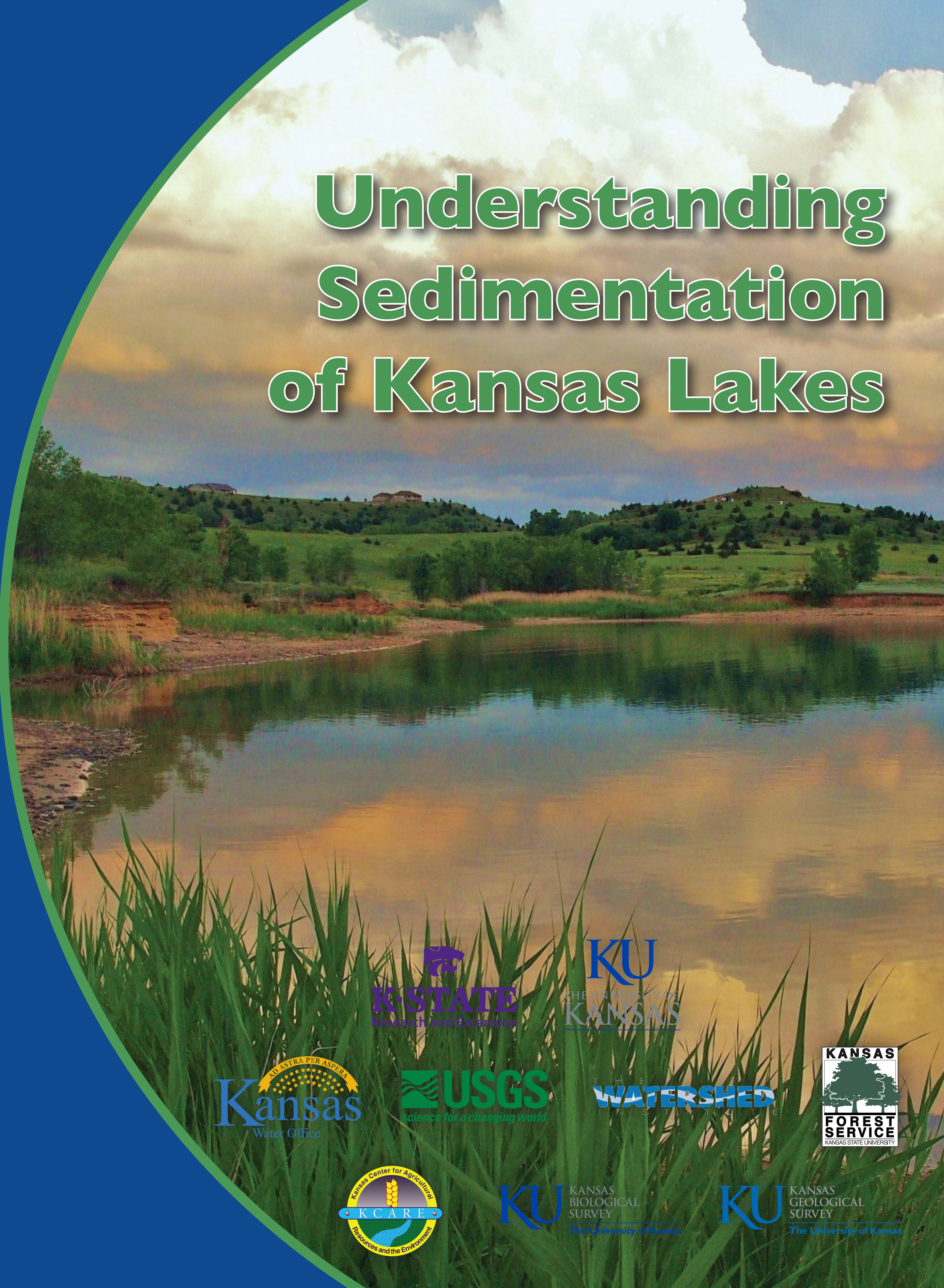
Understanding Sedimentation of Kansas Lakes



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Assessment of Lake Sedimentation from Three Watersheds in Kansas

Back in 2008 the Kansas Water Office wrote an introduction titled 'Reservoirs: Infrastructure for Our Future' for the state research publication Sedimentation in Our Reservoirs: Causes and Solutions. It explained how the water stored in reservoirs was critical to the state's water supply infrastructure, especially during times of drought and how that storage was being lost to accelerated sedimentation.

As we enter fall 2014, Kansas continues to find itself in the midst of the worst drought in decades which emphasizes how vital that statement is. The introduction also went on to stress that Kansas' economy needs a dependable source of water supply and research towards understanding the sources and movement of sediment in our rivers and streams is necessary to achieve that objective. Research is necessary to support and drive management decisions designed to improve the effectiveness of programs and practices to reduce sedimentation rates as well as improve riparian and aquatic habitats while deriving the greatest value from dollars spent in those practices and programs.

Recognizing the importance and value of the issue, by the end of 2008, 14 research agencies/institutions had come together within the state and created a cooperative research plan to measure the existing sediment loads in three watersheds in northeast Kansas while identifying the contributing sources to the observed sediment loads. This publication is the result of that cooperative research effort.

The findings contained with this publication will be used to drive subsequent policy discussions within the state, enhance the effectiveness of programs and practices and ultimately, implement cost-effective sediment reduction activities in areas where they are needed most. This provides assurance that sediment transport in our watersheds is minimized while supporting a viable Kansas economy through a reliable water supply infrastructure for generations to come.

Tracy Streeter

Tracy Streeter
Director, Kansas Water Office

Assessing the Baseline Streamflow and Sediment Contribution in Three Northeast Kansas Watersheds

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Interpretive Summary

A watershed modeling study of three watersheds in Northeast Kansas was conducted to determine current streamflow yield and suspended sediment contribution from surface runoff to water bodies. The three study watersheds, Banner Creek Lake Watershed (BCLW), Centralia City Lake Watershed (CCLW), and Atchison County Lake Watershed (ACLW), of comparative size from 6,000 to 12,000 acres and located within the same Western Corn Belt Plains eco-region in Kansas, were selected for the analysis. The BCLW was primarily grassland, while the CCLW and the ACLW were predominantly in cropland production.

To assess hydrologic and water-quality impacts of the watersheds, the Soil and Water Assessment Tool (SWAT) was used as a watershed model. Three SWAT models were built for current land management conditions and calibrated for streamflow from 2009 to 2011 at the three USGS gage station sites in BCLW, CCLW, and ACLW. The field-scale reconnaissance survey data were utilized in model setups. Continuous daily simulations of hydrologic and water-quality conditions in the watersheds were conducted with SWAT for the following three time periods: (a) a short term 2-year calibration period, (b) a 20-year medium range period from 1990 to 2010 with daily weather records acquired from the National Climatic Data Center, and (c) the long-term (100 years) period with stochastically generated daily precipitation and temperature based on the statistical weather pattern from the 20-year period. Annual and monthly average water yield and suspended sediment yield were collected from the SWAT model output for each time period. Among the watersheds, BCLW was found to have the highest water yield while producing the lowest sediment yield, which was an indicator of grassland capability to retain water in the field. Between the two cropland dominated watersheds, ACLW showed higher sediment yields than CCLW, which was due in part to steeper slopes of the fields and larger number of impoundments in ACLW, and higher percentage of winter wheat and lower acreage of corn in CCLW.

The results of this study were based on current land use and climate conditions in Northeast Kansas. Both of these conditions may change in the future. Temperature increase and seasonal changes of precipitation events predicted by climate models can significantly alter the streamflow and sediment assessments of this study and should be accounted in future projects.

Introduction

The Great Plains streams and ecosystems, integral parts of the diminishing North American unpolluted fresh water supply that once encompassed 160 million hectares, have been continually degraded by urbanization and agricultural operations (Dodds et al., 2004). In Northeast Kansas, stream, lake, and reservoir sedimentation is a prevailing water-quality concern. A major source of non-point source pollution is rainfall runoff initiated from agricultural fields. While many practices have been implemented in agricultural areas to mitigate the pollution and stream degradation, determining the current state or "baseline" is crucial in understanding potential future changes of water-quality and agricultural production in Kansas impacted either by climate change or anthropogenic activity.

Three watersheds of comparative size and located in Northeast Kansas were selected for the baseline assessment study. Watershed models are valuable tools that simulate hydrological, physical, biological, and other processes in the watershed on continuous (sub)-daily temporal scale or for a specific rainfall event (Singh, 1995), and can be used for analysis and assessment of current and future water-quantity and water-quality conditions in the watershed (White et al., 2009). Model results can be summarized either on a subwatershed level or spatially aggregated over individual fields. Soil and Water Assessment Tool (SWAT) is a widely used watershed model that was utilized in this study (Arnold et al., 1998; Gassman et al., 2007; Douglas-Mankin et al., 2010). The SWAT model has been extensively tested and applied to determine and assess areas of non-point source pollution in many watersheds in Kansas, for example, within the Watershed Restoration and Protection Strategies initiative (WRAPS, 2011), and has proven to be successful in identifying targeted areas within a watershed (Devlin et al., 2005; Daggupati et al., 2011; Nejadhashemi et al., 2011; Douglas-Mankin et al., 2012).

Therefore, the objectives of this project were to develop a SWAT model for the studied watersheds using the most up-to-date and detailed watershed information, calibrate the model for streamflow, and analyze the streamflow and sediment baseline conditions within the watersheds. The baseline assessment can be further used for targeting implementation of best management practices and monitoring future changes in stream, lake, reservoir sedimentation.

Table 1. Delineation and HRU properties of total watershed areas and USGS gage drainage areas of the three studied watersheds.

	BCLW	CCLW	ACLW
Total Area (acres)	12,447	8,021	5,794
USGS Gage Basin Area (acres)	5,837	2,832	3,608
# Subs in gage basin	10	5	7
# HRUs	1193	662	791
# LU Classes	8	14	18
# Soil Classes	19	8	19
# Slope Classes (%)	3 (0-3, 3-6, 6-999)	3 (0-3, 3-6, 6-999)	3 (0-3, 3-6, 6-999)

Materials and Methods

Study Areas

Three watersheds of similar size, Banner Creek Lake Watershed (BCLW), Centralia City Lake Watershed (CCLW), and Atchison County Lake Watershed (ACLW), are located within the same Western Corn Belt Plains eco-region in Northeast Kansas (Figure 1). The BCLW is located on the western side and ACLW is on the eastern side of the Middle Kansas River watershed (HUC-8 code 10270103), whereas the CCLW is situated at the eastern tip of the Lower Big Blue River watershed (HUC-8 code 10270205).

Banner Creek Lake Watershed

The BCLW, an unregulated part of HUC-12 watershed 102701030205, occupies the drainage area of 5,037 ha (12,447 ac) of the Banner Creek Lake, as shown by the yellow solid line in Figure 2a. BCLW is a grassland dominated watershed (72% of total BCLW area) with only 3.8% of total area in cropland. The detailed field reconnaissance of BCLW was conducted in May and June of 2009, and survey field data were collected and geo-referenced by Devlin and Boyer (2012). The survey area is outlined by the green solid line in Figure 2,a. It was found that most of the grassland was grazed (67%), with 27% of the grassland area hayed and 95% of the grassland area in good to excellent condition. Cropland was mainly conventionally tilled and terraced. Since cropland occupied a small percentage of total BCLW area, condition of the cropland area was not expected to strongly affect non-point source pollution. The relief generally consists of rolling hill slopes; slopes in 85% of the area were above 3% with a median slope of 3.8%. Soils in the BCLW are generally clay loam with silt loam in the flood plain and of hydrologic groups B and C. A large number of smaller impoundments were present in BCLW.

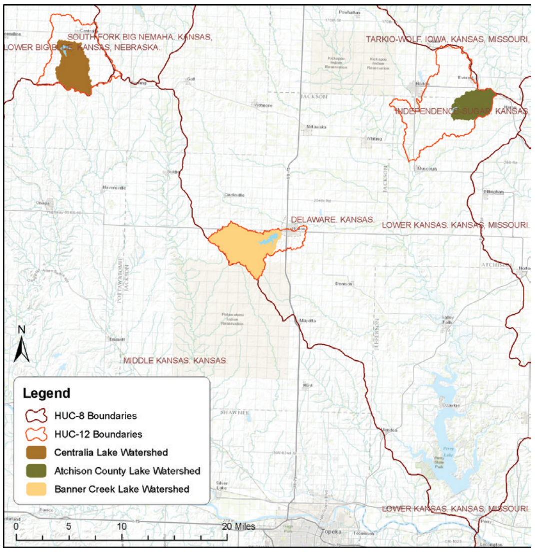


Figure 1. Map of the three studied watersheds located north of Topeka, Kansas.

The USGS stream gage station 392652095484100 (95°48'41" Lon.; 39° 26'52" Lat.) was located upstream of Banner Creek Lake at M Road near Holton, KS (USGS, 2011). Daily streamflow time-series were acquired from April 2009 to December 2010. Two NCDC weather stations ID# 141529 (8.3 km west of the USGS station, elevation 1177 m) and ID# 143759 (5.4 km east of the USGS station, elevation 1052 m) with records of 20 years or longer were located within 10 km of the USGS station (NCDC, 2010). In addition to two NCDC stations, daily precipitation data were also collected at the USGS gage station and used for validation of storm occurrence within the watershed when data were taken from one of two NCDC stations.

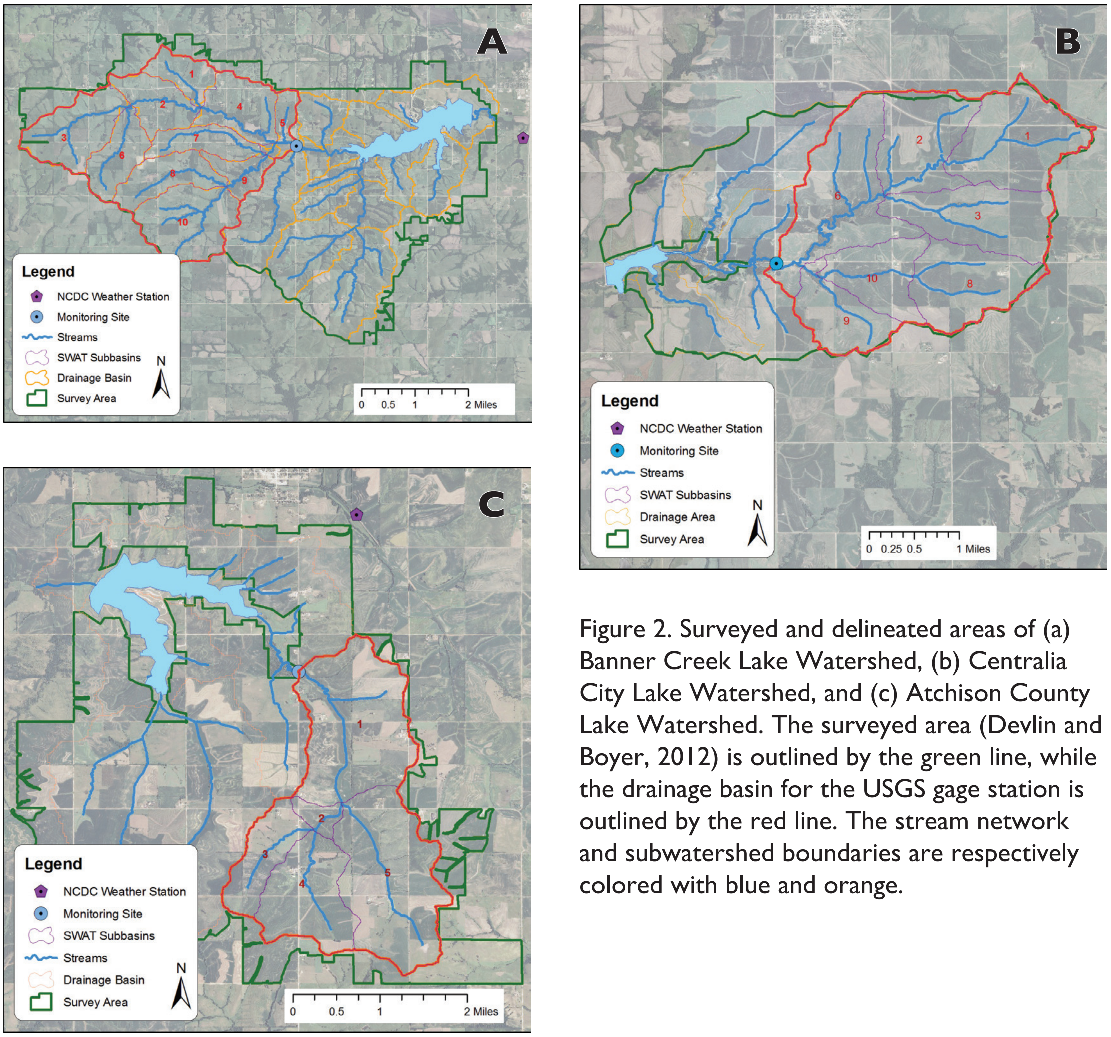


Figure 2. Surveyed and delineated areas of (a) Banner Creek Lake Watershed, (b) Centralia City Lake Watershed, and (c) Atchison County Lake Watershed. The surveyed area (Devlin and Boyer, 2012) is outlined by the green line, while the drainage basin for the USGS gage station is outlined by the red line. The stream network and subwatershed boundaries are respectively colored with blue and orange.

Atchison County Lake Watershed

The ACLW is an unregulated part of HUC-12 watershed 102701030203 that occupies a drainage area of 2,345 ha (5,795 ac) of the Atchison County Lake (Figure 2b). ACLW is a cropland dominated watershed (67% of total ACLW area) with about 6% of total area in grassland. The area, outlined by the green solid line in Figure 2,b, was surveyed by the K-State team in the summer of 2009 and 2010 (Devlin and Boyer, 2012). Soybeans and corn were found to be two major crops (55% and 44% in 2009) in the ACLW. The cropland area was 81% in no-till, 88% terraced, and 47% terraced with subsurface drainage tiles. Terraces were predominantly in average to good condition. The grassland was 82% grazed. The relief generally consists of hill slopes above 3% in 60% of the area, and a median slope of 3.8%. Soils in the ACLW are generally fine silt loam of hydrologic groups C and D. Many smaller ponds/lakes were present in ACLW.

The USGS stream gage station 393817095260100 (95°26’01” Lon.; 39° 38’17” Lat.) was located upstream of Atchison County Lake on Clear Creek at Decator Road near Horton, KS (USGS, 2011). The NCDC weather station ID# 1413810 with the records of 20 years or longer was located about 7.8 km northwest of the USGS station and at elevation 1030 m (NCDC, 2010).

Centralia Lake Watershed

The CCLW, an unregulated part of HUC-12 watershed 102702050503, occupies 3,359 ha (8,300 ac) of the drainage area of the Centralia City Lake in Nemaha County (Figure 2c). CCLW land use is mainly cropland (60% of total CCLW area) with 16% of grassland. In the surveyed area of the CCLW outlined by the green solid line in Figure 2c (Devlin and Boyer, 2012), most of the land was in cropland, and soybeans and corn occupied more than 80% of cropland area. No-tillage practice and fields with terraces and waterways were prevalent in the area. Grassland was mainly grazed (>70%). The relief consists of hill slopes with 40% of the area above 6%, and only 15% of the area below 3%. Soils in the CCLW are mainly clay loam and silt loam and of hydrologic groups C and D.

The USGS stream gage station ID# 394126096073500 (96°07’35” Lon.; 39°41’26” Lat.) was located upstream of Centralia City Lake at Black Vermillion River tributary (USGS, 2011). The NCDC weather station ID# 141408 was located 10 km north of the USGS station (NCDC, 2010).

SWAT Models

Overview of SWAT

Soil and Water Assessment Tool (SWAT) is a continuous-simulation, physically based hydrologic and water-quality model developed by the USDA Agricultural Research Service to assess the impacts of land practice management and climate variations on non-point source pollution in complex watersheds, from catchment to river basin scale (Arnold et al., 1998; Neitsch et al., 2005; Gassman et al., 2007; Douglas-Mankin et al., 2010). SWAT incorporates a set of both physically and empirically based equations to simulate various hydrologic and water-quality processes on a daily scale.

In SWAT, a watershed is divided into subwatersheds according to flow accumulation and stream network delineation procedures. Within each subwatershed, geo-referenced homogeneous units with uniform average slope, land use, and soil type are further identified and aggregated into Hydrologic Response Units (HRU). Within each HRU, modeling components include hydrology, sediment transport, nutrient transformation, plant growth, soil percolation, and agricultural management. The hydrologic cycle on a given day j is *simulate*d based on the water balance equation within the HRU (all balance variables have units of mm H_2O):

$$SW_j = SW_0 + \sum_{(i=1)}^{j} (PR - RO - ET - IN - GW)$$

where *SW* is the soil water content, *PR* is the amount of precipitation, *RO* is the amount of surface runoff, *ET* is the amount of evapotranspiration, *IN* is the amount of water entering the vadose zone from the soil profile, and *GW* is the amount of return flow. The subscript 0 indicates the initial water content at the beginning of the simulations.

SWAT uses the NRCS runoff curve number method (USDA NRCS, 2004) with daily adjustment according to soil moisture conditions to estimate surface runoff, the Penman-Monteith method for estimation of evapotranspiration, and the Muskingum method for channel routing (Chow et al., 1988). Also SWAT uses daily weather data (minimum and maximum temperature, precipitation depth, solar radiation, wind speed, and relative humidity) applied uniformly to all HRUs within a subwatershed according to the nearest weather station.

The overland erosion is modeled in SWAT as the sheet-and-rill erosion and calculated based on the Modified Universal Soil Loss Equation (MUSLE; Williams, 1975):

$$\mathrm{SED}=\mathrm{R}_{\mathrm{MUSLE}}\cdot\mathrm{K}_{\mathrm{USLE}}\cdot\mathrm{C}_{\mathrm{USLE}}\cdot\mathrm{P}_{\mathrm{USLE}}\cdot\mathrm{LS}_{\mathrm{USLE}}\cdot\mathrm{CFRG}$$

where $R_{MUSLE} = 11.8(R0 \cdot q_{PEAK} \cdot A_{HRU})^{0.56}$ is the daily runoff factor, C_{USLE} is the peak runoff rate, A_{HRU} is the area of HRU, K_{USLE} is the USLE soil erodibility factor, C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor, and CFRG is the coarse fragment factor, that improves the original USLE model (Wischmeier and Smith, 1978) by replacing the annual rainfall energy factor with a daily runoff factor, and thus allowing erosion to be simulated on a daily basis. Additional sources of channelized erosion processes, such as ephemeral gully erosion, are not simulated in SWAT and must be accounted by other methods.

Outputs from all HRUs within a subwatershed are summed and routed through the stream network to the watershed outlet where they can be compared with monitoring data for model calibration and validation (Neitsch et al., 2004, 2005).

Model Setup

Three SWAT models were built for the three studied watersheds using input watershed database information from online and local sources. Drainage areas of the watersheds were delineated with the GIS module in SWAT using 10 m × 10 m digital elevation models for Jefferson, Jackson, Brown, and Nemaha Counties (USDA-NRCS, 2010). Main watershed outlet for each watershed was set downstream of the corresponding lake, Banner Creek Lake in BCLW, Centralia City Lake in CCLW, and Atchison County Lake in ACLW, to coincide with available catchment delineations of the National Hydrology Dataset within the corresponding HUC-12 watersheds (BASINS, 2010). SWAT model contained 15 subwatersheds for BCLW, 12 subwatersheds for CCLW, and 11 subwatersheds for ACLW ranging from 300 to 2,000 ha. The stream network was created during the delineation process and followed the NHD flowlines (Fig. 2; BASINS, 2010).

Outlet of one of the subwatersheds (subwatershed 1 in BCLW, subwatershed 6 in CCLW, and subwatershed 5 in ACLW) was set at the site of the USGS gage station upstream of the lake. Subwatersheds upstream of that outlet represent the USGS gage station drainage area: subwatersheds 1 to 10 in BCLW, 1 to 5 in CCLW, and 1, 2, 3, 6, 8, 9, 10 in ACLW. The SWAT model was calibrated at that outlet.

Each studied watershed was spatially divided into three groups of high, medium, and low slope areas using 3% and 6% slope thresholds. The areas of high slope (>6%) occupy 52% of the

BCLW, 46% of the CCLW, and 20% of the ACLW, while the areas of low slope (<3%) occupy 14% of the BCLW, 42% of the CCLW, and 40% of the ACLW. The slope analysis shows the prevalence of high slope areas in BCLW and CCLW (>45%), while low slope areas are prevalent in ACLW and CCLW (>40%).

Land use data were collected from the reconnaissance survey conducted by Devlin and Boyer (2012) in 2009 and 2010. A total of 17 land use classes were created in SWAT to represent various land covers, land uses, and management operations (Table 2). Grassland was split into grazed and hayed Little Bluestem grass. In addition, generic pasture and grass waterways were also classified for CCLW and ACLW. Corn and soybeans fields were divided into subclasses based on the implemented management practices, no-till or conventional tillage, and terraced and no-terraced. Cropland and grazing management operations were adopted from the survey conducted in Jefferson, Nemaha, Jackson, and Brown counties by the Kansas Department of Health and Environment (KDHE, 2010) and applied to the corresponding HRUs.

Spatial overlay of areas of different land use, soil, and slope classes generated 878 HRUs for BCLW, 1200 HRUs for ACLW, and 1199 HRUs for CCLW. Data from the National Climatic Data Center cooperative weather stations were used for weather input. Daily maximum and minimum temperature and precipitation data series were used as inputs into SWAT models. At the monitored USGS gage stations in each watershed, the streamflow discharges were collected from April 2009 to December 2010 and averaged daily.

Calibration

The three SWAT models were run from 1/1/2006 to 12/31/2010 with a three-year (1/1/2006-12/31/2008) spin-up period. Daily SWAT-simulated streamflow from 4/1/2009 to 12/31/2010 were compared with data from the stream-monitoring USGS station.

Monthly model performance was assessed using coefficient of determination (R2), Nash-Sutcliffe model efficiency (NSE), and percent bias (PBIAS) (Moriasi et al., 2007). A set of 11 model parameters were selected for model calibration (Table 3). The parameters were selected from SWAT modules on surface flow, baseflow, evapotranspiration, and weather (snowmelt and freezing). The streamflow calibration was declared acceptable when calibration coefficients reached the satisfactory/good threshold (Moriasi et al., 2007). For example, the performance of simulated monthly streamflow exceeded the “satisfactory” threshold of NSE=0.5 for both BCLW (NSE=0.50) and ACLW (NSE=0.63) but not for CCLW (NSE=0.39). The lower value of the NSE for the CCLW model was due to lower model performance in 2010 (NSE=0.27), compared to NSE=0.68 in 2009.

Table 2. Land use classification used in SWAT modeling.

		Tillage			Watershed (% of total)		
	Land use	**No-till**	**Conv**	**Terrace**	**BCLW**	**CCLW**	**ACLW**
1	Corn	×		×		9.8	25.1
2	Corn	×				2.1	2.0
3	Corn		×	×		5.3	1.8
4	Soybeans	×		×		20.4	33.6
5	Soybeans	×				6.5	1.1
6	Soybeans		×	×		6.5	3.4
7	Soybeans		×			4.1	
8	Winter wheat					8.5	0.2
9	Crop (Other)				5.4	15.2	7.7
10	Grazed				54.2	17.9	4.4
11	Hayed				13.5	0.9	2.6
12	Grass (Other)				19.1		
13	Waterway						5.9
14	Residential				3.2	2.2	5
15	Forest				4.6	0.7	5.1
16	Wetland						0.2
17	Water				0.1	0.1	1.7

Table 3. Values of SWAT parameters adjusted during the calibration procedure.

Parameter	Default Value	Adjustment Range	Final Adjusted Value
SMTMP	0.5	-5 to 5	1
SFTMP	0.5	-5 to 5	-1
TIMP	1.0	0 to 1.0	0.5
ESCO	0.95	0.01 to 1.0	0.8
EPCO	1.0	0.01 to 1.0	0.2
SURLAG	4	1 to 12	2
GW_DELAY	31	0 to 500	10 to 15
ALPHA_BF	0.048	0.0 to 1.0	0.08
GWQMIN	0	0 to 5000	100
GW_REVAP	0.02	0.02 to 0.20	0.1
REVAPMN	1	0 to 500	0.08
RCHRG_DP	0.05	0.0 to 1.0	0.1
CANMX	0	0 to 5	2.2 to 4.2

Time Series Generation with a Stochastic Weather Generator

The SWAT watershed model simulates hydrologic processes on a continuous daily temporal scale. To obtain a better understanding of watershed hydrologic and water-quality conditions, it is preferable to run the model for a longer period of time, which requires long-term weather records. If such records are unavailable but data for a shorter time period exist, a stochastic weather generator can be used to produce longer daily time series that keep the same basic statistics of original weather patterns. In this study, we used the weather generator called WINDS (Weather Input for Non-point Data Simulation; Wilson et al., 2006), which simulates many years of weather realization based on statistics computed from daily time series of weather data.

A two-step procedure is used by WINDS. The first step analyzes historical daily weather records to obtain relevant statistical information. Each climate variable is represented by cosine functions with three harmonics and seven coefficients using the theory of harmonic analysis and the modified nonlinear Gauss method (Richardson, 1981):

$$W(t_j) = W_{mn} (b_0 + b_1 \cos(t_j + b_2) + b_3 \cos(2t_j + b_4) + b_5 \cos(3t_j + b_6)), t_j = (2\pi day_j)/365$$

where W are the statistics of climate variable (mean, standard deviation, skew coefficients), W_{mn} is the annual mean value, day_j is the calendar day, and b_0 to b_6 represent seven harmonic coefficients. Mean, standard deviation, and skews are computed daily for all non-precipitation data. Since the precipitation climate variable is a discontinuous function, a 28-day interval is used. Transitional probabilities of wet days given that the previous day is wet and given that the previous day is dry are calculated using the cosine fit function (Wilson et al., 2006).

The second step uses calculated statistics to generate time series of weather variables. Non-precipitation variables are represented by continuous functions and simulated with a statistical framework of Markov processes. Discrete precipitation events are modeled using a first-order, two-state Markov chain. A transitional probability function is used to identify a rainfall event, and a log-normal probability density function distribution is used to determine precipitation depth for that rainfall event. Cross-correlations between non-precipitation variables are applied for predicting daily values. This two-step process allows WINDS to produce a continuous daily weather variable time series that closely resembles historical statistics.

Twenty-one years (1990 to 2010) of historical daily records at the NCDC weather stations in BCLW, ACLW, and CCLW were used to calculate statistics of data series, and based on these statistics to generate a pool of 100-year daily time series for daily precipitation and minimum and maximum temperatures for each weather station. The primary statistics (daily mean and standard deviation) were calculated for each calendar day of the each generated dataset and compared with the statistics of the historical dataset. For each station, a single generated dataset that exhibited the best fit to the historical statistics (usually R2>98%) was selected for the SWAT simulation.

Results

For each watershed, three SWAT model simulations were conducted. The same SWAT model was used for each simulation, but different time periods and weather time-series were applied. The first simulation used the time period from 4/1/2009 to 12/31/2010 with the weather data used for model calibration, the second simulation considered a 21-year period of available NCDC station weather data from 1/1/1990 to 12/31/2010, and the third simulation used WINDS generated 100-year daily weather time-series.

Average annual streamflow yield and the total suspended sediment (TSS) yield from surface runoff were obtained from outputs of the SWAT model for each subwatershed within the USGS gage station drainage area of BCLW, ACLW, and CCLW. The streamflow yield (called water yield in SWAT) is composed of overland runoff, baseflow yield, and lateral flow yield. The units of streamflow yield were converted to tons per square mile, whereas the units of sediment yield were converted to acre-foot per square mile (Table 4).

In each simulation, the water yield was found to be the lowest in the CCLW and the highest in the BCLW (Table 4). Among three simulations, the largest water yields were during the first simulation with the shortest simulation time. This outcome was expected, as years 2009 and 2010 were wet years with the annual precipitation higher than the historical average. In the second simulation of 21 years, dry years in the 1990s and 2000s balanced the high water contribution during wet years and thus lowered the average annual water yields from the first simulation. The drop in water yields were more evident in the cropland dominated watersheds, ACLW and CCLW, which were more sensitive to drought. The third simulation, with the stochastically reproduced 100-year weather data, produced only slightly different water-yield results that the second simulation. The probabilistic nature of the generated weather data in the third simulation smoothed out the extreme high and low flow events, and, therefore, avoided the impacts of extreme floods of 1993 and droughts of 2006 on watershed hydrology. However, the simulated water yields from all simulations were consistently lower than the ones observed from 2009 to 2011 at the USGS gage stations (Lee, 2011). The reason for discrepancy could be the following: although the calibration results were declared satisfactory, the period of calibration was very short and the difference in high stream flow peaks from excessive surface runoff between the monitored and simulated data could contribute to the

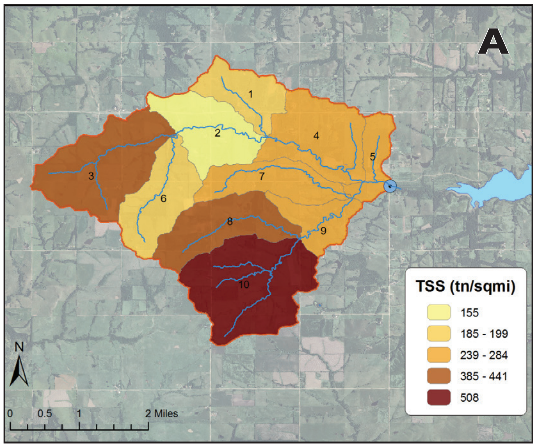
Table 4. Water yield and total suspended sediment yield for three simulation periods.

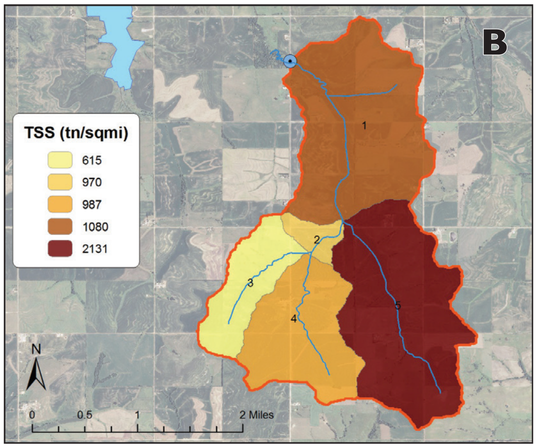
	Period (yrs)	BCLW	CCLW	ACLW
Water yield (acre-ft/mi^2)	2	664	275	445
	20	631	199	376
	100	654	207	347
TSS yield (ton/mi^2)	2	513	1,677	4,555
	20	297	1,097	3,167
	100	291	1,186	2,911

overall difference in annual water yield averaged over less than a 2-year period.

The sediment yield was the lowest for the grassland dominated watershed BCLW. This is a direct result of lower erosion potential of grasslands compared to several times higher erosion potential of croplands. As a result, the TSS yield was three times higher in the CCLW and almost nine times higher in the ACLW than in the BCLW. The row-crop production was widely adopted in CCLW and ACLW, while it was minimal in BCLW (>75% of all fields in CCLW and ACLW compared to only 5.5% in BCLW). A presence of lakes/ponds and impoundments within the ACLW that are capable of retaining large portion of overland sediment but not well simulated in the SWAT model might improve the comparison and force a substantial reduction in sediment yields.

There is another important factor that can increase sediment yield in agricultural watersheds and was not fully accounted in SWAT: the gully erosion. Gully erosion exhibits in the form of soil particle detachment from classical and ephemeral gullies. During high peak flows a network of concentrated-flow channels (i.e., ephemeral gullies and classical gullies) upslope from established stream channels can produce an amount of suspended sediment comparable with loads from the sheet-and-rill erosion. From the





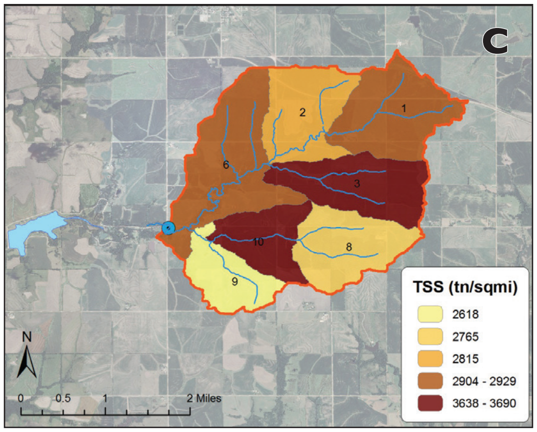
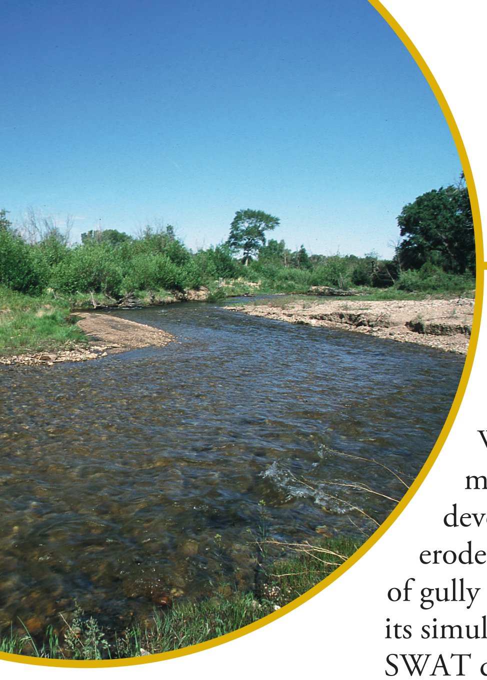


Figure 3. A subwatershed map of the annual average total suspended sediment yield for the USGS gage station drainage areas of: (a) Banner Creek Lake Watershed, (b) Centralia City Lake Watershed, and (c) Atchison County Lake Watershed. The darker the color, the higher the average annual suspended sediment yield.



reconnaissance survey data and aerial imagery in BCLW and the neighboring Delaware River Watershed it was observed that majority of grassland contains a developed network of concentrated eroded flow paths or gullies. Modeling of gully erosion is extremely difficult and its simulation usually of high uncertainty. SWAT does not include gully erosion in TSS yield calculations.

Spatial distributions of total suspended sediment yields produced by each sub-watershed within the USGS gage station drainage area in BCLW, ACLW, and CCLW are shown in Figure 3. The maps can be used for spatial targeting of implementation of conservation structures and best management practices aimed at reducing sediment erosion on the agricultural fields. The following conservation structures can be used for implementation: terraces complemented by contour farming on steep slopes, grass waterways on eroded gully-like lands, ponds, etc. The management practices consist of no-till, reduced or conservation tillage, contour farming, and crop rotations among others.

Conclusions

SWAT models were developed for three watersheds in Northeast Kansas. The models accommodated the field-by-field land use information collected with the reconnaissance survey of the studied areas but lacked field-scale data on classical and ephemeral gullies. The models were calibrated for a 2-year period and then used for the simulation of 21-year period using actual weather data from NCDC stations. The models were also used to simulate 100 years utilizing a stochastically generated daily precipitation and temperature based on statistics of the 21-year weather data. The results showed that the BCLW produced the highest streamflow yield but contributed the lowest total suspended sediment load from surface runoff when compared to the yields generated in ACLW and CCLW. This confirmed the fact that grassland dominated watersheds, such as BCLW, normally produce less overland erosion then cropland-prevailing watersheds, such as ACLW and CCLW. The shortcomings of the SWAT model in accounting for gully erosion may increase total sediment yield if it is properly accounted based on survey or external modeling data. The difference in sediment yields between two cropland dominated watersheds, ACLW and CCLW, were due to higher average field slopes in ACLW, larger number of impoundments in ACLW, higher percentage of winter wheat in CCLW that is known to contain erosion in the field significantly better than corn and soybeans, and lower acreage of corn in CCLW.

The results of this SWAT modeling study were based on current land use and climate conditions. Both of these factors may change in the future, predictable for the worse of water-quality in the watersheds (Brunsell et al., 2010). According to the Intergovernmental Panel on Climate Change reports (IPCC, 2000, 2007) an increase of temperature and shifts of extreme precipitation events toward early spring months along with drier summers (Siebenmorgen et al., 2010; Sheshukov et al., 2011) can significantly alter the results of this study. Changes in land use can affect overland erosion either way depending on expansion of cropland and/or urbanization of Northeast Kansas (Karl et al., 2009).

Recommendations

- Survey watersheds for the presence of classical and ephemeral gullies and document gully sediment contribution.
- Continue monitoring streamflow for longer time periods for better understanding of watershed hydrologic conditions and increased capability of model calibration.
- Incorporate available climate change projections developed specifically for Northeast Kansas in water-quality and water-quantity assessments of watersheds.

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Bathymetric and Sediment Surveys of Atchison County Lake, Banner Creek Reservoir, and Centralia City Reservoir

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The Kansas Biological Survey conducted bathymetric and sediment surveys of the three sediment study reservoirs, Atchison, Banner Creek, and Centralia City. Atchison County Lake was constructed in 1935 on Clear Creek. The 5976-acre watershed is dominated by cropland (79%), predominantly row crops, and 16% grassland. Banner Creek Reservoir is located one and a half miles west of Holton, Kansas. Constructed during 1994-1997, Banner Creek Reservoir was built as a water supply for the city of Holton and Jackson County. The watershed for Banner Creek Reservoir is a 12,000-acre area in which 88 percent is grass and woodland. Centralia City Lake is located 2 miles south and 1 mile west of Centralia, Kansas. The dam was constructed in 1991 at the confluence of two streams, forming two long arms of the lake. The watershed is predominantly cropland (60%, 2005 LULC survey), and grassland (38%, including Conservation Reserve Program areas).

Bathymetric Surveying Procedures

KBS operates a Biosonics DT-X echosounding system (www.biosonicsinc.com) with a 200 kHz split-beam transducer and a 38-kHz single-beam transducer. Latitude-longitude information is provided by a global positioning system (GPS) that interfaces with the Biosonics system. ESRI's ArcGIS is used for on-lake navigation and positioning, with GPS data feeds provided by the Biosonics unit through a serial cable. Power is provided to the echosounding unit, command/navigation computer, and auxiliary monitor by means of a inverter and battery backup device that in turn draw power from the 12-volt boat battery. Prior to conducting the survey, existing geospatial data of the target lake was acquired, including georeferenced National Agricultural Imagery Project (NAIP) photography. The lake boundary was digitized as a polygon shapefile from the Farm Service Agency (FAS) NAIP 2008 georeferenced aerial photography obtained online from the Data Access and Service Center (DASC) at the Kansas Geological Survey (http://www.kansasgis.org).

