2008; Rosgen, 1996).

Riparian Corridor Widths

Between 1857 and 1956, the results in average corridor widths confirm the North Fork sub-watershed increased in corridor width while the other two stream corridors decreased. The North Fork increased its average width by about 38%, while Irish Creek lost 43% and the Black Vermillion lost 8% of riparian corridor (Table 1). The 8% loss in riparian corridor width is negligible and can be attributed to measurement error, lack of accuracy of the original surveys or losing a single row of trees on one side of the stream. However, between 1956 and 2002 there was a decrease in average riparian corridor widths across all three sub-watersheds of approximately 80-85%. Corridor width averages in the three sub-watersheds decreased from an average width of 790' (241m) to 100' (30.5m). The eighteen transects illustrate a general increase from 1857 until 1956, then a dramatic decrease in corridor width from 1956 through today (Tables 3 and 4).

An approximate total of 9.52 mile^2 (24.7Km^2) of riparian corridors once established itself in the 410 mile^2 (1062Km^2) Black Vermillion watershed. These 9.52 mile^2 (24.7Km^2) of corridor represent about 2% of the watershed land cover, which is

consistent with Popotnik and Giuliano's, (2000), figure nationwide. We have lost as much as 8.17 mile^2 (21.2Km^2) (86%) of riparian corridor in the watershed equating to about 1.35 mile^2 (3.5Km^2) remaining (0.3%), again similar to national findings (Popotnik & Giuliano, 2000).

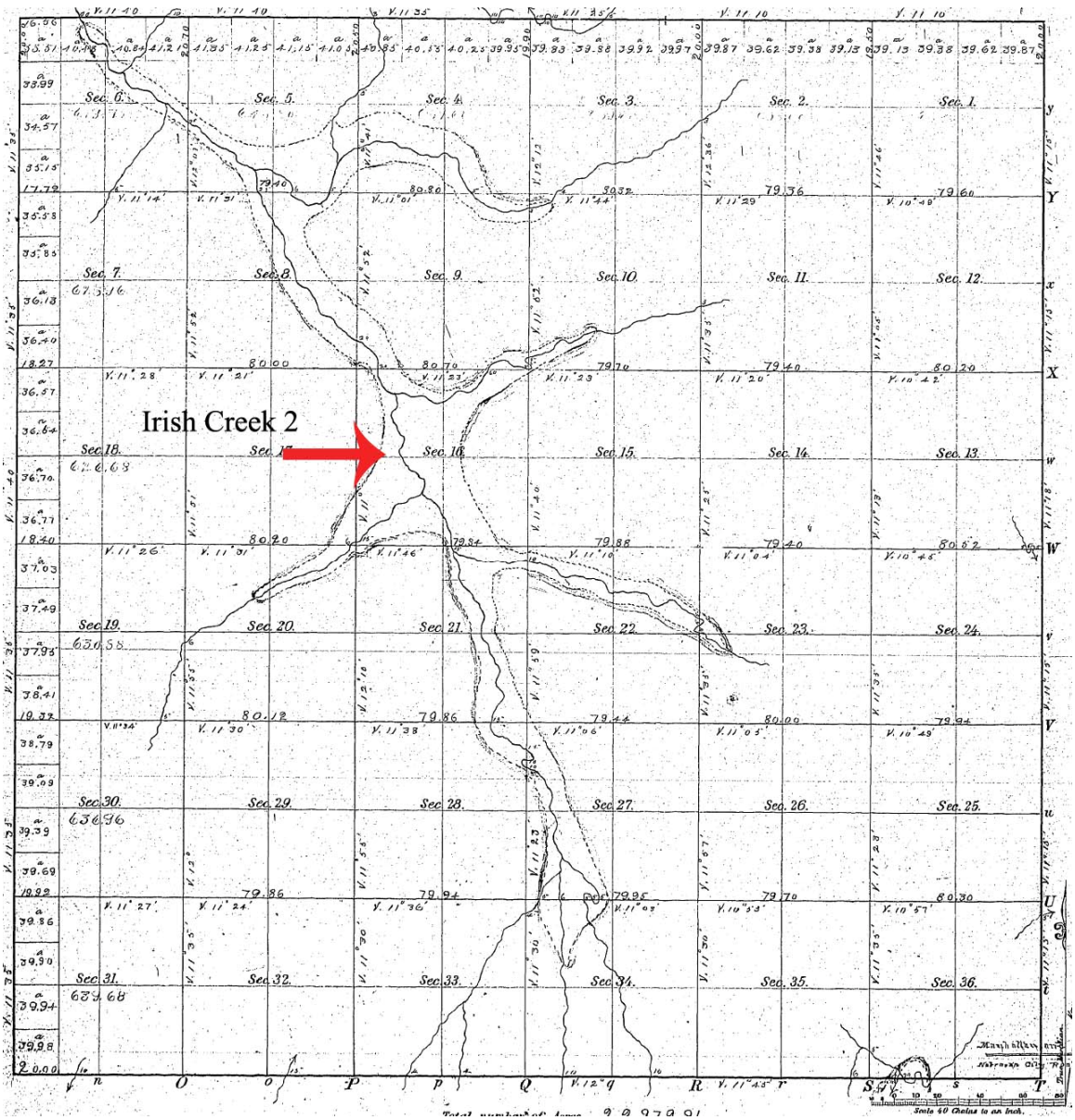
I had expected to see a constant decrease in corridor widths over time instead of the slight increase in widths followed by a sharp decrease. Similar studies are suggesting that gallery forest and woody vegetation are expanding into grasslands even today (Briggs et al. 2005; Knight et al. 1994), a situation we might have seen pre-1956 in the Black Vermillion system. This expansion seems to be due to the suppression of fire and lack of grazing. As noted by Knight et al. (1994), a reduction in frequency or intensity of fire allows forest expansion of seedlings because there is no fire or the fire is less intense than it once was to kill woody seedlings. However, gallery forests were not allowed to expand in the Black Vermillion watershed post-1950. I suspect sometime in the 1950's we would have seen many of the riparian corridors being taken out and replaced by tillage land prompting the sharp decline in corridor widths. Also during this time, we see private channelization begin as evidenced in the aerial photographs from 1956.

The construction process of channel improvement of streams tends to destroy riparian corridor vegetation. The watershed work plans from 1966 illustrate construction of watershed ponds and minimal channel improvement throughout the three sub-watersheds. Recall that Irish Creek was not to be channelized at all according to the SCS work plans dated 1966. However, aerial photography illustrates a different outcome. Using Irish Creek reach 2 (Figure 3.8) as an example location, we can see that private channel improvements were made. Similar improvements were made throughout the watershed and are continued today.

Irish Creek reach 2 is an excellent example of channel modification destroying riparian corridor vegetation. Using the transect measures at this site, we can see a loss of riparian corridor width of more than 1000' (305m), from 1056'(322m) to 0' at transect 1 and 2376' (724m) to 0'at transect 2. Figure 5.1 illustrates what the area looked like during the survey of 1857. Compare the 1857 riparian corridor to the 1956 aerial photo of the same place, Figure 5.2. The stream has been channelized as evidenced by the meander scars in the fields and old riparian vegetation left standing. Today, little

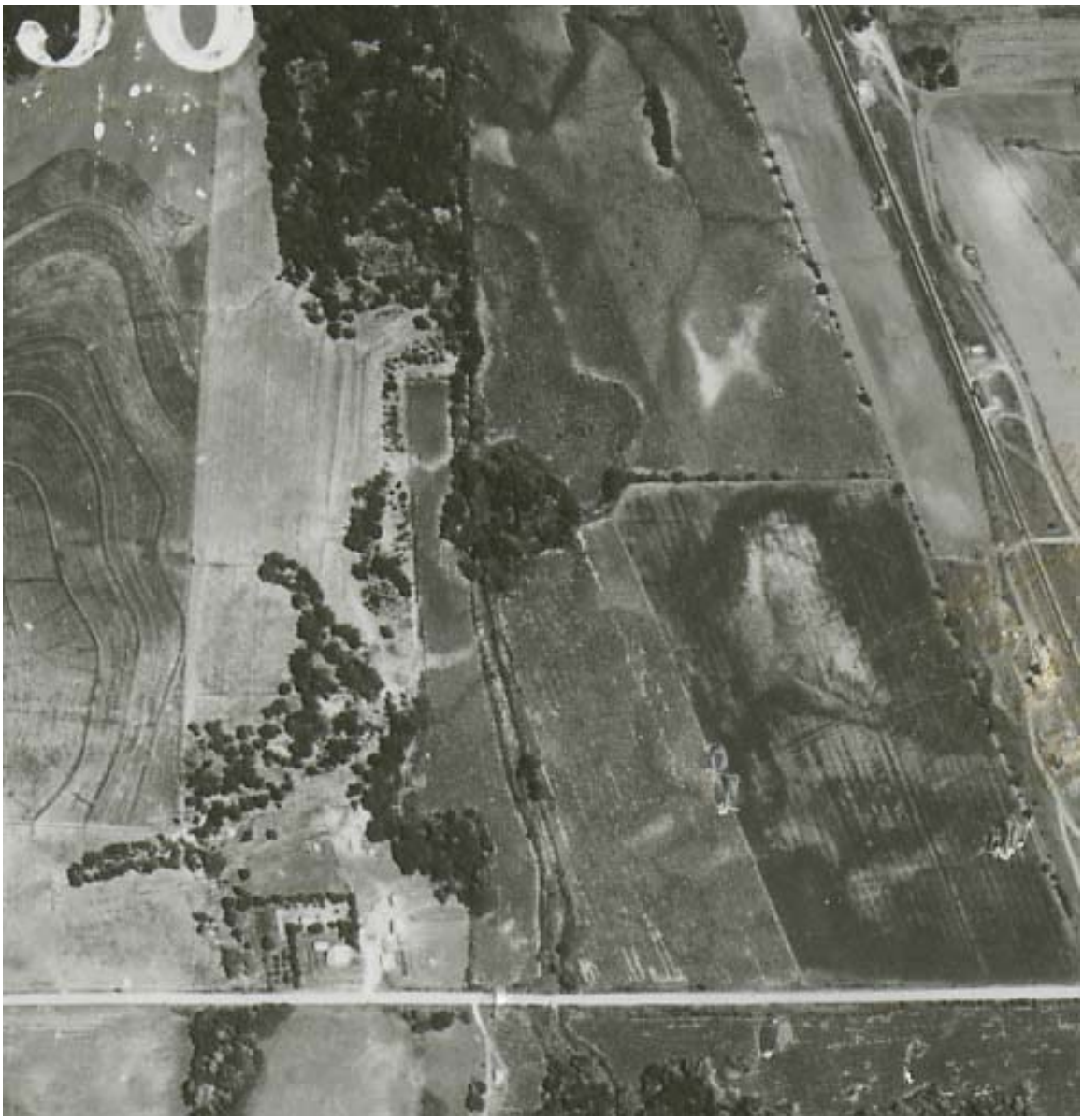
vegetation has been allowed to re-establish along Irish Creek reach 2 and there are reaches farmed to 17' (5m) vertical stream bank edges, Figure 5.3 and Figure 5.4. Transformations of stream corridors like this example are all too common in all three sub-watersheds. According to the US-COE report dated 1998, the streams in the watershed have lost a total length of 15.8 miles, more than was designed and permitted.

