HILLSDALE RESERVOIR WATERSHED STREAMBANK EROSION ASSESSMENT

ArcGIS® Comparison Study: 1991 vs. 2008 Aerial Photography

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Executive Summary

Federal reservoirs are an important source of water supply in Kansas for approximately two-thirds of Kansas' citizens. The ability of a reservoir to store water over time is diminished as the capacity is reduced through sedimentation. In some cases reservoirs are filling with sediment faster than anticipated. Whether sediment is filling the reservoir on or ahead of schedule, it is beneficial to take efforts to reduce sedimentation to extend the life of the reservoir.

The Kansas Water Authority has established a *Reservoir Sustainability Initiative* that seeks to integrate all aspects of reservoir input, operations and outputs into an operational plan for each reservoir to ensure water supply storage availability long into the future. Reduction of sediment input is part of this initiative.

The Hillsdale Reservoir Watershed Streambank Erosion Assessment, an ArcGIS® Comparison Study, was initiated to partially implement the *Reservoir Sustainability Initiative*. This assessment identifies areas of streambank erosion to provide a better understanding of portions of the Marais des Cygnes River basin for streambank restoration purposes and to increase understanding of streambank erosion to reduce excessive sedimentation in reservoirs across Kansas. The comparison study was designed to guide prioritization of streambank restoration by identifying reaches where erosion is most severe in the Hillsdale Reservoir watershed.

The Kansas Water Office (KWO) 2011 assessment quantifies annual tons of sediment eroding from the Hillsdale Reservoir watershed streambanks over a 17 year period between 1991 and 2008. A total of 11 streambank erosion sites, covering 6,965 feet of unstable streambank were identified through the assessment, with 73% of the unstable streambanks in the watershed identified as having poor riparian condition. The assessment also identified estimates totaling approximately 1,073 tons of sediment being transported from the streambank erosion sites annually. The majority of the 1,073 tons of sediment is transported each year from Rock Creek and a portion Bull Creek; contributing approximately 382 and 286 tons of sediment annually, respectively. Results buy 12-digit Hydrologic Unit Codes (HUC) indicate that a majority of the identified 2,869 tons of eroded sediment is transported annually from HUC12 (102901020103) at 407 tons of sediment annually. Assuming a bulk density of 40 lbs/cubic foot sediment in Hillsdale Reservoir; streambank sources account for only 1.2 of the 166 acre feet (1%) of sediment annually deposited in Hillsdale Reservoir. Based on estimated stabilization costs of $71.50 per linear foot from an assessment conducted by The Watershed Institute (TWI), streambank stabilization for all identified streambank erosion sites in the Hillsdale Reservoir would cost approximately $498,000 with an estimated sediment reduction at 912 tons per year with an 85% stabilization restoration efficiency.

Several streambank gully erosion problems in areas adjacent to streambanks were also identified through the streambank erosion assessment. The assessment of streambank gully erosion in the Hillsdale Reservoir watershed concluded seven total gully erosion sites alongside streambanks, four in croplands and three in grasslands; all demonstrated identifications of high priority gullies, but were still in the beginning stages of headcutting. Locations of gullies included one in the upper headwaters of Bull Creek, three located on Wade Creek and three located on Scott Creek. Both Wade and Scott Creek are located in the southwestern portion of Hillsdale Reservoir watershed.

The KWO completed this assessment for the Hillsdale Reservoir Watershed Restoration and Protection Strategy (WRAPS) Stakeholder Leadership Team (SLT). Information contained in this assessment can be used by the Hillsdale WRAPS SLT to target streambank stabilization and riparian restoration efforts toward high priority stream reaches or HUC12s. Similar assessments are ongoing in selected watersheds above reservoirs throughout Kansas and are available on the KWO website at www.kwo.org, or may be made available upon request to agencies and interested parties for the benefit of streambank and riparian restoration projects.

Introduction

Wetland and riparian areas are vital components of proper watershed function that, when wisely managed in context of a watershed system, can moderate and reduce sediment input into reservoirs. There is growing evidence that a substantial source of sediment in streams in many areas of the country is generated from stream channels and edge of field gullies (Balch, 2007).

Streambank erosion is a natural process that contributes a large portion of annual sediment yield, but acceleration of this natural process leads to a disproportionate sediment supply, stream channel instability, land loss, habitat loss and other adverse effects. Many land use activities can affect and lead to accelerated bank erosion (EPA, 2008). In most Kansas watersheds, this natural process has been accelerated due to changes in land cover and the modification of stream channels to accommodate agricultural, urban and other land uses.

A United States Geological Survey (USGS) study in the Perry Reservoir watershed in northeast Kansas showed that stream channels and banks are a significant contributor of reservoir sedimentation in addition to land surface erosion (Juracek, 2007). A naturally stable stream has the ability, over time, to transport the water and sediment of its watershed in such a manner that the stream maintains its dimension, pattern, and profile without either aggrading or degrading (Rosgen, 1997). Streams that have been significantly impacted by land use changes in their watersheds or by modifications to stream beds and banks go through an evolutionary process to regain a more stable condition. This process generally involves a sequence of incision (downcutting), widening and re-stabilizing of the stream. Most streams in Kansas are in some stage of this process (SCC, 1999).

Streambank erosion is often a symptom of a larger more complex problem requiring solutions that frequently involve more than just streambank stabilization (EPA, 2008). It is important to analyze watershed conditions and understand the evolutionary tendencies of a stream when considering stream stabilization measures. Efforts to restore and re-stabilize streams should allow the stream to speed up the process of regaining natural stability along the evolutionary sequence (Rosgen, 1997). A watershed-based approach to developing stream stabilization plans can accommodate the comprehensive review and implementation.