After boat launch and initialization of the Biosonics system and command computer, system parameters are set in the Biosonics Visual Acquisition software. The temperature of the lake at 1-2 meters is taken with a research-grade metric electronic thermometer and input to the Biosonics Visual Acquisition software to calculate the speed of sound in water at the given temperature at the given depth. Start range, end range, ping duration, and ping interval are also set at this time. A ball check is performed using a tungsten-carbide sphere, lowering the sphere to a known distance (1.0 meter) below the transducer faces. The position of the ball in the water column (distance from the transducer face to the ball) is clearly visible on the echogram. The echogram distance is compared to the known distance to assure that parameters are properly set and the system is operating correctly.

Using the GPS Extension of ArcGIS, the GPS data feed from the GPS receiver via the Biosonics echosounder, and the pre-planned transect pattern, the location

of the boat on the lake in real-time is shown on the command/navigation computer screen. The transect pattern is maintained except when modified by obstructions in the lake (e.g., partially submerged trees) or shallow water and mudflats. Data are automatically logged in new files every half-hour (approximately 9000-ping files) by the Biosonics system.

The Biosonics DT-X system produces data files in a proprietary DT4 file format containing acoustic and GPS data. To extract the bottom position from the acoustic data, each DT4 file is processed through the Biosonics Visual Bottom Typer (VBT) software. A set number of qualifying pings are averaged to produce a single depth report (for example, the output for ping 31 {when pings per report is 20} is the average of all values for pings 12-31). All raw *.csv files are merged into one master *.csv file using the shareware program File Append and Split Tool (FAST) by Boxer Software (Ver. 1.0, 2006).

The master *.csv file created by the FAST utility is imported into Microsoft Excel. Entries with depth values of zero (0) are deleted, as are any entries with depth values less than the start range of the data acquisition parameter (0.49 meters or less) (indicating areas where the water was too shallow to record a depth reading). A new field – Adj_Depth – is calculated as AdjDepth = Depth + (Transducer Face Depth), where the Transducer Face Depth represents the depth of the transducer face below water level in meters (Typically, this value is 0.2 meters; however, if changes were made in the field, the correct level is taken from field notes and applied to the data). Depth in feet is also calculated as DepthFt = Adj_Depth * 3.28084. To set depths relative to lake elevation, the depth in feet is subtracted from the water surface elevation on the date of the bathymetric survey (obtained from the United States Geological Survey (USGS) Kansas Water Science). Ingest to ArcGIS is accomplished by using the Tools – Add XY Data option. Points are interpolated to a triangulated irregular network (TIN) or raster in ArcGIS, using the lake perimeter as a constant contour and boundary.

Sediment Surveys

KBS operates a Specialty Devices Inc. sediment vibracorer mounted on a dedicated 24’ pontoon boat. The vibracorer uses 3” diameter aluminum thinwall pipe in user-specified lengths. The system uses an 24-v electric motor with counter-rotating weights in the vibracorer head unit to create a high-frequency vibration in the pipe, allowing the pipe to penetrate sediments and substrate as it is lowered into the lake using a winch. Once the open end of the core pipe has penetrated to the substrate, the unit is turned off and the unit is raised to the surface using the winch. At the surface, the pipe containing the sediment core is disconnected from the vibracore head and the sediment extruded from the pipe and measured.

At each site, determined using GPS, the core boat is anchored and the vibracore system used to extract a sediment core down to and including the upper several inches of pre-impoundment soil (substrate). The location of each core site is recorded using a GPS. Cores are carefully extruded from the core pipe, and the interface between sediment and substrate identified. Typically, this identification is relatively easy, with the interface being identifiable by changes in material density and color, and the presence of roots or sticks in the substrate. The top 15 cm of sediment are collected and sealed in a sampling container. The samples are then shipped to the Kansas State University Soil Testing Laboratory (Manhattan, KS), for texture and other analyses.

To assess bulk density, the syringe method described by Hilton et al (1986) was used, employing a cutoff 35-ml syringe inserted into the exposed core to extract a 15-cc sample of the sediment. Samples were ejected from the syringe using the plunger and sealed in sample canisters. Where permitted by core length, samples were taken from the lower, midpoint, and upper parts of the core (e.g., 10-cm above sediment-substrate interface; midpoint of core length; 10 cm below sediment top). Shorter cores (30-50 cm) were sampled only at the upper and lower end, and very short (length < 20 cm) were sampled only at the midpoint. In the lab, samples were weighed, dried at 100ºC for 48 hours, and weighed again. At several sites, a bulk density sample was taken from the substrate as well for comparison to sediment bulk density.

Sediment sampling on the three study reservoirs was carried out in several phases. Banner Creek Reservoir and Centralia City Reservoir were cored in 2009, while surface samples only were taken from Atchison in 2010. Atchison County Lake was not cored in 2009-2010 due to the difficulty of launching the sediment coring pontoon boat. In 2011, however, an abandoned boat ramp was discovered on the south shore of the lake, and with the assistance of the Atchison County Highway Department, the ramp was cleared sufficiently to launch the coring boat. In 2011, additional coring also was undertaken on Centralia. For all cores, the stream channel was avoided. Data from sediment coring included sediment thickness at the core site, and a top sample of each core was analyzed for texture (percent sand, silt, and clay) and nutrients (total nitrogen and total phosphorus). Additionally, a series of surface sediment samples were taken in 2011 at every cove and drainage inlet around the perimeter of Centralia City Lake and analyzed for total nitrogen and total phosphorus.

Radionuclide Analysis of Atchison County Lake Sediment

Rates of sedimentation may not be constant throughout time for a reservoir, particularly if significant changes have occurred in the watershed due to changes in agricultural and soil conservation practices and other forms of land use/ land cover conversion. Thus, a marker or markers that provide dates along a sediment core can provide *chronostratigraphic* data on sedimentation rates and possible changes in rates over time.

Radionuclides are often used as chronostratigraphic dating tools, specifically ^{137}Cs (cesium) and $^{239+240}$Pu (plutonium). Aboveground testing of nuclear weapons, principally by the United States and and the Soviet Union in the post World War II period, resulted in atmospheric fallout of radionuclides that were deposited on land and in lake sediments. The highest peak of accumulation of these radionuclides occurred in 1963-64, and a decrease in activity for post-1963 sediments due to the ratification of the Limited Test Ban Treaty of 1963 which banned aboveground testing of nuclear devices (Ketterer et al, 2004, 2006).

In practice, a series of samples along the length of a sediment core are tested for the presence of radionuclides;, and if a "spike" in radionuclides occurs at some point along that core, we can assume with a reasonable degree of confidence that the point at which that spike occurs indicates 1963-64 on the core. Core AT-2 in Atchison County Lake was sliced into a series of 10-cm sections, and each section was further analyzed for texture, nutrients, and radionuclides ($^{239+240}$Pu).

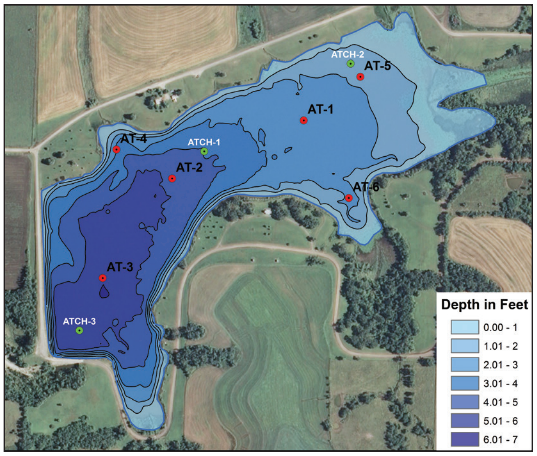

Figure 1. Depth map and coring locations for Atchison County Lake.

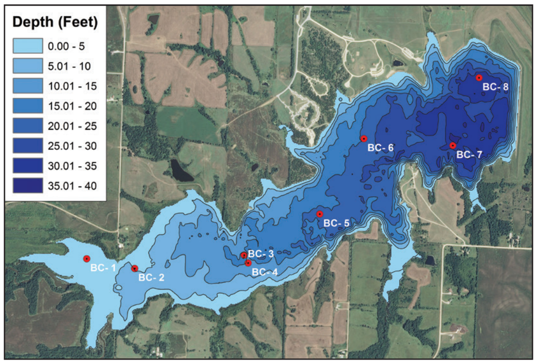

Figure 2. Depth map and coring locations for Banner Creek Reservoir.

Results

Bathymetry. As expected, Atchison County Lake was the smallest and shallowest of the three reservoirs surveyed, with a maximum depth of 6.8 feet (Table 1; Figure 1). Nearly half of the lake is three feet or less in depth, and extensive growths of aquatic plants have covered the easternmost part of the lake. Banner Creek Reservoir and Centralia City Lake, being newer, were considerably deeper (maximum depths 36.6 feet and 27.4 feet) (Table 1; Figure 2; Figure 3).

2009-2010 Sediment Coring (Banner and Centralia). Eight sites were cored in Banner Creek Reservoir on August 6, 2009. Sampling sites were distributed across the length of the reservoir (Figure 2). Silt percentages were highest at the inflow end (BC-1, 60%), decreasing to 28% (Site BC-8) at the dam. Sediment

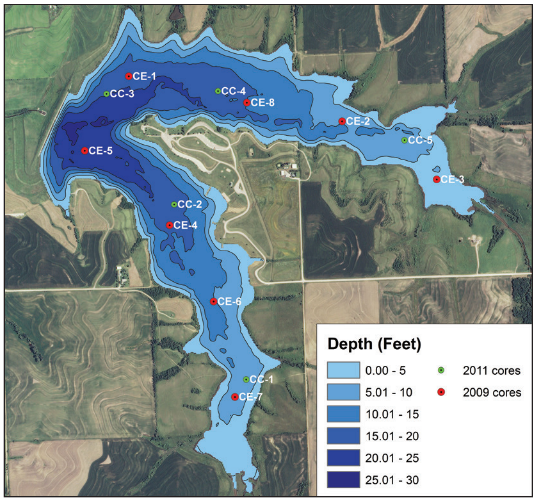

Figure 3. Depth map and coring locations for Centralia City Lake.

Table 1. Reservoir Statistics

Lake	Area (acres)	Volume (acre-feet)	Avg depth (ft)	Max depth (ft)	Lake surface elevation (ft AMSL, NAVD88)
Atchison	62.5	178	2.8	6.8	1,055.4
Banner	480	7,395	14.7	36.6	1,078.1
Centralia	374	4,006	10.3	27.4	1,265.5

compositions at sites BC-3 through BC-8, essentially the upper midpoint of the lake down to the dam end were predominantly clay (>50%) (Table 2). Average sediment thickness across the eight sites was 38 cm, or ~3.1 cm/year since 1997. Centralia City Lake also was cored on August 6, 2009 ("CE" series of cores), and again on July 28, 2011 ("CC" series of cores) (Table 2; Figure 3). Sediment thickness

Table 2 Sediment Sampling Site Data

CODE	UTMX	UTMY	Sediment thickness (cm)	%Sand	% Silt	% Clay
Atchison Lake (2010 Samples)						
ATCH-1	289114	4390501		0	38	62
ATCH-2	289401	4390673		2	70	28
ATCH-3	288869	4390150		16	12	72
Atchison Lake (2011 Samples)						
AT-1	289310	4390563	> 250		See text	
AT-2	289051	4390448	> 250			
AT-3	288915	4390253	> 250			
AT-4	288942	4390505	120			
AT-5	289421	4390648	225			
AT-6	289398	4390410	> 250			
Banner Creek Reservoir (2009 samples)						
BC-1	259476	4370138	27	8	60	32
BC-2	259779	4370076	22	6	56	38
BC-3	260471	4370160	81	4	46	50
BC-4	260495	4370110	2		(Insufficient sample)	
BC-5	260948	4370420	39	4	36	60
BC-6	261226	4370896	13	10	38	52
BC-7	261788	4370853	60	6	38	56
BC-8	261953	4371281	60	14	28	58
Centralia City Lake (2009 samples)						
CE-1	744418	4397376	67	0	3	97
CE-2	744305	4397885	15	12	54	34
CE-3	743618	4398688	30	9	66	25
CE-4	744070	4398291	35	0	30	70
CE-5	745494	4398536	40	0	30	70
CE-6	744990	4398845	10	11	38	51
CE-7	743853	4399085	22	0	56	44
Centralia City Lake (2011 samples)						
CC-1	744479	4397470	25		See text	
CC-2	744095	4398403	45			
CC-3	743735	4398992	43			
CC-4	744329	4399006	30			
CC-5	745324	4398745	20			

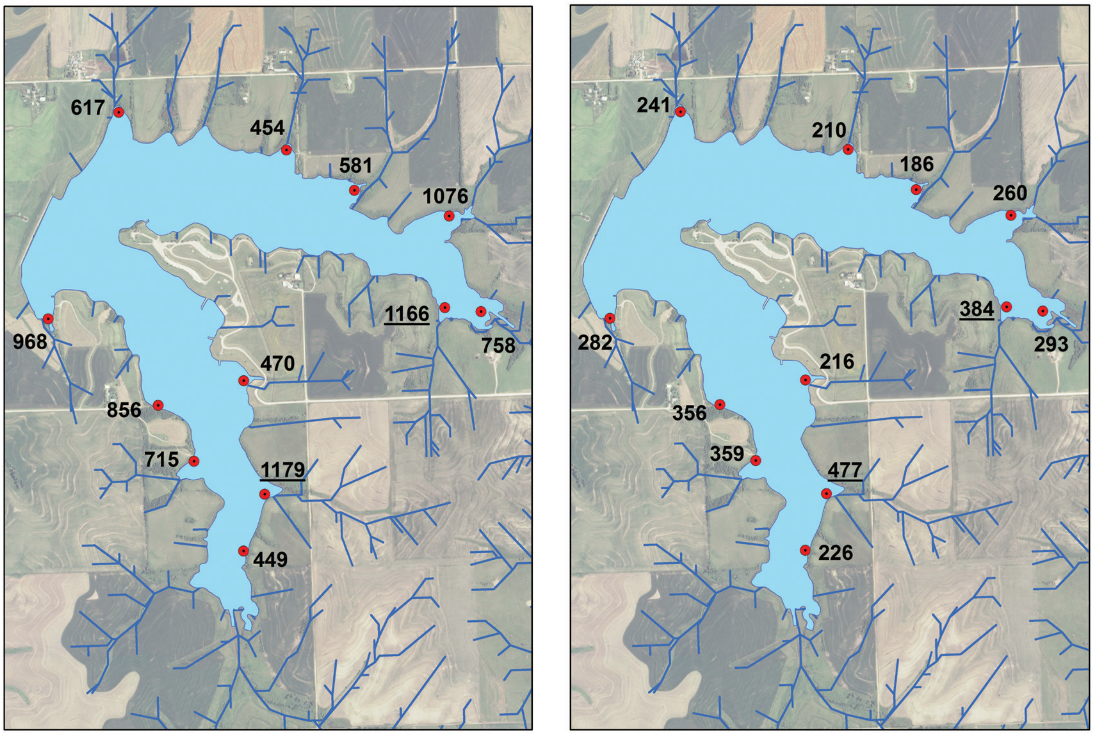

Figure 4. Nutrient data at spot sample locations in Centralia City Lake. Left: Total nitrogen in parts per million (ppm). Right: Total phosphorus in ppm.

for the “CE” sites ranged from 10 cm (site CE-6, southern arm of the lake) to 67 cm (Site CE-1, at the dam). Sediment composition was dominated by silt and clay, with clay dominating the composition in the lower part of the reservoir and silt in the upper ends of the two arms (Table 2; Figure 3). Sediment texture was not analyzed for the 2011 series of Centralia sediment cores; however, sediment thicknesses are consistent with the patterns of sedimentation indicated by the 2009 “CE” series of cores. Average sediment thickness using all twelve sites was 31 cm, or ~1.6 cm/year since 1991.

2011 Spot Sediment Sampling (Centralia). Twelve surface sediment samples were taken in 2011 at every cove and drainage inlet around the perimeter of Centralia City Lake and analyzed for total nitrogen and total phosphorus (Figure 4). Values for total nitrogen ranged from 449 parts per million (ppm) in the southern arm, to 1179 ppm, also in the southern arm. Total phosphorus ranged from 210 ppm (eastern arm) to 477 ppm (southern arm). On first examination, there appears to be no strong spatial pattern to the levels of total N and P in Centralia City Reservoir; however, the highest and second-highest levels of both N and P are found at inlets for two streams that drain the central ridge separating the two arms of the lake (Figure 4). Moreover, both streams drain the same parcel of cropland.

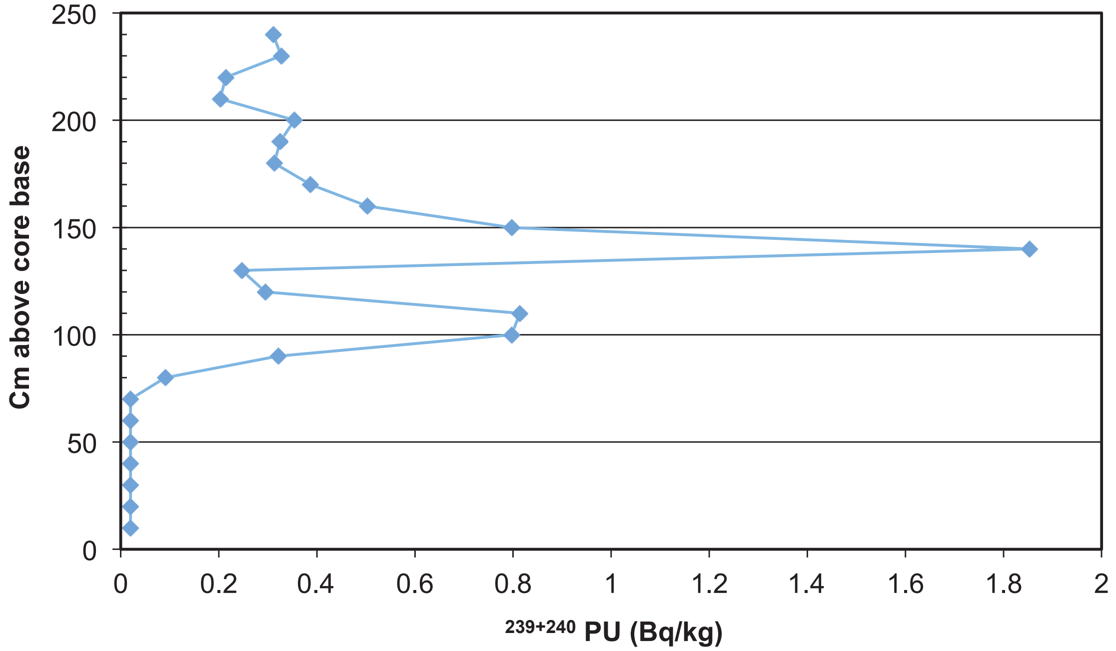

Figure 5. Radionuclide levels ($^{239+240}$Pu) in 10-cm slices of core AT-2 from Atchison County Lake.

2011 Sediment Coring (Atchison). Six sediment cores were taken from Atchison County Lake on August 18, 2011 (Figure 1). Sediment thickness for four of the six cores exceeded the length of the coring pipe (250) cm (Table 3). Radionuclide analysis of the sliced sediment core AT-2 indicate that core intervals AT-2-10 through AT-2-70, inclusive, contained no detectable $^{239+240}$Pu. Plutonium is first detected in core interval AT-2-80 (0.091 ± 0.001 Bq/kg $^{239+240}$Pu); Pu was also present in all further intervals of the core (AT-2-80 through AT-2-240, inclusive), with a maximum activity of 1.85 ± 0.01 Bq/kg $^{239+240}$Pu found in core interval AT-2-140. No $^{239+240}$Pu radionuclide levels are below detectable levels in the first 70 cm of sediment deposited (corresponding to the years immediately following construction, the 1930s and 1940s), with a minor peak at 100-110 cm (possibly corresponding to 1950s aboveground nuclear testing), and the peak level attained at the 130-140 cm sample, and declining thereafter (Figure 5). The $^{239+240}$Pu peak at 130-140 cm above the base of the core is interpreted as indicating 1963 (Ketterer et al, 2004, 2006). If we assume that the first 140 centimeters of sediment were deposited between 1935-1963 (28 years, inclusive), this implies a sedimentation rate of 5.0 cm/year during that period. The remaining 110 cm of sediment was thus deposited between 1964-2011 (47 years), or 2.3 cm/year during that period, a rate of sedimentation less than half that of the earlier period. Examination of archival aerial photography for the 1930s through the present suggests that field-level conservation practices, including terracing, grassed waterways, and watershed impoundments, were not substantially in place until the 1960s and 1970s.

Texture and nutrient analyses performed on the 10-cm slices of core AT-2 reveal some interesting trends. The proportions of clay and silt in the sediment have

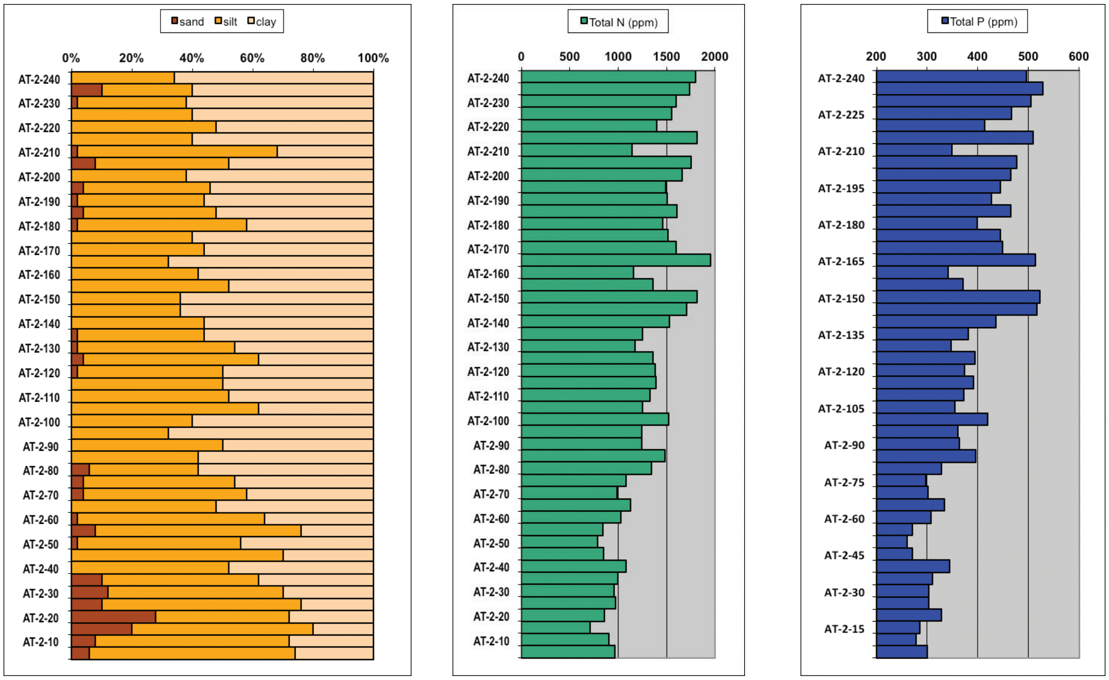

Figure 6. Texture analysis, total nitrogen (ppm), and total phosphorus (ppm) in 10-cm sections of core AT-2, Atchison County Lake.

shifted over time, with silt initially being dominant and clay a minor fraction; since at least 1963 (as dated by radionuclide analysis), the proportion of clay is substantially greater than the silt (Figure 6). The chronosequence of sediment texture additionally indicates at least seven discrete and intermittent occurrences of sand, with the largest of these occurrences in the early years of the lake (near the base of the core). Total nitrogen and total phosphorus have also increased over time in the sediment. Total N at the base of the core is less than 1000 ppm, increasing to over 1500 ppm at the top; total phosphorus, likewise, has increased from less than 300 ppm at the base to over 500 ppm at the top (Figure 6).

Conclusions

Sediment deposits primarily consisted of clay in all three reservoirs. Sedimentation rates vary across the three reservoirs, from approximately 3 cm/year for Banner Creek Reservoir to 1.6 cm/year for Centralia. The sedimentation rate for Atchison County Reservoir has changed over time, as radionuclide analysis suggests that the sedimentation rate in the first 25-30 years of existence was double that of the past forty-seven years. Conservation practices may have also changed the nature of the sediment load coming in to Atchison County Lake, shifting from a silt-dominated load with intermittent sand layers to a clay-dominated load. Concurrent with the shift in sediment composition has been an increase in the nutrients (total N and total P) in the lake as manifested in the sediment record.

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Biological Impairment in Three Kansas Reservoirs and Associated Lotic Ecosystems due to Sediment and Nutrients

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Executive Summary

A series of impoundment and stream water quality measures were determined for a reference impoundment (Banner Creek Reservoir) and two non-reference impoundments (Centralia and Atchison County Lakes). In addition to core sample chemistry from these impoundments, water quality, habitat and biological measures from major tributaries to these impoundments were also collected to assess overall watershed impacts from erosion and sediment additions to these aquatic ecosystems. Due to limited number of study watersheds, the robustness of this study is limited by low sample size, both temporally and spatially, rendering some conclusions more speculative than analytical. In general there were few significant water quality differences between reference and non-reference impoundments, except for turbidity and nitrogen. However phosphorus, total suspended solids (TSS) and volatile suspended solids (VSS) values were higher in non-reference impoundments, as were nitrogen and turbidity. Banner Creek (i.e. reference stream) had statistically lower concentrations of nutrients than either non-reference steam, but no stream differences were found for stream turbidity, TSS, VSS or inorganic suspended solids (ISS). V* and A*ave values, which are measures of unconsolidated stream bed materials in a stream reach, were higher in Banner Creek due to loose, un-compacted sands while the non-reference stream bottoms were mostly silt or silt and sand mixtures. Stream nutrients were highly related to impoundment nutrient values suggesting that normal flows were a major contributor to impoundment concentrations. No meaningful relationships between stream turbidity, TSS, VSS and impoundment measures were found, and core chemistry related to few other ecosystem parameters. Banner Creek Reservoir cores had a higher % silt than other impoundments, and overall % clay strongly correlated to TP in the cores.

Phytoplankton and zooplankton communities showed few differences between these two treatment groups (reference vs. non-reference). The reference impoundment had higher phytoplankton richness and somewhat higher diversity values, but zooplankton richness in this same reference impoundment was lower, as were most measures of zooplankton diversity. Stream habitat and macroinvertebrate community metric values were not significantly different for the most part unless the data from one of the non-reference site-dates was removed from the ANOVA analysis. Macroinvertebrate values were highly variable within and between dates and sites, thus preventing a clear separation between reference and non-reference stream conditions. In general, reference stream macroinvertebrate communities were more diverse and had more taxa than non-reference stream sites. V* and A*ave measures were not good predictors of macroinvertebrate metrics and were marginally associated with stream or impoundment water quality.

Overall, reference and non-reference watershed groups did not exhibit significant differences in suspended or bed sediment for the aquatic ecosystem sites that were studied, but nutrient differences for those sites were significant. It appears that high nutrient concentrations generally associated with low macroinvertebrate metric scores, suggesting a causal relationship between the two. There were no clear differences between baseline (normal flows) sediment measures for the reference and non-reference impoundments and streams. For this same study, USGS reported "annual sediment yields were 360, 400, and 970 tons per square mile per year at Atchison County, Banner, and Centralia Lake watersheds respectively". Despite marked differences in land use the reference stream and watershed (i.e. Banner Creek) had similar baseline values for turbidity, TSS and other indicators of instream sediment concentrations while the estimate sediment yield for this watershed was higher than Atchison but lower than Centralia. Collectively, this information suggests that factors other than land use are contributing to sediment yields and concentrations even within watersheds that are predominately in permanent ground cover (e.g. pasture, hay meadows range land). Differential nutrient loading may instead be associated with differences in sediments derived from within the stream channel, rather than directly from contemporary overland flow.

Background

Sedimentation in reservoirs has become an increasing concern in Kansas, leading to collaboration of various agencies and research units working to address issues such as sedimentation assessment methods, management practices to control sedimentation, and economic issues of reservoir rehabilitation (KSU 2008). These issues led to creation in 2008 of a Sediment Baseline Assessment Work Plan whose goal is to identify baseline conditions of Kansas streams and watersheds. The various academic and state groups examined seven watershed characteristics for assessment: geomorphology, hydrology, and geology/soils which comprise the physical setting and process portion of the baseline assessment methodology; riparian condition and land use which encompass the management opportunities in the watersheds; and biology and chemistry which will be used to assess the current condition and then measure movement toward the desired outcome in the streams and lakes of the watersheds. For more details of the plan see the Sediment Baseline Assessment Work Plan on-line at the workgroup's website *http://www.kwo.org/reservoirs/Sediment_Baseline_Group.htm*.

The workgroup compared a "reference" reservoir, Banner Creek Lake that appeared to have a low sedimentation rate with two reservoirs in the same general physiographic setting that appeared to

Table 1. Reservoirs and tributary study sites with stream site codes and locations. Coordinate datum is NAD83 and transects at which coordinates were taken are indicated. See Appendix 1 for specific site maps.

Impoundment	Stream	Code	Location	Latitude	Longitude	Transect	Description
Banner	Banner Creek	B1	upper site	39.44754	-95.81076	1	Downstream of USGS 392652095484100 (BA1). Follow foot path on east side of road M.
Banner	Banner Creek	B2	middle site	39.44747	-95.81005	1	
Banner	Banner Creek	B3	lower site	39.44709	-95.80898	1	
Centralia	Black Vermillion	C1	upper site	39.69001	-96.12675	6	Downstream of USGS 394126096073500 (CE1).
Centralia	Black Vermillion	C2	lower site	39.69060	-96.12693	1	
Atchison	Clear Creek	A1	only site	39.63734	-95.43303	5	Upstream of USGS 393817095260100 (CL1), between 326th and Decatur Rds.

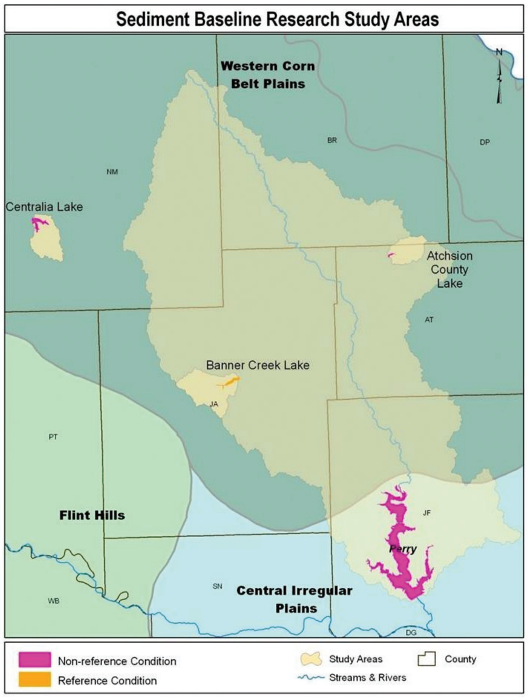

Figure 1. Northeastern Kansas and the three study reservoirs: Centralia Lake in Nemaha Co., Atchison County Lake, and Banner Creek Lake in Jackson Co. From the Sediment Baseline Assessment Work Plan (see www.kwo.org/reservoirs/SedimentGroup/Rpt_Sediment_Baseline_Assessment_Work_Plan_022009_cbg.pdf).

have much higher sedimentation rates, Atchison County Lake and Centralia Lake (Figure 1). The Work Plan states that "the ultimate goal would be to use policy and management (where applicable) to change the characteristics of the higher sedimentation rate reservoir to emulate those of the lower sedimentation rate reservoir."

In summer and fall of 2010, the Central Plains Center for BioAssessment (CPCB) sampled Banner Creek Lake, Centralia Lake, and Atchison County Lake (named Clear Creek Lake on some maps) and their tributaries to assess biological impairment due to sedimentation. Three stream sites on Banner Creek were sampled, while two stream sites were sampled on Centralia Lake's tributary Black Vermillion River, and one stream site was sampled on Atchison Co. Lake's tributary Clear Creek (Table 1). The Work Plan provides details about each watershed.

Methods

Sampling Dates

CPCB's first stream sampling event occurred between 1 – 14 July 2010 with lakes sampled July 13 and 14. The second stream sampling period was 6 – 14 October 2010, with lakes sampled October 6 and 7.

Tributary Sampling

Reach Layout. We established three sampling sites along Banner Creek, the tributary to Banner Creek Lake; two along Black Vermillion River, a tributary to Centralia Lake; and one on Clear Creek, the primary tributary to Atchison County Lake. The number of sites in each stream system was limited by the scarcity of permanent flowing water that allowed for macroinvertebrate colonization and water quality sampling at normal flows. While small watershed size typically limits watershed heterogeneity and can reduce sampling efforts, stream systems draining these watersheds often experience intermittent flows and support limited faunal assemblage. Therefore, site selections were limited to stream segments that were least likely to be stressed by low or no flow conditions. At each site, a center transect was marked with flagging tape and latitude and longitude was recorded. A reach length of 20 times the average of five wetted widths was delineated around the center transect, and 10 – 12 transects were laid out and numbered sequentially from downstream to upstream (Figure 2). The establishment of transects along each stream study reach was, in part, to facilitate the sediment depth sampling of the modified V* method used in this study (see Sediment sample section below).

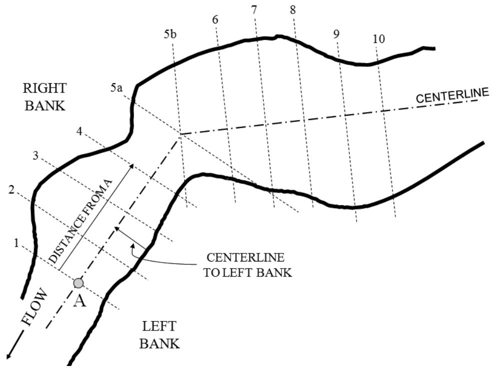

Figure 2. Placement of transects in each stream reach which is 20 times the average wetted stream width. Sediment depths were measured at 10 – 20 locations along each transect using a stainless steel probe.

Water Quality. At the downstream transect (transect 1), before the crew entered the water, a 1-liter surface sample from mid-channel was collected in a labeled amber glass bottle that was preserved on ice and returned to the lab for processing suspended chlorophyll *a*, filtered and unfiltered TN and TP (Ebina *et al.* 1983), TSS, and VSS (APHA *et al.* 2005). Nutrient analyses on unfiltered water samples represented total phosphorus (TP) and total nitrogen (TN). Filtered (0.45 mm, 47 mm diameter glass fiber filter) water samples analyzed for phosphorus and nitrogen represented total dissolved phosphorus (TDP) and dissolved nitrogen (TDN). *In situ* measurements (DO, pH, conductivity, salinity, air and water temperature, and turbidity) were measured with a Horiba U-10 water quality checker at the same location. The Horiba U-10 was two-point calibrated prior to each sampling event. The Horiba and chemistry measurements were taken within two weeks of the habitat, macroinvertebrate, and sediment assessment. The lag period between these measurement efforts were characterized by no runoff events and all were taken at normal flow levels.

Habitat. To assess habitat we used the Habitat Development Index (HDI, Huggins and Moffet 1988) and the Ohio EPA's Qualitative Habitat Evaluation Index (QHEI) (Ohio EPA 2006). The same person evaluated habitat at all sites and all events. Velocity was measured at one transect with a Swoffer flow meter following protocol established by the United States Geological Survey (Rantz *et al.* 1982) and using a form developed for the USEPA National Stream Surveys (USEPA 2007). Digital photos were taken at each site (available upon request).

Sediment Deposition. We examined the extent of sedimentation using a modification of the V* methodology of the U.S. Forest Service (Lisle and Hilton 1992, Hilton and Lisle 1993). By definition V* ("v star") is the ratio of the volume of fine sediment in a pool relative to the total volume of fine sediment and water in the same pool. V* is most appropriately used in permanent pools of stream reaches with riffle-run-pool morphology, hard substrates, and mild gradients, such as Rosgen B2, B3, or C channel types (see Rosgen 1996). However, preliminary work in the sand-bottom streams examined in this study suggested that the majority of pools to be measured were scour pools, where little to no sediment was deposited due to prevailing hydraulic conditions. Instead, the majority of fine sediment deposition appeared to be in stream runs, where flow velocity decreased and larger particles tended to settle to the bottom. Given the proven utility of the V* approach in previous studies, we believe that the V* concept may provide valuable insights into sediment deposition in sand-bottom streams. However, based on our initial findings, we determined that an adaptation of the Lisle and Hilton V* methods would be necessary to describe sediment deposition for these systems.

As a first step, rather than measuring sediment only in pools, we measured the depths of fine sediment and water along each transect of the study reach, including runs, riffles, and bars. Cross-sectional areas and reach volumes were calculated from these measurements (Figures 3 through 5). To account for stream sinuosity, at each bend of the centerline, two transects were placed and the inside angle between them was recorded (see 5a/5b in Figure 2).

Field Measurements

Each site was visited twice, and each site had between 10 and 20 transects. At each transect, a survey rod was placed perpendicularly to the center line of the stream. Starting at the waterline on the left bank, sediment and water depths were measured using a graduated stainless steel probe at 10 to 20 intervals along the survey rod, ending at the waterline on the right bank. For each measurement location, the following data were recorded: distance from the left bank, water depth to the bottom surface, sediment depth, and dominant substrate (sand, silt, clay, cobble, gravel, bedrock, or other). Sediment sizes for dominant substrate were classified using USEPA EMAP methodology (USEPA 2007). In fall sampling events, detritus (e.g., leaf litter, sticks, etc.) covered some portions of the stream bed, and the detritus layer depth was also measured (if greater than > 0.5 cm thick). For purposes of calculation, the detritus layer depth was subtracted from the sediment depth measurement.

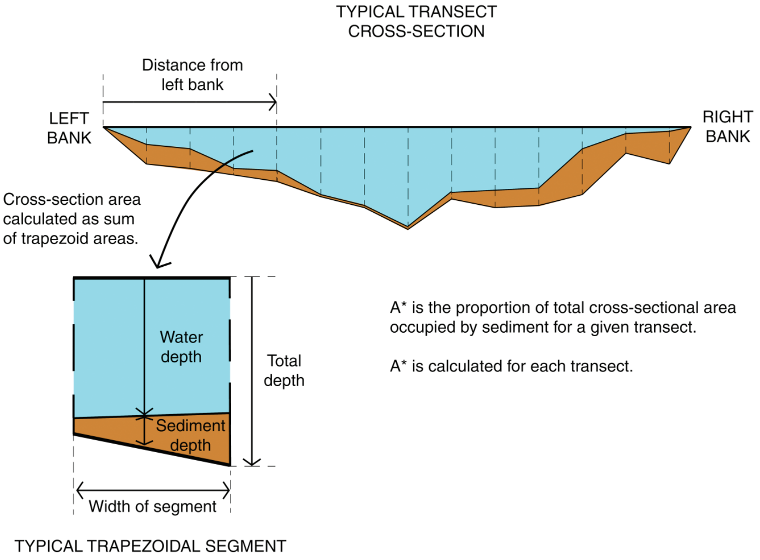

Figure 3. Typical transect cross-section for estimation of stream and sediment volume. Measurements of water depth, sediment depth, and distance from the left bank were used to calculate the area of roughly 10 to 20 trapezoidal segments across the channel. Estimations of total cross-sectional areas were made by summation of the area of these trapezoidal segments.

Calculation of Metrics

Cross-sectional area was estimated as a series of trapezoids, similar to the velocity-area method commonly used in flow calculation (USEPA 2007). Knowing the distance of each measurement from the left bank, the depth of the sediment, and the depth of the water, we were able to estimate the total cross-sectional area of the stream (sediment plus water) and the cross-sectional area of the sediment for each transect. Then, using the spacing between transects, we were able to estimate the sediment volume and total volume of the reach. Both V* (the ratio of the sediment VOLUME to the total VOLUME for each cross-section) and A* (the ratio of the sediment AREA to the total AREA for each cross-section) were subsequently calculated.

Based on these data, five metrics of sediment deposition were calculated to estimate sediment parameters: A*, V*, A*ave, mean A*ave, and mean V*. V* represents the sediment volume across all site transects for one site visit, A* represents the sediment cross-section of one transect for one site visit, and A*ave represents the average of the sediment cross-section for all transects at a site for one site visit. Calculations designated as mean represent the mean for a given metric across multiple site visits.

For a given transect, the cross-sectional area of the sediment and the cross-sectional area of the whole stream are calculated as a sum of trapezoidal areas (Figure 3):

$$A_{sediment} = \sum_{i}^{\textit{number of measurements}} \tfrac{1}{2}(d_{sediment_i} + d_{sediment_{i+1}})(L_{i+1} - L_i)$$

and

$$A_{total} = \sum_{i}^{\textit{number of measurements}} \tfrac{1}{2}(d_{total_i} + d_{total_{i+1}})(L_{i+1} - L_i)$$

where $d_{sediment}$ is the depth of sediment, d_{total} is the total depth, L is the distance from the left bank, and the subscripts i and $i+1$ indicate consecutive measurements along the transect.

A*, the proportion of the cross-sectional area of a transect occupied by sediment, is then calculated for each transect as:

$$A^*_j = \frac{A_{sediment}}{A_{total}}$$

where *j* indicates the transect number for a given site and sampling event.

To estimate the sediment and total volumes of a site, a sum of smaller volumes was calculated. The volume between each transect was calculated by multiplying the area of the downstream cross-section by the spacing between it and the next transect upstream (Figure 4), then these volumes were added to get the total volume estimate for the study reach:

$$V_{sediment} = \sum_{j}^{\textit{number of transects} - 1} (A_{sediment_j})\,(S_j)$$

and

$$V_{total} = \sum_{j}^{\textit{number of transects} - 1} (A_{total_j})\,(S_j)$$

where *j* indicates the transect number for a given site and sampling event, A*j* is the cross-sectional area of transect *j* as calculated above, and S*j* is the distance along the centerline upstream from transect *j* to transect *j+1*. V*, the proportion of site total volume occupied by sediment is then calculated as:

$$V^* = \frac{V_{sediment}}{V_{total}}$$

Additionally, we calculated three summary metrics to represent the ranges of condi-

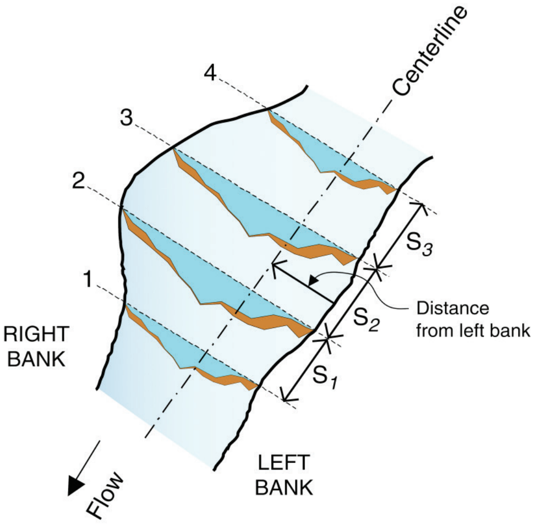

Figure 4. Plan view of transect layout and spacing for use in stream and sediment volume calculations. Distances between transects (e.g., S1, S2, S3) are measured along the established centerline of the stream. Volumes are calculated by multiplying the cross-sectional area of each transect by the spacing to the next transect.