Figure 5.1 Irish Creek reach 2, 1857 survey map.



Note: Riparian corridor outlined in black with stream delineated through center of riparian corridor.

Figure 5.2 Irish Creek reach 2, 1956 aerial photograph.



Note: Notice meander scars in the adjacent fields, the straight channel and no woody riparian vegetation (North is up).

Figure 5.3 Irish Creek reach 2, 2006 aerial photograph.

Figure 5.4 Irish Creek reach 2 riparian corridor (Keane, 2007).

Note: Corn is approximately 5' tall, old woody roots still visable.

A limitation of this study is there were no aerial photos readily available between 1857 and 1956. An ongoing attempt to get the aerial photographs continues and when successful will be included in this study. Studying photos from the 1930's or 1940's would have helped in understanding when channel modification had begun and if the riparian corridors had actually widened even more than what I was able to discern in the 1956 photos. I have a suspicion corridor widths would have had a slight decrease from the 1930's until the 1950's due to drought before the dust bowl and private machinery being able to handle larger workloads. Another limitation is the accuracy of the survey

drawings. Even though I attempted to compensate for differences between drawings and notes, there is still doubt in my mind that the survey is as accurate as the aerial photographs. However, the baseline corridor widths are still close, within approximately 10%.

The Future of Riparian Corridors

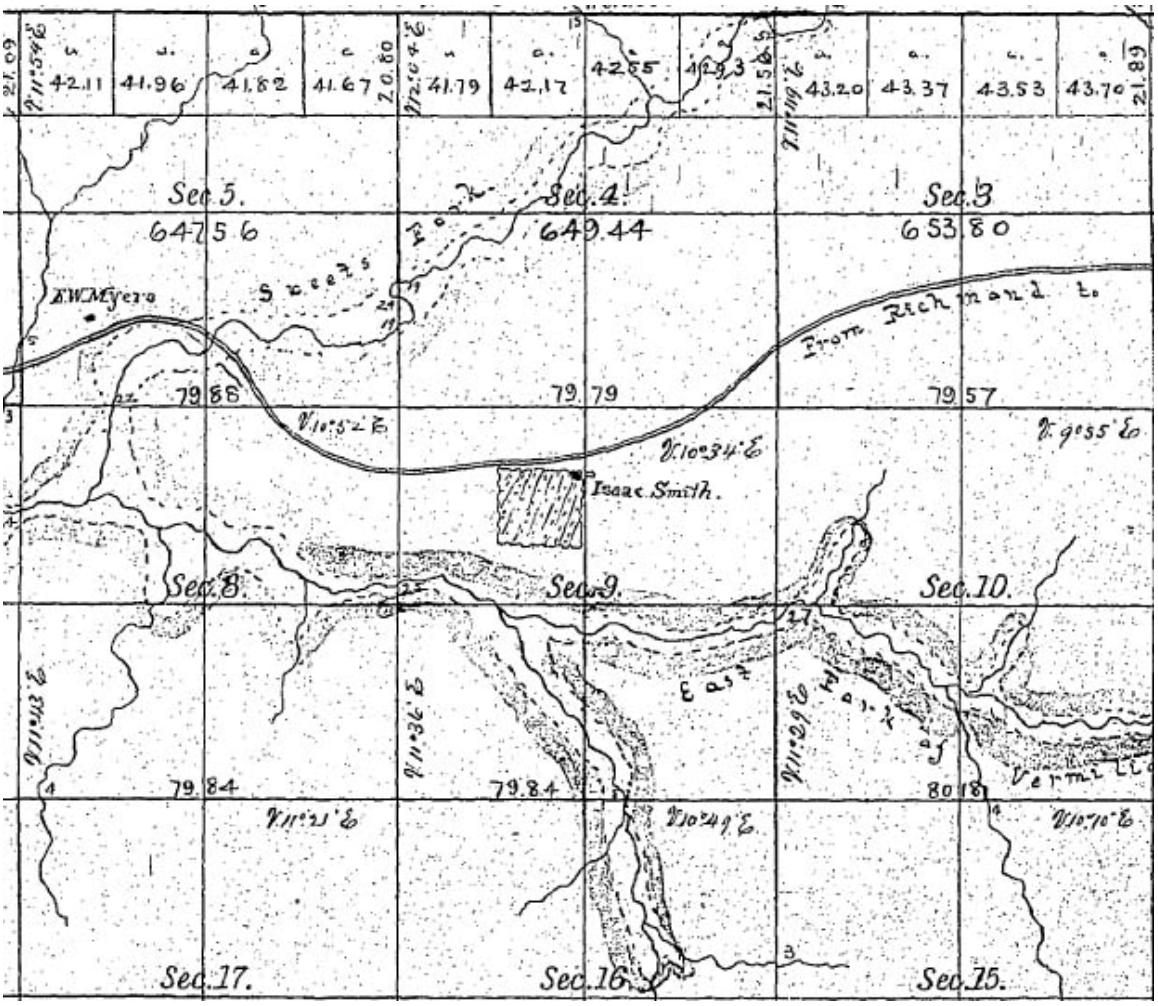
The future of these and other riparian corridors may be a bit bleak. A large increase in prices per bushel of corn and soybeans over the last couple of years may decrease the amount of current CRP land, allowing farmers to work the land back into tillage agriculture. The NRCS currently helps landowners with stream buffers and discourages farming to bank's edge. Another change in land cover will again change the amount of runoff to the streams causing a new adjustment of the streams to the new discharge. Once again, farmers may work the land from bank to bank without regard to stream stability and water quality. Ways to combat these land use changes are through education of policy makers and stakeholders, increase pay for CRP lands, and targeting riparian corridors for conservation. If the land use changes back to tillage agriculture from CRP lands, then we can expect more degradation and soil erosion, which in turn will begin to fill our reservoirs with more sediment at a much faster pace. Everything in the landscape is interconnected and interrelated, allowing one change in the landscape to have profound effects in not only the immediate area, but also far reaching, especially downstream.

Land Cover Changes

The land cover in Kansas has changed significantly since 1857 when the original territory surveys were done. Land cover in the watershed consisted of native, tallgrass prairie with woody riparian corridors and bottomland forests in 1857 (KSLS, 2005). The landscape was disturbed by fire, grazed by bison and probably would have been in a mostly native state in 1857, meaning little human disturbance. There were no towns located within the watershed, and few roads crossed through the watershed. At the time of the survey in 1857, there was one homestead in the watershed and that was of Isaac Smith. This homestead was located to the east of the confluence of the North Fork and

Black Vermillion, Township 4S, Range 10E, the NW ¼ Section 9 (Figure 5.5). There is no mention of what types of agriculture were on the homestead.

Figure 5.5 Isaac Smith homestead with road to north.



Note: Sweets Fork is actually the North Fork of the Black Vermillion.

The land cover in 2007 is very different from that of 1857. Almost the entire watershed has been developed or changed in some fashion (Figure 1.17). Most of the northern and middle portions of the watershed are in tillage agriculture. Irish Creek is divided between tillage agriculture and grazing lands, both of which can change the porosity of the soil through compaction. Open tillage fields are known to cause quicker overland flow, contain less storage capacity for precipitation and provide less absorption of precipitation causing a flashy stream system with little to no base flow (Knighton, 1998; Leopold et al. 1964; Rosgen, 1996). Livestock have been allowed to graze near the

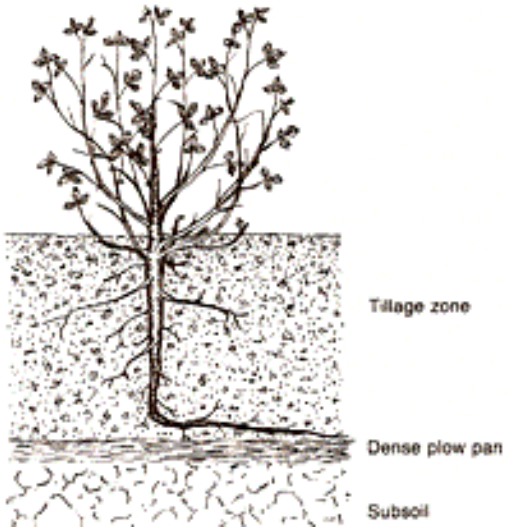
streams, trampling small seedling trees, destroying other vegetation and compacting soil, all which tend to increase soil erosion and precipitation runoff.