Other research in Kansas documents the effectiveness of forested riparian areas on bank stabilization and sediment trapping (Geyer, 2003; Brinson, 1981; Freeman, 1996; Huggins, 1994). Vegetative cover based on rooting characteristics can mitigate erosion by protecting banks from fluvial entrainment and collapse by providing internal bank strength. Riparian vegetative type is an important tool that provides indicators of erosion occurrence from land use practices. The riparian area is the interface between land and a river or stream. Riparian areas are significant in soil ecology, environmental management and because of their role in soil conservation, habitat biodiversity and the influence they have on aquatic ecosystems overall health. Forested riparian areas are superior to grassland in holding bank stabilization during high flows, when most sediment is transported. When riparian vegetation is changed from woody species to annual grasses and/or forbs, sub-surface internal strength is weakened, causing acceleration of mass wasting processes (extensive sedimentation due to sub-surface instability) (EPA, 2008). The primary threats to wetlands and forested riparian areas are agricultural production and suburban/urban development.

Reservoir sedimentation is a major water quantity concern, particularly in reservoirs where the state owns water supply storage. Reservoirs are a vital source of water supply, provide recreational opportunities, support diverse aquatic habitat, and provide flood protection throughout Kansas. Excessive sediment can alter the aesthetic qualities of reservoirs and affect their water quality and useful life (Christensen, 2000). Sediment deposition in reservoirs can be attributed to many factors, including precipitation, topography, contributing-drainage area of the watershed and differing soil types. Decreases in reservoir storage capacity from sediment deposition can affect reservoir allocations used for flood control, drinking-water supplies, recreation and wildlife habitat. Land use has considerable effect on sediment loading in a reservoir. Intense agricultural use in the watershed, with limited or ineffective erosion prevention methods, can contribute large loads of sediment along with constituents (such as phosphorus) to downstream reservoirs (Mau, 2001).

Another form of erosion contributing to sedimentation in many watersheds in Kansas is the development of gullies alongside streams. Streambank gullies develop from the wearing away of the surface soil along drainage channels by surface water runoff. These gullies are associated with the loss of vegetation on the soil and down cuts forming deep widening channels. The potential for surface erosion is associated in part with the amount of bare, compacted soil exposed to rainfall and runoff. Increased risk of erosion and sediment delivery is associated with high soil erodability; little ground cover; steep, long, continuous slopes; high intensity storms; high drainage density of the slope; and close proximity to streams.

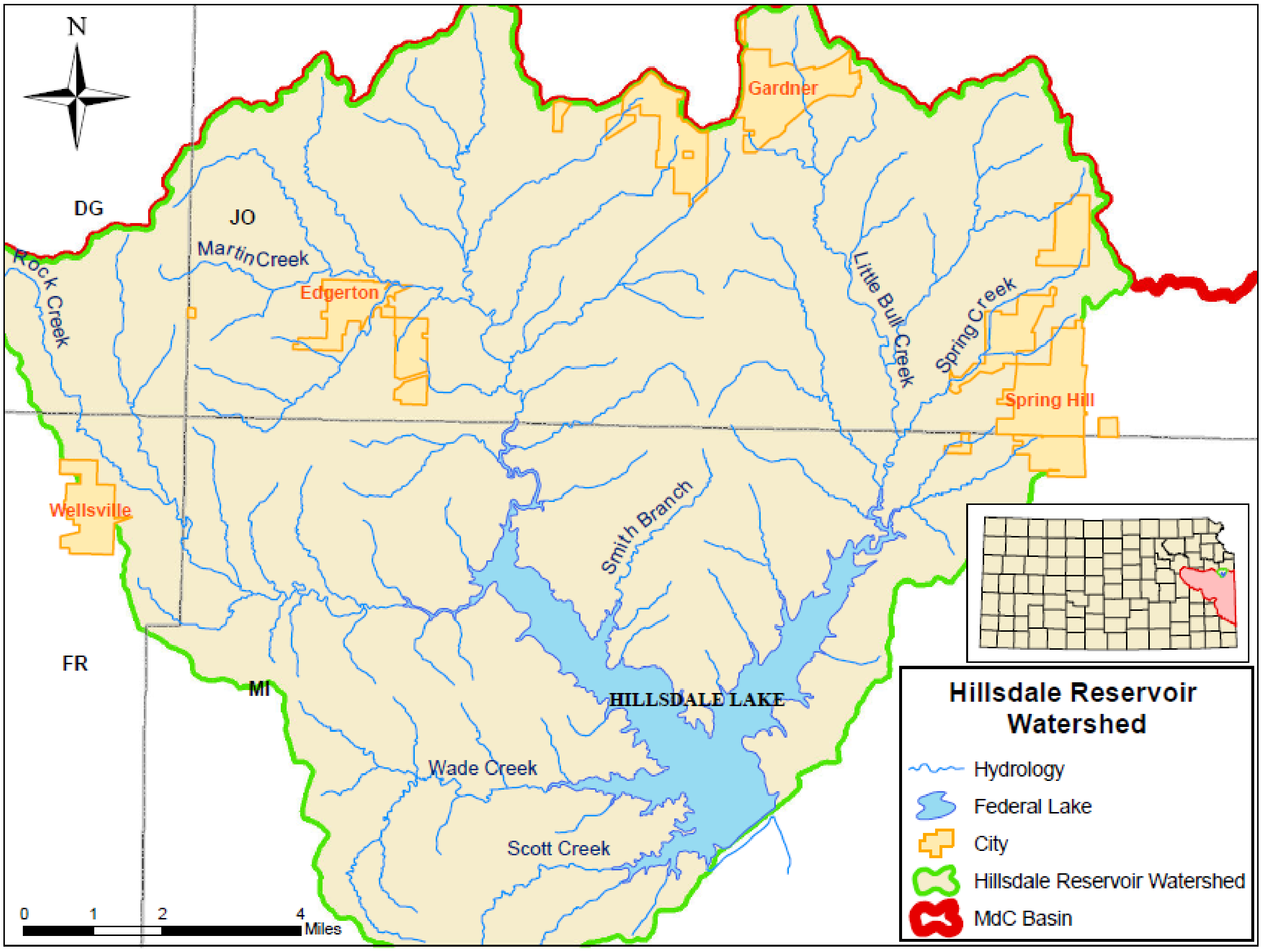
Gully erosion can contribute a tremendous amount of sediment at the watershed scale and can occur in both cropland and grassland. The amount of sediment input is based on rainfall/runoff and gully frequency within a given watershed. In each case, the gullies observed are unstable and will continue to be unless best management practices (BMPs) are implemented. A common BMP for gully erosion is the rock chute. Rock chute designs require bank shaping and the placement of erosion control fabric and sorted rock. Rock chutes are designed to direct flow down through the chute center. The rock creates flow resistance slowing down water velocities.