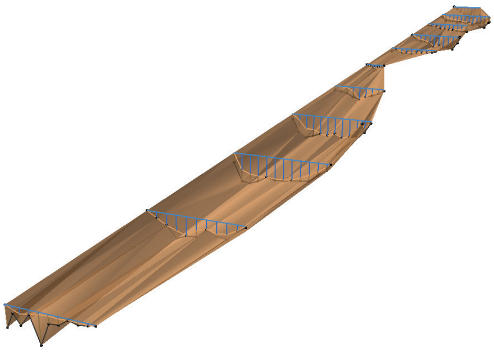

Figure 5. Visualization of sediment thickness, water depth, and transect layout as measured at Clear Creek in July 2010. This illustration reflects spacing, depth, and width, but not direction. Not to scale.

tion that occur for a given site across space and time: A*ave (the average of A* for all transects of a given site for a given sampling event), mean A*ave (the mean of A*ave for all sampling events for a given site), and mean V* (the mean of V* for all sampling events for a given site):

$$A^{*}_{ave} = \frac{1}{n} \sum_{j=1}^{n} A^{*}_{j} = \frac{1}{n}(A^{*}_{1} + A^{*}_{2} + \ldots + A^{*}_{n})$$

$$\text{mean } A^{*}_{ave} = \frac{1}{k} \sum A^{*}_{ave} = \frac{A^{*}_{ave_1} + A^{*}_{ave_2}}{2}$$

$$\text{mean } V^{*} = \frac{1}{k} \sum = (V^{*}_{1} + V^{*}_{2} + \ldots + V^{*}_{k}) = \frac{V^{*}_{1} + V^{*}_{2}}{2}$$

where *j* indicates the transect number, *n* is the number of transects, and *k* indicates the number of visits to the site.

Overall, five metrics of sediment deposition were calculated to estimate sediment parameters: V*, A*, A*ave, mean A*ave, and mean V*. V* represents the sediment volume across all site transects for one site visit, A* represents the sediment cross-section of one transect for one site visit, and A*ave represents the average of the sediment cross-section for all transects at a site for one site visit. Calculations designated as "mean" represent the arithmetic mean of a given metric across multiple site visits.

Macroinvertebrates. HDI protocols were used to collect macroinvertebrate samples. Within the stream reach, an aquatic kick net (500-µm mesh) was used to collect macroinvertebrates from a variety of habitats for a total of three minutes. Habitats within each macrohabitat (i.e. pool, riffle, run, or glide) in each site were subsampled in proportion to occurrence in the site. On bottom substrates, approximately 0.09 m^2 (1ft^2) of substrate was disturbed to a depth of 1-2 cm. A sweep of similar area was used in vegetated habitats, root wads, and areas associated with woody debris. The subsamples from each site were combined into a single sample jar and preserved with 10% buffered formalin and rose bengal solution.

The samples were returned to the CPCB lab for sorting and identification using the CPCB Standard Operating Procedures (SOP). These and other SOPs are available to download from the CPCB webpage at www.cpcb.ku.edu/datalibrary/assets/library/protocols/BenthicLabSOP.pdf. Samples were sorted to remove at least 300 organisms (300 + 10%) from the sample, using a modified Caton gridded tray. Sorted organisms were placed into 80% alcohol for storage and identification to the lowest practical taxonomic level. Macroinvertebrates were identified to the proper taxonomic level described in the SOP for each taxa group. Chironomid and oligochaete specimens were slide-mounted prior to taxonomic identification. References for each taxon are listed in the SOP. Voucher specimens of difficult to identify taxa as well as rare taxa are retained for a minimum of three years after project end dates.

Macroinvertebrate metrics were calculated in Ecomeas 1.6 (http://cpcb.ku.edu/media/cpcb/datalibrary/assets/databases/ecomeas01_6.mdb), a software program developed at CPCB that calculates most commonly used diversity indices and other ecological measures of community structure. Nondistinct taxa were disregarded in the taxa richness calculation so as not to elevate the richness estimates, but were included in the calculation of all other metrics. Metrics calculated and examined included total abundance, taxa richness, richness/abundance, a number of diversity indices, and Fager's Number of Moves (an estimation of alpha diversity). These same metrics were used in examining plankton community differences.

Impoundment Sampling

Water Samples. Throughout the riverine, transitional, and main basin of each lake ten sampling sites were evenly distributed to capture variance in lake conditions. Latitude and longitude of each site was recorded so that re-sampling of these original sites could be easily accomplished. During each sampling event, *in situ* water chemistry (DO, pH, conductivity, salinity, air and water temperature, and turbidity) was measured with a Horiba U-10 water quality checker at each of the ten sites. In addition, Secchi depth measurements were obtained from the shaded side of the boat.

From the ten sampling sites, a main basin site found to be one of the deepest points in each lake was designated for depth profiles of *in situ* chemistry, sediment core sample, a vertical plankton tow and a liter, surface (i.e. 0.25 m depth) grab sample for laboratory analysis obtained with a Van Dorn sampler. . *In situ* measurements a this site were taken at approximately 1 m depth increments to determine if the lake was stratified. If stratified, a bottom water sample was collected with a Van Dorn sampler for laboratory analysis. Additionally, at the larger Banner and Centralia Lakes with larger more defined riverine areas a surface grab sample was also collected from one riverine site in each lake to assess possible spatial difference within lab chemistry. Water samples were transferred to labeled 1-liter amber glass jars, stored on ice, and returned to the CPCB lab for processing of suspended chlorophyll *a*, TP, TDP, TN and TDN (Ebina *et al.* 1983), total suspended solids (TSS), and volatile suspended solids (VSS) (APHA et al. 2005). Inorganic suspended solids measurements (ISS) were calculated as TSS minus VSS. During each sampling event, a duplicate field sample was taken either at a lake or a stream site, as well as a sample in a nutrient-spiked jar. For details regarding accuracy and precision requirements, see EPA Award X7 97703210 QAPP (http://www.cpcb.ku.edu/research/assets/2009MODIS/QAPP_modis_r1_2009Jul25.pdf).

Table 2. Samples collected at each lake during each sampling event in July (Jul) and October (Oct) 2010. One-liter water samples were returned to the CPCB lab for analyses of TN, TP, TDN, TDP, chlorophyll *a*, TSS, and VSS.

	In situ water chemistry		Secchi depth		Primary water samples (1-liter)				Zooplankton tow		Phyto-plankton (1-liter)		Sediment cores	
					Surface		Bottom							
Impoundment	**Jul**	**Oct**	**Jul**	**Oct**	**Jul**	**Oct**	**Jul**	**Oct**	**Jul**	**Oct**	**Jul**	**Oct**	**Jul**	**Oct**
Banner	10	10	10	10	2	2	1	1	1	1	1	1	2	2
Centralia	10	10	10	7	2	2	1	0	1	1	1	1	2	2
Atchison	10	8	10	10	1	1	0	0	1	1	1	1	1	1

Sediment Core Samples. A single sediment core was taken at each primary water chemistry site, kept upright on ice, and delivered to the KU Department of Geography where subsamples (0 – 10, 10 – 20, and 20 – 30 cm depth if possible) were analyzed for particle size, bulk density, TP and TN. Sediment subsamples were sent to Kansas State University for analysis of TP and TN. A total of 10 sediment cores were collected and analyzed during this project.

Zooplankton. A single vertical plankton net tow was conducted at each main basin primary site to collect quantitative samples for zooplankton identification and enumeration. Zooplankton were collected with 80-µm mesh plankton net having a mouth diameter of 20 cm; the sample was transferred to a 500-ml plastic bottle and preserved with 70% ethanol (70 ml of 100% ethanol for each 30 ml of sample volume) then placed in the cooler for transport to the lab for processing. Each vertical tow started approximately 10 cm above the substrate surface and extended to the surface. The tow distance was recorded and the filtered volume of water was calculated for each tow and used to determine the taxon count of organisms per liter.

Zooplankton samples were sub-sampled using a Hensen-Stempel 1 ml pipette. These subsamples were transferred to a 65mm diameter Syracuse glass dish and specimens identified and enumerated at 20-40x magnification, against a black microscope stage. When necessary, multiple subsamples were enumerated until at least 250 individuals, including cladocerans, copepods, and rotifers were counted and the total volume enumerated was then calculated. Cladocerans were identified to species when possible. Copepods were identified to sub-order. Rotifers were identified to phylum. As previously stated, at least 250 individuals were identified from each study sample. All data were recorded on standard datasheets. Once counts were completed, correction factors were calculated for each sample and densities (i.e. numbers per liter) were determined for each of the major groups listed above, based on the original volume of reservoir water filtered in the tow and the total subsample volume used in reaching the ≥250 individual specimen counts (pers.com., A. Dzialowski 2010). Zooplankton metrics were calculated using Ecomeas 1.6.

Phytoplankton. At each main basin primary site, a near-surface (≈ 0.25 m) phytoplankton sample was obtained using a 1.5 L Van Dorn bottle submerged vertically so that the top of the Van Dorn bottle was about 10 cm below the water surface. A 250 or 500 ml sample was preserved with 1 to 3 ml of Lugol's solution. Different water chemistry and densities of algal material require different concentrations of preservative; hence a general guideline was that there be sufficient Lugol's to turn the sample the color of weak tea.

To facilitate phytoplankton enumeration, the preserved field samples were shaken vigorously and 100 ml aliquots were removed and allowed to settle in 100 ml glass beakers. Beakers with samples were covered with Parafilm© and left to settle for two weeks. After two weeks, 80 ml of liquid was pipetted off each sample with a 5 ml pipette, with care taken not to disturb bottom materials, and discarded. The remaining 20 ml was put into a 100 ml bottle for long-term storage and 5 ml of water was added to it. Sub-samples were shaken vigorously for a 25 seconds and then 1 ml, 3 ml, or 5 ml of algal concentrate was settled overnight in 10 cm long fiberglass settling chambers, each with a 12.5 mm diameter opening. For each sample, 50 fields were counted for each sample under 400x magnification on a calibrated Wild Heerbrugg inverted microscope with ocular eyepiece attachment.

Algae were typically identified to genus. Within some genera, distinct species difference were noted and separate species were assigned a species number (e.g. *Scenedesmus* sp. 1, sp. 2, sp. 3).

Results and Discussion

Our assessment of the potential impact of erosion and sedimentation within the stream and reservoirs of this study was based on the a priori assumption that the Banner Creek watershed represented a reference condition in regards to upland soil loss and sedimentation of aquatic ecosystems. The recognition of Banner watershed as a reference watershed and both Atchison and Centralia reservoir watersheds as sediment-impaired watersheds in general comes from past information and data collected by various agencies and organizations over the past several decades. In fact, all studies conducted as part of this "Baseline Sediment Studies" effort were, in part, designed around these past determinations and the current a priori assumption that good land management and limited cultivation lends itself to reduced sediment loading to aquatic ecosystems. Our study attempted to identify the relationship between sediment losses, stream loadings (reference vs. non-reference watersheds), and changes in the aquatic biological quality of streams and impoundments located within the same drainage areas.

In presenting our results we first compared the water quality and sediment quality/quantity in both the streams and impoundments that comprise both watershed groups (reference vs. non-reference treatments). Treatment group comparisons were the only way we could achieve a large enough sample size (≥ 3 samples) to perform standard parametric statistical comparisons. Our assumption was that a number of key water quality indicators such as turbidity, TSS, VSS, ISS (TSS - VSS), and nutrients would be lower in Banner Creek watershed samples, reflecting better overall water quality. In addition we also expected that biological community metrics showing a more diverse community composed of a large number of sensitive species would be found in the Banner Creek ecosystems. Both one- and two-way GLM ANOVAs were performed on most water quality metrics calculated for impoundments and streams (Hintze 2004). However, only the stream macroinvertebrate metrics could be statistically analyzed since just two phytoplankton and two zooplankton samples were collected during the study.

Stream and Impoundment Water Chemistry

One-way ANOVAs (i.e. season or reference/nonreference) for stream and impoundment water chemistry showed few significant differences except for season and nutrients. Seasonal differences were limited to water temperature and pH for streams and impoundments, while stream salinity and impoundment dissolved oxygen values also varied seasonally. These differences were expected considering the temporal span between sampling events and the close relationship of these parameters with air temperature, hydrology, and normal biological phenology. Nutrients variables (TP, TDP, TN and TDN) were typically lower in the reference (Banner Creek) ecosystems. Two-way ANOVAs that considered both time and treatment differences together showed similar results to those of the one-way ANOVAs. Except for the significant interaction terms between time and treatment for water temperature, pH, and salinity in stream samples, no other interactions were found to be significant. These findings allowed us to combine the seasonal data for those variables of most interest (e.g. nutrients, turbidity) and calculate one-way ANOVAs using all measurements for these variables. These results were similar to both the original one-way and two-way ANOVAs (Table 3).

Overall, water samples from the Banner Creek stream sites had lower nutrient concentrations than stream sites in the two nonreference watersheds for both total and dissolved forms (Figure 6). Examination of these box plots suggest that most all of the nitrogen in these streams is in a dissolved form (TDN), probably as nitrate nitrogen. However, based on differences between the median and geometric mean values for TP and TDP, it appears that more than one-half (about 54%) of the phosphorus in these streams is in a particulate form. While there were no statistical differences between reference and nonref-

Table 3. Results of Analysis of Variance (ANOVA) tests for treatment effects (i.e. reference vs. non-reference) for various stream and impoundment chemistry parameters. Significantly ANOVA models are noted in bold print. The last column "Difference in mean values" shows actual differences in non-reference mean values when compared to reference mean values for significant models where + indicates and increase and – a decrease in mean values.

Waterbody	Parameter	n	p	F-ratio	Difference in mean values
Stream	Turbidity	12	0.44	0.64	
Stream	TSS	12	0.30	1.22	
Stream	VSS	12	0.43	0.68	
Stream	ISS	12	0.29	1.22	
Stream	**TDP**	**12**	**0.00**	**12.91**	**+ 87.2 μg/L**
Stream	**TP**	**12**	**0.00**	**15.36**	**+ 163.1 μg/L**
Stream	**TDN**	**12**	**0.00**	**14.86**	**+ 1,823.8 μg/L**
Stream	**TN**	**12**	**0.00**	**20.93**	**+ 2,063.0 μg/L**
Lake	**Turbidity**	**99**	**0.01**	**6.79**	**+ 38.9 NTU**
Lake	TSS	13	0.20	1.90	
Lake	VSS	13	0.07	3.97	
Lake	ISS	13	0.20	1.87	
Lake	TDP	13	0.07	4.01	
Lake	TP	13	0.08	3.81	
Lake	**TDN**	**13**	**0.01**	**10.12**	**+ 997.2 μg/L**
Lake	**TN**	**13**	**0.00**	**22.67**	**+ 1,164.9 μg/ L**

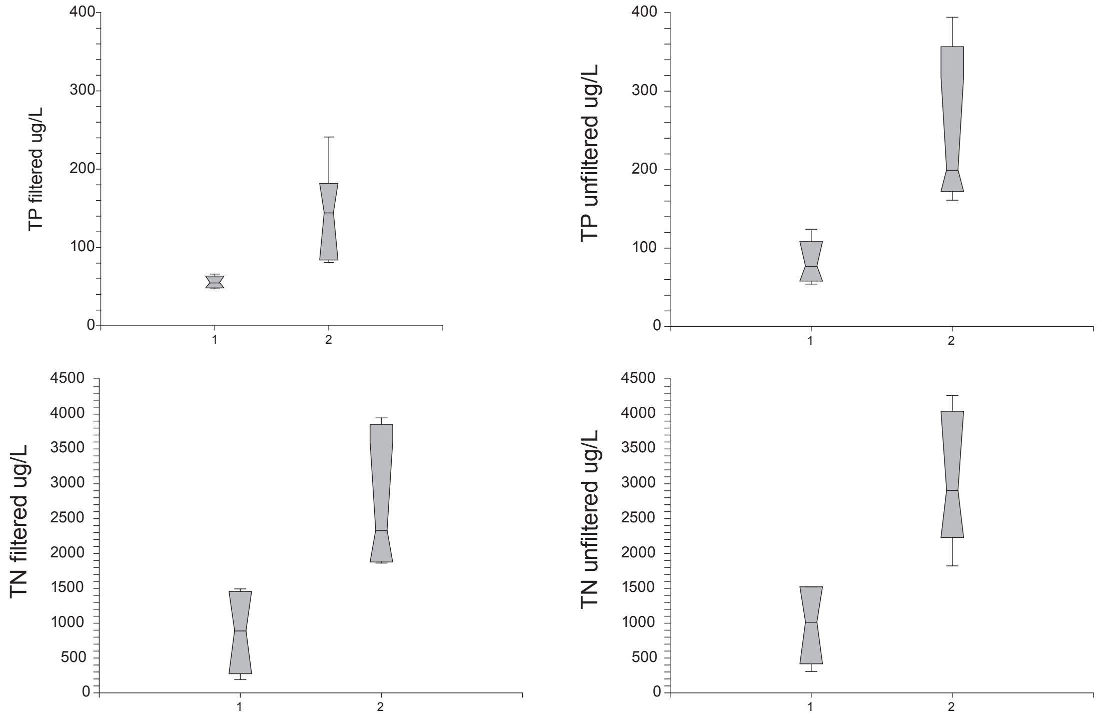

Figure 6. Box plots of total phosphorus and nitrogen concentrations in both filtered and unfiltered water samples from reference (1) and (2) stream sites.

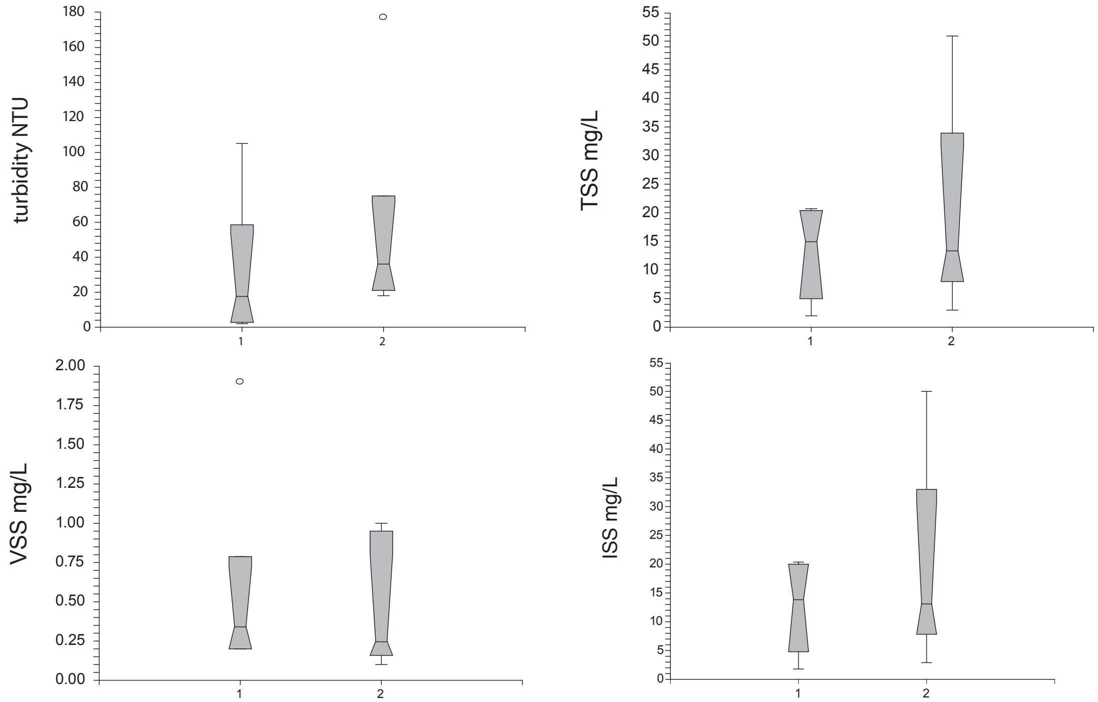

Figure 7. Box plots of turbidity TSS, VSS, and ISS concentrations in water samples from reference (1) and non-reference (2) stream sites. A single outlier TSS value (352 mg/L) was removed from the non-reference group because of suspected bottom disturbance by the Horiba Water Checker® sonde during *in situ* sampling.

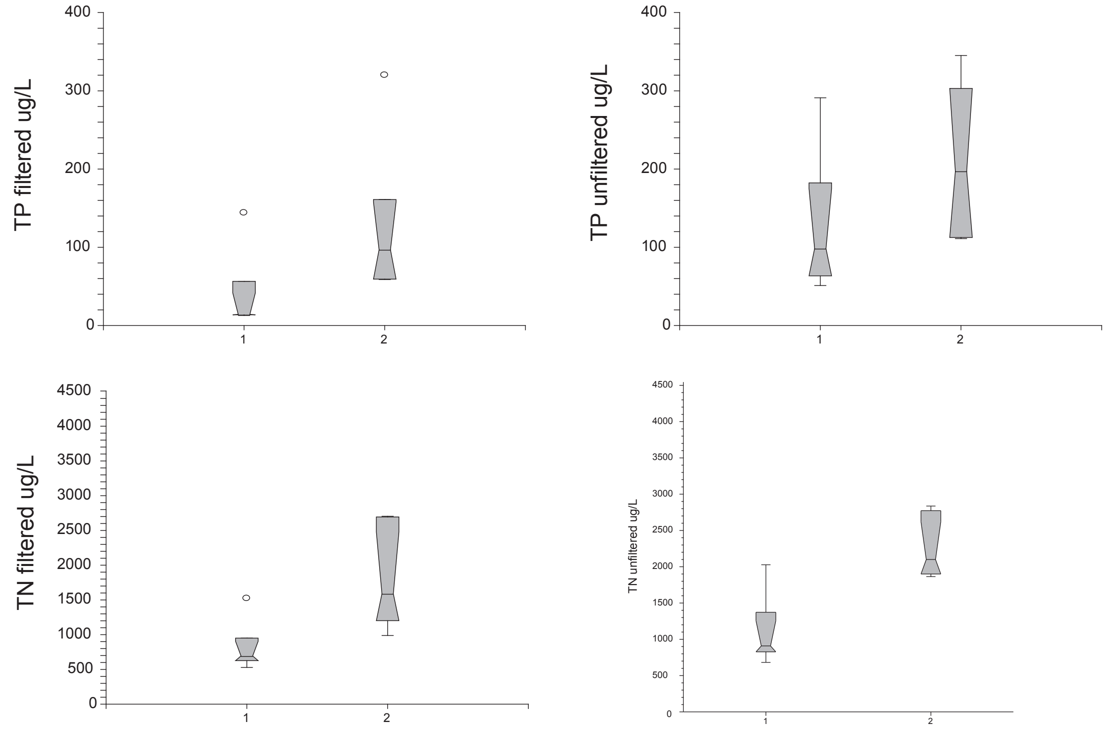

Figure 8. Box plots of total phosphorus (TP) and total nitrogen (TN) concentrations in both filtered and unfiltered water samples from reference (1) and non-reference (2) impoundment sites.

erence, box plots of turbidity, TSS, VSS, and ISS suggest that while turbidity was somewhat lower in the reference stream, all forms of suspended solids were higher (Figure 7). It would seem that most TP in these streams is attached to suspended material (e.g. sediment, fine particulate organics), and that the higher non-reference TP values are due to the amount of TP attached to suspended material and not the amount of sediment itself.

Two-way ANOVA results for lakes indicated that there were significant interactions between sampling period and treatment for water temperature, conductivity, turbidity, pH, TN and TDN. Again while we could expect all measured parameters to show seasonal differences, the significant interaction term associated with the above parameters suggests the occurrence of a time/treatment effect that could influence the direct interpretation of both factors (time and treatment effects). However, the ANOVA outcomes for impoundments tend to be supported by box plots for these and other parameters (Figures 8 and 6) and by previously noted differences in stream values. Only turbidity and TN were found to be significantly different in impoundment groups (Table 3), which is similar to the finding for the streams, where turbidity was not significant but was generally lower in the reference stream (Figure 7). Box plot results for TN and TDN show a distinct separation in reference and non-reference values. A similar pattern was observed for TP and TDP, but with a larger overlapping data cloud (Figure 8). Impoundment turbidity was very different between reference and non-reference groups. While the median values for TSS, VSS, and ISS were also noticeably different between groups,

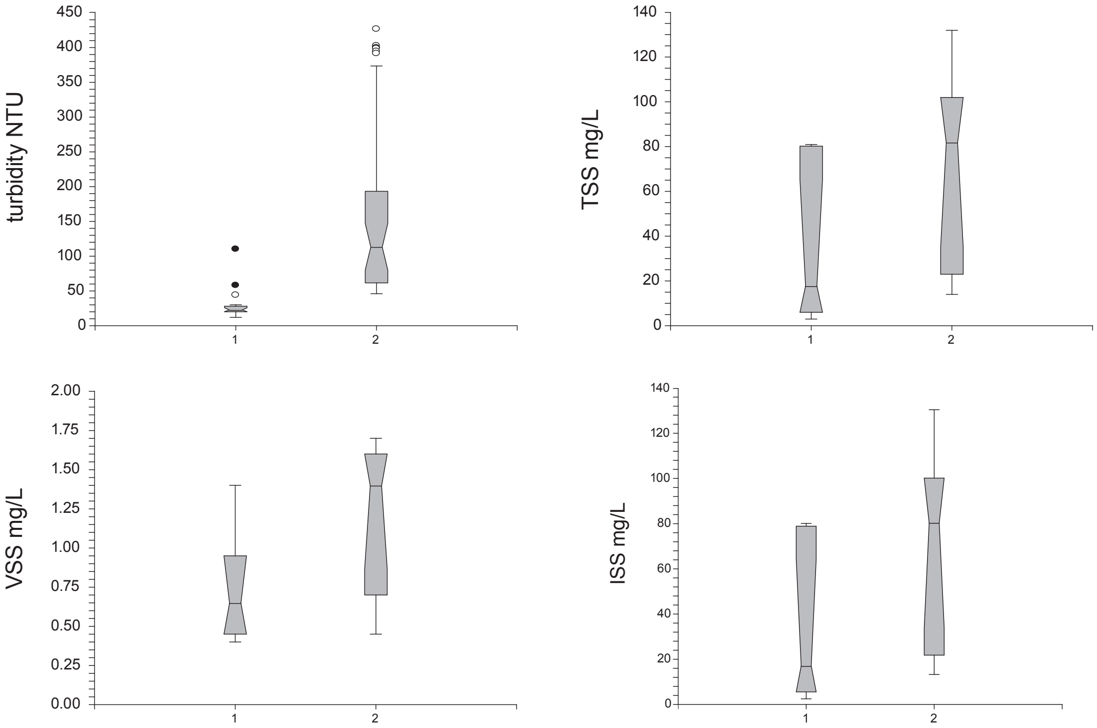

Figure 9. Box plots of turbidity, total suspended solids (TSS), volatile suspended solids (VSS), and inorganic suspended solids (ISS) concentrations in water samples from reference (1) and non-reference (2) impoundment sites.

individual measurements were highly variable causing the upper and lower quartiles to broadly overlap (Figure 9). It should be noted that nearly all the TSS measured in these impoundments was ISS and probably represented eroded and resuspended soils and other inorganic materials.

In general, reference stream nutrient concentrations at normal flows were a good predictor of impoundment nutrient concentrations (Table 4). All significant models in Table 4 were positively related to the independent variable that comprised the simple regression models. These findings suggest that nearly all of the nutrient load is being delivered to these impoundments. However, stream turbidity, TSS, VSS, and ISS were not related to impoundment measures of these same parameters suggesting that impoundment characteristics and dynamics (e.g. mean depth, mixing) may be as important of determinants as incoming stream concentrations in regards to these parameter concentrations.

A number of significant robust regression models were found in which both phosphorus and nitrogen variance could be explained by TSS or VSS (Table 4). The best models for impoundment phosphorus were generated when impoundment VSS or TSS was used as the independent with as much as 81% of the variance in TP being explained by VSS alone. Similarly a portion of the variance in impoundment TN could be explained with impoundment VSS and TSS. The model with the highest R^2 (0.87) was the model where the dependent was TDN and VSS was the independent variable. In addition VSS and TSS were both good predictors of impoundment TN. No sig-

Table 4. Robust regression information for significant models (alpha = 0.05) except for the model where impoundment TP is the dependent and stream TP is the independent which had a p value of 0.06. However this model was thought to be biologically significant and the p value just failed the alpha value cutoff so it was included for discussion.

Dependent variable	Independent variable	N	Model p value	Intercept p value	Relationship	R^2
Impoundment TP	Stream TP	12	0.06	0.11	+	0.31
Impoundment TN	Stream TN	12	0.00	0.00	+	0.64
Impoundment TSS	Stream TSS	12	0.41	0.00	+	0.07
Impoundment TP	Impoundment VSS	11	0.00	0.97	+	0.81
Impoundment TDP	Impoundment VSS	12	0.00	0.19	+	0.69
Impoundment TP	Impoundment TSS	11	0.00	0.00	+	0.70
Impoundment TDP	Impoundment turbidity	13	0.00	0.00	+	0.55
Impoundment TDN	Impoundment VSS	9	0.00	0.02	+	0.87
Impoundment TN	Impoundment VSS	12	0.00	0.19	+	0.75
Impoundment TDN	Impoundment TSS	12	0.00	0.00	+	.79
Impoundment TN	Impoundment TSS	13	0.00	0.01	+	0.58

Table 5. Results of Analysis of Variance (ANOVA) on core samples from impoundments draining reference/non-reference watershed ecosystems as the treatment groups. Significant differences ($p<0.05$) between treatment groups were found for those parameters in bold. A filter was also applied to restrict analysis to the first 10 cm of the sediment cores. The last column "Difference in mean values" shows actual differences in nonreference mean values when compared to reference mean values for significant models where + indicates and increase and – a decrease in mean values

Parameter	n	p	F-ratio	Filter	Difference in mean values
Bulk Density	26	0.82	0.05	none	
% clay	26	0.20	1.78	none	
% silt	**26**	**0.03**	**5.13**	**none**	**–12.2 %**
% sand	26	0.28	1.21	none	
TN	26	0.13	2.40	none	
TP	26	0.09	3.19	none	
Bulk Density	10	0.86	0.03	top 10 cm	
% clay	10	0.47	0.57	top 10 cm	
% silt	10	0.21	1.86	top 10 cm	
% sand	10	0.28	1.32	top 10 cm	
TN	10	0.43	0.69	top 10 cm	
TP	10	0.27	1.39	top 10 cm	

nificant TN model could be found when impoundment turbidity was used as the independent variable.

Impoundment Sediment

Lake sediment core samples were taken at one or two sites per lake and analyzed in 10 cm segments. Only % silt in all the core segments differed based on reference condition (p=0.03). The remainder of the parameters did not differ between reservoir groups (reference vs. non-reference) amongst either all the depths of the cores or when restricted to just the first 10 cm (Table 5).

Interestingly, Banner Reservoir sediment had a significantly higher percentage of silt than the non-reference impoundments thus the negative 12.2% in mean values for silt between reference and non-reference groups (Table 5), although there was considerable spread in the silt values within treatments (Figure 10). This significant difference in silt did not occur when considering only the upper 10 cm of the core length. Banner Reservoir is a much younger impoundment than the non-reference impoundments, which might have affected the overall contribution of silt to the cores that were taken.

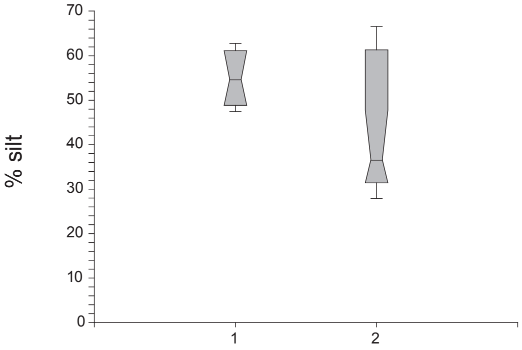

Figure 10. Box plot of % silt in core samples from reference (1) and non-reference (2) impoundments.

We also tested (one-way ANOVAs where seasonal data was combined) for differences between impoundment core locations (i.e. main basin vs. riverine segment). ANOVA tests on total core values indicated that there were significant differences between basin and riverine mean values for all parameters listed in Table 4. It appears that TP, TN, and % clay values are higher in the basin while mean values for bulk density, % silt, and % sand were higher in the riverine segment.

Analyses of relationships within sediment core properties revealed several interesting relationships between physical properties of the sediment and nutrients. Bulk density was positively related to the percent of sand and silt but negatively related to clay (Table 6). The best predictor of sediment TP and TN was % clay, then bulk density. While % clay and bulk density are highly related to each other, the % clay explained more of the variance of both TP and TN. Phosphorus is often observed bound to clay particles in runoff and stream flows (e.g. Ulen 2003, Schroeder *et al.* 2004). Danish researchers (de Jonge *et al.* 2004) found that particulate inorganic phosphorus (PIP) positively correlated with clay content while dissolved inorganic phosphorus (DIP) was negatively related to clay, suggesting that the sediment TP in our impoundments might be mostly PIP.

No meaningful relationships (i.e. robust regression) or correlations (i.e. Pearson's correlation coefficient) were found between impoundment water chemistry and core chemistry. Stream chemistry also was not related to core chemistry except for some weak correlations ($r \leq 0.61$)

Table 6. Robust regression information for significant sediment core models (alpha ≤ 0.05) of bulk density and nutrients.

Dependent variable	Independent variable	n	Model p value	Intercept p value	Relationship	R^2
Bulk density	% Sand	26	0.00	0.00	+	0.76
Bulk density	% Silt	25	0.00	0.00	+	0.82
Bulk density	% Clay	25	0.00	0.00	–	0.83
TP	Bulk density	25	0.00	0.00	–	0.90
TP	% clay	26	0.00	0.01	+	0.94
TN	Bulk density	26	0.00	0.00	–	0.71
TN	% clay	25	0.00	0.02	+	0.88

between stream TDP and % clay (positive) and silt (negative). Though clay and silt have both been related to particulate phosphorus, it is difficult to determine whether those relationships extend to dissolved phosphorus in these systems given the limited number of samples available.

Stream Sediment Volumes

Originally we calculated only the V* values for each stream segment studied, but later we also calculated two other related variables. This was done to investigate the inter-relationships between these variables and their potential relationship(s) other stream factors. These stream bed variables were V* (the calculated ratio of reach sediment volume to total reach volume), A* (the calculated ratio of cross-section sediment area to cross-section total area), and the final A*ave value (average of ratios for all cross-sections in a particular stream segment). We expected these variable values to be lower in the reference watershed stream (Banner Creek) assuming that this stream would receive less sediment input and retain less sediment in the wetted channel. As expected, V* and A*ave were highly correlated ($r = 0.83$, $p = 0.00$), but both were used to explore possible relationships with other stream or lake variables. Interestingly, Banner Creek had the two highest V* and A*ave values which was unexpected but was the result of the inclusion of measures of loose, unconsolidated sand throughout most of the open channel flow areas (Table 7). Consistently high V* values in Banner Creek contributed to a significant one-way ANOVA for treatment effects (reference vs. non-reference) when using V* as the response variable ($p = 0.02$) but not when A*ave was used ($p = 0.09$). This may or may not indicate that these two stream bed factors are measuring different bed phenomena.

Interpretation of Table 7 and ANOVA results suggest that the reference stream had more unconsolidated material occurring in its wetted channel than did the non-reference stream channels. It should be noted that the material stored in the non-reference stream segments was almost all soft silt while the reference bed materials were mostly sand. If we consider that the historic stream condition in this region was a primarily sandy-bottom substrate, then Banner Creek might still be thought of as a reference stream. However, we did not find difference in variables that, in

Table 7. Mean values for V* and A* variables from each sampling events, with events ranked from low to high by V*.

Stream system and site	Reference or Non-reference	Sampling event	V* rank	V*	A* average
Clear Creek Site 1	Non-ref	July	2	0.24	0.28
Clear Creek Site 1	Non-ref	October	1	0.17	0.23
Banner Creek Site 1	Ref	July	10	0.40	0.41
Banner Creek Site 1	**Ref**	**October**	**11**	**0.48**	**0.66**
Banner Creek Site 2	Ref	July	7	0.32	0.33
Banner Creek Site 2	**Ref**	**October**	**12**	**0.64**	**0.60**
Banner Creek Site 3	Ref	July	9	0.37	0.36
Banner Creek Site 3	Ref	October	5	0.29	0.30
Black Vermillion Site 1	Non-ref	July	8	0.33	0.34
Black Vermillion Site 1	Non-ref	October	3	0.25	0.25
Black Vermillion Site 2	Non-ref	July	4	0.26	0.37
Black Vermillion Site 2	Non-ref	October	6	0.32	0.42

part, represented suspended sediment and other matter (TSS, VSS, ISS, turbidity), suggesting that these streams do not differ in respect to suspended sediment (see Table 3). Additionally, we expect TSS, VSS, and turbidity to increase with the volume of unconsolidated sediment on the streambed as measured by V* and A* ave. This was not the case as both V* and A*ave were not significantly correlated (Pearson and Spearman correlations, alpha = 0.05) with any of the suspended sediment measures including turbidity.

In summary, V* and A*ave show little relationship to either traditional measures of suspended sediment or reference condition, if Banner Creek is in fact a reference stream with regards to geomorphology and substrate condition.

These stream bed variables did seem to be marginally related to impoundment chemistry (Table 7), but these relationships may not be causal and only two were significant ($p \leq 0.05$). Both mean V* and A*ave were significantly and negatively

correlated with TP and turbidity in study impoundments.

We also examined the relationships between mean V* and A*ave and stream nutrients. Using both Pearson (parametric) and Spearman (nonparametric) correlations, we found that both correlation methods indicated that V* was significantly correlated to both stream TP and TN values. Spearman correlations using ranked data found that TDP, TP and TN were significantly correlated with mean V* values (Figure 11). As with Pearson correlations, significant Spearman correlations were negative in nature with r values that varied from -0.57 (V* and TN) to -0.73 (V* and TP). None of these correlations may represent causal relations, but may only be predictive associations since it is difficult to understand why phosphorus and nitrogen values would rise when V* values decrease or conversely why stream nutrients would decrease with increases in V* values. It might be that TP and TN values go down in streams because of settling of particulates that increase the V* estimates since the TP and TN values were most strongly correlated with V*.

Lastly, the relationship between V* and impoundment TP values might be related to the fact that V* shows the same relation with stream TP and stream values have already been determined to be good predictors of impoundment nutrients, although marginally for TP (see Table 4).

Phytoplankton (Impoundments)

A number of phytoplankton metrics were calculated from the impoundment samples taken during the course of this study (Table 9). Because only two samples were available for each impoundment, only a visual comparison of the data was attempted. In general, Banner Reservoir had consistently higher total abundance, taxa richness, and diversity values. The highest Shannon and Brillouin's diversity index values were noted in Atchison in July while the highest total abundance was in Centralia Reservoir. Typically, summer community metric values were higher than those for October samples. Based on taxa richness and consistently higher diversity values, it is tempting to say that Banner Reservoir has a more diverse phytoplankton community compared to the two other impoundments.

When we examined the ratio of cyanobacteria cells to total algal cell counts we found that Banner Creek Reservoir samples had over 75% (i.e.78 – 79 %)

Table 8. Pearson correlation coefficients between mean V* and A*ave values and mean impoundment nutrient and turbidity values.

Impoundment parameters	**Mean V***		**Mean A*ave**	
	r	**p**	**r**	**p**
TDP (µg/L)	-0.56	0.25	-0.55	0.26
TP (µg/L)	**-0.90**	**0.01**	**-0.86**	**0.03**
TDN (µg/L)	-0.70	0.12	-0.66	0.16
TN (µg/L)	-0.77	0.08	-0.70	0.13
Turbidity (NTU)	**-0.80**	**0.05**	**-0.74**	**0.09**

of all algal cells that were cyanobacteria taxa. Both non-reference impoundments experienced at least one high cyanobacteria event (i.e. July). The summer sample for Atchison was 33% cyanobacteria while the summer sample for Centralia was 99% cyanobacteria. It appears that high cyanobacteria abundances can be common in all impoundments.

Lastly, a one-way ANOVA test, where data from all dates was used, indicated no significant difference in the mean concentrations of chlorophyll *a* between reference and non-reference impoundments. However, it should be noted that the mean chlorophyll *a* value for Banner Creek Reservoir was 25 µg/L compared to the non-reference mean of 18 µg/L. Robust regression produced three significant models when nutrient variables were used as the independent variable, but neither turbidity, TSS, VSS, or ISS values were found to explain any chlorophyll *a* variance. The best chlorophyll model was with TN as the independent variable. TN explained about 73% of the chlorophyll variability and was negatively related to chlorophyll concentrations. This relationship is difficult to explain biologically and may only represent a correlative agreement between measured variables. The other chlorophyll *a* model of interest was when TP was used as the independent variable and had a R^2 value of 0.39. This model indicated that TP had a negative relationship with chlorophyll similar to the TN model.

Interestingly, stream chlorophyll a showed relationships with both stream nutrients and TSS, VSS, and ISS (Table 10). All of the suspended solids models had R2 values greater than 0.99 and positive relationships with chlorophyll a. Dissolved nutrient model R2 values were not as strong, with total dissolved (i.e. filtered) phosphorus values explaining over 80% of the recorded variation in chlorophyll a concentrations and TDN explaining 60%.

Table 9. Community metric values for phytoplankton samples taken during the two periods for reference and non-reference impoundments. All phytoplankton grab samples were taken at the surface (0.25m) at the deepest station within the main basin.