Adjacent Land Cover

Land cover adjacent to the riparian corridors has changed the most over time. Lush tallgrass prairie used to fill the hillsides of northeast Kansas, now only patches of native grasslands can be found. Most of the area is now open tillage agriculture with bare soils and little to no vegetation to absorb the energy from raindrops. Splash erosion is the source of the most erosion over time (Knighton, 1998). The foliage of the prairie used to intercept precipitation and slow water on its way to the ground through stem flow. The deep roots would have allowed water to infiltrate the pore spaces much deeper than current conditions. These porous conditions also provided a higher storage capacity than current, dense plow pan conditions. Often in tilled fields, we find an impermeable layer, called a dense plow pan that has formed at a constant depth due to the tillage itself, Figure 5.6 (Harpstead et al, 2001). Open fields create a new scenario of more and quicker runoff to the stream and less base flow during the drier season causing flash flooding and deeper bankfull depth (Knighton, 1998; Leopold et al. 1964; Rosgen, 1996).

Figure 5.6 Dense plow pan (Harpstead, 2001).

Note: Dense plow pans can inhibit root growth and water infiltration. The tillage zone above the compacted soil allows roots to freely grow, while the compacted dense plow pan inhibits deeper penetration into the soil.



The NRCS encourages practices that help streams recover from past abuse. For instance, NRCS now cost-shares planting riparian woodlands and native plant buffer strips along streams. They also discourage farming bank to bank and allowing cattle to enter the streams. Of course, these are recommendations and are not always followed by landowners. We still have people who believe that using dynamite to clear the way for water and straighten the stream is the best alternative, which is a mindset we as land planners must overcome.

Alterations to the watershed's land cover have played havoc with the hydrologic cycle. During the pre-development era, more precipitation would be intercepted by dense prairie vegetation and percolate into the soil causing less runoff to the stream. More percolation into the soil means aquifers could be recharged, streams could have a constant supply of base flow water, less discharge at bankfull and streams would not flash flood as often, if ever. The opposite is now true with less dense vegetation during the rainy season and more exposed soils; less water percolates into the soil and more runoff goes straight to the stream with more pollutants from the land. In this scenario, runoff water tends to be warmer, more polluted, able to maintain a higher velocity overland and increased stream flows and discharges compared to historic conditions (Knighton, 1998; Leopold et al. 1964; Naiman & Decamps, 1997). Implications for our streams and reservoirs are bleak, as we have seen what the extra sediment can do in the system. This is why even narrow riparian corridors are important. As mentioned previously in the literature review, riparian corridors can slow down and filter overland flow runoff, cool water temperature of both the stream and overland flow and slow velocities of floodwaters and overland flow.

Many changes in hydrology have taken place due to the watershed work plans and private channelization. In an attempt to control flooding of agricultural land, many small watershed ponds were built in the watershed by the NRCS. These ponds are to release water at a constant rate, creating a simulated bankfull discharge over a longer period and allowing flash flooding both before and after the pond. Many of these ponds seem to have silted in with sediment from above and have lost flood storage capacity, creating more flow to the streams than originally planned. Many areas have been cleared to make way for more agricultural fields allowing an unobstructed overland flow directly to the

streams. As mentioned previously, this unabated flow creates a flashy hydrograph and tends to erode banks at a faster pace than historical regimes.

As mentioned before, the NRCS encourages and helps landowners design and maintain riparian corridor buffers. The unfortunate part of this situation is that it may take decades for riparian corridors to establish from fresh plantings. In addition, the mindset of clearing all riparian vegetation and straightening the stream is still prevalent in the watershed. The advantages of riparian corridor buffers offered by the NRCS are numerous and include control of soil erosion, improved soil quality, reduction of flooding, economic gains through federal programs, and a demonstration of land stewardship by the landowner (NRCS, 2008). Riparian buffers also remove 50-75% of sediment, nutrients, pesticides and certain pathogens (NRCS, 2008; Naiman & Decamps, 1997). The good news is education and promotion of the advantages of riparian corridors has begun, however some landowners still need convincing.

Riparian Vegetation Changes

Riparian corridors in this watershed seem to have more species richness in 2007 than the 1857 survey. It is hard to say definitively if a change in species richness or diversity happened. I don't believe I have a complete list of species from 1857, as the surveyors would have noted species of cultural interest, such as species used for food and lumber. I didn't find that surveyors noted buckbrush (*Symphoricarpos orbiculatus*) or indigobush amorpha (*Amorpha fruticosa*). Indigobush amorpha is a shrub that is important in stabilizing streambanks, along with willows and cottonwoods. According to the intermediate disturbance hypothesis, there would have probably been greater species diversity and richness in 1857. This is due to the riparian corridors being connected to the floodplains then where flood disturbance would have been prevalent. Now the floodplains are not connected to the stream, lessening the amount of flood disturbance encountered by riparian species. In addition to species diversity and richness, I am not sure we can say much about age diversity either due to the lack of 1857 trunk diameters.

Pioneer species, such as willow and cottonwood, are coming back to re-establish riparian corridors at a new lowered elevation, Figure 5.7. Honey locust and green ash, upland pioneer species, are establishing themselves on the abandoned floodplain, when

the old floodplain has been left alone. However, most riparian corridors have been confined to one row of trees, at most, as a buffer between the agricultural field and the stream channel.

Figure 5.7 Main Stem reach 1, willows establishing at a lower elevation (Keane, 2007).

Not only should one look at the species that are present in the riparian corridors currently, but they should look for what is not there. I noticed while going through the corridors that there were very few seedlings and saplings to replace old snags or gaps in the canopy. It seemed to me that most canopy trees had little age diversity. I found this odd and have two explanations. Most species located in the riparian corridors are pioneer species, such as honey locust and green ash, and most of the time they require full sunlight. White-tail deer are in abundance in the riparian corridors and tend to over browse seedlings and saplings. In addition to not having seedlings or saplings, there were no bush honeysuckle (*Lonicera maackii* or *L. morrowii)*. Not having these species in the riparian corridor is a good thing, as bush honeysuckle is invasive and sprouts leaves

early, tending to shade out young seedlings and saplings of larger trees. However, most of these areas were channelized at some point and the riparian corridor during channelization would have been destroyed. A few areas in Irish Creek and lower Main Stem have larger, later successional vegetation such as black walnut, linden and bitternut hickory. These areas appear to have been mostly undisturbed for quite some time and the banks seem to be a bit more stable, and thus are not as apt to retreat as other banks in the watershed without woody vegetation.

The DBH study was inconclusive in as much as determining age diversity. There were not enough of the 1857 survey trees to make a determination about age diversity compared to current conditions. Most trees during the 1857 survey were selected and measured because they were close to a section or quarter section corner and helped locate those corners. I suspect that the measures from 2007 would tend to show statistically that there is no significant difference in DBH, telling us that the floodplain is disconnected from the stream. The reason for this assumption is that an intermediate disturbance regime from flooding would open areas for new growth and that there should be trees that vary in size throughout the corridors. In other words, we should see a mix of different age and size of trees of the same species. I would also venture to say that the stream corridors are beginning to recover. Looking at the average tree DBH versus the range in size, the range is typically larger and the average is small. This may indicate that there are remnant trees from the past, but many of the current riparian trees are smaller in DBH, thus younger. For example, cottonwood averages only about 39cm. The range is much larger, being 137cm (140.2-3.2=137cm). We can see the average is much closer to the smaller end of the range than the larger end.

So what now and who cares?

Landscape architects and land planners can learn a great deal about reaction to change in ecosystems and hydrology by studying streams and adjacent land changes in agricultural systems. Agricultural systems are not very different from urban systems in as much as hydrology and ecology. Typically, fields become a semi-impervious surface draining directly into streams (dense plow pan and compaction from hoofed animals), while the overland flow carries pollutants. We can begin to understand how important a

riparian corridor is in maintaining the stream channel integrity to minimize maintenance and increase sustainability of the stream channel design. We can benefit from the aesthetics of the natural corridor design in urban settings. As mentioned before, corridors filter out sediment and other toxic materials before they reach the stream, lessening the amount of pollutants needing to be filtered out by municipal water plants.

The NRCS and other agencies such as Trout Unlimited, Pheasants Forever and Quail Unlimited, have committed many dollars and time to the propagation and encouragement of maintaining and planting riparian corridors. There are obviously many more miles of riparian corridors to mend, but at least a restoration attempt has begun. "What Now and Why You Should Care?" should be the title of this section, because everyone that depends on water resources has a stake in riparian corridors.

Further Research

This research thesis addresses a small portion of the land history in the Black Vermillion watershed. This thesis could provide many studies through both cultural and environmental eyes. A cultural analysis of the feelings and beliefs about channelization in a watershed may prove useful in future watershed planning and watershed education. Attempting to figure out exactly when and why the extra channelization was done and by whom may help in assessing and educating the public perception of watershed health, management and planning. A study of the overall root structure, or architecture, of specific species of woody riparian vegetation in Midwestern streams would help in understanding the depth and extent of root structures for a particular species. Environmental impacts of channelization and vegetation removal in Midwestern small stream conditions could be studied. Re-generation rates, especially of the forest floor and woody riparian forest, and health could be studied. Possibly tying together bankfull width and proper riparian vegetation corridor widths could be another study. Erosion rates of banks and bed could be studied and gauged to predict future erosion of specific banks and beds in Midwestern conditions.

The next step for this specific thesis research would be quantifying erosion rates from the bed and banks under different riparian corridor conditions. If there is a difference, and I suspect there is, we can locate high erosion potential areas and begin to

rehabilitate the stream by revegetating the banks with proper riparian vegetation at lower elevations. Lessening erosion from the bed and banks lowers sediment loading into reservoirs, a common problem in the Midwest. Many reservoirs throughout the Midwest are filling up with sediment, decreasing their storage capacity for municipal drinking water, flood control and recreational use. A study such as quantifying erosion rates may help in setting TMDL's by providing baseline measures.

The findings of this study can influence design for natural habitat rehabilitation purposes. Design decisions for land rehabilitation purposes should consider reference conditions (historic), and to understand those reference conditions we must study the history of land use and land cover change (Egan & Howell, 2001). This study provides a template for designers to aid in understanding the history of land use and land use change of riparian corridors in Midwestern, agricultural landscapes.