Study Area

Hillsdale Reservoir was constructed on Big Bull Creek, at river mile 18.2, west of Hillsdale, Kansas and northwest of Paola, Kansas (Figure 1). The watershed drains about 144 square miles and includes portions of Douglas, Franklin, Johnson and Miami Counties. The U.S. Army Core of Engineers began construction of the reservoir in 1976 for flood control, navigation, water supply, water quality, recreation and fish and wildlife; navigation is not currently an operating purpose. Gates were closed in September 1981 and the conservation pool was filled in February of 1985. The original conservation pool and designed sedimentation rate of the reservoir were 82,207 acre-feet and 83 acre-feet per year, respectively. Major tributaries in the watershed include Rock Creek, Smith Branch, Spring Creek, Little Bull Creek and

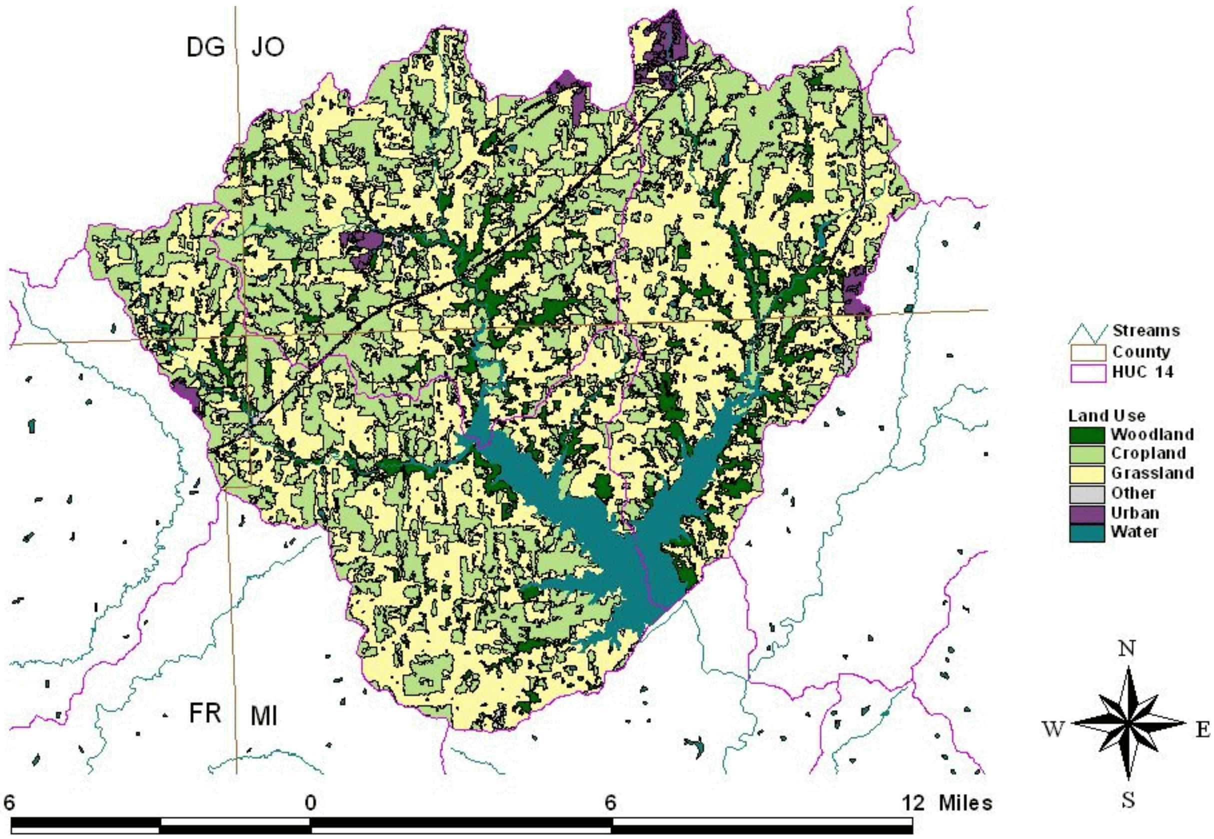
Spring Creek. The most recent bathymetric survey performed by Kansas Biological Survey (KBS) in 2009 reports the conservation storage capacity at 77,499 acre-feet and calculated sedimentation rate at 166 acre-feet per year.