	Atchison		**Banner**		**Centralia**	
Metric	**13 Jul 2010**	**7 Oct 2010**	**14 Jul 2010**	**7 Oct 2010**	**13 Jul 2010**	**6 Oct 2010**
Total Abundance	66,039	9,811	1,279,716	439,620	3,171,697	20,440
Taxa Richness	14	9	35	24	14	12
Gleason's Index	2.90	2.25	5.73	4.25	2.15	2.78
Margalef's Index	1.17	0.87	2.42	1.77	0.87	1.11
Menhinick's Index	0.05	0.09	0.03	0.04	0.01	0.08
McIntosh's Index	0.61	0.45	0.47	0.53	0.12	0.57
Simpson's Index	0.15	0.31	0.28	0.22	0.77	0.19
Simpson's Compliment	0.85	0.69	0.72	0.78	0.23	0.81
Simpson's Reciprocal	6.60	3.23	3.55	4.48	1.30	5.22
Shannon's Index (H')	0.95	0.66	0.87	0.87	0.25	0.82
Standard Deviation	5,184	1,547	110,472	39,069	733,716	2,028
Brillouin's Index	0.95	0.66	0.87	0.87	0.25	0.82

Table Table 10. Robust regression information between chlorophyll a, total nitrogen (TN) and phosphorus (TP), and measures of suspended solids TSS, VSS, and ISS.

Dependent variable	Independent variable	N	Model p value	Intercept p value	Relationship	R^2
chlorophyll *a*	TSS	12	0.0000	0.2149	+	0.9923
chlorophyll *a*	VSS	10	0.0000	0.0267	+	0.9911
chlorophyll *a*	ISS	12	0.0000	0.2483	+	0.9925
chlorophyll *a*	TN (filtered)	10	0.0084	0.2946	+	0.6017
chlorophyll *a*	TP (filtered)	10	0.0003	0.1775	+	0.8197
TSS	VSS	10	0.0000	0.0010	+	0.9988
TSS	ISS	10	0.0000	0.0008	+	1.0000
VSS	TSS	10	0.0000	0.0008	+	0.9988
VSS	ISS	10	0.0000	0.0008	+	0.9987
ISS	TSS	10	0.0000	0.0008	+	1.0000
ISS	VSS	10	0.0000	0.0010	+	0.9987

Table 11. Community metric values for zooplankton samples taken during the two periods for both reference and non-reference impoundments. All zooplankton tows were taken at the deepest station within the main basin.

	Atchison		Banner		Centralia	
Metric	13 Jul 2010	7 Oct 2010	14 Jul 2010	7 Oct 2010	13 Jul 2010	6 Oct 2010
Total Abundance	n/a	n/a	n/a	n/a	n/a	n/a
Taxa Richness	8	9	6	4	7	6
Gleason’s Index	3.31	3.70	2.48	1.65	2.90	2.48
Margalef’s Index	1.26	1.43	0.90	0.54	1.08	0.90
Menhinick’s Index	0.50	0.55	0.37	0.25	0.43	0.37
McIntosh’s Index	0.55	0.61	0.45	0.33	0.41	0.37
Simpson’s Index	0.24	0.18	0.33	0.47	0.38	0.42
Simpson’s Compliment	0.76	0.82	0.67	0.53	0.62	0.58
Simpson’s Reciprocal	4.24	5.66	2.99	2.13	2.62	2.36
Shannon’s Index (H’)	0.73	0.80	0.54	0.40	0.47	0.47
Standard Deviation	33	25	48	71	52	59
Brillouin’s Index	0.70	0.77	0.52	0.39	0.46	0.46

n/a = not applicable since only a subsample of about 250 individuals were identified to calculate metrics.

Typically TP is noted to be the limiting nutrient in aquatic ecosystems in our region which is probably the reason TP produced a more explanative model than TN (filtered).

While TSS, VSS, and ISS are all highly correlated with each other (R2 >0.99) nearly all of the suspended solids are ISS (e.g. soils, minerals). However, the most likely meaningful biological model is between VSS as an independent measure of organic matter (e.g. algal biomass) and chlorophyll a concentration as the dependent variable.

Zooplankton (Impoundments)

Zooplankton community diversity and richness were higher in both non-reference impoundments, although some of these differences were relatively small (Table 11). Atchison "lake" had the highest taxa richness (8-9) while Banner had the lowest (4-6), with Centralia falling in between these values. The more commonly used diversity indices (e.g. Gleason's, Margalef's, Shannon's and Brillouin's) suggested that zooplankton diversity with both non-reference impoundments were higher than those for Banner Creek Reservoir except for the two information-based indices (i.e. Shannon's and Brillouin's), which were slightly higher in July than those in Centralia for this same time period.

Macroinvertebrates (Streams)

Macroinvertebrates were collected from all stream sites while QHEI and HDI were concurrently evaluated. The two highest HDI scores were on Banner Creek, but otherwise no significant HDI relations between reference versus non-reference stream samples were observed (p=0.35). However Banner Creek had significantly higher QHEI scores than the non-reference stream sites (p=0.001). QHEI is an index that is scaled to evaluate fish habitats, thus large stream reaches included large habitat parameters such as percent fish cover, stream depth, canopy cover, while HDI was developed to evaluate macroinvertebrate habitats actually collected as part of the macroinvertebrate sampling process. Thus the HDI is focused on small scale features sampled for macroinvertebrates such as leaf packs, root wads, macrophytes, and algal mats (Huggins and Moffet 1988).

Assuming similar water quality condition exists in all study reaches (which is not true), we would expect most macroinvertebrates indices to mirror habitat indices (e.g. high habitat richness —>high taxa richness). As with HDI, one-way ANOVA (seasonal data collections were combined) results revealed that indices did not differ between reference and non-reference sites (alpha = 0.05, Table 12). Black Vermillion site 2 in October had the highest values for taxa richness and also for Gleason's, Margalef's and Menhinick's diversity indices. When this site is filtered from analyses, ANOVA tests indicated that there was a difference in these scores based on reference condition (see filter = yes, Table 12). However, we have no statistical or biological reason for removing this site and date from the analysis other than to show that biologically this non-reference site was more like reference sites.

Examination of box plots (Figure 11) for selected macroinvertebrate metrics indicates that there was considerable variability within treatment groups (i.e.

Table 12. ANOVA tests results for treatment effects (reference condition and non-reference) for stream habitat and macroinvertebrate indices, with count of samples (n), p value, F-ratio, and degrees of freedom (DF). The last column "Difference in mean values" shows actual differences in non-reference mean values when compared to reference mean values for significant models where + indicates and increase and – a decrease in mean values.

Parameter	n	p	F-ratio	filter	Difference in means values
HDI	12	0.35	0.95	none	
QHEI	12	0.00	19.93	none	+14.0
Gleason's	12	0.20	1.91	none	
Margalef's	12	0.20	1.90	none	
Menhinick's	12	0.18	2.10	none	
Richness:Abundance	12	0.16	2.34	none	
Taxa richness	12	0.22	1.69	none	
HDI	11	0.24	1.58	yes*	
QHEI	11	0.00	15.49	yes*	+13.3
Gleason's	11	0.01	12.63	yes*	+3.3
Margalef's	11	0.01	12.63	yes*	+1.4
Menhinick's	11	0.01	12.43	yes*	+0.12
Richness:Abundance	11	0.01	11.38	yes*	+3.0
Taxa richness	11	0.01	11.46	yes*	+8

* Excluded Black Vermillion Site 2 for October sample period.

reference, non-reference) which may have been due to the combining of seasonal samples as well as within treatment group macroinvertebrate habitat variability. The relationship between HDI scores and most diversity and richness measures is often quite strong and positive for indices that have positive scales (see Figure 12).

It has already been noted that significant differences for most macroinvertebrate metric values occurred between reference and non-reference stream groups if one of the non-reference site values was removed from the analysis (Table 12). The means for these metrics indicated that the reference stream often had higher taxa diversity and more taxa than did the non-reference streams. These results also suggested that for the most part there were little or no overall habitat differences between these treatment groups. Robust regression analyses indicated that these macroinvertebrate metric differences were not related to V*, A*ave, TSS, VSS, or turbidity, but were significantly related to stream nutrients (Table 13). TDP was found to be a significant independent variable in only two of the three metrics listed in Table 13. Both the Taxa Richness and Gleason's Index models included TDP but similar models using TP were produced, however, these models fall short of being significant ($p \approx 0.06$). Most of these regression models were models that identified both TN and TDN as a significant independent variable that explains 50 – 60% of the variance in richness, Gleason's, and Shannon's diversity index values. All simple regression models generated in examining the rela-

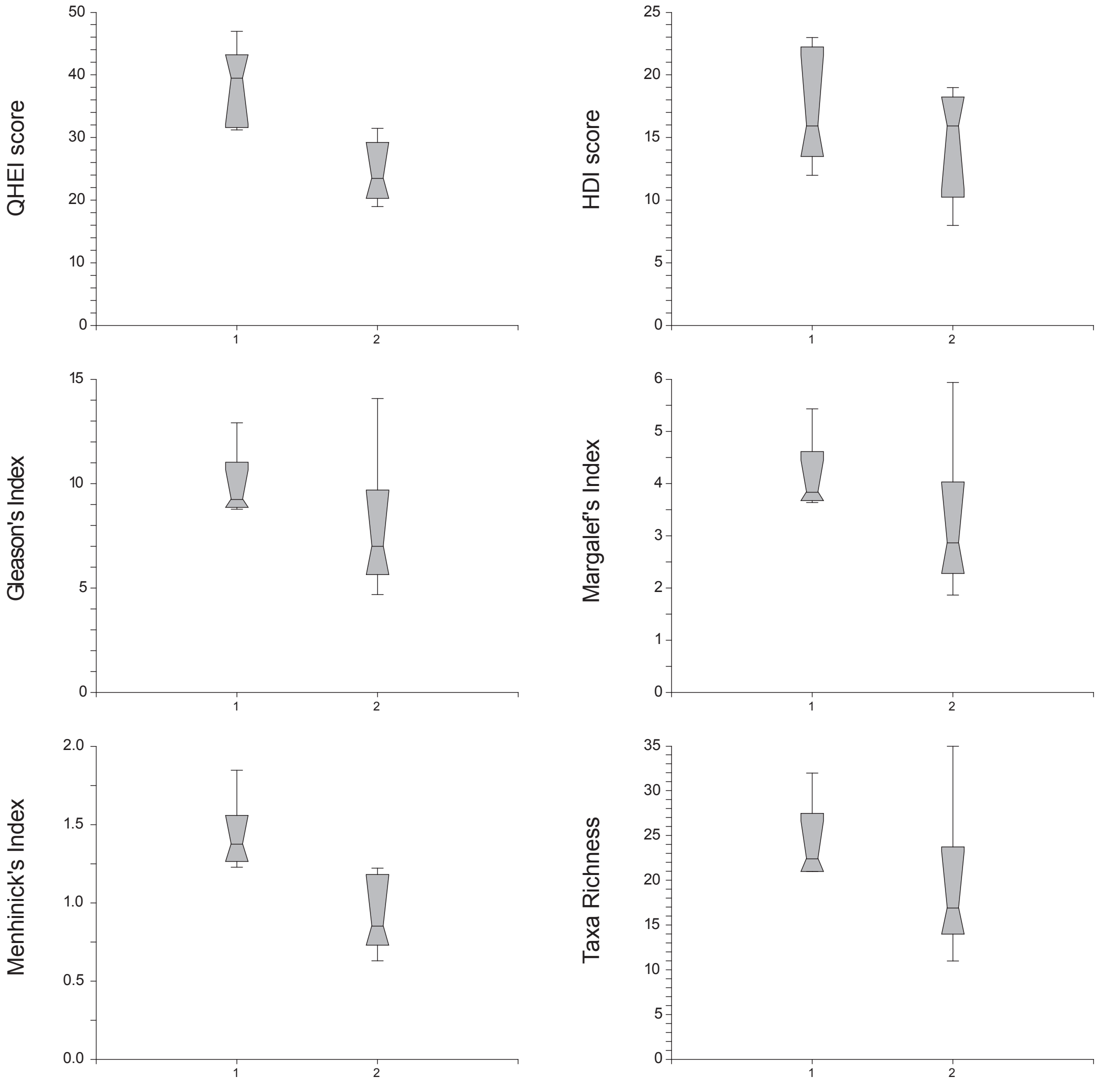

Figure 11. Box plots of habitat and selected macroinvertebrate metrics for stream sites grouped by reference (1) and non-reference (2) watersheds.

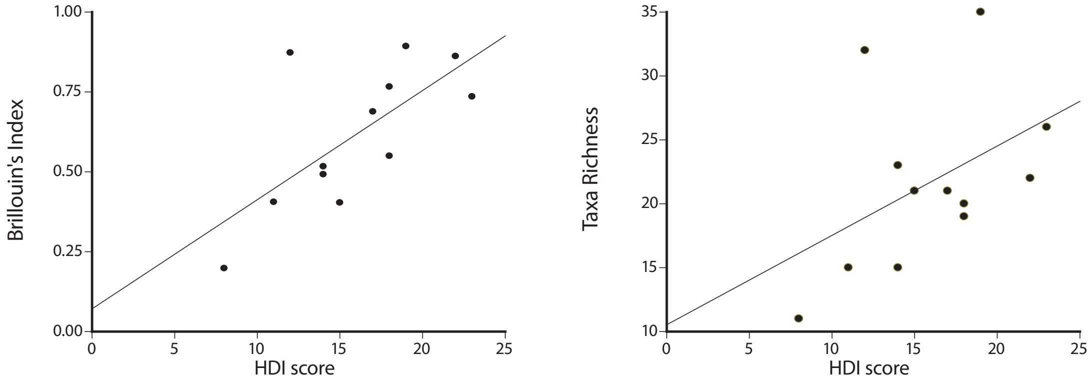

Figure 12. Scatter plots with linear trend lines for HDI habitat scores and Brillouin's diversity index scores or taxa richness for all stream sites and dates.

Table 13. Robust regression information for significant models (alpha = 0.05) where macroinvertebrate metrics are the independent variable.

Dependent variable	Independent variable	n	Model p value	Intercept p value	Relationship	R^2
Taxa Richness	Stream TDP	12	0.01	0.00	–	0.48
Taxa Richness	Stream TN	12	0.00	0.00	–	0.65
Taxa Richness	Stream TDN	12	0.00	0.00	–	0.62
Gleason's Index	Stream TDP	12	0.00	0.00	–	0.56
Gleason's Index	Stream TN	12	0.00	0.00	–	0.65
Gleason's Index	Stream TDN	12	0.00	0.00	–	0.65
Shannon's Index	Stream TN	12	0.02	0.00	–	0.45
Shannon's Index	Stream TDN	12	0.01	0.00	–	0.49

tionships between macroinvertebrates and nutrients indicated that increases in either nutrient resulted in decreases in diversity and richness.

Several multiple regression models that included both phosphorus and nitrogen as independent variables were found to be significant; however in all cases one of the independent variables was noted not to be a significant variable causing us to reject the model outcomes. Even if these multiple regression models were considered biologically significant, they explained little additional variance in the macroinvertebrate metric values (≤ 8% increase). It appears that while macroinvertebrates richness and diversity is adversely impacted by stream nutrient levels found in this study, there are no clear relationships between these organisms and any measure of sediment either suspended or incorporated on the stream bed.

However, it must be remembered that these finding like all other findings in this study should be viewed with care and linked back to other published works in this field of study due to the limited numbers of spatial and temporal samples available for use in this study. In addition, from an ecological perspective the study design adopted for this study has its limitations and did not fully allow researchers to use more definitive analytical approaches. It may well be that all study ecosystems are impacted to a degree where distinguishing subtle differences was not possible with our limited sample size and study design.

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Appendix 1. Photos of Atchison, Banner, and Centralia Lakes showing approximate CPCB stream sampling sites.

Figure 1. Atchison County Lake showing USGS gaging stations ATL and CL1 and CPCB's (pink) and KWO's (yellow) survey reaches on Clear Creek.

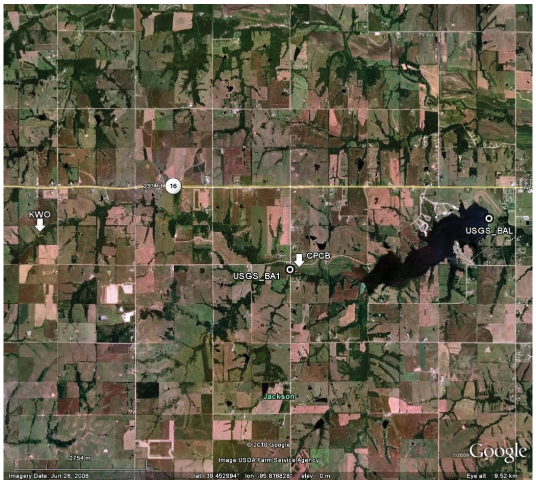

Figure 2. Banner Creek Lake showing USGS gaging stations BA1 and BAL and CPCB's (pink) and KWO's (yellow) survey reaches on Banner Creek.

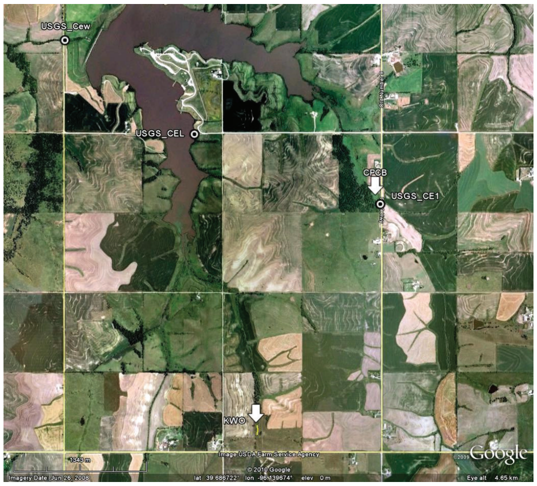

Figure 3. Centralia Lake showing USGS gaging stations CE1, CEL, and Cew, and CPCB's (pink) and KWO's (yellow) survey reaches on the Black Vermillion River.

Appendix 2. Sediment V* form modified by the Central Plains Center for BioAssessment.

Project____________ **Date** ___________ **Stream** ____________ **Site** _______________
Crew _______________ Transect 1 latitude ________________ longitude_____________
Dec.Degrees, circle: NAD83 or WGS84

A. Reach length (m) _________
B. Intended distance between transects (m) ____________
C. # of transects ____________ (Tally at end)

Site comments and sketch (indicate flow, center line, angles from center line, etc.)

Transect measurements

Transect # 1	**Distance from transect #1 = 0 m Center line (string) to left bank (cm) =**													
Measurements (cm)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Distance from left bank														
1. Water depth														
2. Fines depth														
3. Detritus layer depth*														
4. Dominant substrate														
comments														

Transect #	**Distance from previous transect (m) = Center line (string) to left bank (cm) =**													
Measurements (cm)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Distance from left bank														
1. Water depth														
2. Fines depth														
3. Detritus layer depth*														
4. Dominant substrate														
comments														

* If a fines deposit has an organic or detritus layer on it (leaves, sticks, etc), estimate the depth of the detritus layer.

Appendix 3. Nutrient, Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), and other values by site and sampling event in 2010.

Table A. Impoundment values for nutrients, TSS, and VSS for the main sampling sites.

Impoundment	Sampling Event	Site	Total Dissolved Phosphorus (µgP/L)	Total Phosphorus (µgP/L)	Total Dissolved Nitrogen (µgN/L)	Total Nitrogen (µgN/L)	Total Suspended Solids (TSS) (mg/L)	Volatile Suspended Solids (VSS) (mg/L)	Inorganic Suspended Solids (ISS) (mg/L)	Turbidity (NTU)
Atchison	Jul	9	320.0	345.0	1,590.0	1,900.0	23.5	0.4	23.1	127.0
Atchison	Oct	9	100.0	405.0	2040.0	2,270.0	82.0	1.4	80.6	373.0
Banner Creek	Jul	1	27.3	104.0	759.0	910.0	27.0	0.8	26.2	58.0
Banner Creek	Jul	9	14.0	93.3	658.0	902.0	8.7	0.5	8.2	14.0
Banner Creek	Oct	1	14.3	67.6	663.0	882.0	7.0	0.4	6.6	44.0
Banner Creek	Oct	9	14.2	51.1	528.0	678.0	3.0	0.5	2.5	23.0
Centralia	Jul	1	161.0	213.0	1,200.0	2,100.0	91.0	1.6	89.4	157.0
Centralia	Jul	6	59.3	111.0	987.0	1,870.0	23.0	1.2	21.9	46.0
Centralia	Oct	1	58.7	182.0	2,700.0	2,780.0	132.0	1.4	130.6	268.0
Centralia	Oct	6	71.7	113.0	2,690.0	2,840.0	14.0	0.7	13.3	52.0

Table B. Impoundment core values for measured parameters.

Impoundment	Sampling Event	Site	Depth Range (cm)	Bulk Density (g/cm^3)	Clay %	Silt %	Sand %	Total Nitrogen (ppm)	Total Phosphorus (ppm)
Atchison	July	9	0-10.0	0.4	65.2	32.7	2.2	1,999.0	1,065.6
Atchison	July	9	10.0-20.0	0.4	65.7	32.2	2.1	2,181.8	905.6
Atchison	July	9	20.0-31.0	0.4	70.6	27.9	1.5	1,816.0	853.0
Atchison	October	9	0-10.0	0.3	69.7	29.7	0.6	2,401.7	931.0
Atchison	October	9	10.0-20.0	0.4	69.3	30.1	0.6	2,437.4	961.1
Atchison	October	9	20.0-30.0	0.4	70.0	28.8	1.1	2,285.2	821.8
Banner Creek	July	1	0-10.0	0.7	36.3	59.8	3.9	1,144.1	554.5
Banner Creek	July	1	10.0-21.0	1.0	35.7	62.7	1.6	984.7	502.5
Banner Creek	July	9	0-10.0	0.3	46.9	48.6	4.5	1,772.4	687.8
Banner Creek	July	9	10.0-19.0	0.5	47.5	47.4	5.0	1,223.3	664.0
Banner Creek	October	1	0-10.0	0.8	33.0	61.4	5.6	1,252.2	481.8
Banner Creek	October	1	10.0-20.5	1.1	31.3	60.1	8.6	1,105.6	467.1
Banner Creek	October	9	0-10.0	0.5	46.2	49.6	4.1	2,032.3	629.7
Banner Creek	October	9	10.0-16.0	0.5	47.1	49.4	3.5	1,787.7	627.4
Centralia	July	1	0-10.0	1.0	23.1	61.5	15.4	975.9	395.5
Centralia	July	1	10.0-20.0	1.4	26.8	58.1	15.0	1,054.3	476.6
Centralia	July	1	20.0-21.5	1.8	25.5	61.2	13.3	949.6	413.3
Centralia	July	6	0-10.0	0.2	57.0	31.8	11.2	2,213.2	1,005.8
Centralia	July	6	10.0-20.0	0.3	58.4	36.4	5.1	1,787.2	941.1
Centralia	July	6	20.0-30.0	0.4	60.5	36.9	2.7	1,829.1	942.3
Centralia	October	1	0-10.0	1.1	20.7	66.5	12.8	918.4	341.7
Centralia	October	1	10.0-20.0	1.0	23.5	63.2	13.4	1,037.8	346.7
Centralia	October	1	20.0-23.0	1.1	20.8	61.9	17.3	949.9	383.8
Centralia	October	6	0-10.0	0.2	59.6	34.2	6.2	3,106.7	1,003.0
Centralia	October	6	10-20.0	0.3	61.3	37.0	1.8	2,643.0	884.4
Centralia	October	6	20.0-24.5	0.4	57.8	37.7	4.5	2,057.9	864.9

Table C. Stream values for nutrients, TSS, VSS and turbidity.

Watershed	**Sampling Event**	**Site**	**Total Dissolved Phosphorus (µgP/L)**	**Total Phosphorus (µgP/L)**	**Total Dissolved Nitrogen (µgN/L)**	**Total Nitrogen (µgN/L)**	**Total Suspended Solids (TSS) (mg/L)**	**Volatile Suspended Solids (VSS) (mg/L)**	**Inorganic Suspended Solids (ISS) (mg/L)**	**Turbidity (NTU)**
Atchison	Jul	9	241	344	1,990	2,360	51.00	0.90	50.10	177
Atchison	Oct	9	162	208	2,680	2,950	3.00	0.10	2.90	37
Banner Creek	Jul	1	61	124	1,430	1,500	20.33	0.42	19.92	33
Banner Creek	Jul	9	50.1	59.3	365	544	2.00	0.20	1.80	3
Banner Creek	Oct	1	47.1	103	1,490	1,520	20.20	0.34	19.86	43
Banner Creek	Oct	9	62.6	62	303	453	6.00	0.20	5.80	2
Centralia	Jul	1	66	93.5	1,440	1,520	20.75	0.35	20.40	105
Centralia	Jul	6	48.7	54.2	189	305	10.00	1.90	8.10	3
Centralia	Oct	1	137	161	3,940	4,260	13.50	0.25	13.25	22
Centralia	Oct	6	80.7	394	1,880	2,870	352.00	4.80	347.20	41

Effects of Long-Term Management on Surface Soil Properties of Upland Soils in Northeast Kansas

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Interpretative Summary

Sedimentation of lakes and reservoirs in Kansas is due to a combination of historic land use as well as erosion of streambeds and streambanks. This paper contributes to the present-day understanding of post-settlement land use and management effects on soils. The most stable upland landscape was selected for comparison between cropland and pasture. Transects were not randomly selected, but rather, were targeted in order to keep as many factors constant, with land use as the variable. In general, croplands were more eroded and lower in soil organic carbon (SOC), and had lower infiltration rates than pastures. Pastures generally had lower Mehlich III soil test phosphorus (P) levels than did croplands. While many producers in northeast Kansas have switched to no-till practices on cropland, the usage of additional practices that increase SOC would likely increase infiltration rates and reduce the risk of erosion and runoff.

Introduction and Literature Review

Mollisols are defined by the presence of a mollic epipedon, the criteria for which are explained in Soil Taxonomy (Soil Survey Staff, 1999). In lay terms, mollisols are the thick, dark, organic matter-rich soils common to those formed under prairie vegetation, and now commonly cropped or managed as pastures. The thickness of the mollic epipedon can be (and often is) altered by erosion and by organic matter decomposition, both of which are exacerbated by tillage. Since the 1930's erosion phases have been mapped in soil surveys (Olson et al., 2005a), which means that the mappers fully realized that the soils they were observing had been altered by erosion, and thought that this was an important to document. According to Olson et al. (2005a), as of 1991, there were 20 million acres of eroded Mollisols mapped in the USA, mostly in the Midwest and Great Plains states.

The effects of management practices (tillage, fertilization, residue removal, crop rotation, etc.) are well understood and were recently summarized by Hatfield and Sauer, 2011. However, the effects on a given soil are a function of its inherent soil properties and thus, the results and degree to which they are expressed is a product of the inherent properties and management practices. Land use is dynamic. For example, for a given field in northeastern Kansas, it was grassland for thousands of years until the area was settled in the 1840s to 1860s. The best agricultural land was either plowed for crops, or grazed by livestock. Starting in the 1950s, programs for reducing agricultural production and conserving soil resources would place many acres back into grassland, or for cropland, the use of terraces and other structures. Conventional tillage was predominant until reduced and conservation tillage began in the 1970s, increasing to ≈70% no-till practices today in northeast Kansas (Presley, 2011). Today, the landscape of northeastern Kansas represents a patchwork quilt of land uses, and thus, presents an excellent opportunity to sample soil series under multiple land uses and compare today's soil descriptions with his-

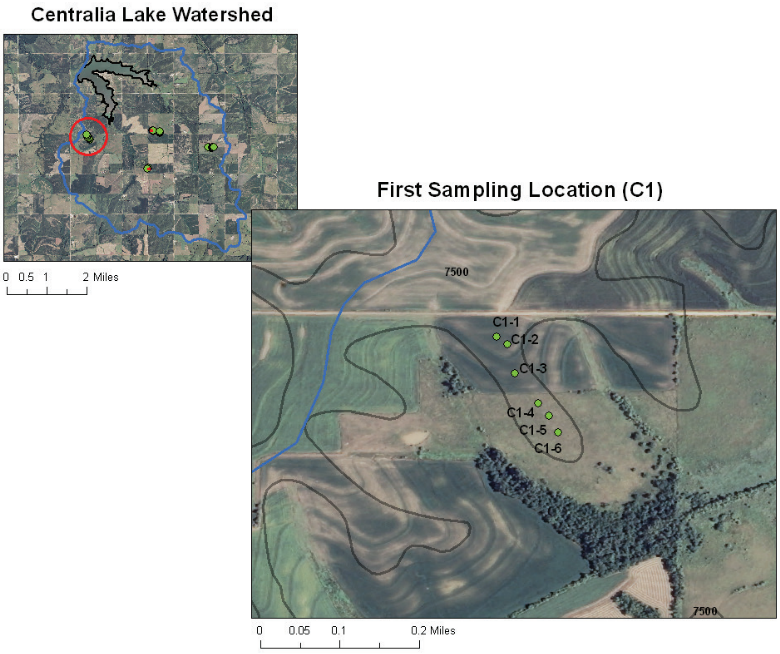
torical descriptions contained in soil surveys completed between ≈1950 and ≈1970.

Veenstra (2010) examined 82 representative soil profiles from 21 counties in Iowa that were originally sampled and described between 1943 and 1963 by the USDA. She found that after 50 years of agricultural land use many (60%) were different from their original descriptions, and that changes in the thickness of the mollic epipedons caused about half of the changes in classifications observed in the U.S. system of taxonomy. Veenstra studied soils across the landscape, and while some soils lost mollic epipedon thickness, other soils (footslopes especially) gained. Kimble et al. (1999) studied soils on eroding landscape positions only, thus observed higher levels of soil loss and greater reductions of mollic epipedon thickness. Thirty-two percent of the sites were no longer Mollisols and 27 to 71% of the mollic epipedon had been lost. Amundson et al. (2003) observed that much of the central U.S. has a very high proportion of endangered soil series, due to the impact of erosion on mollic epipedons.

The goal of this project was to examine the effects of land use and management on Mollisols of northeast Kansas, with a focus on upland soils in watersheds above the Atchison, Banner Creek, and Centralia lakes. The objective is to characterize the influence of land use (cropland versus grassland) on the morphology, mollic epipedon thickness, organic C content, and infiltration rate.

Site Locations and Methods

The study sites are located on narrow upland summits of the Pawnee clay loam soil series (fine, smectitic, mesic Oxyaquic Vertic Argiudolls) (Soil Survey Staff[a]). The mapunit that was selected was the Pawnee clay loam, 1 to 3% slopes. This soil type is frequently cropped, but there are many pastures interspersed in the study watersheds. Our goal was to perform transect perpendicular to the slope and between a cropped field and a pasture. Each transect was composed of multiple stops in order to gain an understanding of the average soil properties for each field. Two complete cropland/pasture transects were completed for Atchison, and four transects were completed in each of the Banner and Centralia watersheds (Figure 1). All sites were on privately owned land and per-


Centralia Lake Watershed

First Sampling Location (C1)

Figure 1. Transect sampling method. The smaller figure shows the locations of the four transects completed for the Centralia Lake watershed, and the smaller figure illustrates the layout of a typical transect between a cropland field and adjacent pasture. The entire transect occurs on one soil type and attempts to minimize difference in slope.

mission was secured from the landowners prior to sampling.

Soil pedons were investigated using a hydraulic, truck-mounted soil probe. Pedons were sampled to the depth of refusal, usually by large rocks common in the glacial till parent material. All pedons were described using the Field Book for Describing and Sampling Soils (Schoeneberger et al., 2002). Samples were split by genetic horizon, air-dried, sieved to 4 mm, removed of visible organic materials, ground with mortar and pestle, and sieved to 0.25 mm for measurement of total C by dry combustion with a LECO TruSpecCN analyzer (LECO Corp., St. Joseph, MI) (Nelson and Sommers, 1996). Bulk density was determined for each horizon (from a second soil profile) by the core method (Blake and Hartge, 1986). The percentage of C was multiplied against bulk density to compute total soil C pool in Mg ha^{-1}. Soil samples were submitted to the Kansas State University Agronomy Soil Testing Lab for the measurement of Mehlich-3 phosphorus.

A network of automated mini-disk infiltrometers (Madsen and Chandler, 2007) provided 24 in-situ measurements per site of near-saturated (K_{-2cm}) infiltration (Figure 2). The networks were deployed around two pedons per pair (one for each land use.)

Results and Discussion

Data from the soil profile descriptions are presented in Table 1. A calculation was performed to determine how different the mollic epipedon thickness was relative to the pasture. This is referred to as the percent (%) eroded, although any loss of C in the soil is recognized to result from both erosion and accelerated soil organic matter decomposition from tillage. The cropland sites of the Atchison and Centralia watersheds were on average 63 and 38% eroded, respectively. The Banner watershed sites were different in that for two of the transects (2 and 3) the cropland sites had a thicker mollic epipedon than the pasture. This could be explained in one of two ways: It is possible that the pasture

Table 1. Summary of mollic epipedon thickness (cm) by watershed. The mollic epipedon is roughly equivalent to what is referred to as topsoil, in that it has high organic matter and dark colors. The % eroded means how eroded the cropland is compared to the pasture condition.

Watershed	Transect	Cropland	Pasture	% eroded	Average
Atchison	1	19	48.3	61	
	2	14.5	41.5	65	63
Banner	1	26.5	42.8	38	
	2	39.3	38.3	0	
	3	33.3	29	0	
	4	16.5	24.3	32	18*
Centralia	1	26	41.3	37	
	2	34.3	41.6	18	
	3	17.3	40.3	57	
	4	19.7	33.6	41	38

*If the two Banner watershed transects with zero % eroded values are ignored, the average % erosion for Banner is 35%.

Figure 2. Soil sampling was completed by coring with a hydraulic truck-mounted soil probe, and infiltration measurements were collected using an automated mini disk infiltration network.

Table 2. Surface hydraulic conductivity rates (K) measured with tension infiltrometers (-2 cm). The values reported are averages. The USDA-NRCS hydraulic conductivity value reported for the Pawnee clay loam, 1-3% slopes (mapunit 7500) is 3 um sec^{-1}. Therefore, these results do not differ greatly from the measured values, however, the values for the pastures in Atchison County and Banner Creek watersheds are more rapid than predicted. This allows for greater water movement into the soil profile after a precipitation event, and thus, can lead to less runoff.

		K (-2 cm) µm sec^{-1}	SOC Mg ha^{-1}	Mehlich III Extractable P ppm
Atchison	Crop	5.17	118.4	7.0
	Pasture	10.21	104.3	7.4
Banner	Crop	5.31	47.0	36.6
	Pasture	7.81	55.4	9.3
Centralia	Crop	3.99	51.1	19.3
	Pasture	3.38	91.3	1.6

site had been significantly degraded prior to being replanted to permanent vegetation, or that it is currently experiencing erosion from a process such as overgrazing. The alternative is that the cropland sites within these transects are less eroded than expected, or that the landowners have been exceptionally good stewards and employing soil management practices that sequester soil organic matter. When averaged across all four transects, the Banner watershed site is 18% eroded, but if you ignore the two sites that were 0% eroded, this value would be 35%, which is more similar to the values observed in the Centralia watershed.

Surface hydraulic conductivity rates (K) measured with tension (-2 cm) infiltrometers (Table 2) ranged between 3 and 11 µm sec^{-1}, which is within the typical range (1 to 10 µm sec^{-1}) expected for low bulk density soils (Figure 3). The USDA-NRCS hydraulic conductivity value reported for the Pawnee clay loam, 1-3% slopes (mapunit 7500) is 3 um sec^{-1} (Soil Survey Staff[b]). The values for the pastures in Atchison County and Banner Creek watersheds are more rapid than the cropland K. This allows for greater water movement into the soil profile after a precipitation event, and thus, can lead to less runoff. For the Centralia site the values were similar, and were overall the lowest of the study.

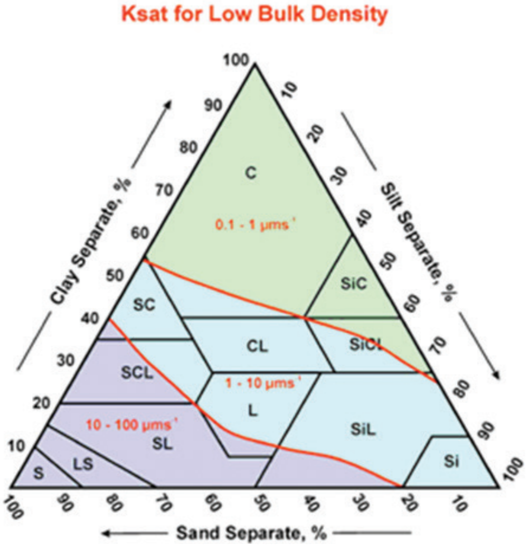


Figure 3. Typical ranges in saturated hydraulic conductivity (Ksat) for soils. The values recorded in this study are within the expected ranges. Source for the diagram: *http://soils.usda.gov/technical/handbook/contents/part618ex.html*

The mass of SOC for the mollic epipedons are reported in Table 2. The Atchison site, despite being the most eroded of the three (Table 1) contained the most SOC because of high SOC concentrations (values not shown), which is puzzling. Due to the small number of transects sampled in this watershed (two), we will avoid drawing conclusions from this data. The SOC of both the Banner and Centralia watersheds were greater for the pasture, particularly so for the Centralia site. Interestingly, despite the greater SOC mass for Centralia pastures, this did not lead to greater K values in the Centralia watershed.

The Mehlich III Extractable P values were greater for the cropland transects in both Banner and Centralia by a large margin, while in the Atchison watershed is was similar (≈ 7 ppm). The Atchison values are within the "very low" range for Kansas (Figure 4, from Leikam et al. 2003). The pasture values for Banner and Centralia are also in the "very low" range. The Centralia cropland sites are very near the 20 ppm value, below which the Kansas State University Soil Testing Laboratory recommends that producers add P fertilizer to attain maximum yields. The Banner cropland values are in the high range.

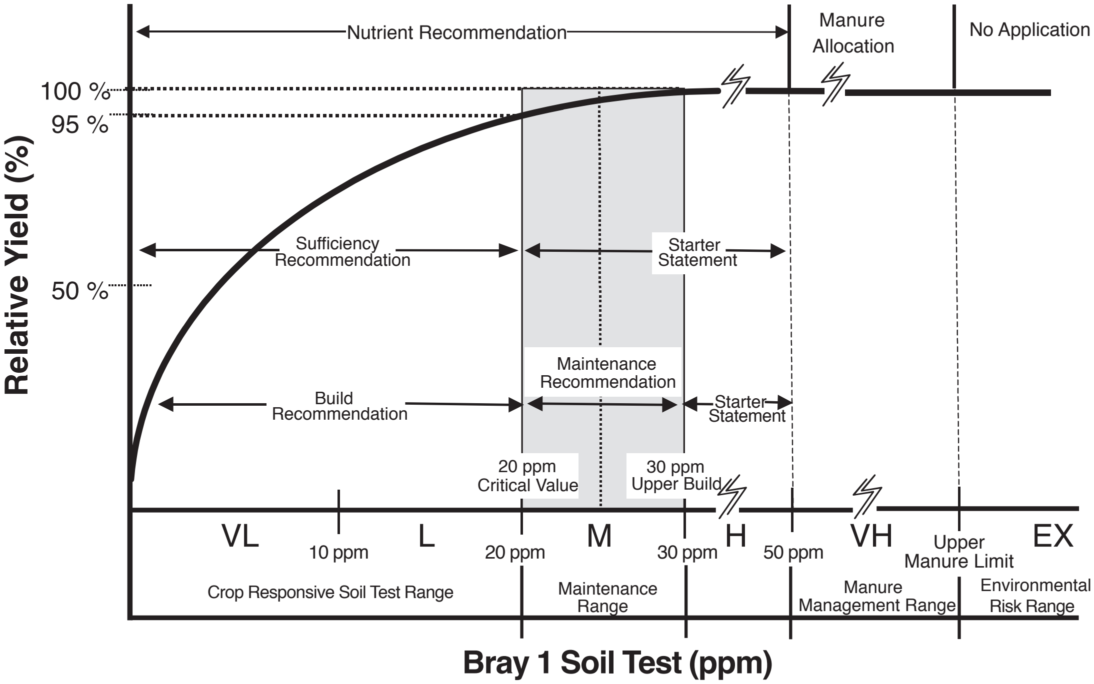


Figure 4. Phosphorus management recommendations for Kansas (Leikam et al., 2003).

Conclusions

This study would benefit from some expansion in the number of transects sampled, yet some trends are apparent. First, it is interesting to note that the watersheds have some different characteristics. Atchison was in some ways had the most unexpected results; the cropland was the most eroded in this watershed, yet the SOC values were much higher than the other sites, and the cropland P values were very low. Since there were only two transects sampled we will view the results for this site with caution. The Banner Creek site was predictable in that the infiltration rate and SOC was higher for pastures, while the P values were higher for cropland. The confounding issue with this site is that two of the transects had just as much if not more topsoil thickness than the pastures. The Centralia site results were a bit more straightforward as the cropland was overall 38% eroded relative to the pasture and the infiltration rate and SOC were lower for the cropland and the P value was higher for cropland.

Overall, these results are an indication that soils are dynamic and that management has impacts on the properties of the surface soil that are a culmination of many years of management. Since soil data is often used as a basic input layer into geographic information system models, etc., it is important that we continually update the soil resource database so that modelers and other types of predictive tools have the best, most up-to-date data for their efforts.

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Recommendations

- Survey more cropland fields under different soil management regimes, e.g. tillage, crop rotations, and/or cover crops.

Fluvial Geomorphology Assessment of Atchison County Lake, Banner Creek, and Centralia Lake, Watersheds

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Interpretative Summary

Erosion from streambeds and streambanks is a major source of sediment in Kansas watersheds. Knowledge of the processes that shape a channel's dimension, pattern, and profile is needed to predict erosion loss rates. The Watershed Institute, Inc. (TWI) completed three fluvial geomorphology surveys above Atchison County Lake, five surveys above Banner Creek Reservoir, and eight surveys above Centralia Lake. Fluvial geomorphology field activities included cross section, profile, sediment size, and streambank erodibility assessment surveys. TWI used the Bank Erodibility Hazard Index (BEHI) assessment to rate streambank erodibility potential and predict erosion loss rates.