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Appendix A - Forms

Bank Stability Forms

Included in Appendix A are bank stability forms mentioned in the main text.

Bank Erosion Hazard Index (BEHI)

Figure A.1 BEHI form considers root depth and density (Rosgen, 2008)

Worksheet 3-11. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001b, 2006b). Use **Figure 3-7** with BEHI variables to determine BEHI score.

Stream:	Location:	
Station:	Observers:	
Date:	Stream Type:	Valley Type:

BEHI Score (Fig. 3-7)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	(A)	Bankfull Height (ft) =	(B)	(A) / (B) =	(C)	

Root Depth / Study Bank Height (E)

Root Depth (ft) =	(D)	Study Bank Height (ft) =	(A)	(D) / (A) =	(E)	

Weighted Root Density (G)

Root Density as % =	(F)	(F)×(E) =	(G)	

Bank Angle (H)

Bank Angle as Degrees =	(H)	

Surface Protection (I)

Surface Protection as % =	(I)	

Bank Material Adjustment:

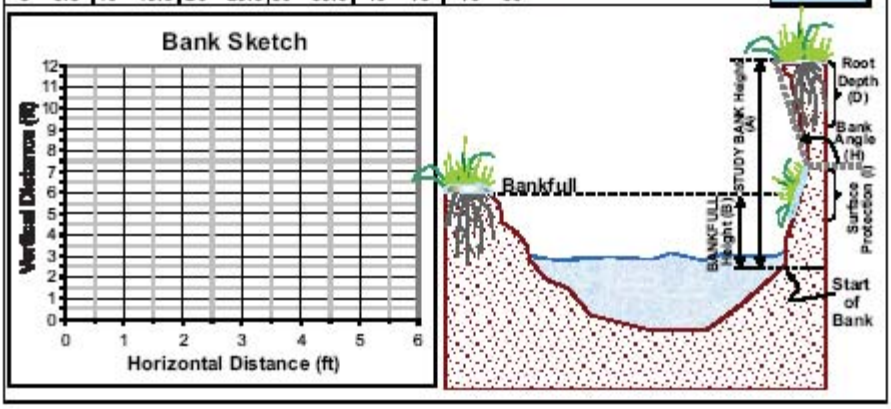
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform med. to large cobble)
Gravel or Composite Matrix (Add 5-10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (No adjustment)

Bank Material Adjustment

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	

Bank Sketch



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Pfankuch Bank Stability Rating Form

Figure A.2 Phankuch bank stability rating form (USDA, 2008)

Pfankuch D.J. 1975. Stream reach inventory and channel stability evaluation. USDA Forest Service Northern Region, Montana.

UPPER BANKS	EXCELLENT		GOOD		FAIR		POOR	
Landform slope	Bank slope gradient <30%	2	Bank slope gradient 30-40%	4	Bank slope gradient 40-60%	6	Bank slope gradient >60%	8
Mass-wasting (existing or potential)	No evidence of post or any potential for future mass-wasting into channel.	3	Infrequent and/or very small. Mostly healed over. Low future potential.	6	Moderate frequency and size, with some raw spots eroded by water during high flows.	9	Frequent or large, causing sediment OR imminent danger of same.	12
Debris jam potential (floatable objects)	Essentially absent from immediate channel area.	2	Present but mostly small twigs and limbs.	4	Present, volume and size are both increasing.	6	Moderate to heavy amounts, mainly larger sizes.	8
Vegetative bank protection	>90% plant density. Vigor and variety suggests a deep, dense, soil binding root mass.	3	70-90% density. Fewer plant species or lower vigor suggests a less dense or deep root mass.	6	50-70% density. Lower vigor and species form a somewhat shallow and discontinuous root mass.	9	<50% density plus fewer species and vigor indicate discontinuous and shallow root mass.	12
Channel capacity	Ample for present plus some increases. Peak flows contained. Width to Depth (W/D) ratio <7.	1	Adequate. Overbank flows rare. W/D ratio 8 to 15.	2	Barely contains present peaks. Occasional over-bank floods. W/D ratio 15 to 25.	3	Inadequate. Overbank flows common. W/D ratio >25.	4
LOWER BANKS								
Bank rock content	65% with large, angular boulders 30cm numerous.	2	40 to 65%, mostly small boulders to cobbles 15-30cm.	4	20 to 40%, with most in the 7.5-15cm diameter class.	6	<20% rock fragments of gravel sizes, 2.5-7.5 cm or less.	8
Obstructions (flow deflectors Sediment traps)	Rocks and old logs firmly embedded. Flow pattern without cutting or deposition. Pools and riffles stable.	2	Some present, causing erosive cross currents and minor pool filling. Obstructions and deflectors newer and less firm.	4	Moderately frequent, unstable obstructions and deflectors move with high water causing bank cutting and filling of pools.	6	Frequent obstructions and deflectors cause bank erosion. Sediment traps' full channel migration occurring.	8
Undercutting	Little or none evident. Infrequent raw banks <150cm high.	4	Some, intermittently at outcurves and constrictions. Raw banks <30cm.	8	Significant. Cuts 15-30cm high. Root mat overhangs and sloughing evident.	12	Almost continuous cuts, some >30cm high. Failure of overhangs	16
Deposition	Little or no enlargement of channel or point bars.	4	Some new increase in bar formation, mostly from coarse gravels.	8	Moderate deposition of new gravel and coarse sand on old and some new bars.	12	Extensive deposits of predominantly fine particles. Accelerated	16
STREAM BED								
Rock angularity	Sharp edges and corners, plane surfaces roughened.	1	Rounded corners and edges. Smooth and flat.	2	Corners and edges well rounded in two dimensions.	3	Well rounded in all dimensions.	4
Brightness	Surfaces dull, darkened or stained. Not "bright".	1	Mostly dull, but may have up to 35% bright surfaces.	2	Mixture, 50-50% dull and bright i.e. 35-65%.	3	Predominantly bright, 65%, exposed surfaces.	4
Consolidation or particle packing	Assorted sizes tightly packed and/or overlapping.	2	Moderately packed with some overlapping.	4	Mostly a loose assortment with no apparent overlap.	6	No packing evident. Loose, easily moved.	8
Bottom size distribution & stable	No change in sizes evident. Stable materials 80-100%	4	Distribution shift slight. Stable materials 50-80%.	8	Moderate change in sizes. Stable materials 20-50%	12	Marked change. Stable materials 0-20%	16
Scouring and deposition	<5% of the bottom affected by scouring and deposition.	6	5-30% affected. Scour at constrictions and where steep. Pool deposition.	12	30-50% affected. Deposits and scour at obstructions, constrictions, and bends.	18	> 50% of bed in a state of flux or change nearly year-long.	24
Clinging aquatic vegetation (moss and algae)	Abundant, growth largely moss, dark green, perennial. In swift water too.	1	Common. Algal forms in low velocity and pool areas. Moss and swifter waters.	2	Present but spotty, mostly in backwater areas. Seasonal blooms	3	Perennial types scarce or absent. Yellow-green, short term bloom present.	4
COLUMN TOTALS								

Reach score of: <38 = Excellent, 39-76 = Good, 77-114 = Fair, 115+ = Poor

Appendix B - Maps & Figures

Included in Appendix B are larger maps and figures from main text.

Figure B.1 Land use map enlarged.