Figure 1. Hillsdale Reservoir Watershed Study Area



Land use in the Hillsdale Reservoir watershed consists of 50% grassland and 35% cropland, with the remaining 15% in feedlots and urban and residential development. Gently rolling uplands, with hilly areas along the streams, characterize the topography, with average annual rainfalls at 39 inches. The majority of the precipitation falls in late spring and early summer (Figure 2).

Figure 2. Land Use Land Cover for Hillsdale Reservoir Watershed, 1999



The one Total Maximum Daily Load (TMDL) developed by the Kansas Department of Health and Environment (KDHE) for Hillsdale Reservoir is eutrophication. Excess nutrient loading from the watershed creates conditions favorable for algae blooms and aquatic plant growth resulting in low dissolved oxygen rates and an unfavorable habitat for aquatic life. Eutrophication from nitrogen and phosphorous is mostly due to runoff from agricultural lands, animal waste runoff from confined animal feeding operations and septic systems situated near the lake. According to modeling done by Kansas State University and the Hillsdale Water Quality Project, Big Bull Creek contributes 40 - 50% of the nonpoint source pollutants while Little Bull Creek contributes only 25% of the nonpoint source pollutants (KDHE, 2001). Agricultural producers in the watershed implement best management practices (BMPs) to prevent nutrient runoff. Some common BMPs include: the use of conservation tillage and cover crops, maintaining buffer strips along field edges and proper timing of fertilizer application (Nejadheshemi, 2009). In order to improve the trophic condition of the lake from its current fully eutrophic status, the desired endpoint will be summer chlorophyll a concentrations at or below 12 ug/l (KDHE, 2001).

Data Collection Methodology

The Hillsdale Reservoir watershed streambank erosion assessment was performed using desktop ArcGIS® ArcMap® 10 software and on-the-ground field data verification and collection. The purpose of the assessment is to identify locations of streambank instability, estimate erosion rates to prioritize restoration needs along streambanks and slow sedimentation rates in Hillsdale Reservoirs. ArcMap® 10, an ArcGIS® geospatial processing program, was utilized to assess color aerial photography from 2008, provided by National Agriculture Imagery Program (NAIP), and compare it with 1991 black and white aerial photography provided by Data Access & Support Center (DASC).

Streambank erosion assessments were performed by overlaying 2008 NAIP county aerial imagery onto 1991 DASC county aerial imagery. Using ArcMap® tools, "aggressive movement" of the streambank between 1991 DASC and 2008 NAIP aerial photos, were identified at a 1:6,000 scale, as a site of streambank erosion. "Aggressive movement" represents areas of 1,500 sq. feet or more of streambank movement from the 1991 to the 2008 aerial photos. Note that the identified streambank erosion sites are only a portion of all streambank erosion occurrences. Any erosion that covers an area smaller than roughly 1,500 sq. feet incurs a high margin of error, making calculations unreliable and ~~are~~is not included. This error can be attributed to some distortions between years when aerial photos are taken and years later when the photographs are digitally georeferenced. Error can also be attributed to shading interference from leafing of trees. Aerial photos are often taken in spring, summer and early fall months. Leafing can affect the ability to locate streambanks.

Identified streambank erosion sites were denoted by geographic polygons features "drawn" into the ArcGIS® software program using ArcMap® editor tools. The polygon features were created by sketching vertices following the 2008 streambank and closing the sketch by following the 1991 streambank, at a 1:2,500 scale. Data provided, based on geographic polygon sites include: watershed location, unique ID, stream name, type of stream and type of riparian vegetation.

The streambank erosion assessment data also includes estimates of the average volume of soil loss, in tons per year, from streambank erosion sites. Estimation of average soil loss is performed utilizing the identified erosion site polygon features and calculating perimeter, area and streambank length into a regression equation. Perimeter and area were calculated through the *field calculator* application within the ArcGIS® software. Streambank length of identified erosion sites were computed through the application of a regression equation, formulated by the KWO. This equation was developed by taking data from the *Enhanced Riparian Area/Stream Channel Assessment for John Redmond Feasibility Study*, a report prepared by TWI and Gulf South Research Corporation (GSCR), and relating the erosion area (in sq. feet) and perimeter length of that erosion area (in feet) to the unstable stream bank length (in feet). The multiple regression formula of that fit (R-square = 0.999) is:

Estimated SB Length = ([Area_SqFt]*-.00067) + ([Perimtr_ft]*.5089609)

The intercept of the model was forced to zero.

Average volume of soil loss was estimated by first calculating the volume of sediment loss and applying a bulk density estimate to that volume for the typical soil type of the eroding area. The volume of sediment was found by multiplying bank height, surface area lost over the 17 year period between the 1991 and 2008 and soil bulk density. This calculated volume is then divided by the 17 year period to get the average rate of soil loss in mass/year:

Average Soil Loss Rate (Tons/yr) =

[Area_SqFt]*[BankHgtFt]*SoilDensity(lbs/ft^3)/2000(lbs/ton)/([NAIP_ComparisonPhotoYear]-[BaseAerialPhotoYear])

Soil Bulk Density, used in the average soil loss rate equation, was calculated by first determining the moist bulk density of the predominant soil in the study area, using the USDA Web Soil Survey website. The predominant soil type found at streambank erosion locations in the Hillsdale Reservoir watershed was Verdigris silt/silty loam, with an average moist bulk density at 1.5 g/cc. This moist bulk density estimate was then converted into pounds per cubic foot and reduced by 15% to get a dry bulk density estimate at 80 lbs/ft^3. This dry bulk density is then compared to the dry bulk density on a soil texture triangle, at 10% clay, 38% sand and 52% silt as a second comparative estimate, at roughly 1.51 g/cc or 94 lbs/ft^3; which is then reduced by 15%. Based on the two methods, 80 lbs/ft^3 was used for the typical bulk density of the predominant soil type in the Hillsdale Reservoir watershed, and used in the average soil loss rate equation.