Centralia Lake and Atchison County Lake watersheds have similar drainage densities, landuse, and topography. For Banner Creek watershed, the elevation difference between the uplands and Banner Creek Reservoir is about 140 feet more than the difference between upland elevations and Centralia Lake and Atchison County Lake resulting in a high drainage density. Banner Creek and Atchison County Lake watersheds have a higher proportion of their respective watershed controlled by small impoundments than in the Centralia Lake watershed. In several survey reaches, small impoundments have influenced channel morphology. Readily observable changes in the channel morphology occur when the percentage of drainage area controlled by small impoundments reaches approximately 40 to 60 percent. Atchison County Lake and Banner Creek watersheds have wooded riparian corridors adjacent to most survey sites. The wooded corridors fluctuate in width ranging from less than one bankfull channel width to well over two bankfull channel widths. Riparian corridors within the Centralia Lake watershed are typically less than the bankfull channel width with little or no woody riparian species.

All three watersheds have bankfull discharges typical of northeast Kansas stream systems. The stream channels are narrow and deep with limited access to floodplains. Most of the surveyed reaches were classified as Rosgen (1996) E stream types; a common Kansas stream type. Bankfull width and cross sectional area are similar in all three watersheds when compared with drainage area, with exceptions to survey sites heavily controlled by impoundments. All but one Centralia Lake survey site is straightened whereas most of the Atchison County Lake and Banner Creek sites have a sinuous course.

Channel straightening has increased the channel slopes in Centralia Lake as well as stream power; an indicator of sediment transport capacity.

Average streambank erosion loss rates using northeast Kansas erosion prediction curves (from Sass and Keane 2012) are 0.21 tons/year/foot for both Atchison County Lake and Banner Creek survey sites. Centralia Lake survey sites had an average erosion loss rate of 0.14 tons/year/foot. TWI suggests that Atchison County Lake and Banner Creek watershed erosion loss averages over-predict actual streambank erosion losses due to a few atypical, highly erosive sites, high proportions of survey site drainage area controlled by impoundments, and the presence of tight cohesive bank materials. The latter two influences are not components in the BEHI assessment, but have an impact on streambank erosion.

Using streambank erosion loss estimates, TWI extrapolated in-channel sediment yields to compare with U.S. Geological Survey (USGS) sediment transport monitoring (March 2009 – September 2011). The predicted sediment yields from in-channel sources are 15,074 tons per square mile in Banner Creek, 2,065 tons per square mile in Centralia Lake watershed and 943 tons per square mile in Atchison County Lake watershed. USGS sediment monitoring results (Foster et al. 2012) were 1,200 tons per square mile at Banner Creek, 2,800 tons per square mile at Centralia Lake, and 1,100 tons per square mile at Atchison County. The extrapolated in-channel sediment yields suggest in-channel sources are the primary sediment source in Centralia Lake and Atchison County Lake and streambank erosion loss estimates over-estimate in-channel erosion in Banner Creek. Due to extensive channelization, Centralia Lake watershed channels are able to transport more sediment downstream since channel slopes are steeper and stream power is higher; two factors that increase a channel's ability to convey flow and transport sediment.

Introduction

The Watershed Institute, Inc. (TWI) completed fluvial geomorphology assessments at selected channel reaches to document channel stability characteristics. Fluvial geomorphology assessments are one of seven watershed characteristics researched as part of this sediment baseline study. In-channel sediment sources can be a significant source of a stream's sediment load (Juracek and Ziegler 2007). Characteristics of a channel's dimension, pattern, and profile can predict the erodibility of in-channel sediments and a stream's capacity to transport sediment. Fluvial geomorphology assessment objectives included:

- Document physical dimensions of typical channels in Banner Creek, Centralia Lake, and Atchison County Lake watersheds
- Assess streambank stability characteristics
- Note dominant riparian corridor characteristics
- Classify each survey reach using Rosgen (1996) stream Classification System
- Predict annual erosion loss
- Validate Simon and Hupp (1986) Channel Evolution Stage

TWI collaborated with University of Kansas Department of Civil, Environmental, and Architectural Engineering (KUCE) to select stream survey reaches using aerial videography. In all, TWI completed three surveys above Atchison County Lake, five surveys above Banner Creek Reservoir, and eight surveys above Centralia Lake. TWI also included survey data from Gulf South Research Corporation (GSRC) geomorphology investigations (2008 and 2010) as GSRC collected similar fluvial geomorphology data for related sediment studies in northeast Kansas. GSRC (2008 and 2010) investigations included 2 surveys in Atchison County Lake watershed and 1 survey each for Banner Creek and Centralia Lake watersheds. Figure 1 shows the fluvial geomorphology sites locations—including the GSRC (2008 and 2010) survey sites—for each watershed.

This chapter provides information on TWI's field surveys, data analysis, results, conclusions, and recommendations of future research.

Procedures

Geomorphology Field Surveys

To determine channel condition and stability, TWI used methods and procedures defined by Rosgen (1994), who developed a hierarchy of river inventory and assessment protocols consisting of four levels. The levels include: (I) Geomorphic Characterization, (II) Morphological Description, (III) Stream State or Condition, and (IV) Validation with each successive level building on the former (Keane 2004). TWI collected field data to fulfill levels I, II and portions of III. The validation level requires long-term monitoring that was not a part of this scope of work.

TWI used the Level III stream "state" or condition classifications to obtain a more refined view of stream reach condition. The Level III stream state examination provides a quantitative basis for comparing streams with similar morphologies but exhibiting different states or conditions. The Rosgen (1996) stream classification protocol and inventory was chosen for the following reasons:

- It employs consistent, objective, quantitative, and reproducible measures (Keane 2004).
- It predicts a river's behavior from its appearance.
- It develops specific hydraulic and sediment relationships for a given stream type and condition.
- It allows for extrapolation of site-specific data to stream reaches having similar characteristics.

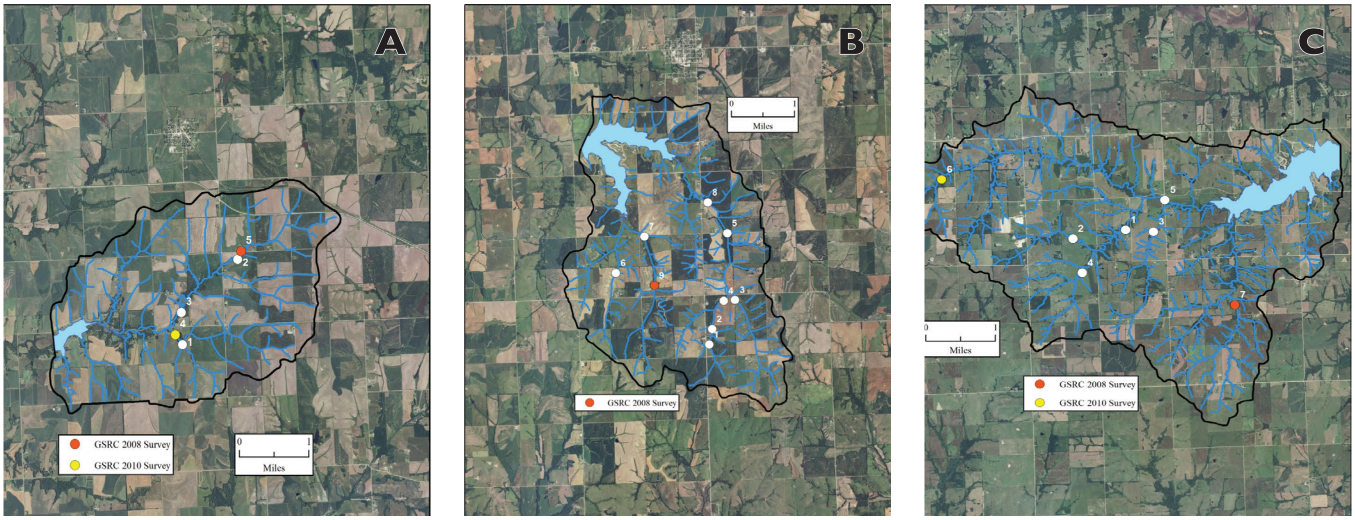

Figure 1. Fluvial Geomorphology Survey Locations for (A) Atchison County Lake, (B) Centralia Lake, and (C) Banner Creek Reservoir.

- It provides a basis for communication among water resource professionals.
- It provides a method to utilize sediment data, bank erosion, and stability predictions. (Rosgen 1996)
- It incorporates all three dimensions of channel form while accounting for variability in channel forming materials (Thorne 1997).

Geomorphology field survey procedures are presented in four categories: channel profile; channel dimensions; channel materials; and Bank Erodibility Hazard Index (BEHI).

Channel Profile. TWI began each survey by completing a visual site reconnaissance to define the survey reach—length equaling at least two meander wavelengths. Once identified, TWI used a Leica TCR407 total station to survey the channel profile. TWI surveyed the channel thalweg; water surface, bankfull indicators, and right and left top-of-bank. Bankfull indicators included the location where the channel ended and a floodplain or terrace feature began (top of bank) or a change in bank slope within the channel area. Bankfull flow is defined as the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and doing the work that results in the average channel morphology characteristics (Dunne and Leopold 1978). For stable stream channels, the bankfull flow corresponds to the incipient point of flooding and has an average recurrence interval of 1.5 years.

During each profile survey, TWI documented the location of changes in streambank erodibility potential using a handheld global position system (GPS) unit. Changes in streambank erodibility potential included a change in the bank height, riparian vegetation, bank materials, rooting depth, and vegetative surface protection. TWI documented each change in streambank erodibility as a different bank condition or type (*i.e.* Bank Type I, Bank Type II, etc…).

Channel Dimensions. TWI surveyed channel cross sections to obtain channel dimension parameters for each identified bank type. The number of cross sections varied among sites, based on the number of identified bank types. TWI surveyed at least one cross section at a riffle or cross-over reach (between meander bends) for stream classification purposes. Again, TWI used a Leica TCR407 total station to survey each cross section. TWI oriented each cross section perpendicular to flow, and recorded data at regular intervals to accurately depict the channel shape from left top-of-bank to right top-of-bank. In addition to the regular measurement intervals, TWI documented special features on the cross sections. These special features included edge of water, channel thalweg, terraces, rooting depth elevations, and bankfull stage indicators.

Channel Materials. TWI conducted channel material surveys or pebble counts at most survey sites. TWI did not complete pebble counts for streams with silt/clay streambed and banks. Channel materials are the rocks, pebbles, and smaller sediments that make up the stream bed. TWI used a procedure, known as the Wolman (1954) pebble count to characterize the streambed sediments. This pebble count requires measuring the intermediate axis (*i.e.*, width) of randomly selected pebbles. The survey reach pebble count provides information on the size

distribution of the stream bed and bank rocks, pebbles, and sediment. TWI stratified each pebble count by survey reach channel characteristics. For example, if 60-percent of a survey is pools and 40-percent riffles, 60-percent of the pebble count samples are collected in pools and 40-percent in riffles. For channels that did not have defined riffle-pool complexes, TWI spaced the sample transects evenly throughout the survey reach. To ensure random sampling, TWI collected pebbles by blindly reaching down until touching a particle (*e.g.*, gravel, cobble, boulder, and bedrock), and then measuring the particle sample's intermediate axis. For small materials such as sands and silt/clay, TWI collected a small pinch of material and the dominant size was determined by visually comparing the sample to a sand grain sizing folder. TWI discarded the samples from collection transects so that the same particles would not be measured a second time. TWI conducted a total of 10 transects per survey recording 10 measurements per transect across the bankfull channel width.

Bank Erodibility Hazard Index (BEHI). In addition to stream erodibility information collected in the channel profile and dimension surveys, TWI made additional observations at each identified bank type. These additional observations included root density percent estimations, dominant bank material compositions, the presence of bank material stratigraphy and soil lenses, and a bank surface protection percent estimation.

Geomorphology Data Analysis

TWI used the geomorphology survey data to assess each site's in-channel erodibility state. In addition to the geomorphology field data, TWI used aerial photography to characterize each site's watershed and determine several geomorphology meander pattern measurements. Data analysis procedures are presented in nine categories: watershed characteristics, survey drainage area, channel dimensions, channel pattern, channel profile, stream classification, discharge classification, BEHI, and channel evolution stage.

Watershed Characteristics. For each watershed, TWI delineated channels in ArcMap™ using 2008 National Agriculture Imagery Program (NAIP) aerial photographs. TWI also delineated grass waterways as they are common drainage conduits in Centralia Lake and Atchison County Lake. Once delineated, TWI calculated the drainage density that is the total length of channels divided by the drainage area. Drainage density describes how a watershed is drained by channels. Watersheds with high drainage densities tend to have a hydrograph with a steeper rising limb and often higher sediment yields.

Next, TWI used the channels delineated by KUCE to determine changes in channel length. KUCE delineated channels using 1942, 1954, 1956, 1957, 1966, 1969, and 2008 aerial photographs. Channels in some of the aerial photographs are difficult to discern and KUCE noted the quality of the channel delineation. TWI used the oldest delineated channel available that included 1942 in Atchison County Lake and Centralia Lake and 1956 in Banner Creek Reservoir. TWI modified the channels so that the 2008 and historic channels encompassed the same reaches. TWI then used ArcMap™ to calculate the channel lengths.

TWI also determined each site's valley slope using the formula:

$$VS = KS$$

where VS is valley slope (feet/feet), *K* is sinuosity that is stream length divided by valley length, and *S* is the average watershed surface slope (feet/feet). Valley slope influences the dimension, pattern, and profile of stream channels and thus is needed information when comparing reaches in different watersheds. In addition to valley slope, TWI noted upland and lake elevations using U.S. Geological Survey (USGS) digital raster graphs (DRG) (USGS 2012).

The last watershed characteristic TWI examined was impoundments. KUCE delineated all impoundments in ArcMap™ software and TWI used the information to determine percent of each site's drainage area that is controlled by impoundments.

Survey Drainage Area. TWI uploaded the recorded GPS locations into ArcMap™ software. In ArcMap™, TWI overlaid the GPS coordinates onto USGS DRGs (USGS 2012). Using the DRG topographic information, TWI created an ArcMap™ shapefile and delineated the drainage area above each site's GPS coordinates. Once delineated, TWI used the ArcMap™ software to calculate the area of each shapefile.

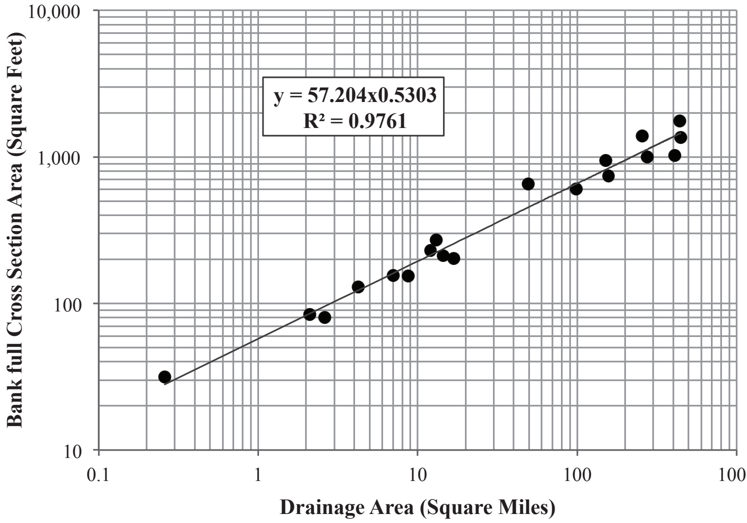

Figure 2. Drainage Area versus Cross Section Area of Northeast Kansas Streams (from Emmert and Hase 1998, TWI 2006, GSRC 2008, and GSRC 2010)

Channel Dimensions. TWI uploaded the total station data into RIVERMorph stream restoration software and plotted the cross section data. TWI used regional curve cross section area data to verify the bankfull stage (see Figure 2). Bankfull elevations can be difficult to identify in disturbed watersheds and the use of regional curves is a way to confirm bankfull elevations (Mulvihill and Baldigo 2012). Regional curves serve as a data-supported basis for estimating the bankfull discharge and associated channel dimensions in ungaged watersheds (Rosgen 1996). Regional curve data are unique to discernible areas of homogeneity concerning landform, underlying geology and soils, climate, hydrology, and biotic communities (Keane 2004). TWI used fluvial geomorphology data from Emmert and Hase (2001), TWI (2006), and GSRC (2008 and 2010) in the regional curves as these studies involved geomorphology data collection in northeast Kansas streams similar to the three study watersheds.

Four survey sites (Site 1 and 4 in Atchison Lake and Sites 2 and 3 in Banner Creek) did not fit the regional curve data in Figure 2. Impoundments upstream of these sites have caused a reduction in the bankfull channel dimensions. TWI used floodplain features and vegetation as bankfull indicators (see Figure 3). For most sites, bankfull elevations corresponded to changes in streambank angles (see Figure 4). Once TWI verified each site's bankfull elevations, RIVERMorph calculated the bankfull dimensions that include: width, mean depth, maximum depth, cross section area, hydraulic radius, wetted perimeter, floodprone width, and bank heights.

Channel Pattern. TWI used aerial photography to measure variations in each site's meander geometry using the geographic information system (GIS) interface in RIVERMorph software. Meander geometry measurements included the lateral extent of meanders (*i.e.*, belt width), the wavelengths of meanders (which documented meander lengths), and the degree of curvature in meanders (*i.e.*, radius of curvature). To determine sinuosity, TWI measured the ratio of stream to valley length in the vicinity of each site. TWI measured multiple meanders to document the variability of pattern dimensions. Figure 5 shows the different meander geometry measurements.

Channel Profile. Using the uploaded total station data, TWI used RIVERMorph software to plot each profile. TWI then used RIVERMorph software to calculate the average bankfull water surface

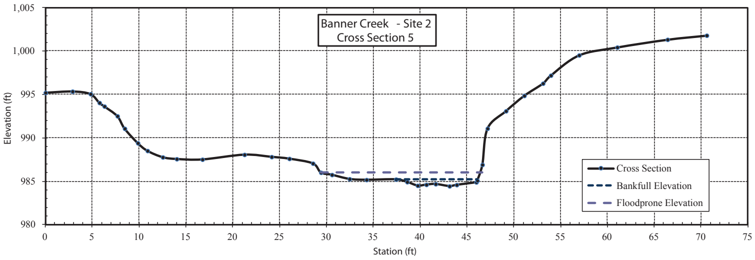

Figure 3. Formation of small floodplain at Banner Creek – Site 2.

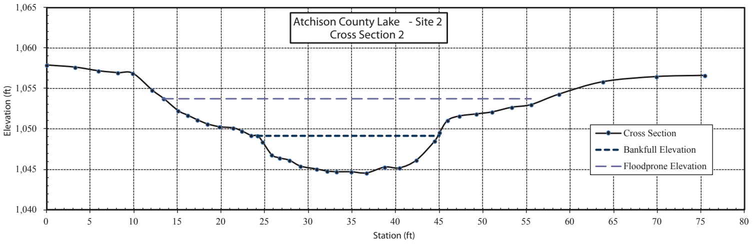

Figure 4. Bankfull indicator at change of streambank angle on left bank.

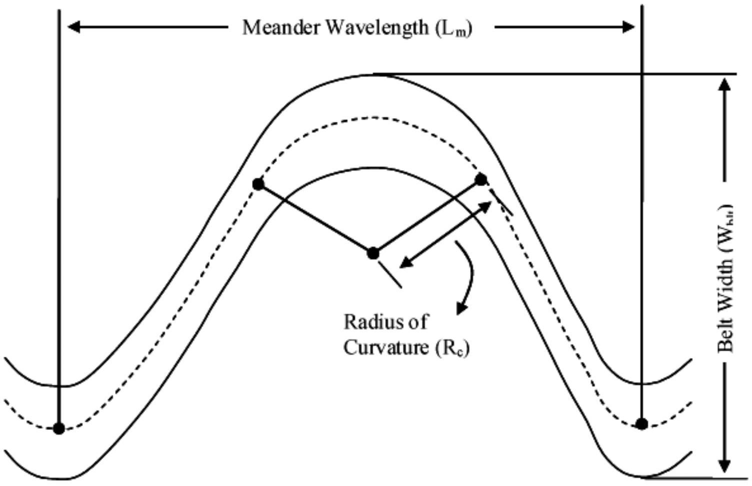

Figure 5. Meander geometry measurements.

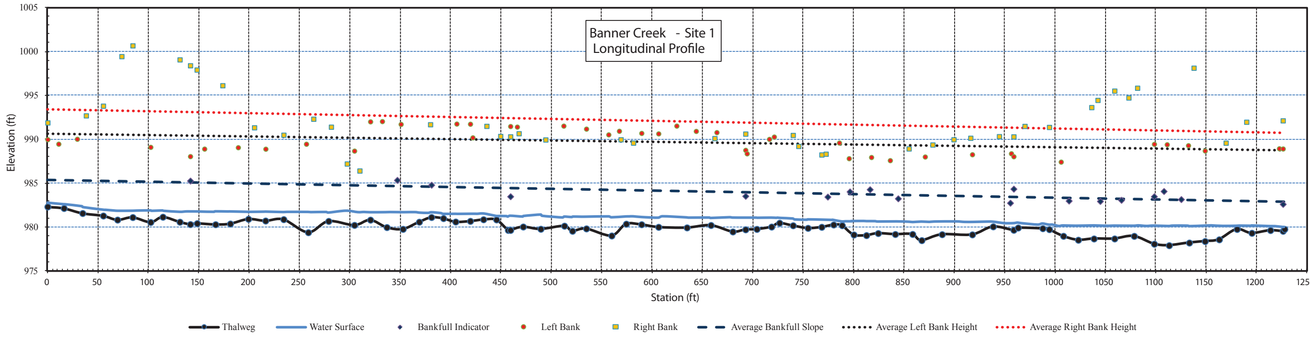

Figure 6. Longitudinal Profile at Banner Creek – Site 1

slope and average left and right-top-of-bank. A representative profile is provided in Figure 6.

Stream Classification. Using the riffle or cross-over channel dimensions (entrenchment ratio and width/depth ratio), average channel materials, average water surface slope, and sinuosity, TWI classified each survey site using the Rosgen stream classification system of natural rivers (see Figure 7).

Discharge Calculation. To estimate discharge, TWI used the Manning relation:

$$u = \frac{1.49\, R^{2/3} S^{1/2}}{n}$$

where u is velocity in feet per second, R is hydraulic radius in feet, S is average water slope in feet per feet, aFnd n is referred to as the Manning resistance coefficient. TWI used the riffle cross section hydraulic radius from the channel dimension analysis, the average water slope from the channel profile analysis, and “n” values from Rosgen (1994) to determine the velocity. Once TWI calculated velocity, the bankfull discharge was determined by:

$$Q_{bkf} = Au$$

where Q_{bkf} is bankfull discharge in cubic feet per second, A is bankfull cross section area in square feet, and u is velocity in feet per second.

Bank Erodibility Hazard Index (BEHI). TWI used the GPS points collected during the longitudinal profile survey to determine the length of each bank type. TWI used RIVERMorph

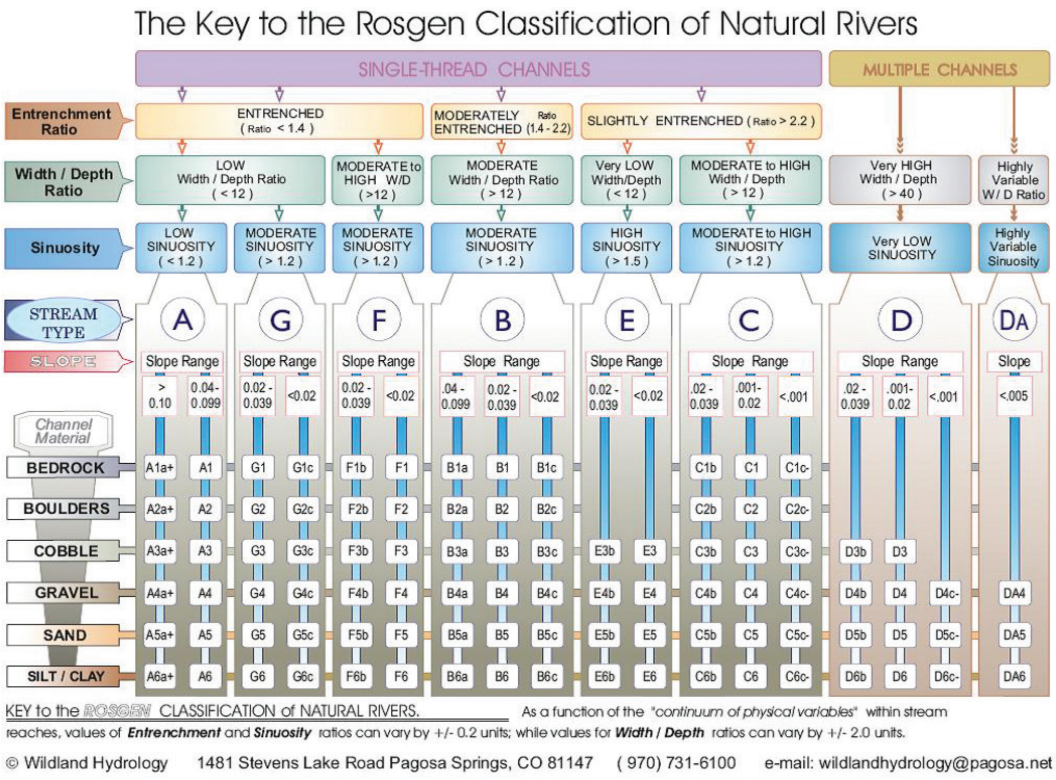

Figure 7. Rosgen Classification of Natural Rivers (from Rosgen 1996)

software to input the BEHI parameters that include:

- Ratio of streambank height to bankfull height.
- Ratio of riparian vegetation rooting depth to streambank height.
- Rooting density percentage.
- Composition of streambank materials.
- Streambank angle.
- Bank material stratigraphy and presence of soil lenses.
- Bank surface protection provided by debris and vegetation.

TWI determined the streambank height, bankfull height, vegetation rooting depth, and streambank angle from the cross section surveys. TWI used field observations to determine the rooting density percentage, composition of streambank materials, bank material stratigraphy, and bank surface protection. Once TWI entered all the parameters, RIVERMorph software calculated the BEHI variables and overall BEHI ratings.

In addition to BEHI, TWI performed near-bank stress (NBS) calculations to rate bank stability. NBS determination is used to identify potential disproportionate energy distribution in the near-bank region that can lead to accelerated bank erosion (Rosgen 2006). Rosgen (2006) developed seven different options for determining NBS. These options range from a reconnaissance level determination to a detailed prediction determination. The NBS assessment uses the following methods (Rosgen 2006):

1. Channel pattern, traverse bar or split channel/central bar creating NBS/high velocity gradient;
2. Ratio of radius of curvature to bankfull width;
3. Ratio of pool slope to average water surface slope;
4. Ratio of pool slope to riffle slope;
5. Ratio of near bank maximum depth to bankfull mean depth;
6. Ratio of near-bank stress to bankfull shear stress; and
7. Velocity profiles/isovels/velocity gradient.

To determine the NBS, TWI used the ratio of the near-bank maximum depth (d_{nb}) to mean bankfull depth (d_{bkf}). TWI measured and recorded the near-bank maximum depth in cross section surveys that corresponds to the deepest part of the channel in the nearest one-third bankfull width of the study bank (Rosgen 2006). TWI used RIVERMorph to calculate the d_{nb}/d_{bkf} ratio based on the surveyed cross-sections. Finally, TWI rated the ratio based on NBS ratings developed by Rosgen (2006) as presented in Table 1.

Table 1. Near-Bank Stress Rating for d_{nb}/d_{bkf}

d_{nb}/d_{bkf} Ratio	**NBS Rating**
< 1.00	Very Low
1.00 - 1.50	Low
1.51 – 1.80	Moderate
1.81 – 2.50	High
2.51 – 3.00	Very High
> 3.00	Extreme

Source: Rosgen 2006

Rosgen (1996 and 2006) developed the Bank Assessment for Non-Point Consequences of Sediment (BANCS) to estimate erosion rates. Rosgen then calibrated BEHI scores to yield a linear relationship between NBS ratings and measured bank erosion rates stratified by BEHI ratings. The BANCS model is only applicable for predicting bank erosion rates in Colorado and Yellowstone National Park; where bank monitoring occurred.

Recently, Sass and Keane (2012) completed a three-year streambank monitoring study in the Black Vermillion watershed and developed bank erosion prediction curves for moderate and high BEHI ratings. Sass and Keane monitored 18 study banks from 2007 to 2010. After developing BEHI-NBS curves using the BANCS methodology, Sass and Keane suggested that some BANCS parameters may not fit northeast Kansas conditions. They postulated that vegetation may play a larger role in bank stabilization as it provides tensile strength in soils and dissipates water velocities.

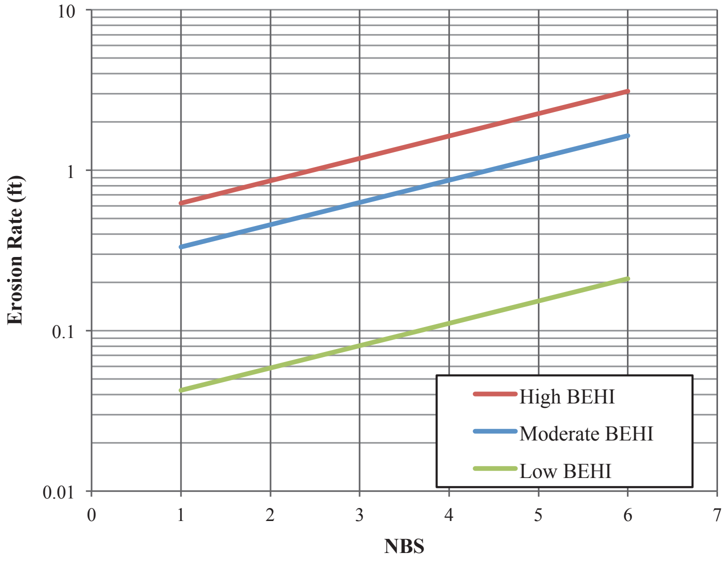

Figure 8. BEHI-NBS erosion prediction curves. Moderate and High BEHI curves are from Sass and Keane (2012).

Sass and Keane (2012) modified the BEHI assessment by removing the rooting density percentage and riparian vegetation rooting depth to streambank height ratio parameters. They added the parameter, “Woody Vegetation Present.” Sites with woody vegetation present receive a score of 2.5 and sites without woody vegetation receive a score of 8.5 (Sass and Keane 2012). Sass and Keane found a stronger relationship between NBS scores and bank erosion rates when using the northeast Kansas BEHI modifications. Finally, Sass and Keane revised the BEHI rating scores as the total points possible changed in the modified BEHI assessment. The modified moderate and high BEHI-NBS erosion prediction curves from Sass and Keane are presented in Figure 8.

TWI’s survey locations have similar characteristics to the monitoring location in Sass and Keane (2012). Almost all of TWI’s survey sites are mapped as Kennebec silt loam (U.S. Department of Agriculture Natural Resources Conservation Service [USDA NRCS] 2012). A majority of monitoring sites in Sass and Keane are mapped as Kennebec silt loam. Also, the three watersheds are found in the same physiographic region as Sass and Keane’s monitoring sites. TWI concluded that erosion prediction curves from Sass and Keane are appropriate to estimate bank erosion in this study. As a result, TWI modified the BEHI scores based on the Sass and Keane’s northeast Kansas modifications.

Sass and Keane’s (2012) study dealt with banks with low to high modified BEHI ratings. However, only two study banks were rated as low, and therefore Sass and Keane were not able to develop low

BEHI-NBS erosion prediction curves. Banks with low BEHI ratings are expected to have erosion loss, but these banks can be difficult to quantify as the erosion loss rate is typically low. To predict erosion loss for streambanks with low BEHI ratings, TWI developed a low BEHI-NBS erosion predication curve that has a similar y intercept difference between moderate and low BEHI-NBS erosion predictions curves as the high and moderate BEHI-NBS erosion prediction curves. Then, TWI used an average slope between Sass and Keane's moderate and high BEHI-NBS curves for the low BEHI-NBS curve. The low BEHI-NBS erosion prediction curve is shown in Figure 8.

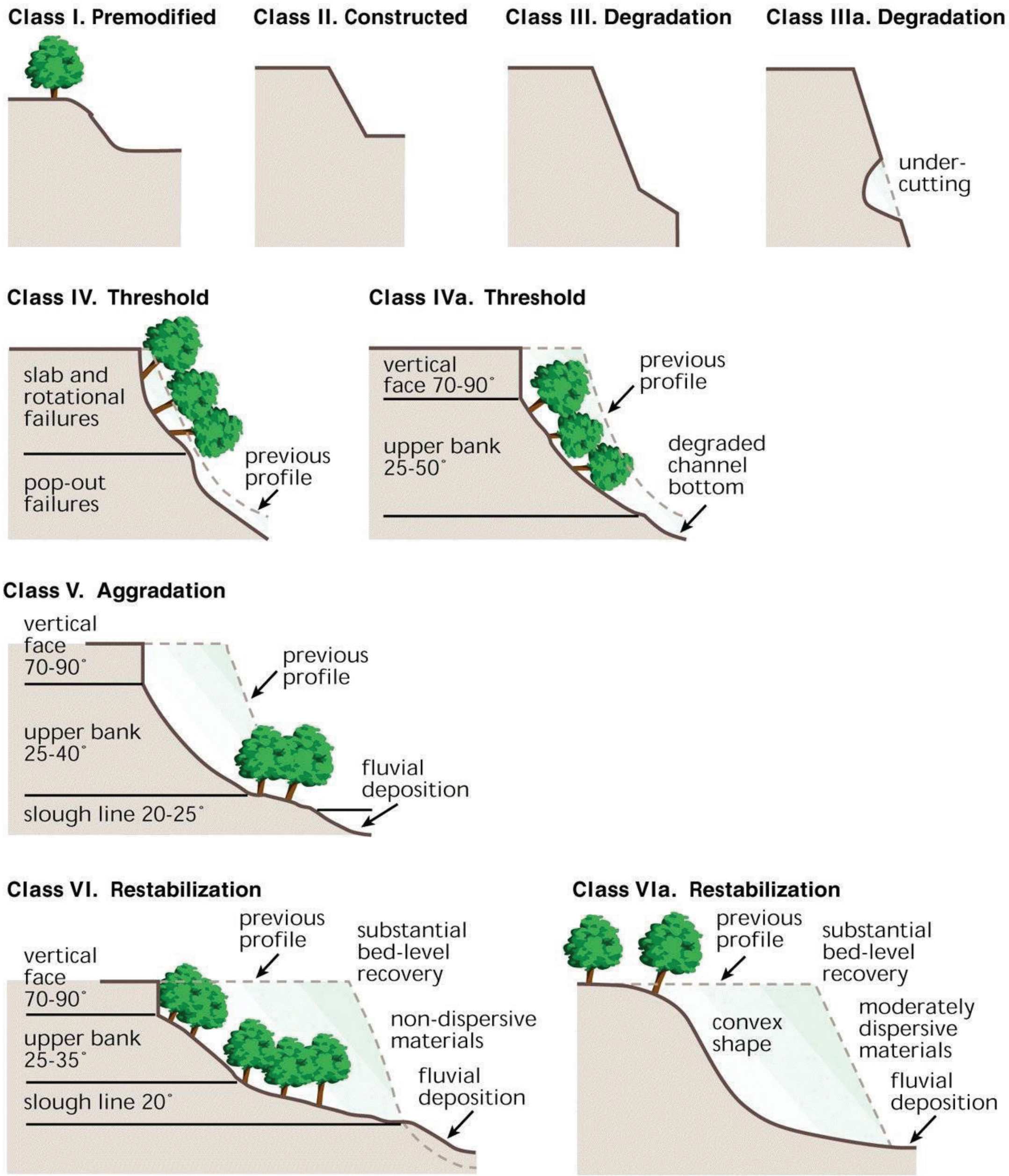

Figure 9. Simon Channel Evolution Sequence (from Simon 1989a).

TWI revised the BEHI scores based on the northeast Kansas modification by Sass and Keane (2012), and used the erosion prediction curves shown in Figure 8 to estimate each bank type's erosion loss. For each site, TWI calculated an overall weighted average BEHI score (based on bank type length to overall survey length), NBS score, and erosion loss rate in tons per year per foot.

Channel Evolution Stage. TWI assessed the stage of channel evolution for each stream survey using the Simon Channel Evolution Sequence. TWI used survey data and field observations to determine the sequence or stage. Simon (1989a) developed six stages of bank-slope development that represent distinguishable bank morphologies characteristic of channel processes. Figure 9 shows the six Simon Channel Evolution stages.

Results

Watershed Characteristics

Drainage densities for each watershed are presented in Table 2. Banner Creek has the highest drainage density at 5.53 channel miles per square mile of drainage. Centralia Lake and Atchison County Lake yielded similar densities of around 4.8 channel miles per square mile of drainage.

Results of the channel length analysis revealed that Centralia Lake was the only watershed where channel length has decreased. Both Atchison County Lake and Banner Creek had more feet of stream in 2008 than in the historic aerial photographs; likely the result of inaccuracies of delineating poor quality images. The results are presented in Table 3.

The local relief in Banner Creek watershed is about 260 feet with the uplands reaching an elevation of 1,340 feet above mean sea level (AMSL) and Banner Creek Reservoir at an elevation of 1,078 feet AMSL. Upland elevations in Centralia Lake watershed reach about 1,390 feet AMSL and the lake is around 1,265 feet AMSL resulting in a local relief of 125 feet. Atchison County Lake watershed peaks around 1,170 feet AMSL and the lake is near 1,055 feet AMSL; a difference of 115 feet. The valleys in all three watersheds are gently sloping with poorly developed floodplains adjacent to terraces. Figure 10 shows the relationship of drainage area to valley slope for each watershed.

Impoundments are much more prominent in Atchison County Lake and Banner Creek. Table 4 shows the percentage of each site's drainage area affected by impoundments. Several sites in Atchison County had over 80 percent of the

Table 2. Drainage Density Results

Watershed	**Drainage Density Miles/Square Mile**
Atchison County Lake	4.76
Banner Creek Reservoir	5.53
Centralia Lake	4.85

Table 3. Changes in channel length

Watershed	Channel Length Change (Feet)
Atchison County Lake (1942-2008)	+ 2,671
Banner Creek Reservoir (1956-2008)	+ 9,804
Centralia Lake (1942-2008)	- 4,688

Table 4. Percent of each site's drainage area affected by impoundments

Atchison County Lake	Impounded (%)	Banner Creek	Impounded (%)	Centralia Lake	Impounded (%)
1	83	1	34	1	1
2	1	2	76	2	8
3	36	3	60	3	6
4	85	4	23	4	6
5	2	5	37	5	11
		6	19	6	9
		7	34	7	16
				8	11
				9	21

Table 5. Site drainage areas

Atchison County Lake	Drainage Area Sq mi.	Banner Creek	Drainage Area Sq mi.	Centralia Lake	Drainage Area Sq mi.
1	0.47	1	3.03	1	0.41
2	1.41	2	0.85	2	0.74
3	3.59	3	1.27	3	1.33
4	1.82	4	1.28	4	1.40
5	1.33	5	9.14	5	3.69
		6	0.75	6	0.65
		7	1.63	7	1.64
				8	4.21
				9	1.21

drainage area flowing through impoundments. Banner Creek has a wide range of impoundment areas ranging from 19 to 76 percent. In Centralia Lake, the drainage area most affected by impoundments was Site 9 at 21 percent.

Survey Drainage Area

Site drainage area ranged from about 0.4 square miles to 4.0 square miles in Atchison County Lake and Centralia Lake. Drainage areas in Banner Creek ranged from 0.75 square miles to over 9.0 square miles. Table 5 presents the drainage area of all survey sites.

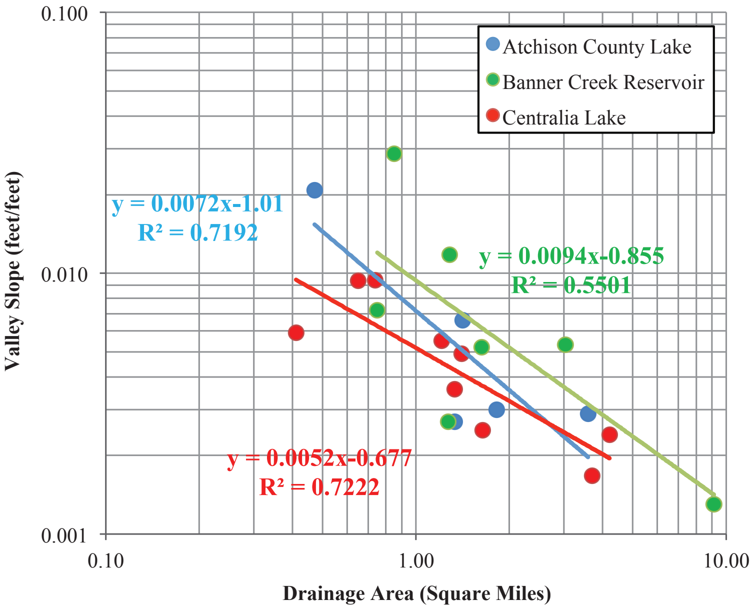

Figure 10. Drainage Area versus valley slope.

Channel Morphology

Atchison County Lake. Table 6 summarizes channel morphology variables for the Atchison County Lake surveys. Sites 2-4 classified as E stream types that are defined as narrow, deep channels with high sinuosities greater than 1.5. Site 4 has a low sinuosity of 1.14 and TWI suspects that this reach was modified at some time even though the historic aerial photographs do not show any channel changes. Site 1 classified as a B stream type that is a moderately entrenched channel with moderate sinuosity. Site 1 has a very high sinuosity of 1.86 and TWI suggests that the stream classification is influenced by reduced flows from a nearby impoundment. Finally, Site 5 is unique in that it has a much wider and shallower channel. It classified as a C stream type that has a moderate to high width depth ratio. Site 5 has a very large width depth ratio, more indicative of a D stream type or braided channel. Figure 11 shows representative pictures of Atchison County site conditions. All sites except Site 5 had a woody riparian corridor. The corridor widths varied to less than one bankfull width to well over two bankfull widths. All channels except site 4 have high sinuosities indicative of a natural meander pattern.

Figure 11. Atchison County Site Photos: (a) Site 1, (b) Site 2, (c) Site 3, and (d) Site 5.