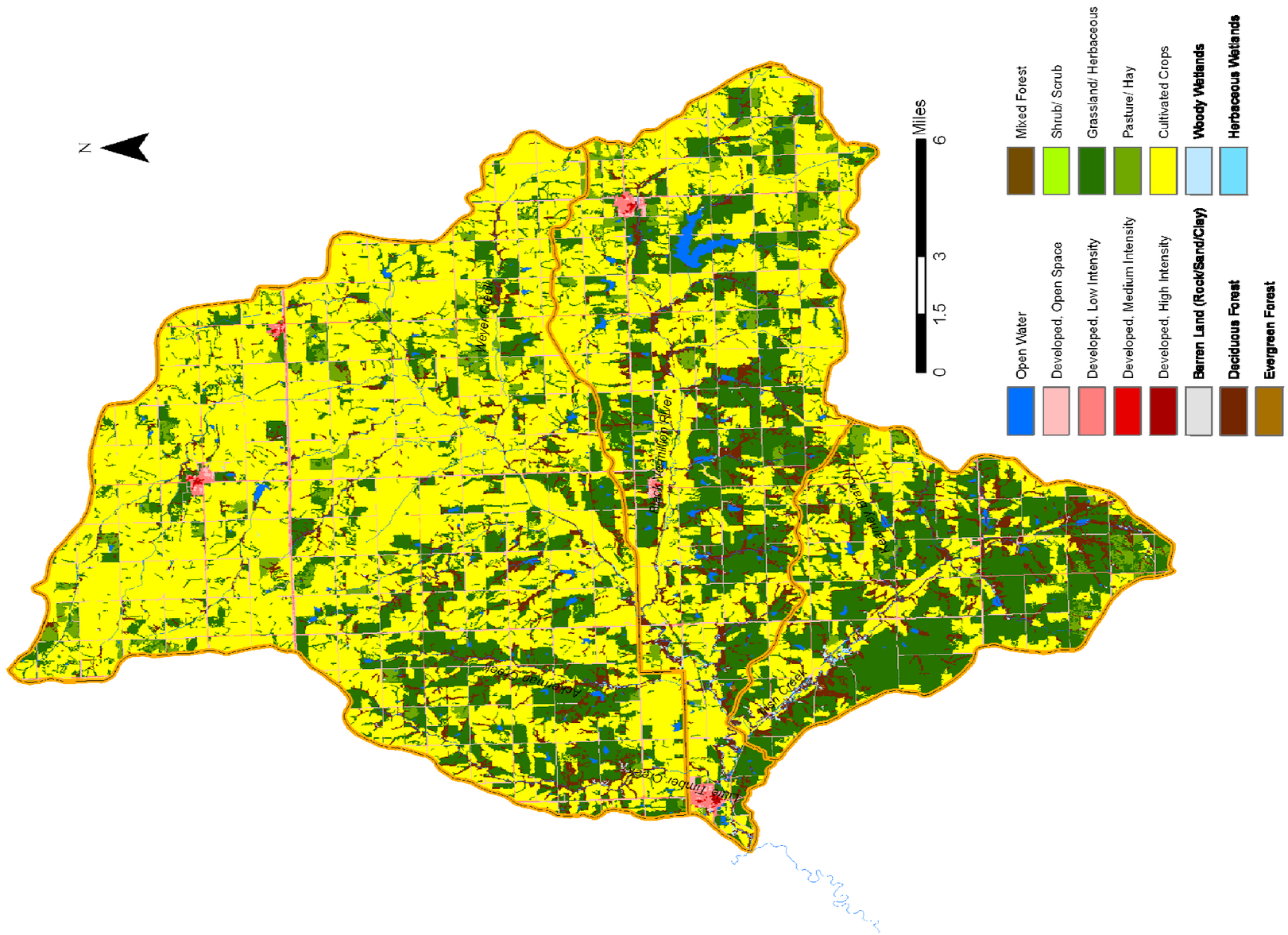


Figure B.2 Watershed map enlarged

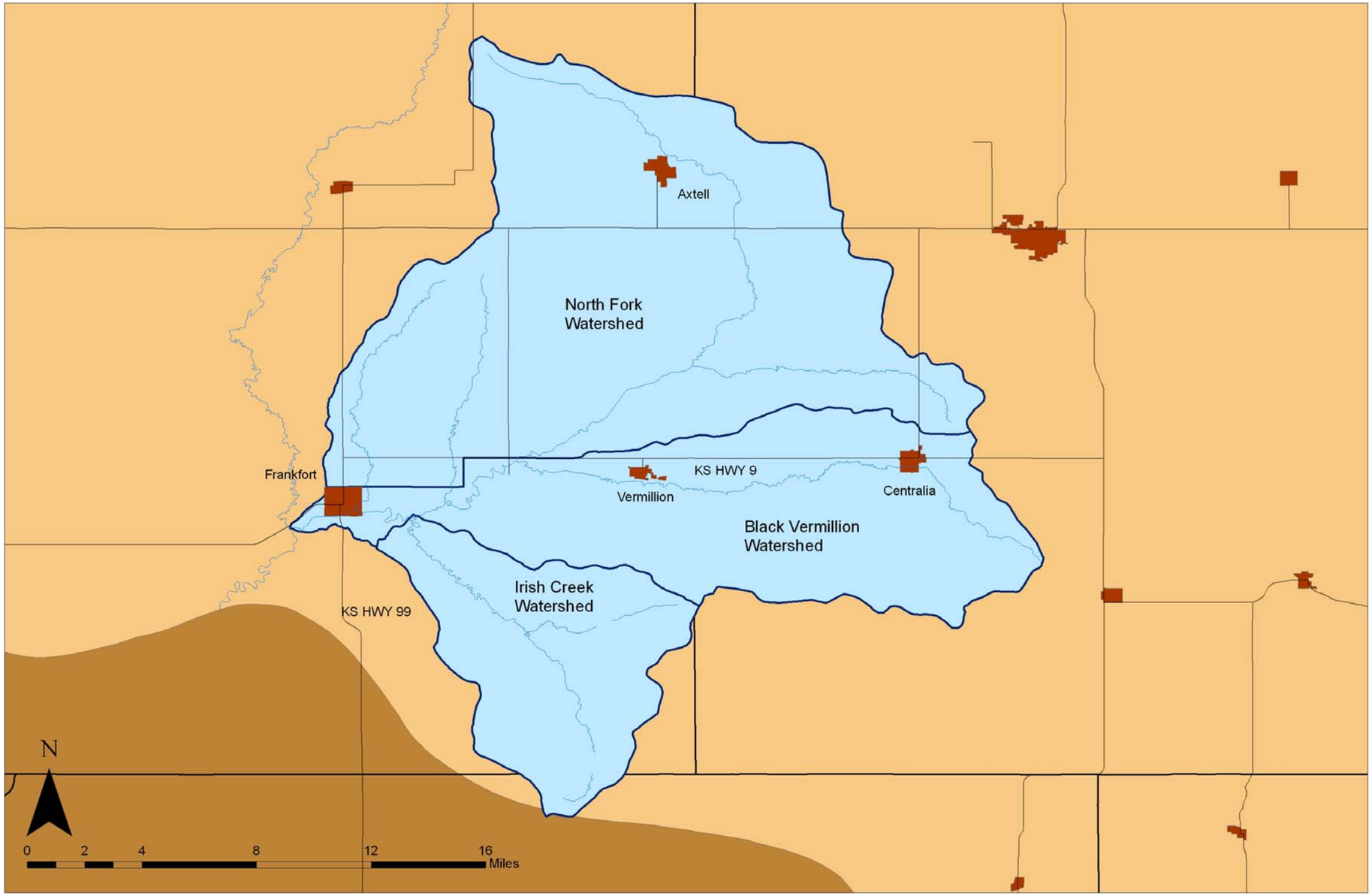


Figure B.3 Geologic cross sections enlarged

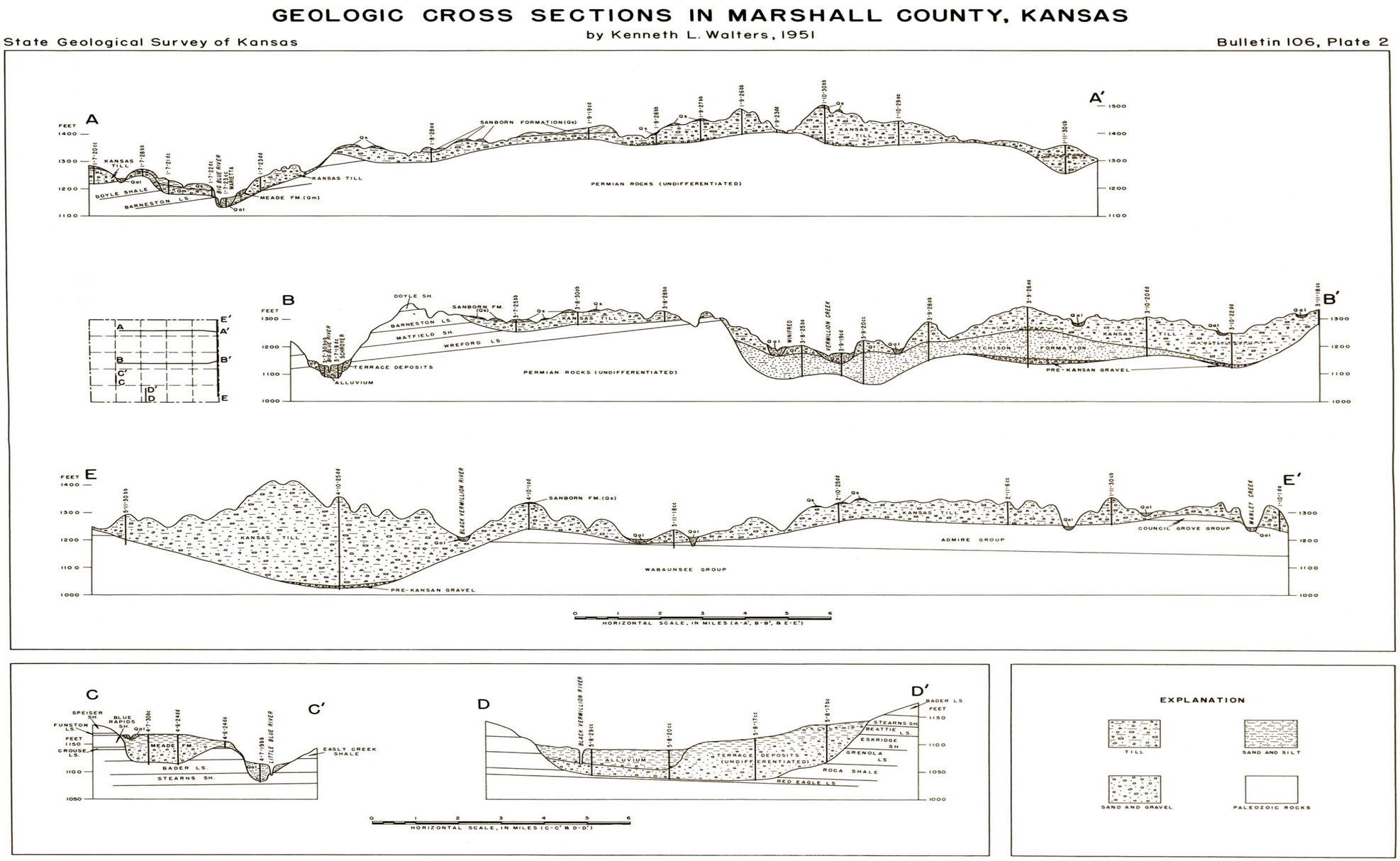


Figure B.4 Kansas Territory Survey Map 1857.