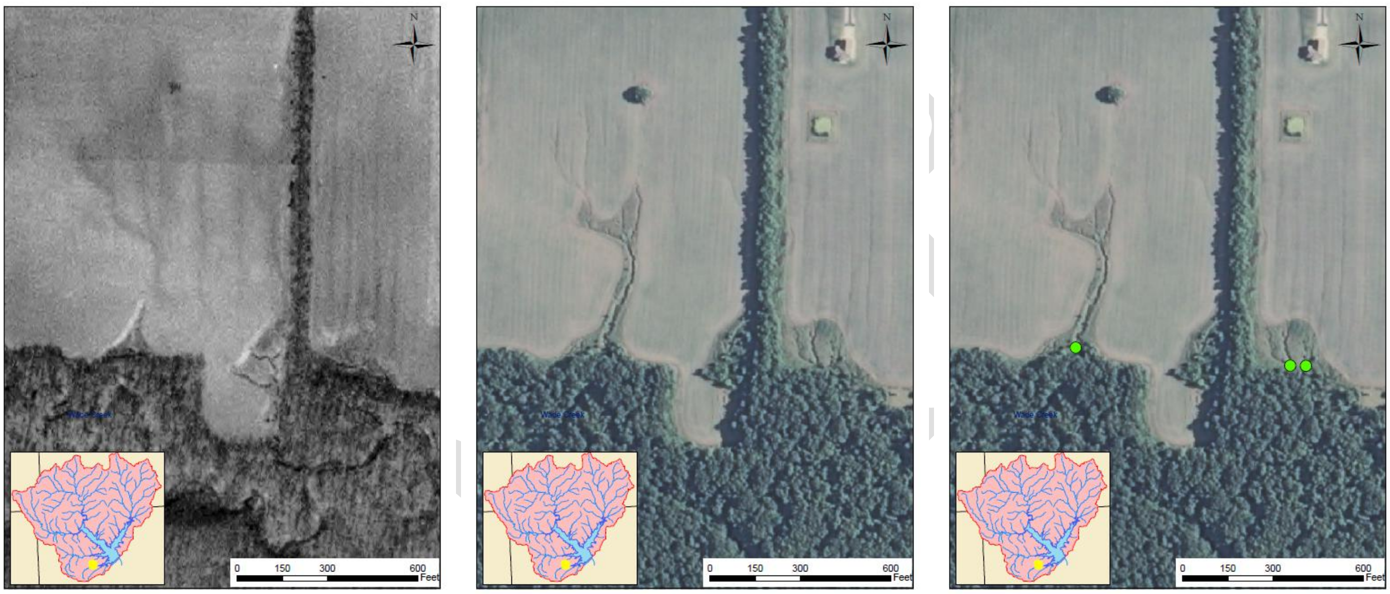
Streambank height measurements, also used in the average soil loss rate equation, were obtained through on the ground field verification in several locations throughout the watersheds (Figure 4). Of the total sites identified, seven sites were selected, spread throughout the watershed, for field verification and streambank height measurements. These field verified streambank height measurements were the basis for extrapolating streambank height measurements for identified streambank erosion sites.

Figure 3. Assessment Field Verification Height Measurement on Little Bull Creek

The streambank gully erosion assessment was performed with similar techniques as the streambank erosion assessment. Using ArcMap® tools, streambank gully erosion sites were indicated by point features in the ArcGIS® software program

(Figure 4). Gully data was compiled and categorized by high, medium or low priority as another effort in rehabilitation prioritization. The identification of a low priority gully indicates that sheet erosion has been identified and a gully could form in the area that is perpendicular to the stream. A low priority gully does not indicate visible channel cutting or any visible streambank riparian erosion. A medium priority gully identifies visible channel cutting perpendicular to the streambank but no visible erosion of the riparian area of the streambank. High priority gullies identify a deeply incised channel cutting perpendicular to the stream, including a significant portion of the riparian area eroded from the streambank. In some instances, gullies were increased to a medium or high priority, even if they exhibit “low priority” gully identifiers, if there was a visibly identified sizeable amount of land erosion or gullies present in the same vicinity.

Figure 4. 1991 DASC & 2008 NAIP Aerial Photo Comparison; Gully Site Identification



As was found with the streambank erosion assessment, limiting factors were also found when performing the streambank gully erosion visual assessment. These limiting factors can be attributed to shading interference from leafing of trees in aerial photos when photos are taken in spring, summer and early fall months. Leafing can affect the ability to locate streambank gully erosions occurrences and the ability to properly prioritize gullies in certain instances.

This assessment did not include rangeland gullies, salt scars or other landscape level sources of sediment

Analysis

To accommodate streambank rehabilitation project focus, the Hillsdale Reservoir watershed study area was delineated into five stream reaches and three 12-digit Hydrologic Unit Code subbasins. Stream reach sections include: Rock Creek, Bull Creek 1, Bull Creek 2, Smith Branch and Little Bull Creek (Figure 5). Stream reach sections were delineated by the stream they are located on, and in one instance, a stream is broken into two sections to keep delineations relatively equal. 12-digit Hydrologic Unit Code (HUC12s) subbasins within Hillsdale Reservoir watershed include 102901020101, 102901020102 and 102901020103 (Figure 6).