Table 6. Atchison County Lake channel morphology results

Site	Bankfull Width (ft)	Hydraulic Radius (ft)	Bankfull Mean Depth (ft)	Bankfull Maximum Depth (ft)	Bankfull Area (sq ft)	Floodprone Width (ft)	Entrenchment Ratio	Width/Depth Ratio	Bankfull Slope (ft/ ft)	Sinuosity	Stream Classification
1	11.7	0.7	1.3	1.3	8.8	17.0	1.5	15.6	0.01120	1.86	B6c
2	16.3	1.4	1.6	4.1	26.7	67.7	4.2	9.9	0.00325	2.04	E6
3	24.3	3.2	4.4	6.9	105.6	249.3	10.3	5.6	0.00091	3.16	E5
4	14.4	1.3	1.4	2.4	19.8	35.4	2.5	10.5	0.00264	1.14	E6
5	36.5	0.9	0.9	2.2	33.2	87.6	2.4	40.2	0.00144	1.89	C6

Table 7. Banner Creek channel morphology results.

Site	Bankfull Width (ft)	Hydraulic Radius (ft)	Bankfull Mean Depth (ft)	Bankfull Maximum Depth (ft)	Bankfull Area (sq ft)	Floodprone Width (ft)	Entrenchment Ratio	Width/Depth Ratio	Bankfull Slope (ft/ ft)	Sinuosity	Stream Classification
1	35.3	3.7	4.0	5.4	142.9	450.0	12.7	8.8	0.00268	2.64	E6
2	9.8	0.8	0.9	1.4	8.4	16.9	1.7	11.4	0.01032	2.78	B6c
3	15.6	1.8	2.1	3.5	32.2	30.3	1.9	7.6	0.00212	1.25	B5c
4	20.3	2.1	2.3	3.9	46.2	41.8	2.1	8.9	0.00759	1.56	E5
5	50.7	5.0	5.7	8.6	288.9	145.0	2.9	8.9	0.00121	1.07	E6
6	11.2	1.6	1.9	2.8	20.8	22.9	2.0	6.0	0.00514	1.57	E5
7	27.2	2.3	2.4	4.4	65.9	62.0	2.3	11.2	0.00487	1.07	E6

Banner Creek. Most Banner Creek sites classified as E stream types. Sites 2 and 3 classified as B streams. Both of these sites are heavily influenced by upstream impoundments that have caused a reduction in bankfull dimensions. Width depth ratios are less than 12 indicating a narrow channel and entrenchment ratios are near 2.2 for most sites that is the division between moderately and slightly entrenched channels. The banks tended to have more clay layers and are taller in comparison to the other watersheds. Table 7 summarizes the channel morphology data and Figure 12 shows pictures of channel conditions.

Figure 12. Banner Creek site photos: (a) Site 1, (b) Site 4, (c) Site 6, and (d) Site 7

Centralia Lake. All Centralia Lake survey sites classified as E stream types. However, none of the survey sites have the sinuosities required for E stream types. All sites except Site 1 have been channelized and sinuosities are near 1.0. The bankfull mean depths tend to be higher than the other watersheds; again due to the channel modifications. The entrenchment ratios are not small enough to classify the sites as incised channels, but the channels are not connected to a floodplain feature. A woody riparian corridor is nearly absent in all surveys and there is typically a narrow grass buffer between the channel and cultivated fields. For site 9, GSRC identified the relic channel adjacent to the current channel and surveyed a cross section using the same elevation control as the current channel survey. Based on the elevation data, the active channel has lowered about 6.3 feet. Figure 13 shows the relic channel cross section overlay with the current stream channel cross section. Table 8 provides a summary of the channel morphology data and Figure 14 shows pictures of some of the Centralia Lake sites.

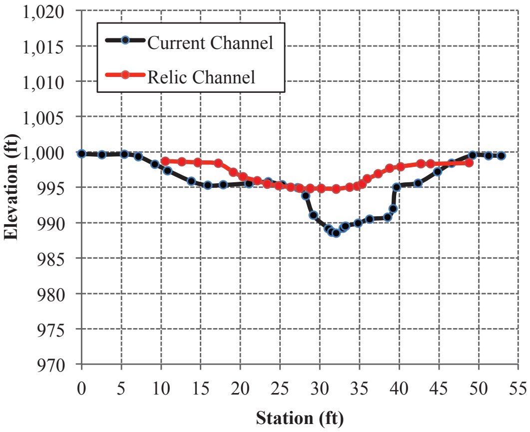

Figure 13. Cross section comparison of Centralia Lake Site 9 current and relic channels.

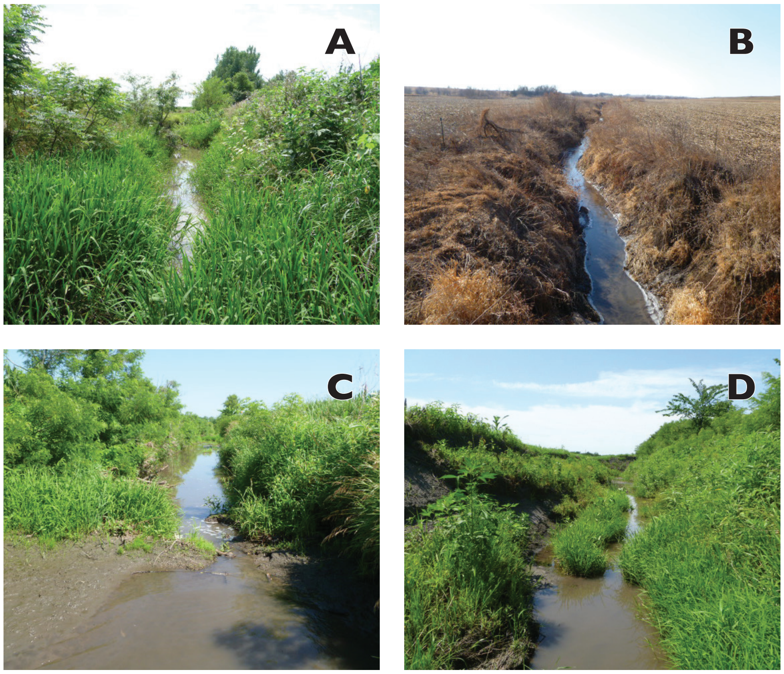

Figure 14. Centralia Lake site photos: (a) Site 2, (b) Site 5, (c) Site 7, and (d) Site 8.

Bankfull Discharge

Figure 15 shows the drainage area versus the calculated bankfull discharge plot. The points with black circles are the surveys with impoundment ratios greater than 60 percent.

BEHI

BEHI results show that most sites rate in the moderate category. Parameters that generally had the most influence were the bank height to bankfull height ratio and surface protection percentage. Most sites are not connected to a floodplain and have high bank heights. Surface protection was usually very sparse or very thick. For instance, most of the Centralia sites had high banks, but the surface protection was very good. Low BEHI rated sites tended to have gently sloping banks with good surface protection. Modifying BEHI assessments following Sass and Keane (2012) lowered most of the BEHI scores in Atchison County Lake and Banner Creek Sites. In some instances, the ratings lowered from moderate to low. In

Table 8. Centralia Lake channel morphology results

Site	Bankfull Width (ft)	Hydraulic Radius (ft)	Bankfull Mean Depth (ft)	Bankfull Maximum Depth (ft)	Bankfull Area (sq ft)	Floodprone Width (ft)	Entrenchment Ratio	Width/Depth Ratio	Bankfull Slope (ft/ ft)	Sinuosity	Stream Classification
1	6.8	1.1	1.7	3.3	11.3	230.0	33.9	4.1	0.00468	1.27	E6
2	11.3	1.1	1.3	2.3	15.0	117.0	10.3	8.5	0.00938	1.00	E6
3	16.0	2.7	3.8	5.5	60.4	340.0	21.2	4.3	0.00350	1.02	E6
4	16.8	2.2	2.6	4.0	43.0	35.1	2.3	6.6	0.00474	1.04	E6
5	22.6	3.6	4.6	8.0	103.4	360.0	15.9	5.0	0.00167	1.00	E6
6	13.1	1.3	1.7	3.0	21.9	30.3	2.3	7.8	0.00938	1.00	E6
7	19.1	2.2	2.3	3.3	43.5	81.0	4.2	8.4	0.00247	1.00	E6
8	25.2	3.6	4.3	6.0	107.7	66.7	2.6	5.9	0.00214	1.10	E6
9	12.6	2.7	4.2	6.5	53.5	215.0	17.0	3.0	0.00429	1.02	E6

Centralia Lake, most of the BEHI scores increased since woody vegetation are nearly absent. The majority of NBS stress scores rated as moderate. Table 9 shows each site's weighted BEHI score and rating, modified BEHI score and rating, NBS score and rating, and predicted erosion loss per site using the BEHI-NBS curves shown in Figure 8.

Channel Evolution

TWI observed numerous accounts of bank failures indicating lateral expansion (see Figure 16). TWI did not observe active streambed degradation, but in many cases there were sediments accumulating in the channel. For stream reaches that had a tributary confluence, TWI followed the tributary upstream from the confluence and found the active knickpoint (see Figure 17). Banner Creek Site 7 had a knickpoint just downstream from the survey reach that has been armored by a low water crossing (see Figure 12d). The crossing has stopped the upstream knickpoint migration. Based on the survey data and field observations, TWI found that sites are transitioning from Class IV to Class V in the Simon Evolution Sequence (see Figure 9).

Conclusions

Many of the Banner Creek and Atchison County Lake surveys exhibited similar channel morphologies. Almost all the sites have a woody riparian corridor adjacent to the channel albeit some corridor widths are less than one bankfull width. TWI surveyed sites in both watersheds that had a significant amount of drainage area controlled by impoundments. Most of the sites have a sinuous channel with bar deposits. In contrast, all but one of Centralia Lake's surveys had been straightened and woody riparian corridors are either nonexistent or narrow and fragmented. TWI found that most channels had a narrow grass buffer with very little woody vegetation. At some sites, TWI observed evidence of woody species removal as a land management practice.

The use of regional curves and the Manning relation yielded bankfull discharges that correlated well with drainage area (see Figure 15). Figure 15 shows that these three watersheds are in the same hydro physiographic province as the bankfull discharge versus drainage area relationships are similar. The watershed correlations would be stronger if TWI removed the sites that are heavily influenced by impoundments, but due to the small dataset these sites are included in the analysis. Petts (1980) found no significant effects on downstream morphology on rivers where the impoundment area was no more than 35-40 percent of the total drainage area. Figure 18 shows that the channel morphology is influenced by upstream impoundments when the impoundment area reaches somewhere between 37 and 60 percent of total drainage area. Due to the small data set, TWI cannot provide a more refined range of impoundment area influence.

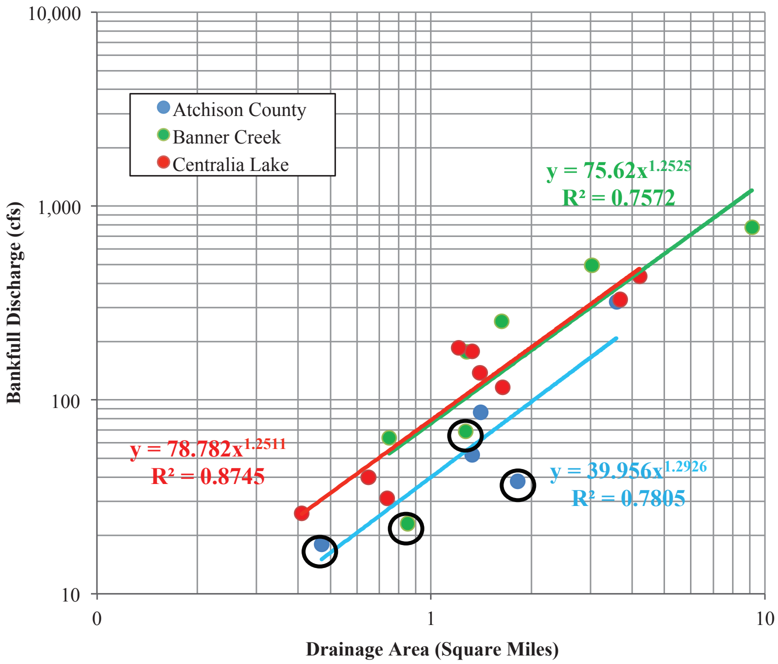

Figure 15. Drainage area versus calculated bankfull discharge.

Bankfull cross section area and width yielded similar correlations with drainage area for all three watersheds (see Figure 19). Bankfull mean depth and bankfull maximum depth show that Centralia Lake's streams tend to have deeper channels. Finally, the average water surface slope versus drainage area relationship show that Centralia Lake and Banner Creek have similar correlations even though the Banner Creek watershed local relief is greater. TWI attributes the differences in Centralia Lake channel morphology to channelization.

Channelizing streams increases slope, reduces roughness, and increases depth of flow (Schumm et al. 1984). Channelization creates upstream-progressing degradation that leads to unstable, over-heightened banks (Simon 1994). Sharkman and Samson (1991) found that channelization decreases flooding as water is mostly contained within and efficiently moved through the channel. Since more water can be conveyed within the channel banks, channelized streams have greater stream power thus higher sediment transport capacity (Harvey and Watson 1986, Simon and Hupp 1990). Figure 20 shows the relationship between stream power and drainage area. Stream power does not decrease as much in Centralia Lake as Banner Creek and Atchison County Lake with increasing drainage area as channelization has increased the slopes in Centralia Lake watershed channels. Increases in stream power create added shear stress on boundary materials that can lead to bank failures (Harvey and Watson 1986).

Bank erosion estimates predict more erosion loss in Atchison County Lake and Banner Creek; both with an average of

Table 9. Bank erodibility summary (weighted averages per site)

Atchison County Lake

Site	BEHI Score	BEHI Rating	Modified BEHI Score	Modified BEHI Rating	NBS Score	NBS Rating	Erosion Loss tons/yr/ft
1	28.3	Moderate	22.2	Moderate	1.70	Moderate	0.12
2	16.5	Low	11.8	Low	1.52	Low	0.07
3	22.1	Moderate	16.3	Low	1.42	Low	0.06
4	22.5	Moderate	18.1	Low	1.76	Moderate	0.02
5	34.9	High	27.7	High	1.72	Moderate	0.79
						Average	0.21

Banner Creek

Site	BEHI Score	BEHI Rating	Modified BEHI Score	Modified BEHI Rating	NBS Score	NBS Rating	Erosion Loss tons/yr/ft
1	24.1	Moderate	18.9	Low	1.80	Moderate	0.08
2	27.1	Moderate	23.8	Moderate	1.79	Moderate	0.44
3	22.2	Moderate	17.8	Low	1.57	Moderate	0.03
4	24.8	Moderate	19.1	Low	1.67	Moderate	0.20
5	21.7	Moderate	16.1	Low	1.54	Moderate	0.05
6	30.3	High	25.4	Moderate	1.35	Low	0.28
7	23.5	Moderate	22.1	Moderate	1.79	Moderate	0.39
						Average	0.21

Centralia Lake

Site	BEHI Score	BEHI Rating	Modified BEHI Score	Modified BEHI Rating	NBS Score	NBS Rating	Erosion Loss tons/yr/ft
1	18.1	Low	20.5	Moderate	1.93	High	0.16
2	19.0	Low	17.5	Low	1.71	Moderate	0.06
3	21.2	Moderate	23.1	Moderate	1.66	Moderate	0.20
4	16.7	Low	19.5	Moderate	1.73	Moderate	0.09
5	16.7	Low	18.3	Low	1.67	Moderate	0.07
6	21.9	Moderate	23.8	Moderate	1.70	Moderate	0.11
7	18.3	Low	20.7	Moderate	1.31	Low	0.08
8	27.9	Moderate	21.7	Moderate	1.53	Moderate	0.23
9	20.4	Moderate	22.2	Moderate	1.54	Moderate	0.29
						Average	0.14

Figure 16. Active bank slumping along left banks.

Figure 17. Active knickpoints in tributaries above survey sites.

0.21 tons/year/foot. The average erosion loss in Atchison County Lake is heavily influenced by Site 5 with an estimated erosion loss of 0.79 tons/year/foot. This site does have high, unstable banks, but the site is aggrading and there is little stream power to move sediment downstream. Also, the erosion loss estimate for Site 1 does not take into account the reduced flows from the impoundment upstream. Since the bankfull elevation has lowered, the bank height ratio has increased resulting in a higher BEHI score. Impoundments also influence the flows for Sites 2 and 3 in Banner Creek.

Reduced flows from impoundments upstream of Site 4 in Atchison County and Sites 2 and 3 in Banner Creek have caused a decrease in bankfull dimensions. As a result, the estimated bankfull discharge is well below the predicted values of the regression analysis (see Figure 15). Channel aggrading and narrowing below dams have also been documented in other channels. Williams and Wolman (1984) found that reaches where flow releases are much less that pre-dam discharges, the channel aggrades and can become narrower. Grant et al. (2003) concluded that low frequency of sediment-transporting flows and a low ratio of sediment supply below dam to supply above dam can yield vegetation encroachment and channel aggradation. Brandt (2000) stated that new water discharge and sediment load conditions will cause channel cross section shape adjustment and that decreased discharge with sediment load will lead to decreased depth and width.

The BEHI assessment does not account for the reduction of flows at these three sites and thus the BEHI scores tend to over predict the erosion potential. Shields et al. (2000) found that reservoirs reduce the frequency and duration of high flows which in turn reduce lateral migration rates by factors of 3 to 6. Other studies have found little difference in lateral migration following dam closure. Wellmeyer et al (2005) found that lateral migration rates did not stabilize after dam closure; however, the dam did not affect the frequency or magnitude of flood peaks. Phillips (2003) concluded that channel responses occurred immediately downstream from dams, but there is little evidence of channel morphology changes further downstream. Furthermore, Phillips stated that sediment loads recover rapidly downstream due to tributary inputs. TWI found that bankfull discharges were lower on surveys below dams when compared to surveys in uncontrolled watersheds (TWI 2004). Based on the data presented, the erosion loss predictions of these three sites heavily controlled by impoundments likely over predict the sediment load contributed by in-channel sources.

Finally, Banner Creek Site 6 has a predicted erosion loss rate of 0.28 tons/year/foot. This site is heavily influenced by clay in the lower banks and streambed. TWI suggests that this overestimates the actual erosion loss due to the tight cohesive bank materials. Sass and Keane (2012) and Harmel et al. (1999) both suggest that including a bulk density or cohesion component into the BEHI assessment would improve erosion predictions. Harmel et al observed that erosion from loose, alluvial banks exceeded erosion from banks with well-developed soil profiles that exceeded erosion from highly compacted banks.

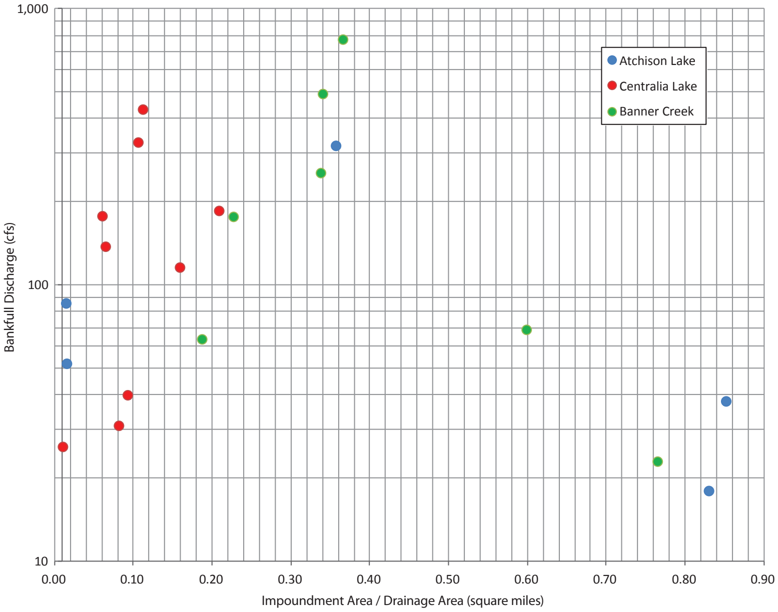

Figure 18. Bankfull discharge versus impoundment area/total drainage area.

For the Centralia Lake surveys, the predicted erosion loss ranged from 0.06 to 0.29 tons/year/foot. TWI observed more bank slumping at these sites than the other watersheds. The slumps tended to be large sections of banks instead of the continuous removal of bank materials during high flow events. Shindala and Priest (1970) noted that fine cohesive particles may fail as a massive landslide where considerable amounts of bank material might move into the stream in a short amount of time. These slumps also had much of the original bank vegetation still growing that has helped to maintain a high surface protection percentage.

Since most of the drainage network is channelized, Centralia Lake channels do have the ability to transport more sediment further downstream as the channel depth and stream power are higher compared to Atchison County Lake and Banner Creek. Generally, sediment that is transported through modified channels becomes trapped downstream when the

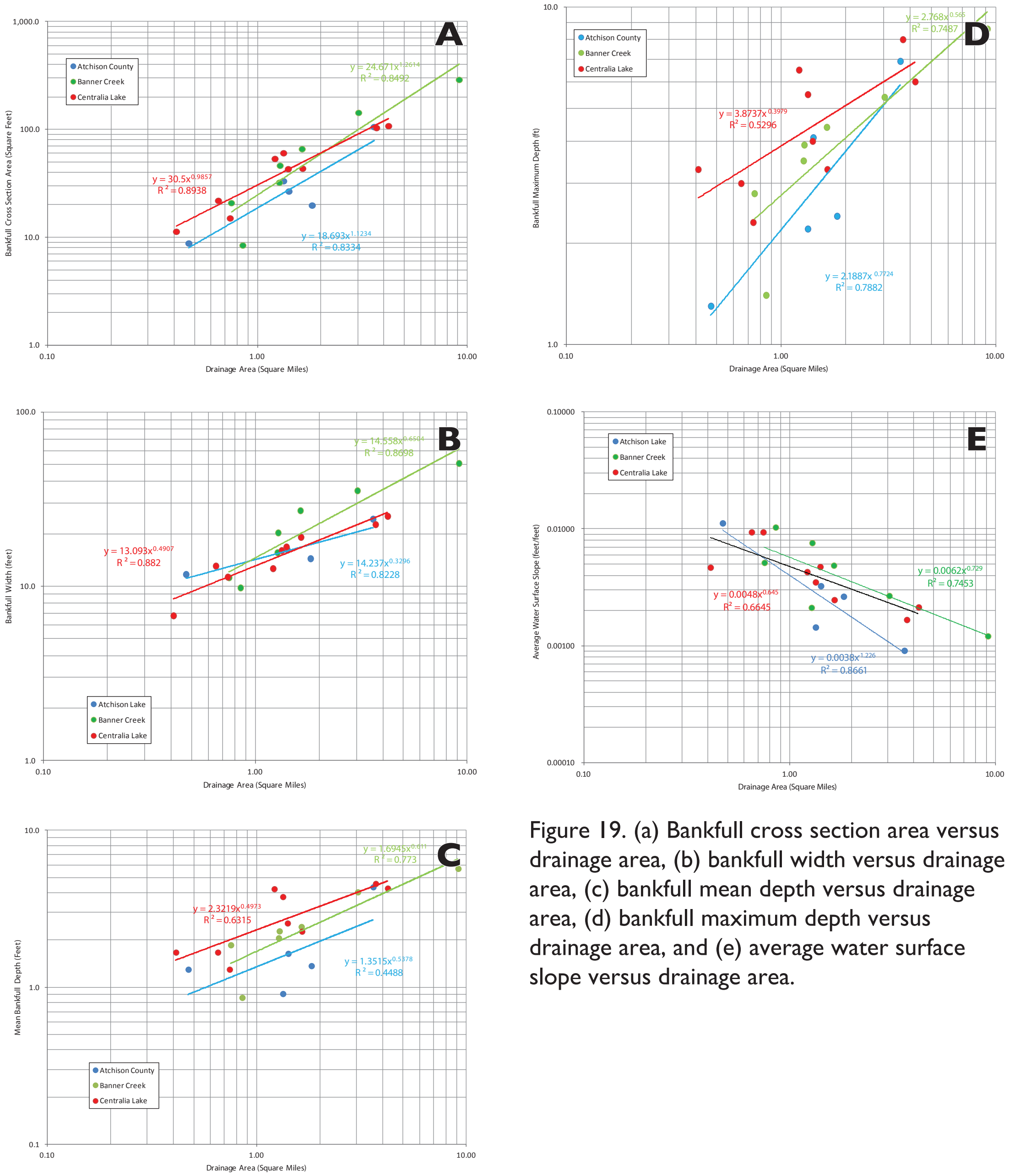

Figure 19. (a) Bankfull cross section area versus drainage area, (b) bankfull width versus drainage area, (c) bankfull mean depth versus drainage area, (d) bankfull maximum depth versus drainage area, and (e) average water surface slope versus drainage area.

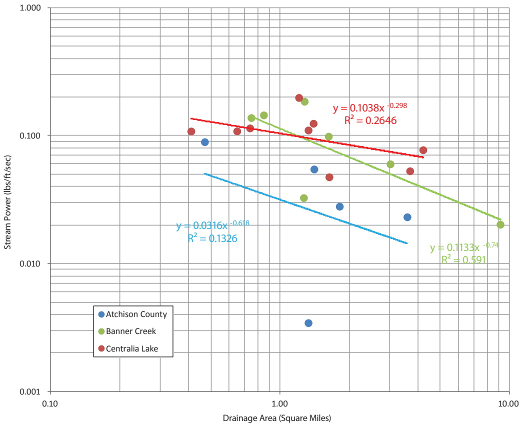

Figure 20. Stream power at bankfull versus drainage area.

channel resumes pre-disturbed channel characteristics (Schumm et al 1984). For Centralia Lake, the west tributary does not flow into pre-disturbed channel reach before entering Centralia Lake. In the east tributary, the channel returns to a pre-disturbed meander pattern about 4,500 feet upstream of Centralia Lake. In all, the streams above Centralia Lake are very efficient in transporting fine sediments. Yields of suspended sediment peak in Simon's threshold stage (Stage IV) and Stages III, V, and VI tend to have moderate transport efficiency (Simon 1989b). Simon and Rinaldi (2000) found that finer boundary sediments tend to take longer to adjust and restrict bed level recovery. As a result, it is likely that higher yields of suspended sediment will continue to reach Centralia Lake for some time.

Lastly, TWI used the erosion loss results to extrapolate in-channel sediment yields. For Atchison County Lake, TWI used an average soil loss rate of 0.05 tons/year/foot. TWI did not use the soil loss rates from Site 1 and 5 as the rate for Site 1 is likely over-predicted due to a high proportion of impoundments in the site's watershed, and Site 5 channel morphology has low stream power to transport sediment. For Banner Creek Reservoir, TWI used an average soil loss rate of 0.20 tons/year/foot. TWI did not use soil loss rates from Site 2 and 3 as the rates TWI predicted are likely elevated due to a high proportion of impoundments in their respective watersheds. TWI used an average soil loss rate of 0.14 tons/year/foot for Centralia Lake.

TWI measured the channel lengths except for the grass waterways as these channel are representative of the average soil loss rates. For the grass waterways, TWI measured the waterway lengths and then made two assumptions. The first assumption is the waterways have low-low BEHI-NBS ratings. The second assumption is the average bank height is 1-foot. TWI used the calculated channel lengths and drainage area to calculate an annual sediment yield in tons per square mile. TWI then used the USGS (Foster et al. 2012) monitoring period from March 2009 to September 2011 to calculate an overall sediment yield. The predicted sediment yields from in-channel sources are 15,074 tons per square mile at Banner Creek Reservoir, 2,065 tons per square mile at Centralia Lake, and 943 tons per square mile in Atchison County Lake. The USGS monitoring results equaled 1,200 tons per square mile at the Banner Creek Reservoir gage, 2,800 tons per square mile at the Centralia Lake USGS gage and 1,100 tons per square mile at the Atchison County Lake USGS gage (Foster et al. 2012).

TWI suggests that much of the sediment source is from in-channel erosion in Centralia Lake and Atchison County Lake watersheds. For Banner Creek Reservoir, predicted in-channel sediment yields were significantly higher than USGS monitored sediment yields. TWI suggest factors that

may contribute to the over-prediction of in-channel erosion include the presence of cohesive bank materials, the influence of impoundments, and the influence of wooded riparian areas. For Atchison County Lake, the original in-channel erosion of 0.21 tons/year/foot would also have been significantly higher than USGS monitoring results. The revised in-channel erosion rate of 0.05 tons/year/foot does appear to be a more realistic estimate. TWI's in-channel erosion estimate (0.14 tons/year/foot) for Centralia Lake do reasonably predict in-channel erosion loss when compared to USGS's monitoring results. TWI argues that Centralia Lake in-channel erosion is highest among the three watersheds due to extensive channelization; a process that degrades the streambed and banks producing excess sediment erosion.

Recommendations

To improve in-channel erosion loss predictions, TWI recommends establishing a monitoring network of permanent cross sections with erosion pins. Measuring actual bank loss will help calibrate in-channel erosion rates for Kansas hydro-physiographic provinces. Monitoring sites should be established to document a variety of channel conditions that include Simon and Hupp (1986) evolution sequence and riparian condition. This information can then be used with a watershed assessment approach that incorporates GIS-based watershed characterization techniques with targeted ground-truthing locations. Using this approach will help predict in-channel sediment yields at a watershed scale; useful information in watershed planning and for targeting locations for best management practices.

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GIS-Based Watershed Characterization using Helicopter Videography and Historical Aerial Photography

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Interpretive Summary

This study used low-altitude helicopter videography coupled with historical aerial photography to characterize streams in the Atchison County Lake, Banner Creek Lake, and Centralia Lake watersheds. Helicopter imagery was used to classify stream segments according to Simon's six-stage channel evolution model. Stream classification was also conducted to map out qualitative assessment of channel erosion, bank height, riparian vegetation, and man-made structures.

Small watershed impoundments and their respective drainage areas were mapped out using a combination of historical aerial photography and U.S. Geological Survey (USGS) 1:24,000 topographic maps. Historical aerial imagery was also analyzed for notable channel and land-use changes.

The results of the stream evolution classification point to several interesting conclusions. First, Centralia appears to have the highest proportion of Stage III channels of the three watersheds (16%), with Banner having the lowest proportion (2%). This indicates that Centralia has had more recent channel disturbances, a fact that is borne out by analysis of historical aerial imagery. The Banner watershed appears to be recovering from widespread historical channel degradation, as 93% of the stream photos were classified in Stage IV.

Interestingly, an analysis of the qualitative classification indicates that streams in the Centralia watershed do not show visible signs of bank erosion, and that streams in Centralia have lower bank heights. These two factors would seem to indicate lower sediment production rates for the Centralia watershed, contrary to the sediment fluxes observed by the USGS. It is possible that sediment production in the Centralia watershed is primarily due to field sources or mobilization of channel bed material (incision) as opposed to bank material. The heavy grass coverage along Centralia streams may also be masking bank erosion. Centralia has a much higher proportion of grassed waterways (77% versus 19% for Atchison and 3% for Banner).

Watershed impoundments in Atchison and Banner may have a significant impact on the sediment production for those two watersheds. In 2008, Centralia had only 7% of the watershed upstream of small impoundments, while Banner had 61% and Atchison 39%.

Introduction

This chapter covers GIS-based characterization of the Atchison County, Banner Creek, and Centralia Lake watersheds using helicopter-based videography and historical aerial photography. The goal of this portion of the Sediment Baseline Study was to document current channel conditions, including watershed-wide mapping of channel evolution stage according to the Simon Channel Evolution Model (Simon and Rinaldi 2006). As an added benefit, each watershed was analyzed for watershed impoundments and significant historical channel changes using six aerial photographs, dating from the 1940s to 2008.

Helicopter-based characterization of stream channels has been used extensively in some regions of the country. In the mid-West, John Thomas with the Hungry Canyons Alliance in Oakland, Iowa, has flown hundreds of miles of streams in western Iowa (Thomas 2009). Benefits of helicopter-based surveillance can include rapid response, wide coverage, and a level of image detail not practically obtainable using fixed-wing aircraft. Watershed Institute, Inc. has also performed helicopter surveillance to identify locations of high streambank erosion on the Cottonwood and Neosho Rivers above John Redmond Reservoir.

The GIS-based evaluation presented here is intended to fill in the blanks between site-specific stream geomorphology surveys conducted by Watershed Institute, Inc. (see next Chapter) and to provide assessment of the overall stream condition in each watershed to the entire Sediment Baseline Group.

Procedures

Helicopter Videography

Helicopter fly-overs of all three watersheds were conducted on 3/13/2009 and 4/6/2012. Due to the early onset of foliage in 2012, the imagery collected on 4/6/2012 is obstructed by trees over large stretches of channel. As a result, the stream channel classification described in this chapter was conducted using the helicopter imagery from 3/13/2009.

Data Collection. On 3/13/2009 imagery was collected using a Sony Handycam HDR-SR12 high-definition video camera coupled with a RedHen VMS 300 GPS-encoding device. The RedHen VMS 300 is a global positioning system (GPS) receiver that encodes the real-time coordinates of the video camera into the audio signal of the video, thus allowing georeferencing of the video using RedHen proprietary post-processing software. All three watersheds were flown in a total of six hours of flight time. Bids were solicited for using a gyroscopically-mounted video system, but costs for this equipment were prohibitively expensive.

The video was collected from a Bell Ranger helicopter, owned and operated by Hawkeye Helicopter based in Osage City, Kansas. The front-left door of the helicopter was removed for the flight, allowing the videographer to lean out of the aircraft to film forward, left, and down from the helicopter. The helicopter flew approximately 300 ft above ground level at an average air speed of approximately 20 mph while filming. A major consideration during flight planning was refueling. For this stream survey, only one refueling trip was necessary (to Topeka). Flying at a slower speed would have enabled the capture of higher quality imagery, but at the cost of additional refueling trips – thus driving up the duration and cost of image acquisition.

All major streams in the watersheds were mapped prior to conducting the helicopter flyover; most streams were terminated at the upstream end where either a) the stream channel was no longer clearly defined, or b) the stream reached a significant impoundment. Figure 1 shows the helicopter path flown for each of the three watersheds.

Processing. Due to variable video quality, and because the GPS-encoded video requires expensive, proprietary software to view in conjunction with GIS software, digital stills were extracted from the video using the Sony Picture Motion Browser software provided with the HandyCam.

Digital stills were extracted such that adjacent photographs overlap by 15-30%. Stills were extracted where the stream channel was most visible. Each photo was manually georeferenced by combining the location of the helicopter, per the VMS 300 GPS coordinates, and the location of stream photographed in geographic information systems (GIS) software. The location on the stream was determined using 2002 and 2008 aerial imagery of the watersheds.

Channel Evolution Classification. The digital stills extracted from the helicopter videography were analyzed and classified based on the Simon Channel Evolution model (Simon and Rinaldi 2006). There are two prevalent versions of the channel evolution model. One

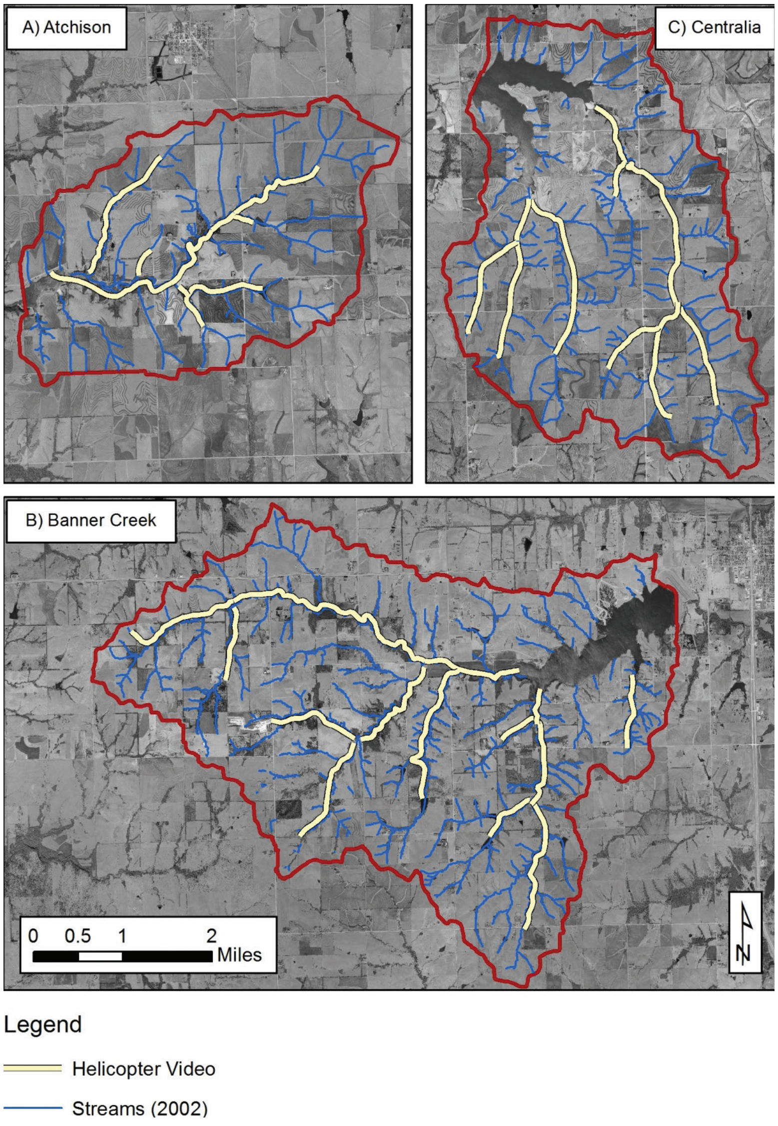


Figure 1. Map of Helicopter Path for Video Collection.

Table 1. Simon Channel Evolution Model

Stage	Label	Description
I	Pre-modified, Sinuous	Stable, Natural Channel, Sediment Inflow = Outflow
II	Constructed	Recent Disturbance, Channelized
III	Degradation	Channel Bed Incising, Sediment Outflow > Inflow
IV	Degradation and Widening	Channel Bed Incising, Channel Widening, Banks Eroding, Slumping, Sediment Outflow > Inflow
V	Aggradation and Widening	Channel Bed Aggrading, Channel Widening, Banks Eroding, Slumping, Sediment Flow Equilibrating
VI	Quasi Equilibrium	Stable Channel, Entrenched, New Flood Terrace

employs five channel evolution stages, while the one used for this analysis defines six stages. Table 1 describes the six stages; Figure 2 shows a schematic of the channel evolution model used for this study.

Simon's evolution model assumes that the stream is reacting to and recovering from channelization. Other major disturbances can cause a stream to follow a similar evolutionary pattern, including incision due to headcutting (perhaps due to downstream channelization), increased runoff due to upstream land use changes, or removal of riparian vegetation.

As mentioned previously, helicopter videography has been successfully employed in Western Iowa (Thomas 2009) to classify channel evolution stage. This project applied helicopter surveillance to much smaller streams than those investigated by Thomas (2009). Consequently, it is very difficult to discern the difference between a channel in Stage IV and V, particularly in areas with dense riparian vegetation. It is also very difficult or impossible to establish that a channel has reached Stage VI. However, the helicopter-based analysis does allow relatively rapid estimation of channel evolution stage over long stretches of stream. The results of the survey are useful for the relative assessment of channel condition across watersheds and for targeting locations for site-specific geomorphic surveys.

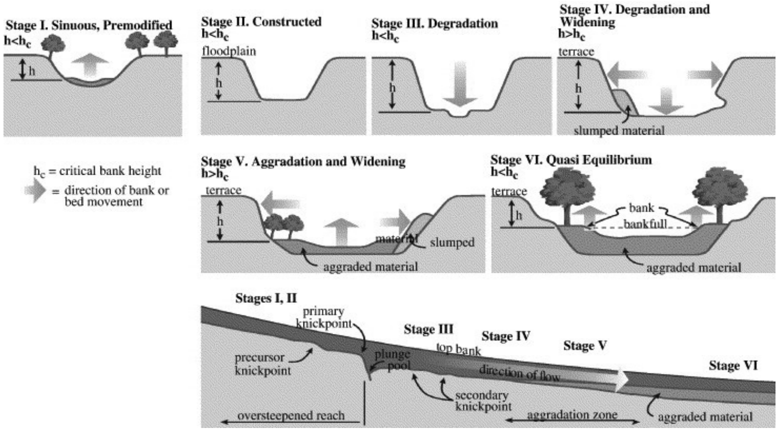
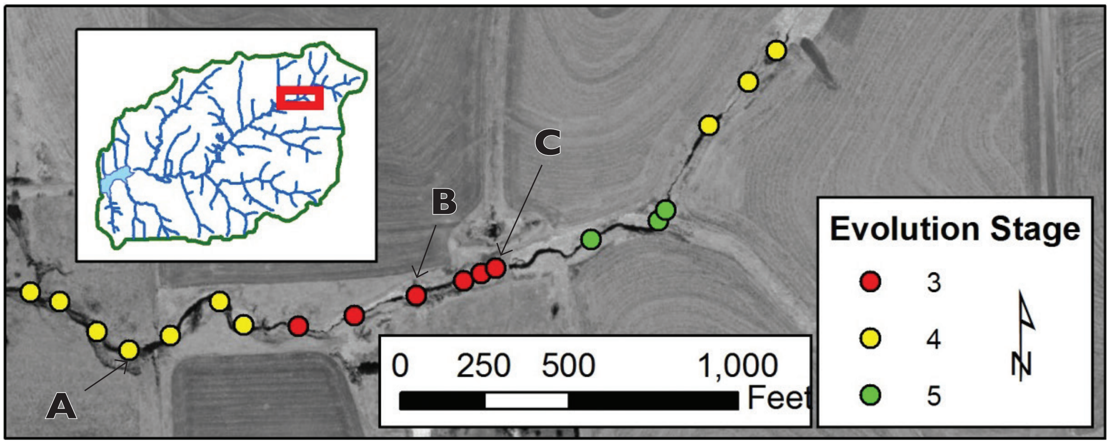


Figure 2. Six-Stage Channel Evolution Model. Figure from (Simon and Rinaldi 2006).

It should be noted that very few stream channels in eastern Kansas can be classified as Stage I due to removal of riparian vegetation, the conversion of land to agricultural use, the wide-spread use of channelization to reclaim cropland, and the historical channelization of small streams and channels into drainage swales or ditches.

In addition, it is unusual to see many streams that fall in Stage II, as a channel will almost immediately move from Stage II to Stage III. As a result, all of the streams classified for the three watersheds in this study fall into Stages III through V. Although some streams may have reached Stage VI, it is not possible to determine that a stream has reached sediment equilibrium from aerial imagery.

Figure 3 shows a section of Clear Creek in the Atchison County Lake watershed (see the inset for location). The map shows locations of stream photos extracted from the helicopter video, along with the channel evolution stage mapped as a result of this research. The photos below the map



Stage 3. Channel appears to be incising. A nick point is visible in upper right corner of image.