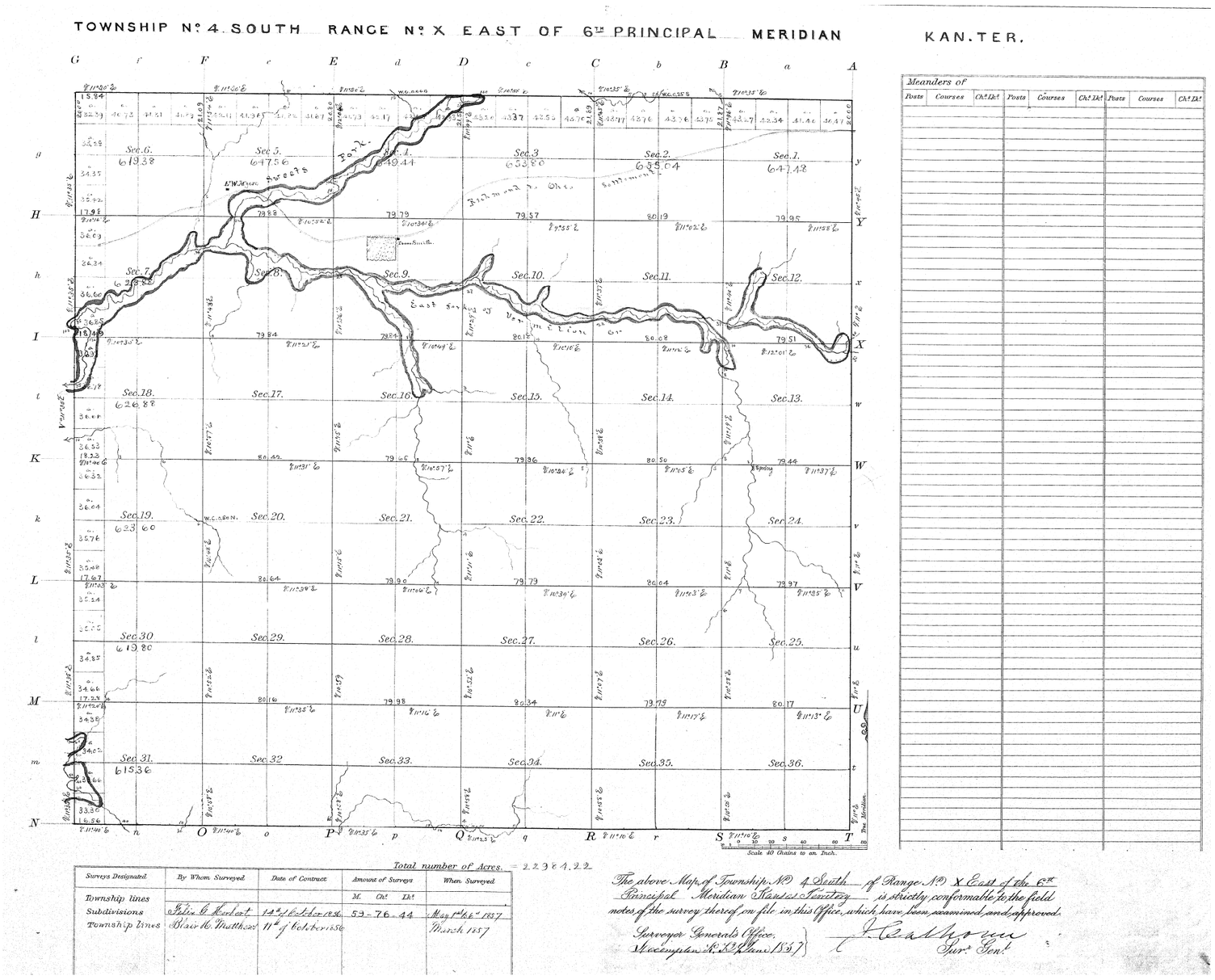
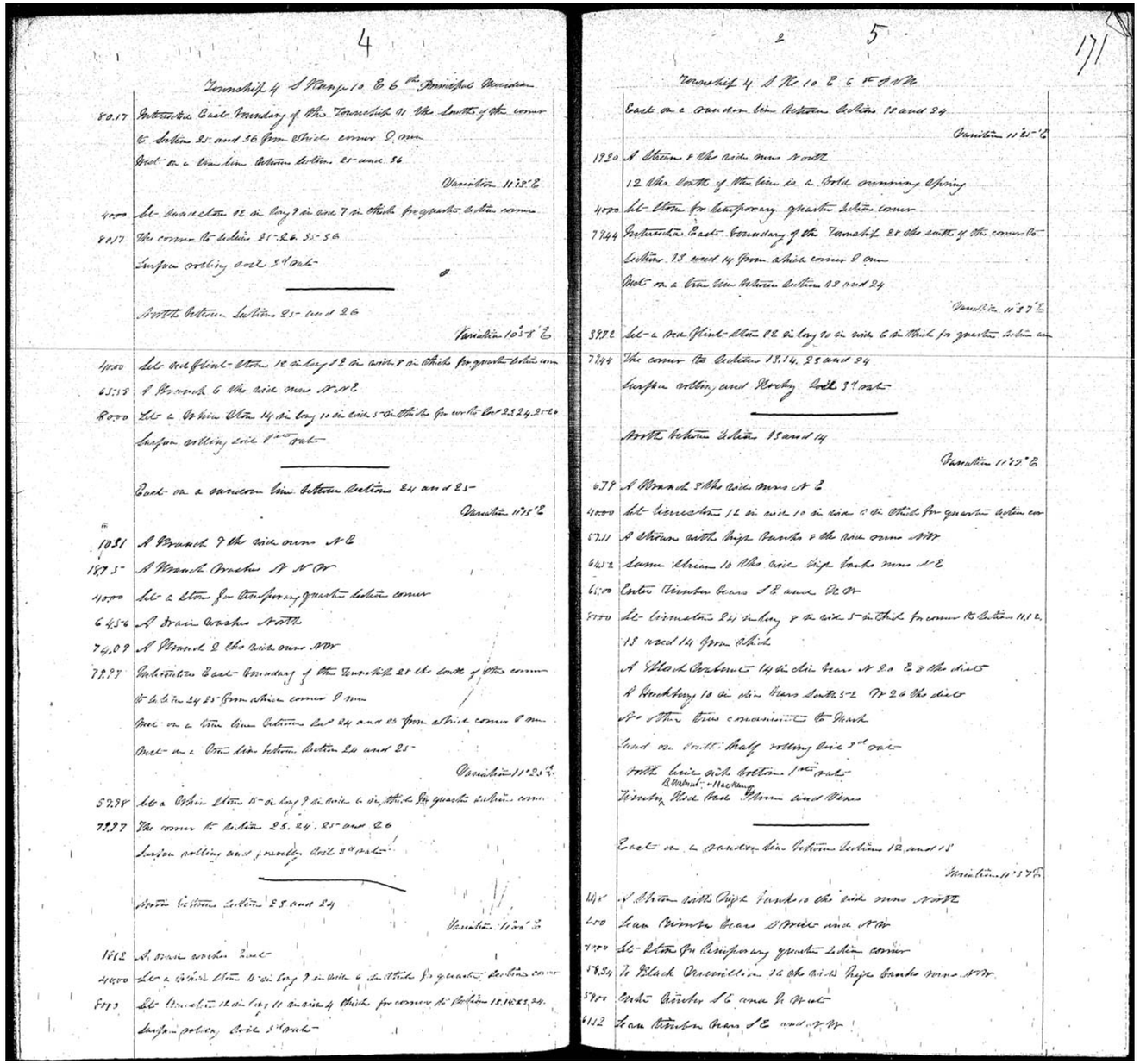


Figure B.5 Copy of Kansas Territory Survey Notes 1857.



4

Township 4 S Range 10 E 6th Principal Meridian

80.17 Intersection East boundary of this Township on the south of the corner to Sections 25 and 36 from which corner I run
Thence on a true line between Sections 25 and 36
Variation 11°15' E
40.00 Set Quarter Section 12 in long 9 in wide 7 in thick for quarter Section corner
80.17 The corner to Sections 25. 26. 35. 36
Surface rolling rock 3rd rate

North between Sections 25 and 26
Variation 10°8' E
40.00 Set Red Stone Stone 12 in long 8 in wide 8 in thick for quarter Section corn
65.55 A Branch 6 links wide runs N N E
80.00 Set a White Oak 14 in long 10 in wide 5 in thick for corner to Lots 23.24.25.26
Surface rolling soil 1st rate

East on a random line between Sections 24 and 25
Variation 11°15' E
10.31 A Branch 9 links wide runs N E
18.75 A Branch 3 links N N W
40.00 Set a Stone for temporary quarter Section corner
64.56 A Drain 3 links North
74.09 A Branch 2 links wide runs N W
78.97 Intersection East boundary of this Township 24 links south of this corner to Sections 24 25 from which corner I run
West on a true line between Lots 24 and 25 from which corner I run
West on a true line between Section 24 and 25
Variation 11°25' E
57.38 Set a White Oak 10 in long 9 in wide 6 in thick for quarter Section corner
78.97 The corner to Sections 23. 24. 25 and 26
Surface rolling and gravelly soil 3rd rate

South between Sections 23 and 24
Variation 11°00' E
16.12 A Drain 2 links wide
40.00 Set a White Oak 10 in long 9 in wide 6 in thick for quarter Section corner
80.00 Set Quarter 12 in long 11 in wide 4 thick for corner to Sections 13.14.23.24.
Surface rolling soil 3rd rate

Township 4 S R 10 E 6th P M

East on a random line between Sections 13 and 24
Variation 11°25' E
19.20 A Stream 4 links wide runs North
12 links South of this line is a Cold running Spring
40.00 Set Stone for temporary quarter Section corner
79.44 Intersection East boundary of the Township 24 links south of this corner to Sections 13 and 14 from which corner I run
West on a true line between Sections 13 and 24
Variation 11°37' E
39.72 Set a red Flint Stone 12 in long 10 in wide 6 in thick for quarter Section corn
79.44 The corner to Sections 13.14. 23 and 24
Surface rolling and Stony soil 3rd rate

South between Sections 13 and 14
Variation 11°13' E
6.39 A Branch 3 links wide runs N E
40.00 Set Limestone 12 in wide 10 in wide 6 in thick for quarter Section cor
57.11 A Stream with high Banks 4 links wide runs N W
64.52 Same stream 10 links wide high banks runs N E
65.00 Enter Hickory Grove S E runs N W
80.00 Set Limestone 24 in long 9 in wide 5 in thick for corner to Sections 11.12.
13 used 14 from which
A Black Walnut 14 in dia bears N 20 E 8 links dist
A Hickory 10 in dia bears South 52 W 26 links dist
No other trees convenient to Mark
Land on South half rolling Soil 3rd rate
North side with bottom 1st rate
B Walnut + Hickory
Hickory, Red Oak, Elm and Ash

East on a random line between Sections 12 and 13
Variation 11°57' E
14.76 A Stream with high Bank 10 links wide runs North
2.00 Same Hickory Grove 8 links wide runs N W
40.00 Set Stone for temporary quarter Section corner
58.54 To Black Walnut in S E 4 links wide high banks runs N W
59.00 Enter Hickory S E runs N West
64.12 Same Hickory Grove S E and N W

Figure B.6 Irish Creek Work plan (SCS, 1966).