Figure 5. Streambank Erosion Assessment Stream Reach Sections

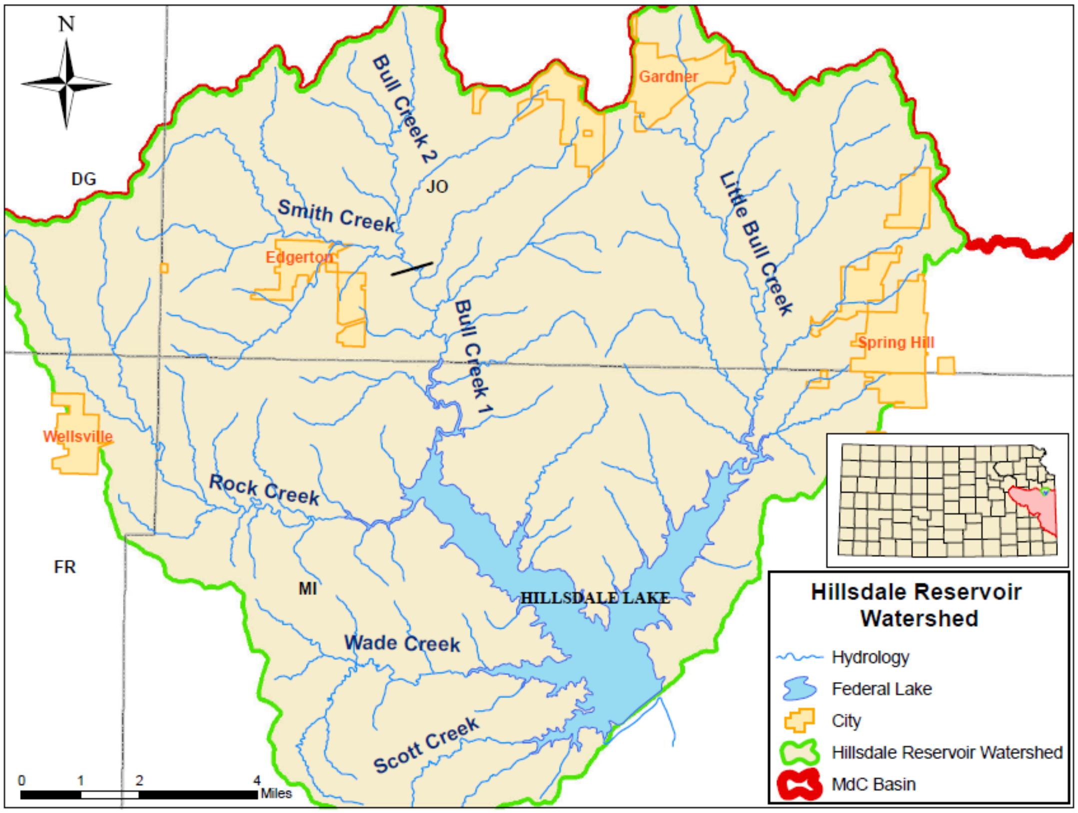
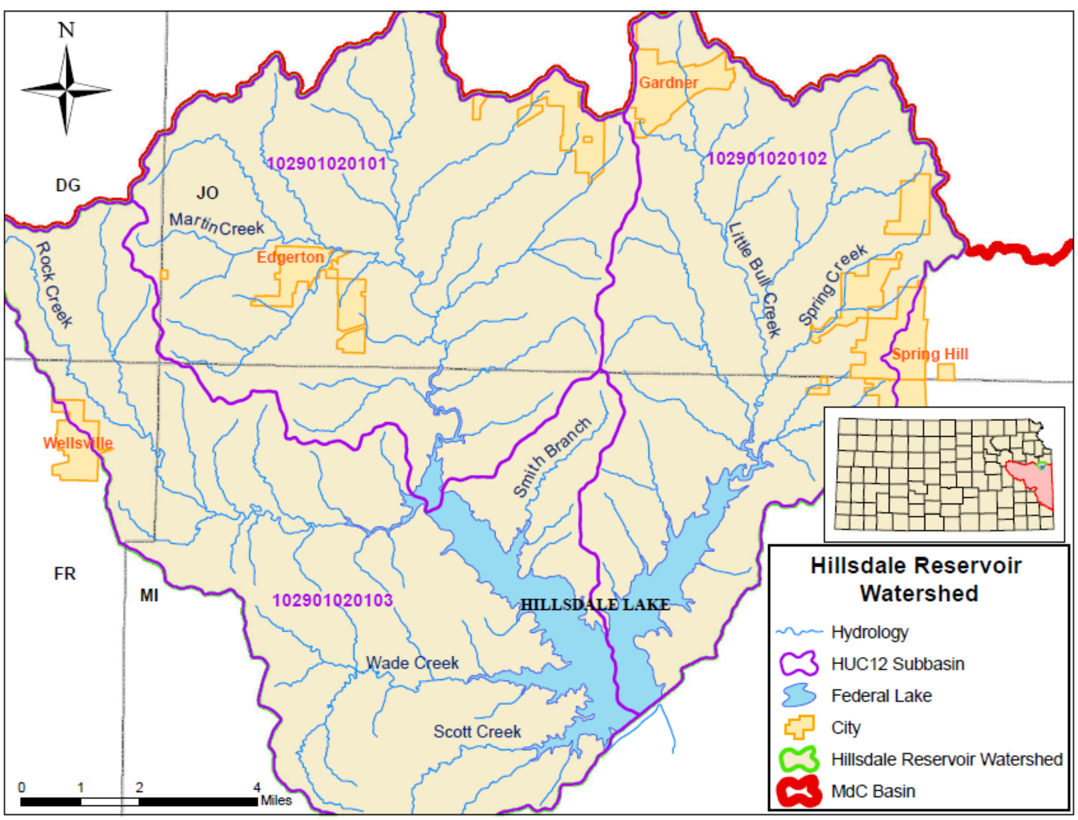