Stage 4. Channel appears to be widening after incision

Stage 5. The channel upstream of the grade control structure appears to be relatively stable.

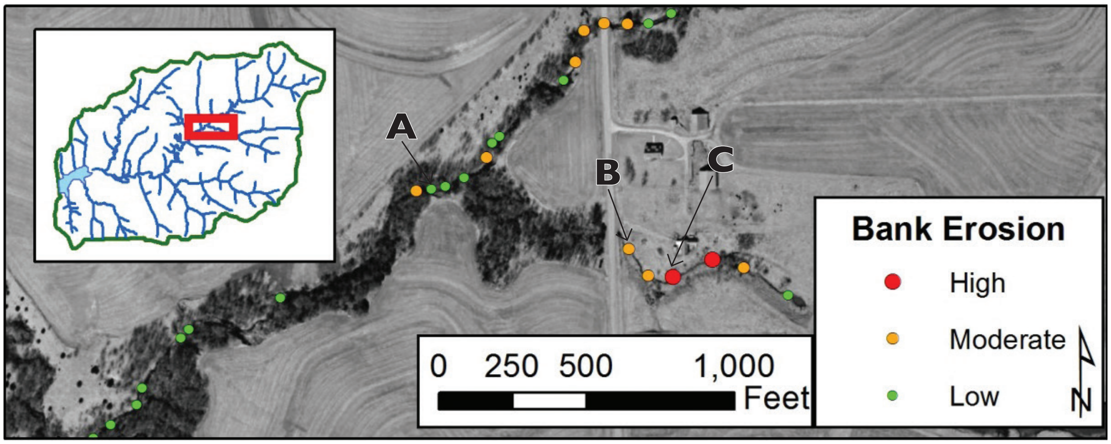
Figure 3. Stream Classification, Sample Photographs

show the progression of the stream from downstream to upstream from Stage IV, where there is ample evidence of channel widening, to Stage III, where the channel is narrower and perhaps still incising. In fact, there is a headcut (or nickpoint) visible in the Figure 3b at the upper end of the Stage III channel.

Not far above the headcut in Figure 3b, there is a concrete grade-control structure (see Figure 3c). This grade control structure appears to maintain an elevation difference of perhaps eight feet between the upstream and downstream reaches. This structure is clear evidence of historical degradation in the downstream channel. The upstream channel appears to be relatively well connected to the floodplain and might be classified in Stage I of the channel evolution model. However, the channel has been disturbed historically (removal of riparian vegetation). As a result, the channel upstream of the grade control structure was conservatively classified as Stage V.

Table 2. Parameters Included in Qualitative Characterization.

Category	Attribute	Values
Photo Quality	Stream_Vis: Is the stream channel visible in the photograph?	Y/N
Vegetation	VegWidth_LOB: Width of riparian vegetation for the left overbank (facing downstream)	<1 or >1 stream width
	VegWidth_ROB: Width of riparian vegetation for the right overbank (facing downstream)	<1 or >1 stream width
	VegDensity_LOB: Density of vegetation for left overbank	<30%, 30-70%, >70%
	VegDensity_ROB: Density of vegetation for right overbank	<30%, 30-70%, >70%
Bank Condition	BankHt_LOB: Height of bank for the left streambank.	High, Moderate, Low
	BankHt_ROB: Height of bank for right streambank	High, Moderate, Low
	Erosion: Evidence of bank or bed erosion	High, Moderate, Low
In Stream Debris	Debris: Is debris evident in the stream channel?	Y/N
Bar Formation	Bar_Presence: Is deposited bar material evident in the stream channel?	Y/N
	Bar_Width: Width of bar deposit relative to stream width.	None, Small, Medium, Large
Structures	Man_Made: Are any man-made structures visible?	Y/N
	Man_Type: What type of man-made structure is visible?	Culvert, bridge, low-water crossing, …
	Constriction: Estimate of % reduction in channel width through a bridge or culvert.	0-10%, 10-30%, >30%
Sinuosity	Meandering: Does the channel appear to have a natural meander pattern, or has it been straightened?	Straight, meandering w/i straight channel, meandering



Low: No significant bank erosion visible in photograph.

Medium: No significant bank erosion, but it appears that cattle have disturbed the stream bed.

High: Cattle disturbance visible on left side of photo and bank erosion evident in right side.

Figure 4. Sample Photographs for Classification of Stream Erosion

Qualitative Characterization. Each photograph extracted from the helicopter videography was classified for fifteen qualitative attributes. These attributes are listed in Table 2. Some of these attributes can be determined with a high level of confidence from the helicopter imagery (e.g., the width of riparian vegetation relative to the stream width). Other attributes are more difficult to establish. For example, the level of erosion in the stream channel can be very difficult to determine in some instances. Figure 4 shows sample images of low, moderate, and high erosion from a single stretch of channel in the Atchison County Lake watershed.

Historical Aerial Photography

Sources. Historical aerial images were obtained for six dates. Kansas State University provided digitally scanned and georeferenced images for the 1940s, 50s, and 60s; images for 1991, 2002, and 2008 were obtained from the Kansas Data Access and Support Center (DASC, Kansas Geological Survey 2012). Figure 5 shows sample imagery for six image dates for a location in the Centralia Lake watershed.

The acquisition date for the photographs from the 1940s-60s is different for each watershed. For Atchison County Lake watershed, the dates are: 1942, 1954, and 1966; for Banner Creek Lake watershed: 1956 and 1969; and for Centralia Lake: 1942, 1957, 1969.

Digital orthophotos from 1991 were obtained for each watershed via download from DASC. Images for 2002 and 2008 are available online via the DASC image server. Of the images available for this study, stream channels and impoundments are most clearly visible in the 2002 images (leaf off condition). The 2008 photographs were collected as part of the National Agricultural Inventory Program (NAIP). As such, the 2008 images were collected during the growing season to document crop type and extent. Channels are obstructed by tree coverage in much of the 2008 imagery.

Impoundment and Watershed Delineation. One hypothesis regarding the differing sediment production rates for the three watersheds is that a large number of small impoundments in a watershed may significantly reduce sediment delivery at the outlet. It has been shown (Foster 2011) that small impoundments can trap sediment; the aggregate impact of multiple ponds in a watershed may lead to much lower sediment flux.

Impoundment extents were digitized based on the 2002 digital orthophotos in order to assess the extent to which each watershed is affected by ponds. The 2002 pond boundaries were checked against images from the five other acquisition dates. If a 2002 pond was present in 1991, for example, the pond perimeter was not edited (same surface area). However, if a new pond was detected, its areal extent was digitized based on that image. This approach was selected for two reasons. First, the total surface area of ponds is heavily influenced by the weather preceding each image acquisition date. This approach minimizes the impact of weather conditions on the comparison of pond areas between image dates. Second, digitizing pond perimeters is time consuming.

The watershed to each small impoundment was digitized based on USGS 7.5-minute topographic maps available as a seamless, statewide Digital Raster Graphics (DRGs) through the DASC image server.

Characterization of Streams. Stream channels were digitized for each of the six images. It should be remembered that the channel is obscured in areas of dense tree coverage. In those areas, the most probable stream channel path was digitized. Figure 5 shows the stream channel delineation for all six aerial photographs for a location in the Centralia Lake watershed.

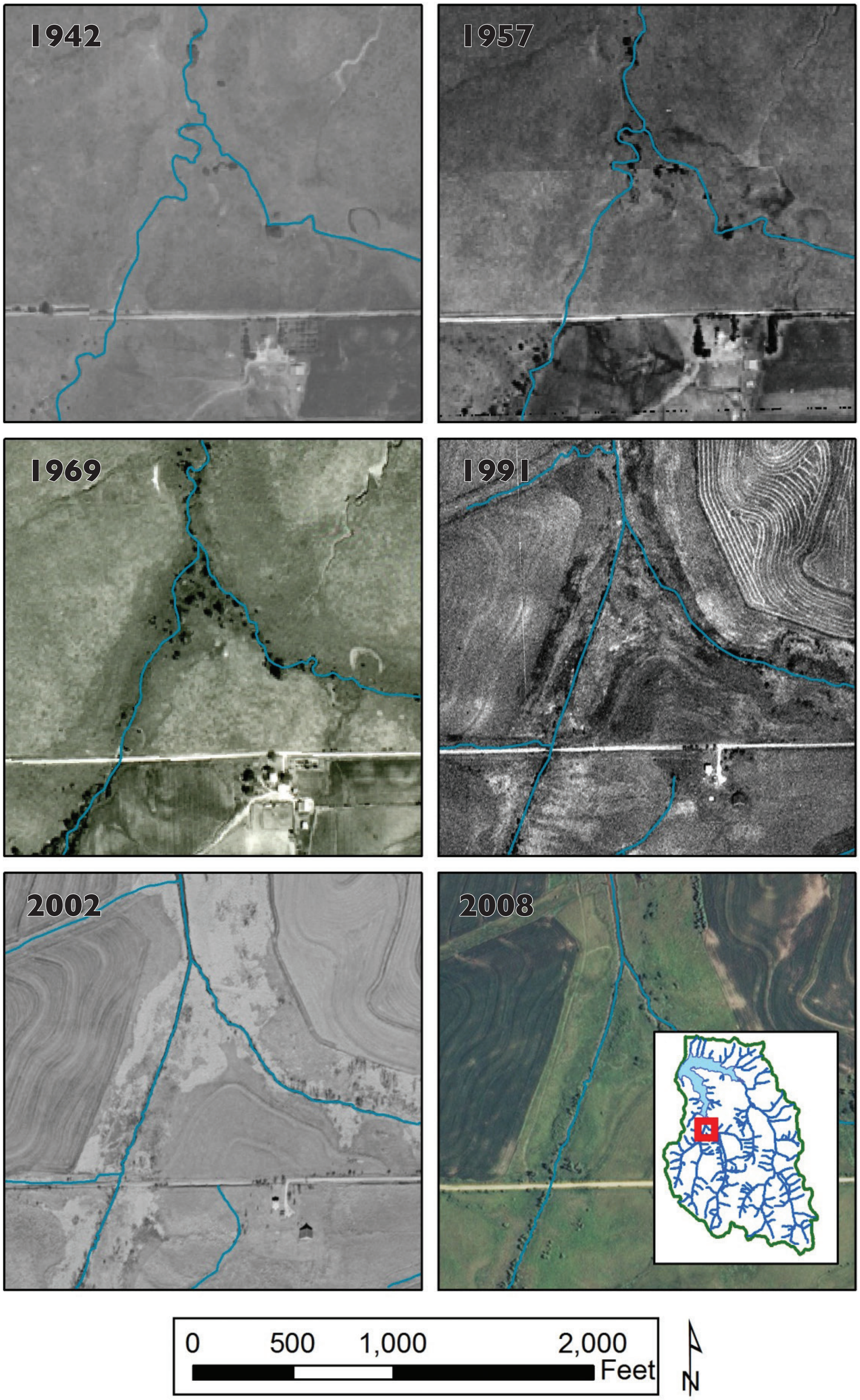


Figure 5. Aerial Photographs Dating from 1942 – 2008

Table 3. Stream Visibility for Helicopter Photographs.

Stream Visible?	**Atchison**	**Banner**	**Centralia**
Y	86%	85%	88%
N	13%	15%	11%
n =	380	636	434

Table 4. Simon Channel Evolution Classification.

Simon Evolution Stage	**Atchison**	**Banner**	**Centralia**
3	11%	2%	16%
4	72%	93%	74%
5	7%	2%	8%
n =	346	615	430

Table 5. Stream Erosion Evident in Helicopter Photography.

Stream Erosion	**Atchison**	**Banner**	**Centralia**
High	29%	35%	13%
Moderate	27%	46%	40%
Low	44%	19%	47%
n =	383	636	438

Table 6. Vegetation Width Adjacent to Stream

Vegetation Width	**Atchison**	**Banner**	**Centralia**
< 1 stream width	24%	33%	75%
> 1 stream width	76%	67%	25%
n =	750	1,261	845

Table 7. Vegetation Type Adjacent to Stream

Vegetation Type	**Atchison**	**Banner**	**Centralia**
Grass	19%	3%	77%
Trees	81%	97%	23%
Other	11%	4%	2%
n =	678	1,223	846

Notable Channel and Watershed Changes. Successive images were analyzed tile-by-tile to look for notable changes in the stream channel, riparian vegetation, or land use. Locations of notable change have been marked with rectangles in GIS layers.

Results

The entire GIS database produced for this study can be downloaded from the Kansas Water Office website. This section presents a summary of the data available in that database.

Channel Evolution Classification. A total of 1450 digital still images were extracted from the high-definition helicopter video collected on 3/13/2009. Table 3 shows the percent of stills in which the stream channel is visible. Centralia has the highest percentage, due to less riparian canopy cover. Overall, 87% of images show the stream channel.

The Simon channel evolution stage was estimated for each image. Where the stream channel was not clearly visible, the evolution stage was estimated based on adjacent imagery. Table 4 gives the breakdown by watershed. Figure 6 maps the Simon Channel Evolution classifications for all three watersheds.

Qualitative Characterization

Table 5 presents the results of the stream erosion characterization for the three watersheds. Overall, the Banner Creek watershed shows the highest proportion of ‘High’ and ‘Moderate’ erosion. Centralia shows the lowest percentage of ‘High’ erosion channels, despite having the highest ratio of streams in Stage III of Simon’s channel evolution model. The results of

the erosion classification are shown in Figure 7.

Table 6 shows the width of riparian vegetation as a function of stream width. It should be noted that the results for the left and right overbanks were combined in this analysis, thus leading to 'n' roughly double the number shown in previous tables. Centralia shows by far the lowest percentage of riparian vegetation > 1 stream width (25%). Table 7 shows the riparian vegetation type along the streams. Again, Centralia is markedly different from the other two watersheds with 77% of the riparian vegetation as grass, while Atchison and Banner have primarily riparian forest (81% and 97% respectively).

Table 8 shows the bank height characteristics for each of the three watersheds. Centralia has the lowest percentage of 'High' bank heights at only 1%, compared to Atchison (8%) and Banner (7%). The proportion of medium and low bank heights is similar for the three watersheds.

Table 9 shows the prevalence of sediment bar deposits in the stream channels of the three watersheds. Banner Creek shows the highest percentage of locations with bar deposits at 25%, while Atchison and Centralia are at 15% and 18%, respectively. Bar deposits can be an indication of aggradation in the channel system.

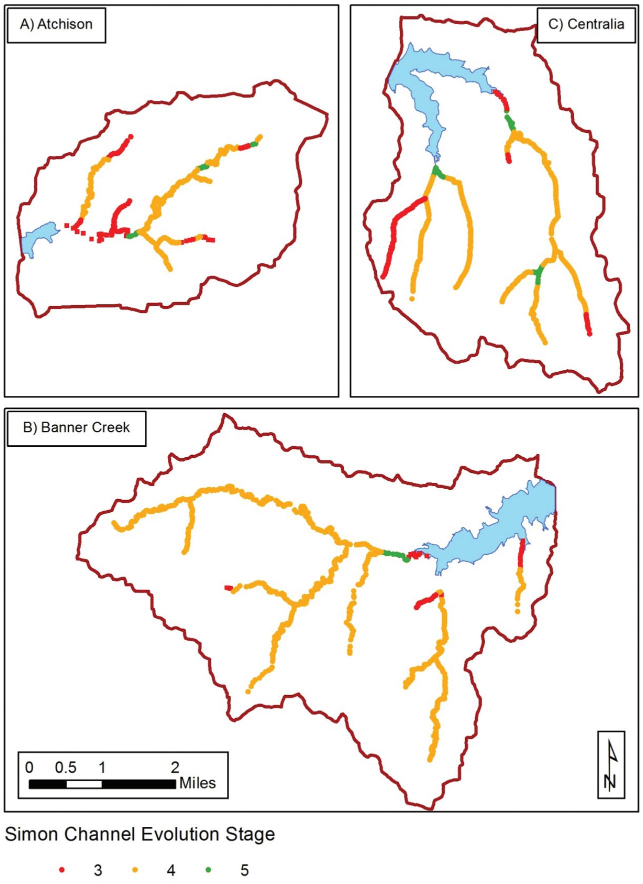


Figure 6. Channel Evolution Stage

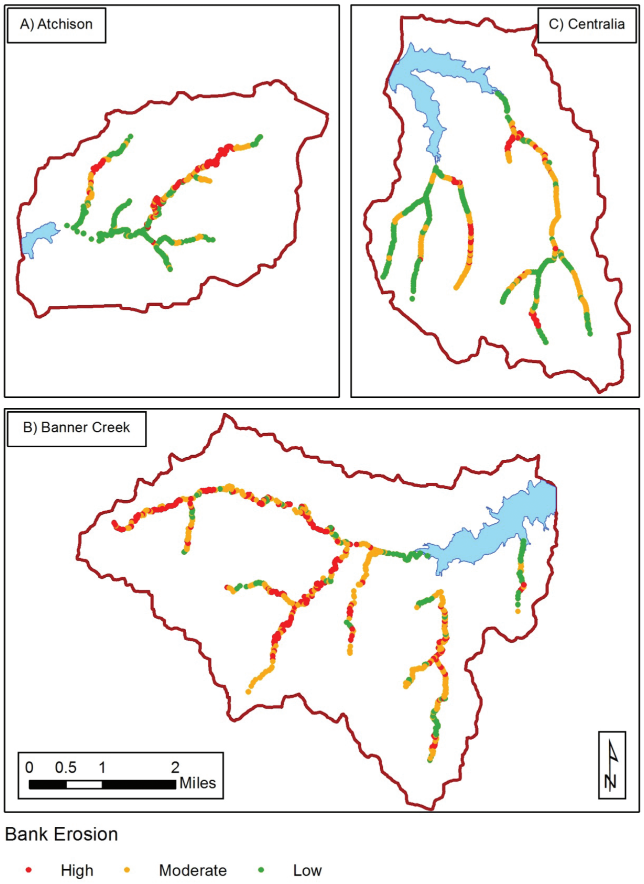


Figure 7. Map of Channel Erosion Assessment

Table 8. Stream Bank Height

Bank Height	**Atchison**	**Banner**	**Centralia**
High	8%	7%	1%
Medium	52%	44%	43%
Low	49%	45%	44%
n =	740	1174	741

Table 9. Bar Deposits Visible in Stream

Bar Deposits Present?	**Atchison**	**Banner**	**Centralia**
Y	15%	25%	18%
N	76%	61%	70%
n =	348	550	388

Table 10. Man-Made Structures Visible in Stream

Man-Made Structures	**Atchison**	**Banner**	**Centralia**
Bridge	22	24	20
Culvert	13	15	10
Drain Outlet	6	7	16
Drop Structure	4	0	0
Low Water Crossing	1	5	11
Total	46	51	57

Table 11. Area of Ponds in Each Watershed

	Total Pond Area (acres)		
Year	**Atchison**	**Banner**	**Centralia**
1940s	0.0	NA	0.6
1950s	0.3	7.3	5.2
1960s	12.9	42.0	13.6
1991	35.1	105.2	14.8
2002	35.3	115.7	16.8
2008	34.5	129.2	18.5

Table 10 summarizes the number and types of man-made structures in the watersheds. As a caveat, some structures are visible in multiple overlapping images and may be counted multiple times. As such, the numbers presented in Table 10 are an indication of the relative proportion of structures in a watershed – not an absolute count. Some structures may also be difficult to spot in imagery. For example, drain outlets entering from the streambank on the side of the channel that the helicopter was flying over may be obstructed from view by the bank itself. Still, it is interesting to note that Centralia has the highest number of man-made structures, with 57 overall. Sixteen of these 57 structures are tile drain outlets; a number that is more than twice that of Atchison and Banner (only referring to drain outlets observed on the main channel by helicopter). Centralia watershed has a large number of terraced agricultural fields, with drainage pipes in place to drain water that collects behind terraces.

There are a total of four drop structures noted for the Atchison watershed. All four of these instances are the same structure – seen in four overlapping photographs.

Watershed Ponds

In sufficient number, small impoundments can significantly reduce the quantity of sediment delivered by a watershed. Table 11 presents the total area of small ponds in each watershed by year. As seen from the table, the total surface area of impoundments has risen in each of the three watersheds since the 1940s. Much of the growth in pond development occurred in the period between the 1960s image and 1991. Atchison experienced a small decline in pond coverage from 2002 to 2008.

Table 12 shows the total area of each watershed that was upstream of at least one small impoundment. This area has increased for each watershed since the 1940s, with the Banner Creek watershed leading the way. Table 13 expresses the area upstream of impoundments as a percentage of total watershed area. In 2002 (the date with the clearest aerial photography), 36% of the Atchison County Lake watershed was upstream of impoundments, while that number was 56% of Banner and just 7% of Centralia.

Figure 8 shows the distribution of ponds within the three watersheds for 2002, along with the watershed areas for these ponds.

Table 12. Area Upstream of Impoundments in Each Watershed.

	Area u/s of Impoundments (mi²)		
Year	**Atchison**	**Banner**	**Centralia**
1940s	0.0	NA	0.0
1950s	0.1	1.1	0.6
1960s	1.7	2.0	1.1
1991	3.8	6.6	1.2
2002	3.4	7.0	1.3
2008	3.7	7.7	1.3

Table 13. Percent of Each Watershed Upstream of Impoundments.

	Area u/s of Impoundments (%)		
Year	**Atchison**	**Banner**	**Centralia**
1940s	0%	NA	0%
1950s	1%	9%	3%
1960s	18%	16%	6%
1991	41%	53%	6%
2002	36%	56%	7%
2008	39%	61%	7%

Significant Channel Changes

The GIS database contains geographic layers highlighting areas of notable channel or landuse change between successive images. Figure 9 shows three examples of notable changes in the Centralia watershed. Figure 9a shows removal of riparian vegetation and channelization that occurred between 1991 and 2002. It appears that at least two large meanders were bypassed during this channel change. This activity could have a lasting impact on the watershed, and could cause significant increase in sediment load if channel incision and degradation propagate upstream.

Figure 9b shows the removal of a drainage ditch. The flow previously carried by this ditch has been routed to the northeast through an existing channel. Figure 9c shows the removal of vegetation and channelization of a reach between 1969 and 1991.

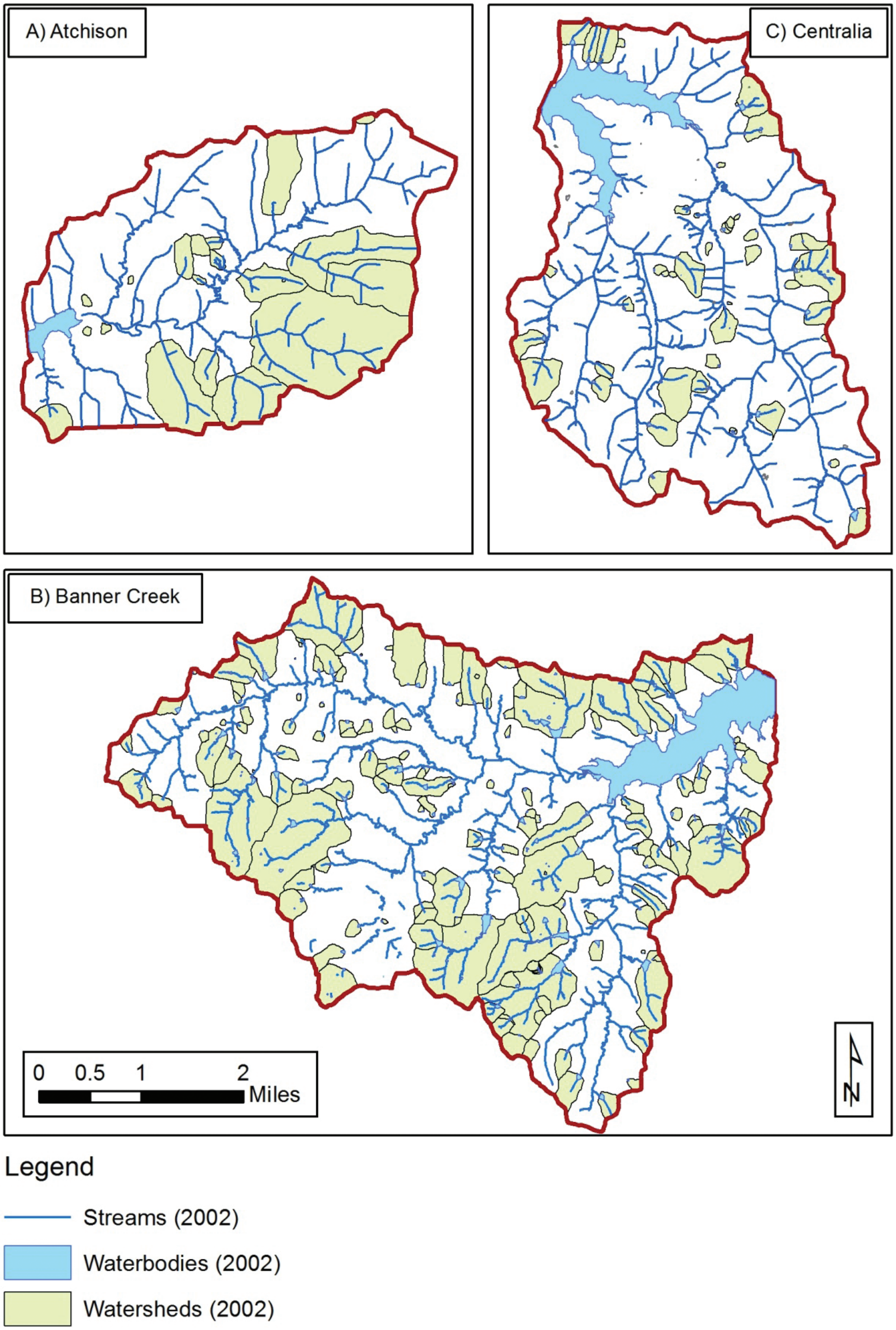


Figure 8. Ponds and Lakes from 2002 Aerial Photography

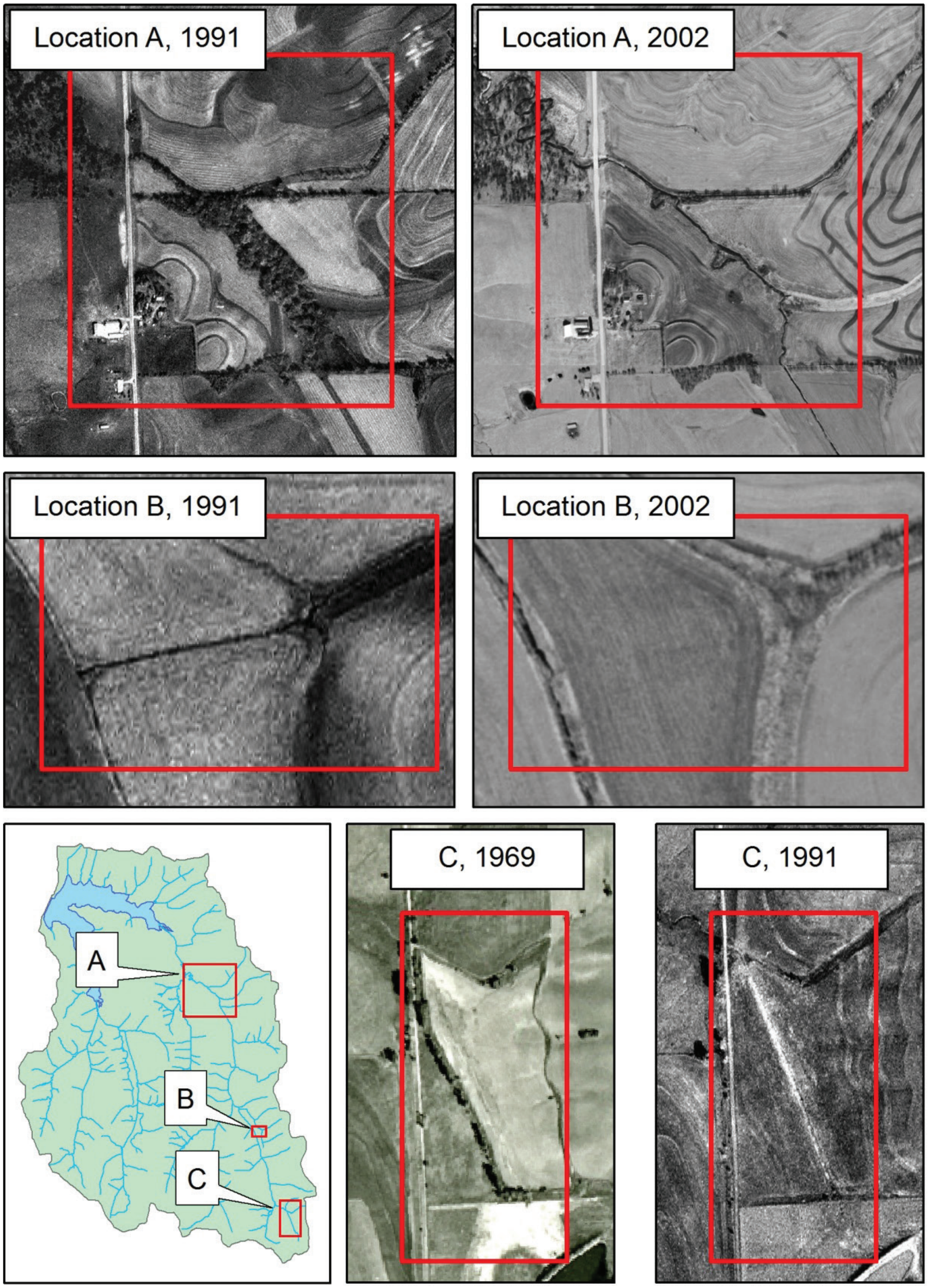


Figure 9. Examples of Channel Changes in Centralia.

Conclusions

This study has produced a GIS database of low-altitude helicopter imagery, aerial photography, along with qualitative characterization of the stream channels. The database is available in its entirety from the Kansas Water Office server at: (website).

The results of the stream evolution classification point to several interesting conclusions. First, Centralia appears to have the highest proportion of Stage III channels (16%), with Banner having the lowest proportion (2%). This indicates that Centralia has had more recent channel disturbances, a fact that is borne out by analysis of historical aerial imagery. The Banner watershed appears to be recovering from widespread channel degradation, as 93% of the stream photos were classified in Stage IV.

Interestingly, an analysis of the qualitative classification indicates that streams in the Centralia watershed do not show visible signs of high rates of channel erosion, and that streams in Centralia have lower bank heights. These two factors would seem to indicate lower sediment production rates for the Centralia watershed, which does not agree with the monitoring efforts of the USGS. However, it is very possible that sediment production in the Centralia watershed is primarily due to field erosion or mobilization of channel bed (as opposed to bank) material and resulting incision or degradation. The heavy grass coverage along Centralia streams may also be masking bank erosion in some cases. Centralia has a much higher proportion of grassed waterways (77%) than Atchison (19%) and Banner (3%).

Watershed impoundments in Atchison and Banner may have a significant impact on the sediment production for those two watersheds. In 2008, Centralia had only 7% of the watershed upstream of small impoundments, while Banner had 61% and Atchison 39%.

Recommendations

The results of this study indicate the need for future research on a number of topics. First, there is a need to further investigate the long-term impact of small impoundments on watershed sediment production. It is well known that small impoundments reduce sediment flux immediately downstream of the structure; however, it is not known how far downstream this impact propagates. Water leaving a small impoundment will be relatively low in sediment, allowing suspension of bed material just downstream of the impoundment. This can lead to stream degradation and incision.

A second area of future research would be the application of aerial LiDAR survey data to develop comprehensive geomorphic surveys of watersheds. LiDAR imagery does have limitations with regard to this approach, for example most LiDAR systems do not penetrate the water surface. So, channel dimensions below the water surface would be unavailable. However, detailed elevation data in the stream channel above the water surface could still be invaluable for mapping channel bank height, slope, and width. Coupled with hydraulic modeling, this approach could provide quantitative insight into channel condition over a large area.

Third, research on the long-term evolution of stream channels could help indicate what factors allow a degraded channel to reach Stage VI of the evolution process as quickly as possible, with as little intervention as possible.

Finally, there is a need for detailed study and evaluation of sediment reduction management practices. Many approaches have been proposed to reduce the rate of sediment accumulation in large reservoirs. Research is needed to determine which of these methods are most cost effective. In addition, efforts should be made to identify management strategies that have wide-spread benefits for the overall stream health and functioning as well as economic activities in the watershed.

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Sediment Loads and Yields, Small Pond Trapping Efficiency, and Downstream Reservoir Trapping Efficiency of Three Headwater Watersheds in Northeast Kansas

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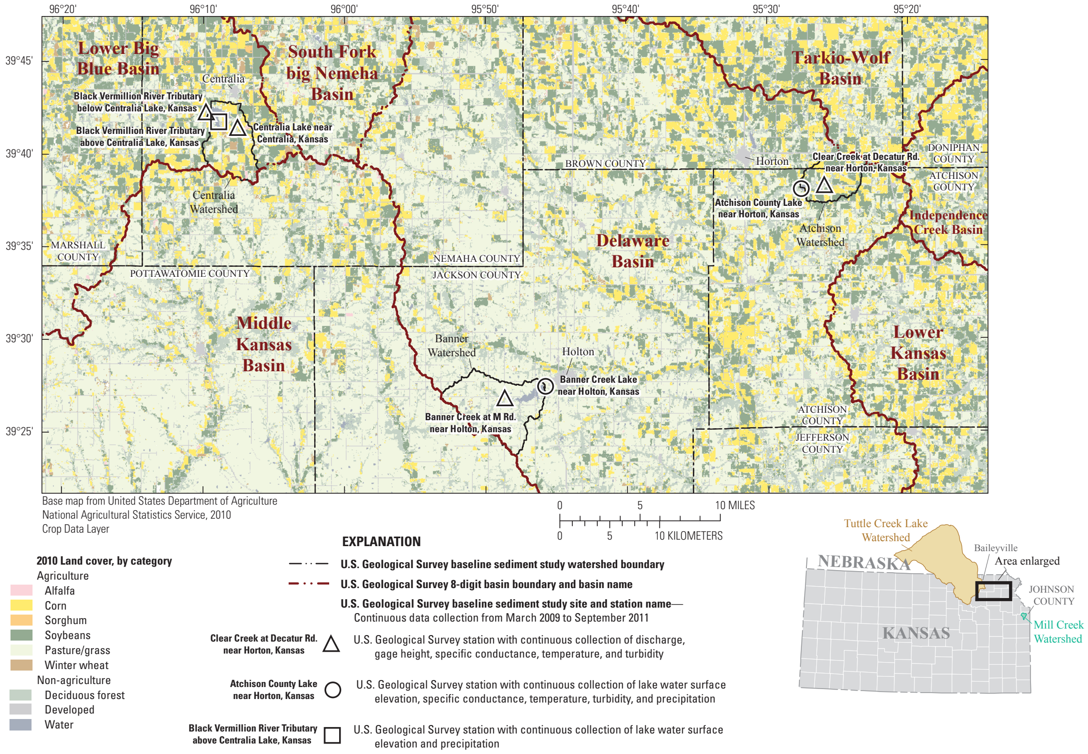
Interpretative Summary

The U.S. Geological Survey, in cooperation with the Kansas Water Office, investigated sediment transport to and from three small impoundments (average surface area of 0.1 to 0.8 square miles) in northeast Kansas during March 2009 through September 2011. Streamgages and continuous turbidity sensors were operated upstream and downstream from Atchison County, Banner Creek, and Centralia Lakes to study the effect of varied watershed characteristics and agricultural practices on sediment transport in small watersheds in northeast Kansas. Atchison County Lake is located in a predominantly agricultural basin of row crops, with wide riparian buffers along streams, a substantial amount of tile drainage, and numerous small impoundments (less than 0.05 square miles; hereafter referred to as “ponds”). Banner Creek Lake is a predominantly grassland basin with numerous small ponds located in the watershed, and wide riparian buffers along streams. Centralia Lake is a predominantly agricultural basin of row crops with few ponds, few riparian buffers along streams, and minimal tile drainage. Upstream from Atchison County, Banner Creek, and Centralia Lakes 24, 38, and 32 percent of the total load was transported during less than 0.1 percent (approximately 0.9 days) of the time. Despite less streamflow in 2011, larger sediment loads during that year indicate that not all storm events transport the same amount of sediment; larger, extreme storms during the spring may transport much larger sediment loads in small Kansas watersheds. Annual sediment yields were 360, 400, and 970 tons per square mile per year at Atchison County, Banner, and Centralia Lake watersheds respectively, which were less than estimated yields for this area of Kansas between 2,000 and 5,000 tons per square mile per year. Although Centralia and Atchison County Lakes had similar percentages of agricultural land use, mean annual sediment yields upstream from Centralia Lake were about 2.7 times those at Atchison County or Banner Creek Lakes. These data indicate larger yields of sediment from watersheds with row crops and those with fewer small ponds, and smaller yields in watersheds which are primarily grassland, or agricultural with substantial tile drainage and riparian buffers along streams. These results also indicated that a cultivated watershed can produce yields similar to those observed under the assumed reference (or natural) condition. Selected small ponds were studied in the Atchison County Lake watershed to characterize the role of small ponds in sediment trapping. Studied ponds trapped about 8 percent of the sediment upstream from the sediment-sampling site. When these results were extrapolated to the other ponds in the watershed, differences in the extent of these ponds was not the primary factor affecting differences in yields among the three watersheds. However, the selected small ponds were both 45 years old at the time of this study, and have reduced capacity because of being filled in with sediments. Additionally, trapping efficiency of these small ponds decreased over 5 observed storms, indicating that processes that suspended or resuspended sediments in these shallow ponds, such as

wind and waves, affected their trapping efficiencies. While small ponds trapped sediments in small storms, they could be a source of sediment in larger or more closely spaced storm events. Channel slope was similar at all three watersheds, 0.40 percent, 0.46 percent, and 0.31 percent at Atchison County, Banner, and Centralia Lake watersheds respectively. Other factors, such as increased bank and stream erosion, differences in tile drainage, extent of grassland, or riparian buffers, could be the predominant factors affecting sediment yields from these basins. These results show that reference-like sediment yields may be observed in heavily agricultural watersheds through a combination of field-scale management activities and stream channel protection. When computing loads using published erosion rates obtained by single-point survey methodology, streambank contributions from the main stem of Banner Creek are three times more than the sediment load observed by this study at the sediment sampling site at Banner Creek, 2.6 times more than the sediment load observed by this study at the sediment sampling site at Clear Creek (upstream from Atchison County Lake), and are 22 percent of the load observed by this study at the sediment sampling site at Black Vermillion River above Centralia Lake. Comparisons of study sites to similarly sized urban and urbanizing watersheds in Johnson County, Kansas indicated that sediment yields from the Centralia Lake watershed were similar to those in construction-affected watersheds, while much smaller sediment yields in the Atchison County and Banner Creek watersheds were comparable to stable, heavily urbanized watersheds. Comparisons of study sites to larger watersheds upstream from Tuttle Creek Lake indicate the Black Vermillion River watershed continues to have high sediment yields despite 98 percent of sediment from the Centralia watershed (a headwater of the Black Vermillion River) being trapped in Centralia Lake. Estimated trapping efficiencies for the larger watershed lakes indicated that Banner Creek and Centralia Lakes trapped 98 percent of incoming sediment, whereas Atchison County Lake trapped 72 percent of incoming sediment during the 3-year study period.

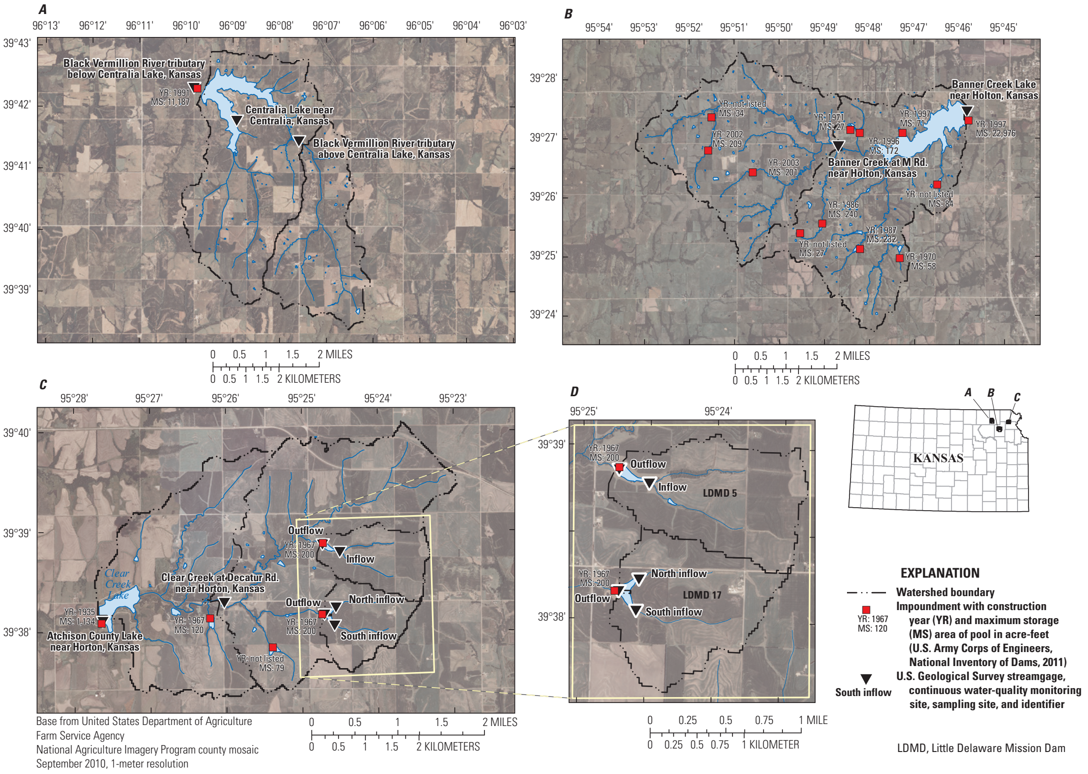
Introduction

To characterize factors affecting sediment transport from small, agricultural watersheds in Kansas, the U.S. Geological Survey (USGS), in cooperation with the Kansas Water Office, collected streamflow and sediment data at sites upstream and downstream from three small impoundments (Atchison County, Banner Creek, and Centralia Lakes) in northeast Kansas from 2009 through 2011. Impoundments selected for study are within watersheds that vary with respect to current agricultural activities and management practices (Figure 1; Table 1). Additionally, two National Inventory of Dams (NID) listed ponds were monitored for sediment trapping efficiency for a two month period to quantify their effect on total watershed sediment yields (Figure 2). This study is one component of a larger effort in cooperation with Academic, State, and Federal agencies to compile sediment budgets for the watersheds upstream from these impoundments. This report and study were supported in part through the Kansas State Water Plan Fund and the USGS Cooperative Water Program.