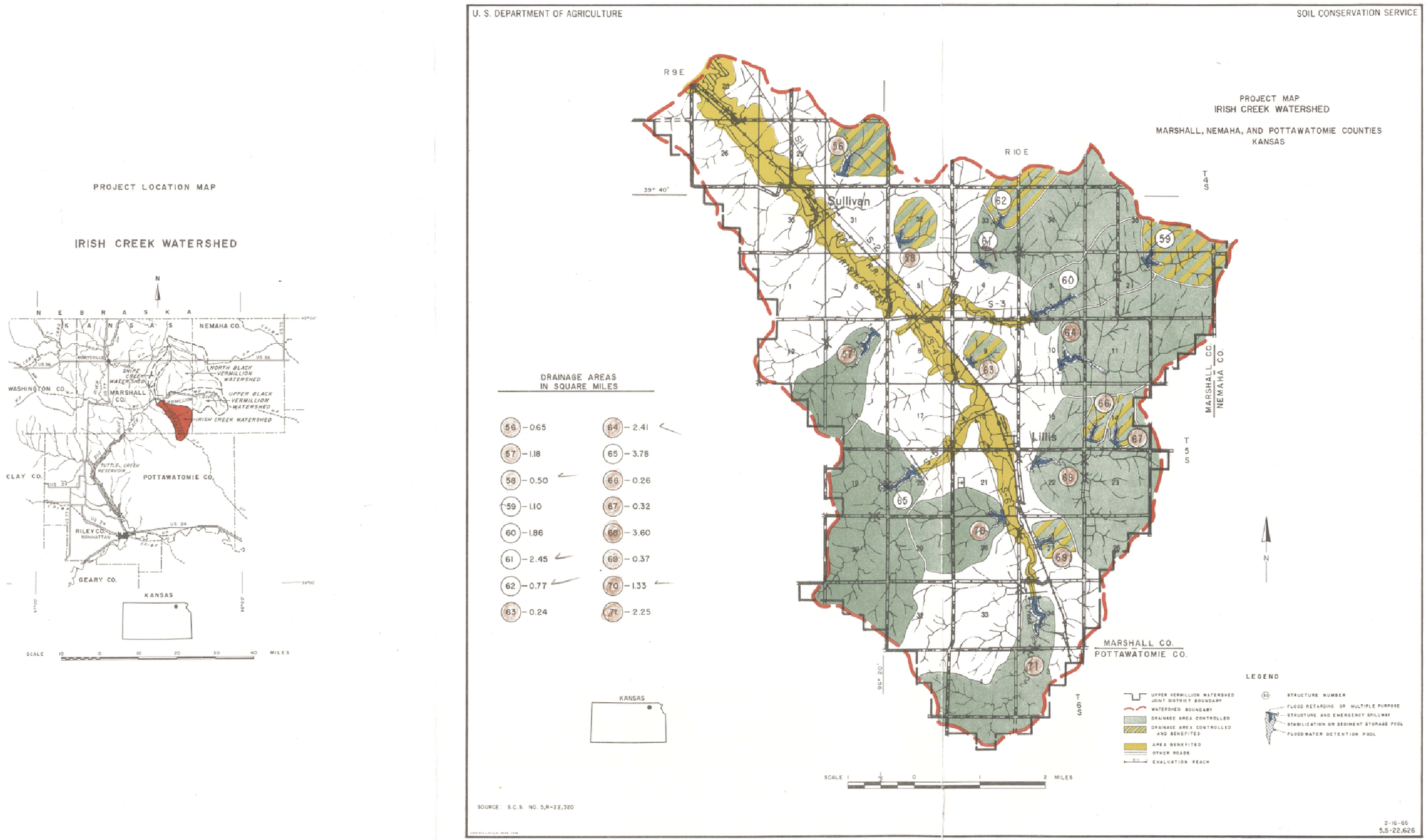


Figure B.7 Main Stem Work plan (SCS, 1966)

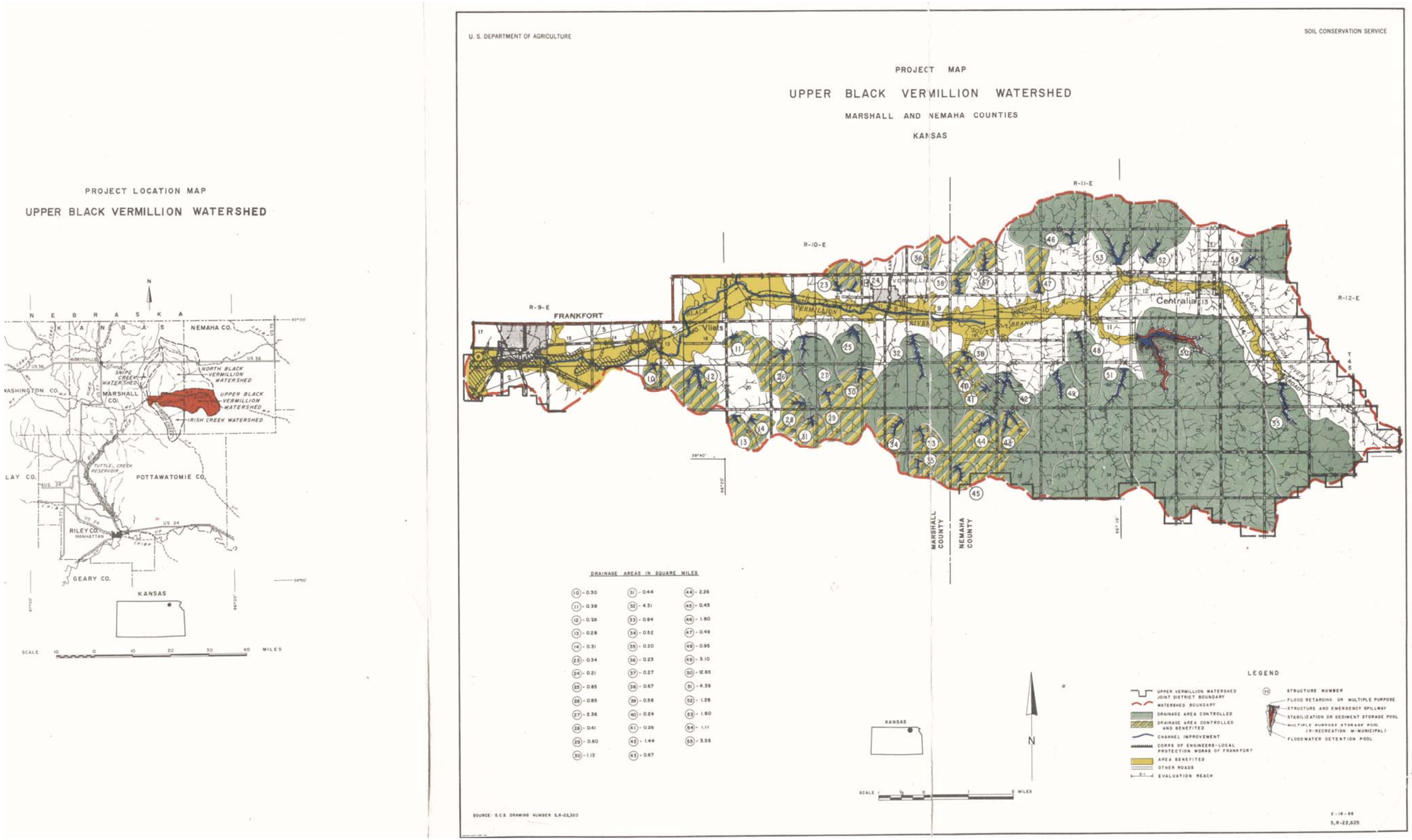


Figure B.8 Centralia Lake Work plan (SCS, 1966).