Figure 6. Streambank Erosion Assessment HUC12 Subbasins



Streambank erosion sites were analyzed for: streambank length (in feet) of the eroded bank; annual soil loss (in tons/year); percent of streambank length with poor riparian condition (riparian area identified as being cropland, grassland or a grassed buffer BMPs for cultivated fields); estimated sediment reduction through the implementation of streambank stabilization BMPs at an 85% efficiency rate; and streambank stabilization cost estimates for eroded streambank sites. Streambank stabilization costs were derived from an average cost to implement streambank stabilization BMPs, as reported in the TWI *Kansas River Basin Regional Sediment Management Section 204 Stream and River Channel Assessment*; at $71.50 per linear foot (Figure 7). Streambank stabilization costs vary based on soil type and materials used for streambank stabilization BMPs and may differ from the estimates developed for the *Kansas River Basin Regional Sediment Management Section 204 Stream and River Channel Assessment* BMP estimates. Due to the lack of sufficient information to accurately develop streambank stabilization average costs in the Marais des Cygnes River basin, TWI estimates were used.

Figure 7. TWI Estimated Costs to Implement Streambank Stabilization BMPs

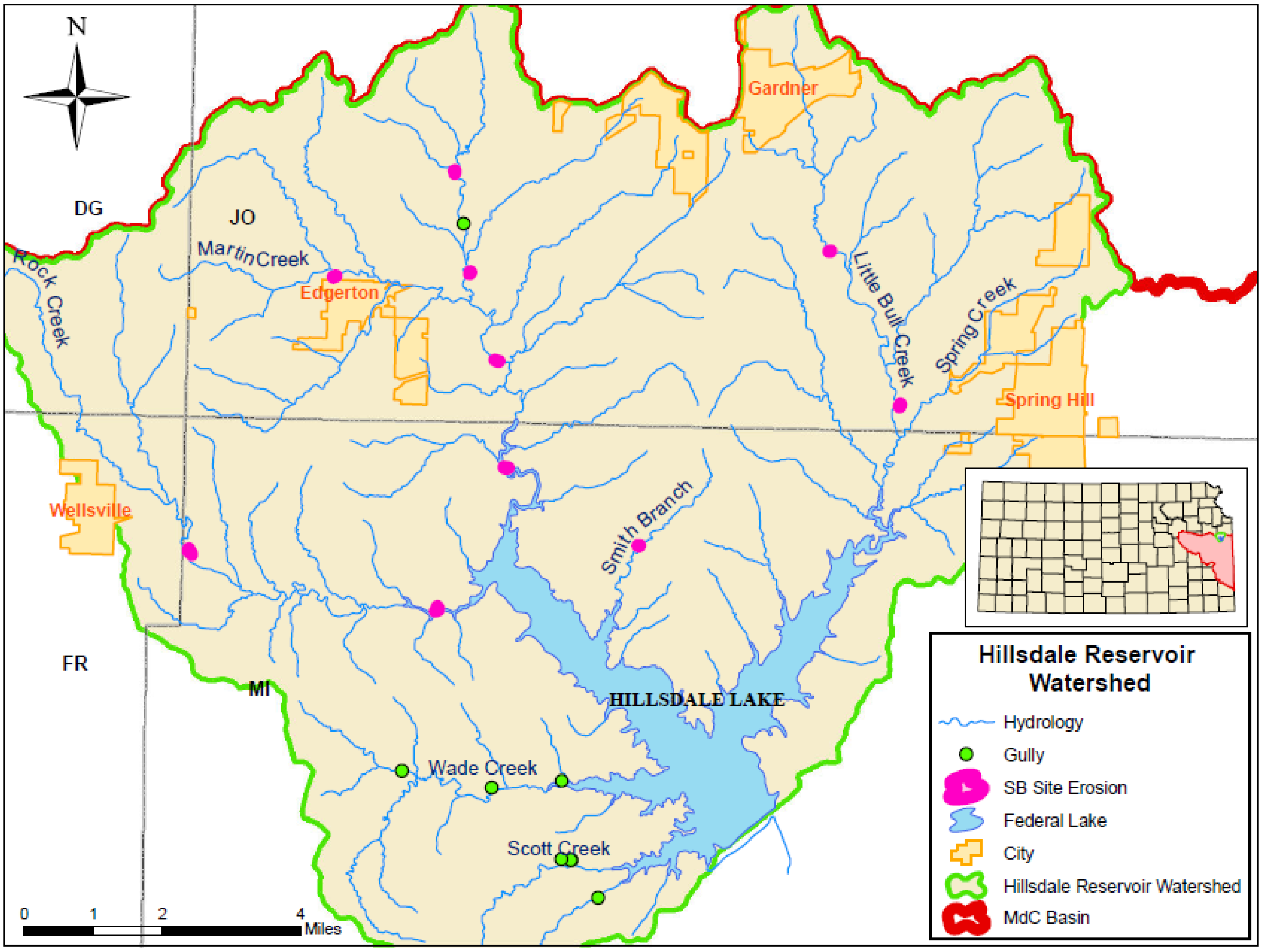
BMP Cost Description	Cost estimate per linear foot (in dollars)
1. Survey and design Rock delivery and placement As-built certification design Bank Shaping	$50 - $75
2. Vegetation (material and planting) Cover Crop Mulch Willow Stakes Bare root seedlings Grass filter strip	$5
3. Contingencies Unexpected site conditions requiring extra materials and construction time	$3 - $5.5
TOTAL	**$58-$85.5**

Streambank gullies were assessed based on the proportion of high, medium and low priority identifications and may be used as supporting data for streambank erosion or streambank gully erosion rehabilitation prioritization. Explanation of prioritization is found in the data collection and methodology above. No further assessment was performed.

Results

The KWO 2011 assessment quantifies annual tons of sedimentation from streambank erosion sites between 1991 and 2008 in the Hillsdale Reservoir watershed. A total of 11 streambank erosion sites, covering 6,965 feet of unstable streambank were identified through the assessment, with 73% of the unstable streambanks identified as having poor riparian condition (Figure 8). The assessment also identified estimates totaling 1,073 tons of sediment being transported from the streambank erosion sites annually. Assuming a bulk density of 40 lbs/cubic foot sediment in Hillsdale Reservoir; streambank sources account for only 1.2 of the 166 acre feet (1%) of sediment annually deposited in Hillsdale Reservoir.

Figure 8. Assessment Identified Streambank Erosion and Streambank Gully Erosion Sites



A majority of the identified 1,073 tons of eroded sediment is transported annually from Rock Creek and Bull Creek 1. Rock Creek was found to contribute approximately 382 tons of sedimentation annually from roughly 2,415 feet of unstable streambank and accounts for an estimated 35% of the total stabilization cost needs in the watershed, totaling $172,650. Installing BMPs for all the identified sites on Bull Creek stream reach one would account for roughly 325 tons of annual sediment reduction at an 85% stabilization/restoration efficiency. Bull Creek 1 was found to contribute approximately 286 tons of sedimentation annually from roughly 1,853 feet of unstable streambank and accounts for an estimated 27% of the total stabilization cost needs in the watershed, totaling $132,461. Installing BMPs for all the identified sites on Bull Creek 1 would account for roughly 243 tons of annual sediment reduction at an 85% stabilization/restoration efficiency (Table 1).

Table 1. Streambank Erosion Assessment Results by Stream Reach

Stream Reach	SB Site Length (ft)	SB Site Sed (T/Yr)	Stabil. Cost Estimate	SB Site (No.)	Yield Loss/ Bank Length	Poor Riparian Condition SB Length (ft)	Est. Sed Reduction (T/Yr)	% SB Length w/ Poor Riparian Cond.
Rock CR	2,415	382	$172,650	2	0.2	2,415	-325	100.00%
Bull CR 1	1,853	286	$132,461	3	0.2	0	-243	0.00%
Bull CR 2	1,389	109	$99,278	3	0.1	1,389	-93	100.00%
Smith Branch	330	25	$23,576	1	0.1	330	-21	100.00%
Little Bull CR	980	271	$ 70,044	2	0.3	980	-230	100.00%
Total	**6,965**	**1,073**	**$498,009**	**11**	**0.7**	**5,113**	**-912**	**73.40%**
Est Stabilization Cost/Linear Ft.			$71.50	**Stabilization/Restoration Efficiency**			0.85	

Results buy HUC12s indicate that a majority of the identified 1,073 tons of eroded sediment is transported annually from HUC12 (…103). HUC12 (…103) was found to contribute approximately 407 tons of sedimentation annually from roughly 2,744 feet of unstable streambank and accounts for an estimated 39% of the total stabilization cost needs in the watershed, totaling $196,226. Installing BMPs for all the identified sites within HUC12 (…103) would account for roughly 346 tons of annual sediment reduction at an 85% stabilization/restoration efficiency (Table 2).

Table 2. Streambank Erosion Assessment Results by HUC12

HUC12 (102901020…)	SB Site Length (ft)	SB Site Sed (T/Yr)	Stabil. Cost Estimate	SB Site (No.)	Yield Loss/ Bank Length	Poor Riparian ConditionSB Length (ft)	Est. Sed Reduction (T/Yr)	% SB Length w/ Poor Riparian Cond.
...101	3,241	395	$231,739	6	0.1	1,389	-336	42.84%
...102	980	271	$70,044	2	0.3	980	-230	100.00%
...103	2,744	407	$196,226	3	0.1	2,744	-346	100.00%
Total	**6,965**	**1,073**	**$ 498,008.91**	**11**	**0.5**	**5,113**	**-912**	**73.40%**
Est Stabilization Cost/Linear Ft.			$71.50	**Stabilization/Restoration Efficiency**			0.85	

Based on estimated stabilization costs of $71.50 per linear foot from an assessment conducted by TWI, streambank stabilization for all identified streambank erosion sites in the Hillsdale Reservoir would cost approximately $498,000, with an estimated sediment reduction at 912 tons per year at an 85% stabilization restoration efficiency.

Several streambank gully erosion problems in areas adjacent to the streambanks were identified through the streambank gully erosion assessment. The assessment of streambank gully erosion in the Hillsdale Reservoir watershed concluded seven total gullies alongside streambanks, four in croplands and three in grasslands; all demonstrated identifications of high priority gullies, but were still in the beginning stages of headcutting. Locations of gullies included one in the upper headwaters of Bull Creek, three located on Wade Creek and three located on Scott Creek, refer back to Figure 8. Both Wade and Scott Creek are located in the southwestern portion of Hillsdale Reservoir watershed.

Conclusion

The KWO completed this Draft assessment in the Hillsdale Reservoir watershed for the Hillsdale Reservoir WRAPSSLT. The Draft and Final report will be submitted for internal review at the KWO. Information contained in the assessment may be used by the Hillsdale Reservoir WRAPS SLT to target streambank stabilization and riparian restoration efforts toward high priority stream reaches within the Hillsdale Reservoir watershed. The KWO continues to recommend streambank stabilization/riparian restoration projects as an effective method of reducing sediment delivery to these reservoirs from streambank sources. Continued land treatment as described in WRAPS plans and streambank protection with buffers is recommended for the Hillsdale Reservoirs watershed. Additional evaluations of gullies are needed to determine the magnitude of sediment contribution from these sources.

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