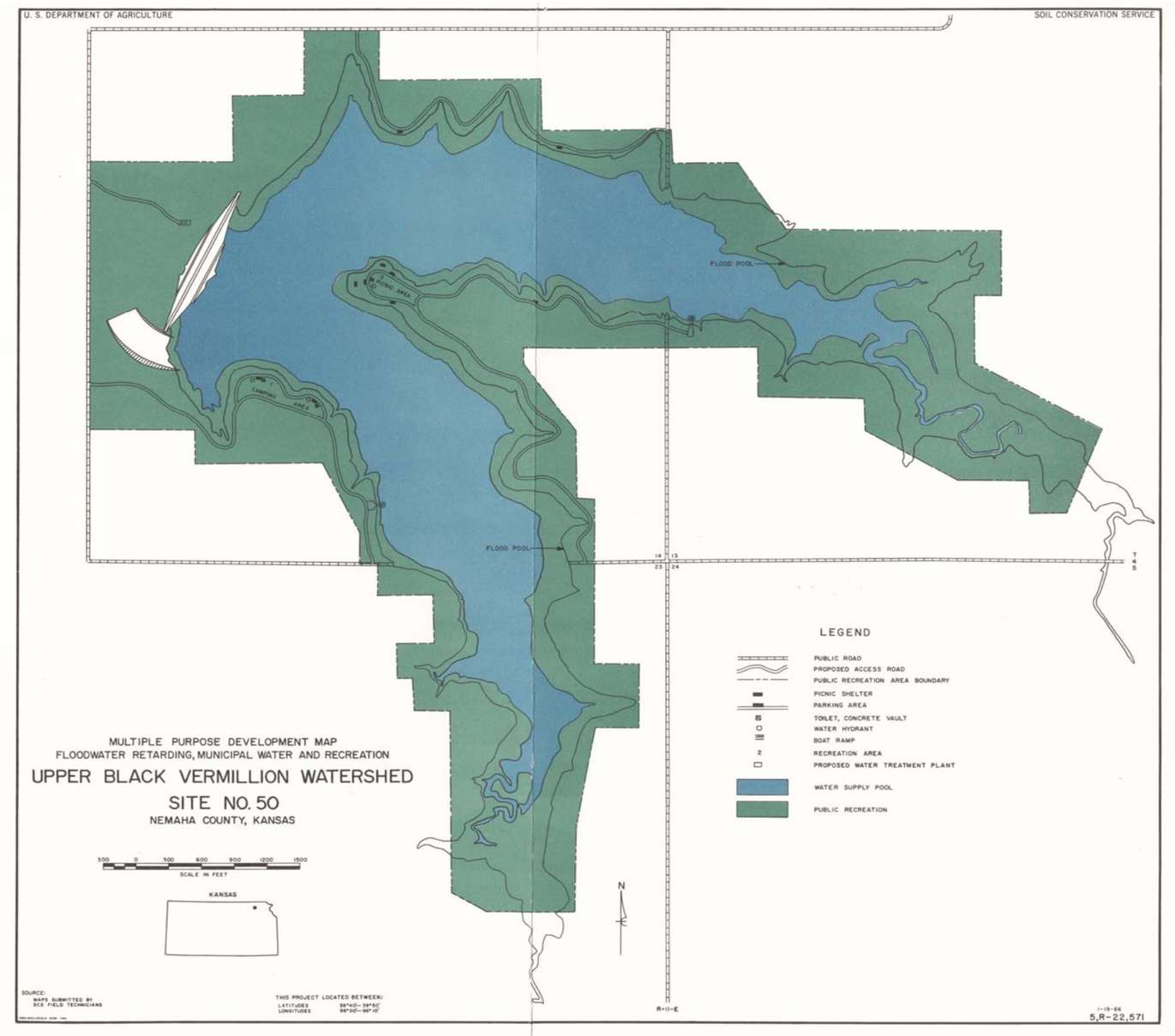


Figure B.9 North Fork Work plan (SCS, 1966).

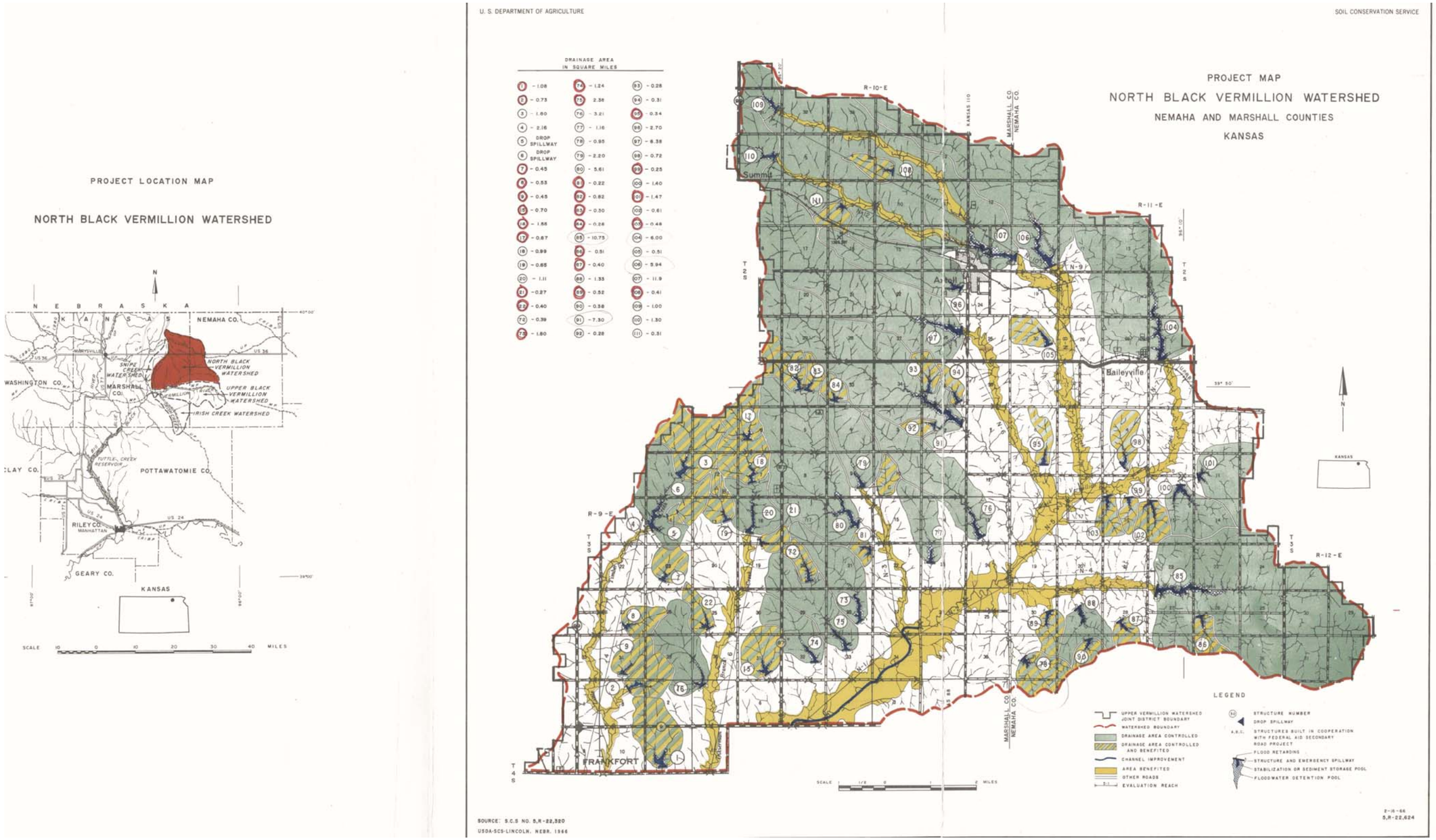
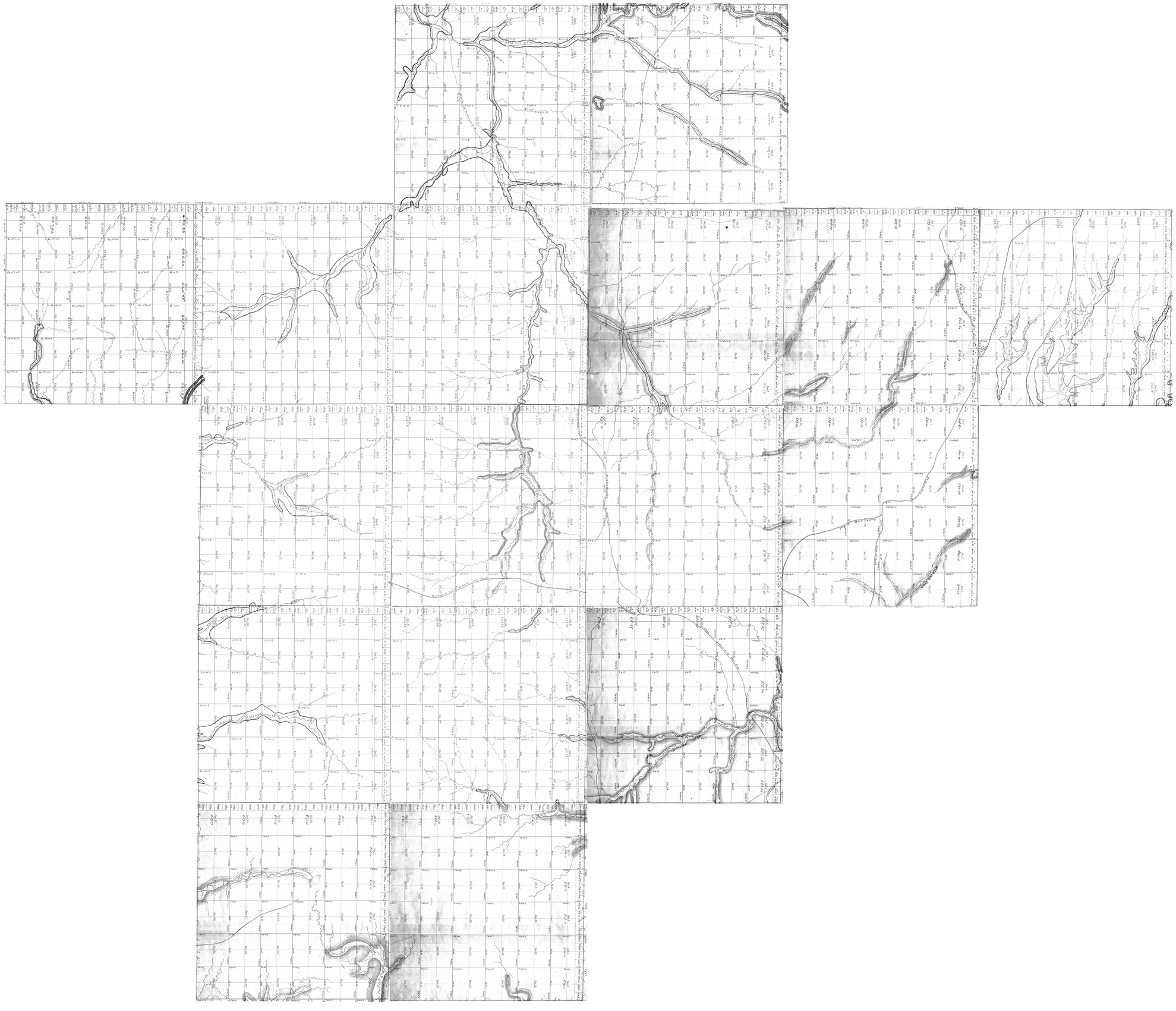



Figure B.10 1857 Survey Map synthesized by author.