Base map from United States Department of Agriculture
National Agricultural Statistics Service, 2010
Crop Data Layer

Figure 1. Description of land use and location of study watersheds in northeast Kansas, 2009-2011.



Base from United States Department of Agriculture
Farm Service Agency
National Agriculture Imagery Program county mosaic
September 2010, 1-meter resolution

Figure 2. Location of streamgages, sediment-sampling sites, watershed boundaries, National Inventory of Dams (NID) listed impoundments, and 2010 aerial imagery from Atchison County, Banner Creek, and Centralia Lakes, 2009 through 2011.

Procedures

Data Collection and Analysis

Sampling sites were installed upstream from and in, or directly downstream from, study impoundments during March 2009. YSI (YSI Inc.) water quality monitors equipped with specific conductance, water temperature, and model 6136 turbidity sensors were installed at each site and were housed in polyvinyl chloride (PVC) pipes with holes drilled to facilitate flow through the installation. Monitors were installed at the stream or impoundment edge, approximately 0–2 feet (ft) above the stream or lakebed. Site locations upstream from study impoundments were selected to represent sediment transport from the largest sub-watershed contributing to each impoundment while accounting for site suitability and attempting to avoid backwater conditions. Data were collected every 15 minutes from March 2009 to September 2011; these data are available on the USGS Kansas Water Science Center Web page (http://nrtwq.usgs.gov/ks/).

Suspended-sediment samples were collected using methods described in Gray and others (2008) and Nolan and others (2005). Samples were analyzed for suspended-sediment concentration (SSC), percentage of sediments less than 63 micrometers (μm) (sand-fine break), and loss of material on ignition (analogous to amount of organic matter). Selected samples also were analyzed for grain-size distribution (percent of sediment less than 2, 4, 8, 16, and 31 μm in diameter). Samples were analyzed at the USGS Sediment Laboratory in Iowa City, Iowa, using methods described by Guy (1969).

Regression Models

Ordinary-least squares regression was used to compute continuous, 15-minute estimates of SSC from in-stream turbidity measurements using methods described in Rasmussen and others (2009). SSC, turbidity, and discharge relations were evaluated at each site using single (SLR) and multiple (MLR) linear regressions for normal and log-transformed data (Table 2; Figure 3). Samples collected during low (less than 0.5 cubic feet per second (ft^3/s)) streamflow, or when turbidity was less than 2 NTU, were not used because of inherent error associated with those low readings (resolution is 0.1 NTU), and accuracy is ± 2 percent of reading or 0.3 NTU, whichever is greater; YSI Incorporated, 2010), including 5 samples from Clear Creek (upstream from Atchison Lake), 4 from Banner Creek, 2 from Banner Lake, and 3 each from Black Vermillion above and below Centralia Lake. Statistics were evaluated for each of the resulting models from each site using guidelines described by Rasmussen and others (2009) and final models were selected based on the most statistically accurate model. A single outlying sample was removed at Banner Creek at M Rd. and Black Vermillion River below Centralia Lake because of their large effect on overall slope, indicating an error in collection or analysis, although the specific issue was not readily apparent. After these outliers were removed from the first regression model assessed, no further samples were removed regardless of where on the regression line they plotted.

Turbidity-SSC regressions were the primary method for computing the continuous SSC record; however, streamflow-based regressions also were

Table 1. Location and contributing drainage area of streamgages and sediment-sampling stations in Atchison, Jackson, and Nemaha counties in northeast Kansas during March 2009 through September 2011.

U.S. Geological Survey identification number	Station name	Contributing drainage area (mi^2)	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)
393817095260100	Clear Creek at Decator Rd. near Horton, Kansas[1, 4]	5.6	39°38'17"	95°26'01"
393806095273700	Atchison County Lake near Horton, Kansas[1]	9.1	39°38'06"	95°27'37"
393806095274100	Clear Creek below Atchison County Lake near Horton, Kansas[2]	9.1	39°38'06"	95°27'37"
392652095484100	Banner Creek at M Rd. near Holton, Kansas[1,4]	9.1	39°26'52"	95°48'41"
392727095454900	Banner Creek Lake near Holton, Kansas[1]	19.1	39°27'27"	95°45'49"
392727095454500	Banner Creek below Banner Creek Lake near Holton, Kansas[2]	19.1	39°27'27"	95°45'49"
394126096073500	Black Vermillion River tributary above Centralia Lake, Kansas[1,4]	4.4	39°41'26"	96°07'35"
394146096085500	Centralia Lake near Centralia, Kansas[3]	12.6	39°41'46"	96°08'55"
394218096095000	Black Vermillion River tributary below Centralia Lake, Kansas[1]	12.6	39°42'18"	96°09'50"

[1] Sediment sampling station, water-quality monitor, and discharge gage.

[2] Separate site number used for lake outflow discharge, location same as elevation and water-quality monitor.

[3] Monitored only for continuous lake elevation.

[4] Upstream sampling site.

[mi^2, square miles]

developed for periods of variable flow in which turbidity sensors were not working. These methods are discussed in detail in the section titled "Estimating Sediment Transport During Periods of Missing Turbidity Data." Regression relations using log-transformed data were retransformed back to a linear scale, which can cause bias when adding load estimates with time. To correct this, a bias-correction factor (Duan's smearing estimator; Duan, 1983) was calculated to correct for potential bias (Helsel and Hirsch, 2002). Uncertainty of regression estimates were determined by calculating 90-percent prediction intervals (Helsel and Hirsch, 2002) (Figure 3).

Similarities between regression equations at Atchison County Lake, Banner Creek at M Rd., and Black Vermillion River above Centralia Lake indicate similarities in sediment grain-size and color. Slopes in regression equations at Banner Creek Lake and Black Vermillion River below

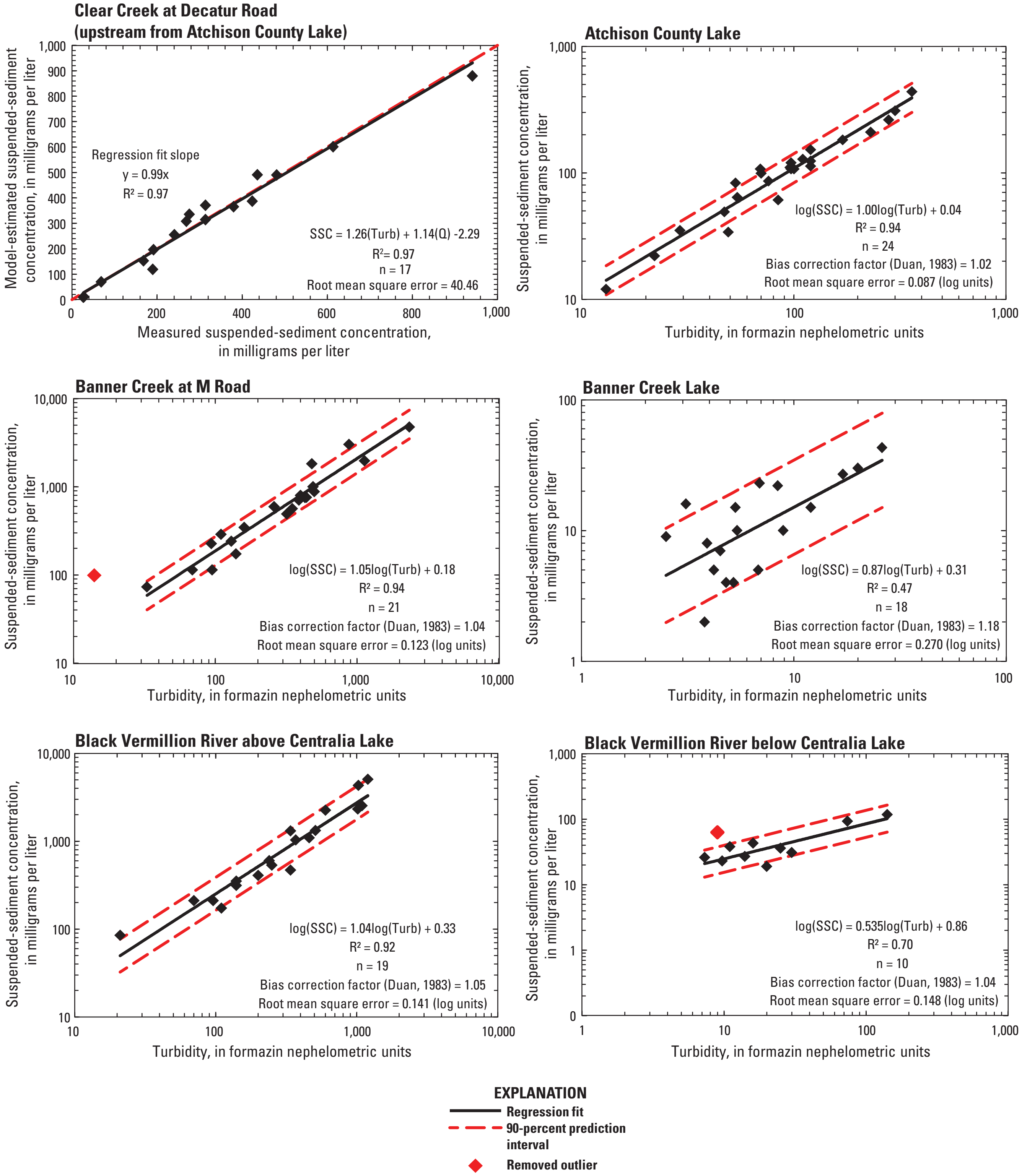


Figure 3. Comparison of measured and model-estimated suspended-sediment concentrations for the multiple linear regression at Clear Creek at Decatur Rd., and single linear regression relations between turbidity and suspended-sediment concentrations with removed outliers in red for other sediment sampling sites during March 2009 through September 2011.

Table 2. Regression models and summary statistics for suspended-sediment concentration computations at study sites during March 2009 through September 2011.

Regression model	R^2	R^2 adjusted	RMSE	Upper MSPE	Lower MSPE	Bias correction factor (Duan, 1983)	Discrete data n	Range of values in variable measurements	Mean	Median	Standard deviation
Clear Creek at Decatur Rd. (upstream from Atchison County Lake)											
SSC = 1.26(Turb) + 1.14(Q) - 2.29	0.97	0.97	40	13	-13		17	Turb:8.7 - 480	182	170	123
								Q: 0.9 - 243	77	71	70
log(SSC) = 0.547log(Q) + 1.50	0.92	0.91	0.13	34	-26	1.04	17	Q: 0.9 - 243	77	71	70
*ln(SSC) = 1.171ln(Q) + 0.618ln(Turb) - 0.93	1.00							Thrb:8.7 - 480	182	170	123
								Q: 0.9 - 243	77	71	70
*ln(SSC) = 1.557ln(Q) + 1.71	0.99							Q: 0.9 - 243	77	71	70
Atchison County Lake											
log(SSC) = 1.00log(Turb) + 0.04	0.94	0.94	0.09	22	-18	1.02	24	Turb:13 - 360	115	97	91
Banner Creek at M Rd.											
log(SSC) = 1.05log(Turb) + 0.18	0.94	0.93	0.12	33	-25	1.04	21	Turb: 33 - 2,340	440	350	513
Log(SSC) = 0.713log(Q) + 1.74	066	0.64	0.28	92	-48	1.20	21	Q: 2.3 - 241	53	20	73
*ln(SSC) = 1.173ln(Q) + 0.886ln(Turb) - 1.20	0.99							Turb: 33 - 2,340	440	350	513
								Q: 2.3 - 241	53	20	73
*ln(SSC) = 1.703ln(Q) + 3.87	0.92							Q: 2.3 - 241	53	20	73
Banner Creek Lake											
log(SSC) =0.865log(Turb) + 0.31	0.47	0.43	0.27	86	-46	1.18	18	Turb: 2.5 - 26	8.3	5.4	6.5
log(SSC) = 0.061log(Q) + 0.96	0.01	-0.05	0.37	133	-57	1.35	18	Q: 0.9 - 240	33	10	60
Black Vermillion River above Centralia Lake											
log(SSC) = 1.04log(Turb) + 0.33	0.92	0.92	0.14	38	-28	1.05	19	Turb: 21 - 1,200	433	340	380
log(SSC) = 0.522log(Q) + 2.17	0.64	0.62	0.31	104	-51	1.25	19	Q: 0.8 - 670	81	20	159
*ln(SSC) = 1.143ln(Q) + 0.869ln(Turb) - 1.01	0.99							Turb: 21 - 1,200	433	340	380
								Q: 0.8 - 670	81	20	159
*ln(SSC) = 1.530ln(Q) + 3.93	0.94							Q: 0.8 - 670	81	20	159
Black Vermillion River below Centralia Lake											
log(SSC) = 0.54log(Turb) + 0.86	0.70	0.67	0.15	41	-29	1.04	10	Turb: 7.3 - 141	35	18	42
log(SSC) = 0.213log(Q) + 1.28	0.40	0.33	0.21	62	-38	1.10	10	Q: 0.6 - 204	60	38	65

* LOADEST generated regression models.

[R^2, coefficient of determination; RMSE, root mean square error; MSPE, model standard percentage error; n. number of discrete samples; Turb, turbidity in Formazin Nephelometric Units (FNU); Q, stream- flow in cubic feet per second; log, $\log_{10}$; LOADEST, S-Plus Load Estimator]

Centralia Lake were less than 1:1 (0.87 and 0.54 respectively) because of very low ranges of observed and measured turbidity and corresponding SSC values (Table 4). Over the entire period of the study, turbidity ranged from 2.5 to 26 NTU at Banner Creek Lake, and 7.3 to 141 NTU at Black Vermillion River below Centralia Lake (Table 4). Long residence times were expected at Banner Creek Lake and Centralia Lake (Centralia Lake outflow being gaged at the Black Vermillion River below Centralia Lake), allowing sediments carried in by the inflow streams to settle out in the impoundment before reaching the outflow structure (residence time is discussed in more detail in the section titled "Trapping Efficiencies"), which explains the limited range of recorded turbidity values. At these low turbidity ranges, sensor accuracy is less because the sensor values are easily affected by random suspended particles (such as small animals or algae) in the sensor's detection zone. This has resulted in the poor coefficient of determination (R^2) values in the regression models for both Banner Creek Lake and Black Vermillion River below Centralia Lake. In the case of Clear Creek at Decator Rd. (upstream from Atchison County Lake), a multiple linear regression (MLR) was determined to be the most statistically valid model based on model standard percentage error (MSPE) as specified in Rasmussen and others (2009). MSPE is the root-mean-squared-error (RMSE, a measure of the variance between regression-computed and observed values) expressed as a percent, and represents the uncertainty associated with the regression-computed values (Rasmussen and others, 2009). The MLR model of SSC ≈ Turb, Q, indicated a MSPE of +13 percent to -13 percent, whereas the SLR model of log(SSC) ≈ log(Turb) (like that used in all other models) indicated a MSPE of +23.09 percent to -18.76 percent. Sediment loads computed using MLR and SLR models were similar, with the SLR model computing about 12 percent less sediment load during the study period than the MLR model. Because the MSPE of the MLR was the lowest, sediment loads from that model were used in the final computations.

Computation of Sediment Concentrations, Trapping Efficiencies, Loads, and Yields

The regression models were used to calculate continuous (15-minute) estimates of SSC at each sampling site. Time-series (15-minute) discharge values (in cubic feet per second, ft^3/s) were multiplied by 15-minute computations of SSC and by a unit-conversion factor [× 1/1,000 mg/g (milligram per gram), × 1/453.6 g/lb (gram per pound), and × 28.32 L/ft^3 (liter per cubic foot)] to compute time-series suspended-sediment discharge in pounds per second (lbs/s). Fifteen-minute sediment discharge computations were summed and multiplied by a unit conversion factor [× 900 seconds × 1 ton/2,000 lbs (pounds)] to compute sediment loads (in tons) for periods of interest.

Sediment and streamflow yields were computed by dividing the total load (in tons) or total flow (in acre-ft) by drainage area (in mi^2). Streamflow yield was converted to depth of runoff (in inches) by a unit conversion factor [× 1 $acre\text{-}ft/mi^2$ × 43,560 $ft^3/acre$ × 1 $mile/5{,}280\ ft^2$ × 12 inches/1 ft], and represents the volume of water covering the entire watershed as depth. The trapping efficiency of each impoundment was calculated by

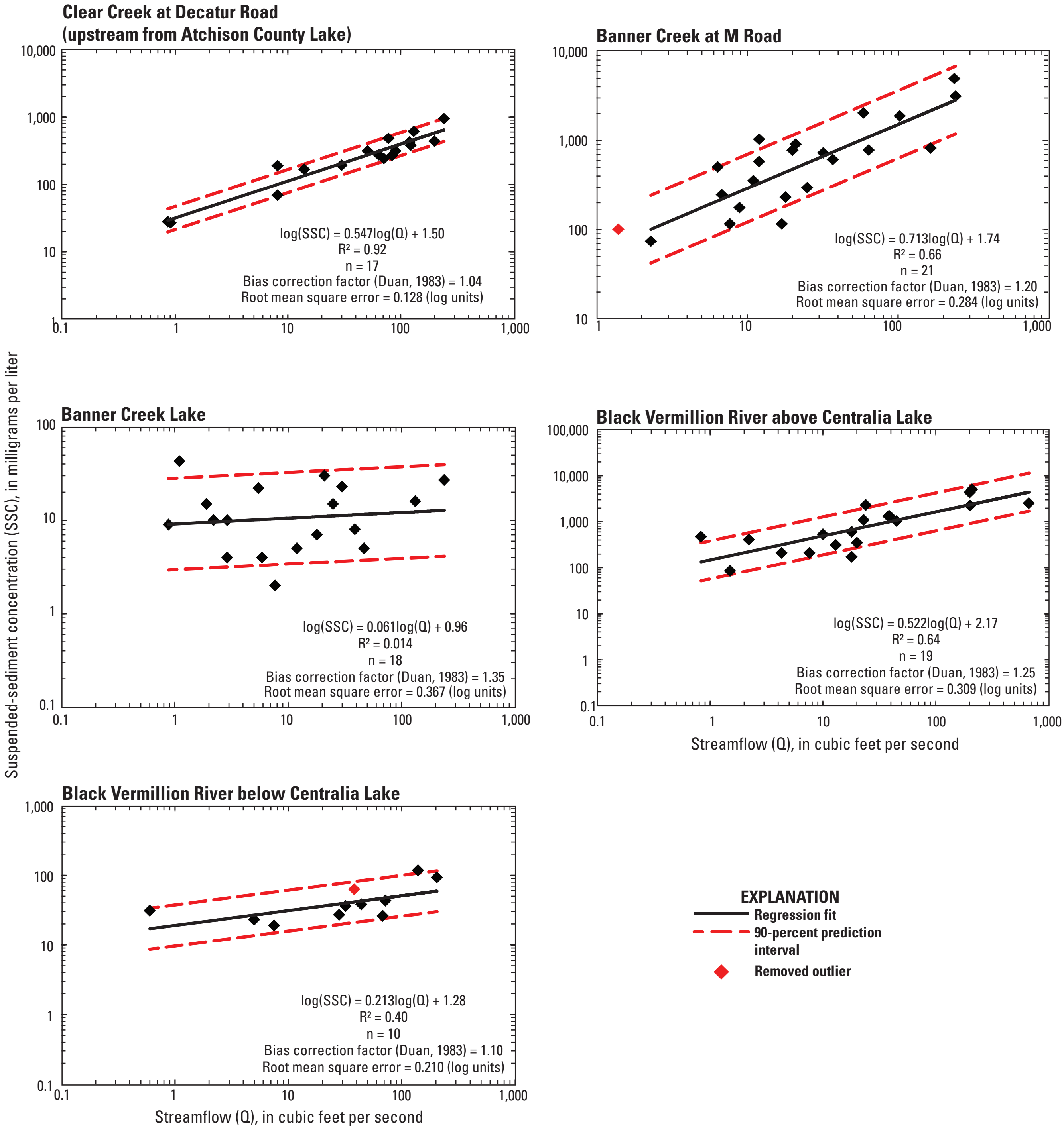


Figure 4. Relations between discharge and suspended-sediment concentration at study sites with removed outliers in red (if removed from turbidity models, also removed from streamflow models) during March 2009 through September 2011.

subtracting the total sediment load transported from the impoundment from the estimated load transported into the impoundment and dividing by the estimated total sediment load transported into the impoundment, and then multiplying by 100.

Suspended-sediment loads and yields were approximated for the ungaged drainage area upstream from each impoundment using data from existing monitoring sites. Sediment yields from upstream monitoring sites were multiplied by the entire impoundment drainage area to estimate total sediment transport to the impoundment for each time period of interest. These methods do not take into account heterogeneity in natural features, precipitation, and land practices across upstream watersheds, but provide an approximation of total streamflow and sediment transport to each impoundment.

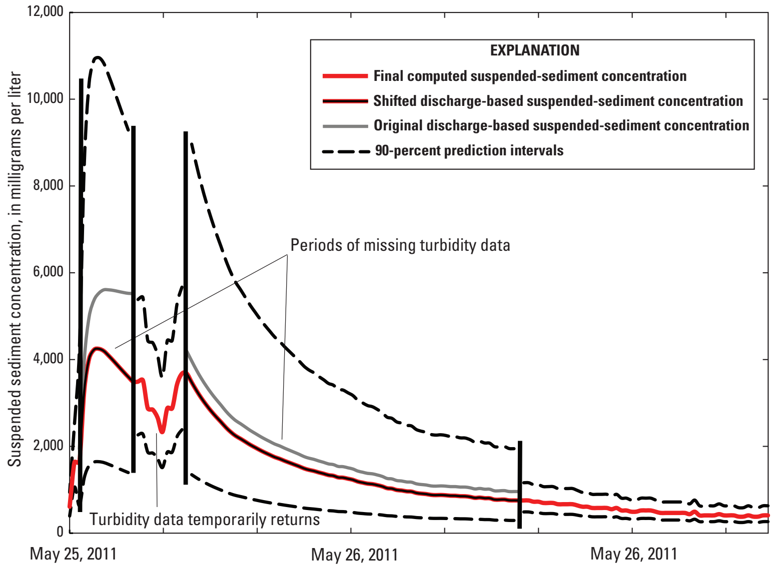


Figure 5. Example hydrograph from Black Vermillion River above Centralia Lake showing differences between discharge- and turbidity-computed models, shifting results (Porterfield 1972), and difference in prediction intervals between models during May 25 through 26, 2011.

Estimating Sediment Transport during Periods of Missing Turbidity Data

Two methods were used to estimate loads during periods of missing turbidity data (because of equipment malfunction or excessive fouling during storms caused by sediment build-up in the housing pipe). During periods of steady flow, turbidity data was estimated based on simple linear interpolation of turbidity between known values. When flow changed during periods of missing turbidity, streamflow models were used to compute SSC (Table 2; Figure 4) using methods described in “Regression Models.” Normal and log-transformed regressions were evaluated, and picked based on statistical comparison. The same samples excluded from the turbidity-based regression models were excluded from the flow-based models.

Differences in computed SSC between turbidity-computed and discharge-computed methods sometimes produced different values of SSC because of differences in model equations (Figure 5). To “smooth” the transition of computed SSC values between methods, the discharge-based SSC was shifted to turbidity-computed SSC based on methods in Porterfield (1972) (Figure 5).

Collection, Analysis, and Computation of Sediment Loads at Selected Upstream Small Ponds

Pond Locations and Descriptions.

Sediment transport to and from two small (surface areas of approximately 0.013 mi^2) watershed ponds were studied to evaluate

Table 3. Location and contributing drainage area of small sub-impoundment gaging sites in the Atchison watershed, northeast Kansas during March 2009 through September 2011.

U.S. Geological Survey identification number	Station name	Contributing drainage area (mi^2)	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)
393847095242900	LDMD 5 Lake Inflow above Atchison Lake near Holton, Kansas[1]	0.68	39°38'47"	95°26'29"
393851095244300	LDMD 5 Lake Outflow above Atchison Lake near Horton, Kansas[1]	0.78	39°38'51"	95°27'43"
393851095244100	LDMD 5 Lake above Atchison Lake near Horton, Kansas[2]	0.78	39°38'51"	95°27'41"
393803095243400	LDMD 17 Lake South Inflow above Atchison Lake near Horton, Kansas[1]	0.36	39°38'03"	95°24'34"
393813095243300	LDMD 17 Lake North Inflow above Atchison Lake near Horton, Kansas[1]	0.32	39°38'13"	95°24'33"
393809095244200	LDMD 17 Lake Outflow above Atchison Lake near Horton, Kansas[1]	0.77	39°38'09"	95°24'42"
393809095244000	LDMD 17 Lake above Atchison Lake near Horton, Kansas[2]	0.77	39°38'09"	95°24'40"

[1] Site number used for lake water-quality monitor.
[2] Site number used for continuous lake elevation.
[mi^2, square miles; LDMD, Little Delaware Mission Dam]

how these ponds affect sediment yields at upstream sediment sampling sites. Two small watershed ponds were selected upstream from Atchison County Lake watershed based on drainage area and land owner permission (Figure 2, Table 3). The two sites selected (Figure 2; Table 6) were Little Delaware Mission Dam 5 (LDMD 5) and Little Delaware Mission Dam 17 (LDMD 17). LDMD 5 drains 0.78 mi^2 and LDMD 17 drains 0.77 mi^2. These two Atchison ponds drain 22 percent of the drainage area upstream from the USGS Clear Creek at Decator Rd. (upstream from Atchison Lake) site, which is 17 percent of the total watershed.

LDMD 5 was constructed in 1967 and drains land used for pasture and row crops (Figure 2). During April through August 2011, soybeans and corn were planted in the surrounding fields, and livestock were frequently present. A grass buffer of at least 60 ft surrounded the pond. The outflow structure was a vertical corrugated steel pipe of 2.5 ft diameter with a top elevation of 1,109.80 ft above North American Vertical Datum of 1988 (NAVD 88).

LDMD 17 was constructed in 1967 and drains land used for row crops (Figure 2). During the period of study, the surrounding fields were planted (soybeans), and no livestock were observed near the pond. A grass buffer of 50 ft was planted at the beginning of the data collection period; no buffer existed before this. The grass buffer did not become fully established during the period studied. The outflow structure was a vertical corrugated steel pipe of 2.5 ft diameter with a top elevation of 1,110.39 ft above NAVD 88).

Data Collection for Selected Small Ponds

To calculate pond trapping efficiency, it was necessary to compute a continuous record of incoming and outgoing streamflow and SSC. Impoundment elevation and turbidity were used to compute these parameters. Each pond was gaged for elevation near the outflow structure using Solinst "Level-Logger Gold" submersible pressure transducers. Fluctuations in elevation data caused by changes in atmospheric pressure were corrected by using a recording barometer Solinst "Baro-logger Gold" installed near the impoundments. The correction for atmospheric pressure was applied using Solinst software (Solinst 2007). Elevation data were verified during each site visit using standard USGS stage measurement techniques (Sauer and Turnipseed, 2010). Turbidity data were collected using YSI 6136 turbidity sensors deployed near the outflow structure and near the impoundment inflow (in the case of LDMD 17, both inflows).

To ensure the best resolution of data relative to the small watershed size, 5-minute recording intervals were used on all sensors. Site visits to clean sensors, verify impoundment elevations, and download data were made approximately every 2 weeks. Measurements of flow or SSC were not verified because of the rapid, high variability of the stormflow and driving distance to the sites. All computed discharges at the two ponds should be considered estimates.

Pond data analysis techniques

Because each impoundment had a static outflow structure, only impoundment elevation and a corresponding stage-storage relation were needed to calculate flow into and out of each pond. Outflow was computed based on the hydraulic characteristics of the outflow structure and inflow was computed using a continuity routing equation (Equation 1).

Where inflow$_2$ is the discharge in cubic feet per second (ft^3/s) at time 2, storage$_2$ is the volume in acre-ft (af) at time 2 as determined by stage-volume tables, Δtime is the time difference between recording intervals in seconds (s), outflow$_2$ is the outflow discharge in cubic feet per second at time 2 based on outflow hydraulics, storage$_1$ is the pond volume in acre-ft at time 1, outflow$_1$ is the outflow discharge in cubic feet per second at time 1, and inflow$_1$ is the inflow discharge in cubic feet per second as computed from the previous time-step.

Initial computed inflows exhibited large, instantaneous increases and decreases in discharge because of the 0.02-foot reso-

Equation 1. Continuity routing equation.

$$Inflow_2 = \left(\frac{2Storage_2}{\Delta time} + \mathrm{Outflow}_2 \right) - \left(\frac{2Storage_1}{\Delta time} + Outflow_1 \right) - Inflow_1 + 2Outflow_1$$

lution of impoundment elevation data, which was recorded at 0.01-foot intervals (± 0.02 ft), and storage, and was estimated based on elevation-storage tables that ranged from 0.08 to 0.21 acre-ft difference for 0.01-ft change in elevation. This oscillation was amplified during windy days that caused wave action, resulting in erratic impoundment elevation. A moving-average smoothing function was applied to the elevation record to address these oscillations.

SSC was computed using YSI 6136 turbidity sensor data and regression procedures outlined in Rasmussen and others (2009). The regression developed for Clear Creek at Decatur Rd. (upstream from Atchison County Lake) (Table 2) was used for SSC calculations in the Atchison watershed, because Lee and Ziegler (2010) indicated that turbidity-SSC relations within the same watershed remain constant because of similarities in soil type in northeast Kansas. A possible source of error in this study is turbidity truncation. Turbidity truncation was observed at the LDMD 17 south inflow during several recorded storm events. The actual peak suspended-sediment concentration was not estimated in final load totals, because truncation only occurred during a small period (a total of 1 hour and 55 minutes during one 5-hour storm, 40 minutes during two other storm events, both which lasted approximately an hour and 15 minutes, both based on inflow hydrograph), and estimations based on interpolating slopes prior to and after truncated periods are prone to large uncertainty. These estimations increased loads roughly 3 to 22 percent when truncated peaks were visual by hydrographic fitting. Because these estimates are qualitative, they are not included in final load computations; however, it is possible that incoming loads were approximately 10 percent higher than computed loads.

LDMD 17 had two inflow streams, hereinafter referred to as north fork (NF) and south fork (SF). Delineation of each inlet in GIS indicated NF drained 46.5 percent of the LDMD 17 watershed, and the SF the other 53.5 percent. For inflow calculations, total inflow was split according to each inlet's percentage of the total drainage area. During one storm, which affected LDMD 17 from May 31 to June 6, 2011, both inlets experienced long periods of missing turbidity data because of sensor malfunction or fouling at different times during the event. To account for the missing data, the missing data from one inflow tributary was set to be equal to the existing data from the other inflow tributary, and the subsequent computed loads were adjusted by percent drainage area. Because recorded turbidity values were not always equal during storms, if both sensors were operational, a large but unknown amount of error was inherent to this method of estimation during periods of missing turbidity data at LDMD 17.

Results

Hydrologic Conditions

Precipitation. Annual precipitation data during 2009 at Atchison Lake and Banner Creek Lake watersheds and at all three watersheds in 2010 were larger than the mean annual precipitation as recorded by nearby meteorological stations (National Oceanic and Atmospheric Administration, 2012) over the stations' period of record. The meteorological station operated by the National Weather

Service (NWS) at Horton, Kansas (near the Atchison Lake watershed) recorded 43.2 in during 2009 and 47.7 in during 2010, as compared to a long-term mean annual precipitation total of 35.6 in (Figure 6). The meteorological station run by the NWS at Holton, Kansas (near the Banner Lake watershed) recorded 38.9 in during 2009 and 41.6 in during 2010, as compared to a long-term mean annual precipitation total of 35.2 in (Figure 6). The meteorological station run by the NWS at Baileyville, Kansas (near the Centralia Lake watershed, NWS site number 00140482, there was no precipitation gage at the Centralia 00141408 NWS station) did not record a complete record during 2009, but did record 35.8 in during 2010, as compared to a long-term mean annual precipitation total of 33.8 in (Figure 6). Lower than average precipitation was recorded at Banner and Centralia watersheds by the NWS during 2011 with 27.4 inches at Holton (mean annual 35.2 in) and 21.6 in at Baileyville (mean annual 33.8 in) (Figure 6). Only Atchison had slightly above average precipitation during 2011 with 36.2 in at Horton (mean annual 35.6 in).

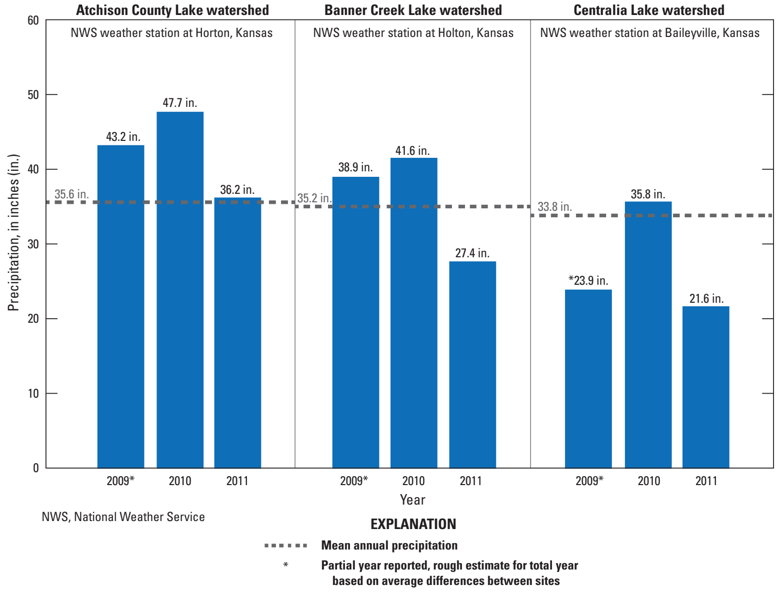


Figure 6. Annual precipitation totals recorded by NWS meteorological monitoring stations.

Streamflow. No historical data exist for the study sites to determine long term mean streamflows to compare to those observed during the study. Because data collection began in March 2009, 2009 is based on only one-half of that year's length, but it is still referred to as "2009" in this report. Because of this, calculated flow totals for 2009 are lower than when taken in comparison to the following complete years of data (Figure7). Duration curves, which graphically represent the relation between the magnitude and frequency of streamflow during a period of time, were computed for March of 2009 through September 22, of 2011 (Figure 8). The lack of streamflow data during the lower flow, winter months in beginning of 2009 likely bias these durations toward high flows compared to normal conditions. The greatest streamflows were generally in 2010 and the lowest in 2011, which corresponds with observed rainfall totals. The Centralia watershed was the exception because of several large storms in late May and early June, 2011 that produced 62 percent of that year's flow.

Total flow into the lakes from March 2009 to September 2011, including the estimated flow for the ungaged part of the watershed, was 15,000, 20,500, and 18,000 ac-ft for Atchison, Banner, and Centralia Lake watersheds respectively (Figure 7). During that time 17,000, 18,000, 13,000 ac-ft of water was released from Atchison, Banner, and Centralia Lake respectively. Lower outflow totals at Banner and Centralia compared to total inflows can be explained by evaporation,

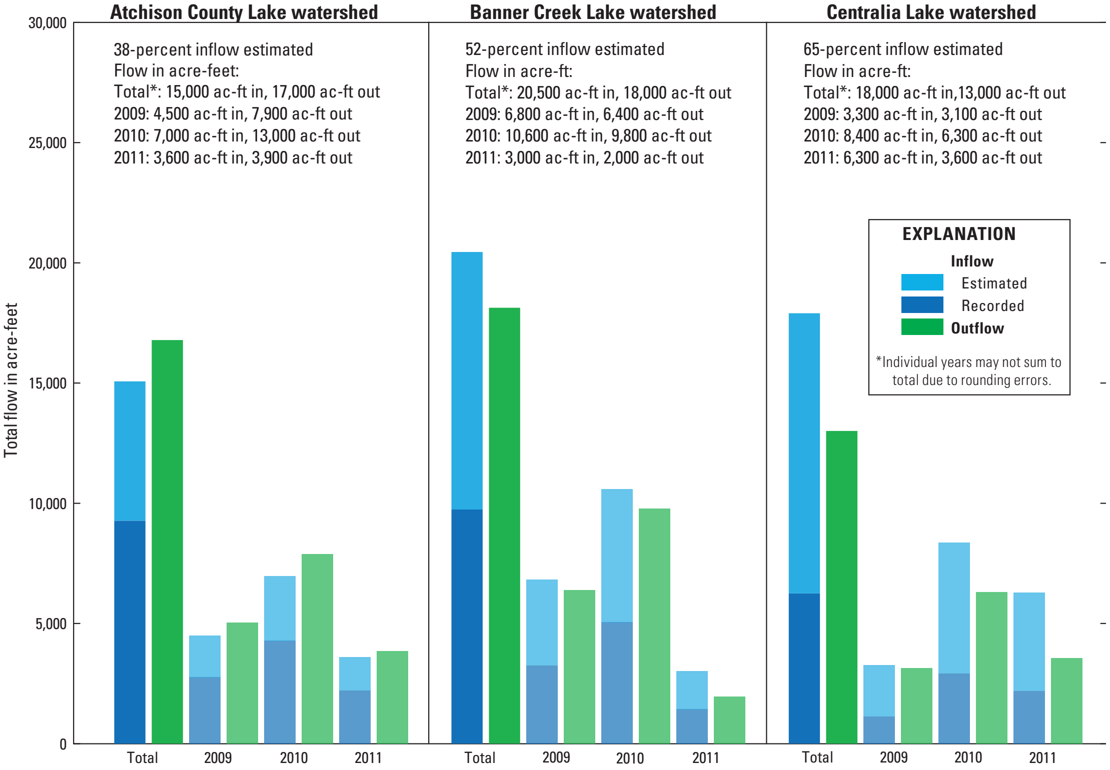


Figure 7. Streamflow duration curves for study sites upstream of lakes during March 2009 through September 2011.

or seepage to groundwater. Evaporation and seepage losses from Banner Lake and Centralia Lake are likely a larger percentage of water loss than Atchison County Lake because Banner Lake and Centralia Lake are larger relative to upstream drainage area, and thus have longer residence times (residence time is the amount a given unit of water will remain in the lake). However, larger outflows than inflows from Atchison County lakes could be explained by a combination of increased rainfall and runoff from the ungaged part of the upstream watershed, and tile drains draining subsurface water into the lake downstream from the Clear Creek at Decator Rd. streamgage (Figure 7).

Duration curves (Figure 7) for each upstream sample site indicate that the

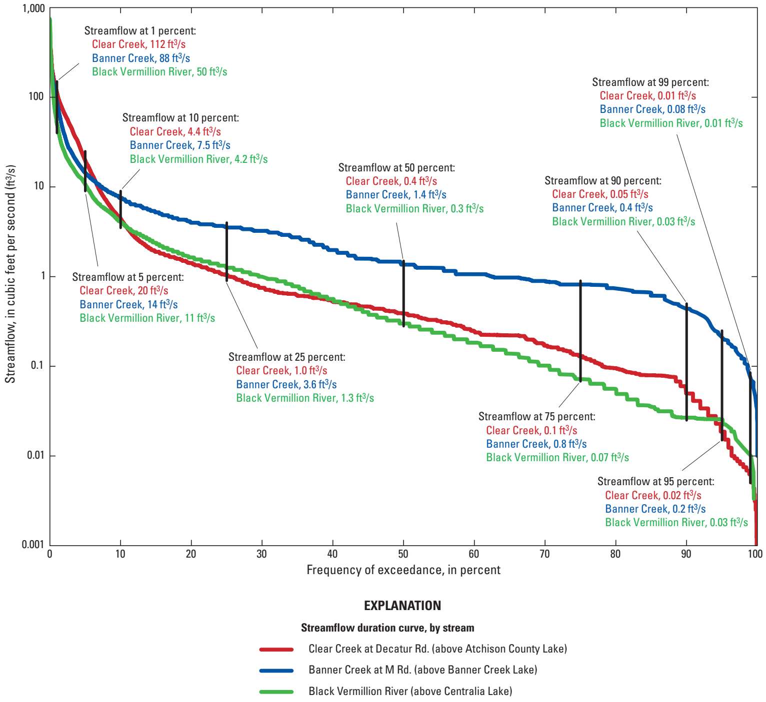


Figure 8. Computed and estimated streamflow into and from each lake for study period during March 2009 through September 2011.

Table 4. Suspended-sediment concentration and percent silt/clay (< 63 µm diameter) from discrete samples collected from study sites during March 2009 through September 2011.

Sample Date	Suspended -sediment concentration (mg/L)	In-situ turbidity (FNU)	Streamflow (ft³/s)	Percent silt/clay <63 µm
Clear Creek near Decatur Rd. (upstream from Atchison County Lake)				
3/24/2009	481	320	78	99
4/9/2009	28	10	0.86	78
4/10/2009	276	210	64	99
4/28/2009	314	250	51	99
6/11/2009	614	360	131	99
6/29/2009	50	37	0.13	98
8/10/2009	113	84	0.46	98
8/17/2009	941	480	243	99
8/17/2009	436	210	200	99
8/17/2009	380	180	123	99
8/17/2009	314	170	90	89
10/15/2009	50	9.5	0.1	63
10/22/2009	69	50	8.1	99
3/25/2010	168	110	14	98
4/23/2010	241	140	71	99
6/14/2010	192	130	30	97
9/1/2010	154	120	0.18	97
9/22/2010	269	170	84	99
11/3/2010	8	6.8	0.39	93
3/25/2011	27	8.7	0.91	93
5/26/2011	190	89	8.1	65
6/2/2011	424	200	120	97
Atchison County Lake				
3/24/2009	262	280	168	99
4/9/2009	107	100	1.6	98
4/10/2009	152	120	122	98
4/28/2009	309	300	72	99
5/18/2009	210	230	7.3	100
6/11/2009	438	360	320	100
7/17/2009	120	97	4.6	99
8/10/2009	34	49	2.9	93
8/21/2009	124	120	7.4	99
10/15/2009	12	13	0.01	93
10/22/2009	22	22	0.01	97
3/25/2010	128	110	54	99
4/22/2010	107	69.5	0.75	99
4/23/2010	61	84.2	287	99
5/25/2010	64	54	3.4	98
6/14/2010	49	47	5.3	97
7/21/2010	86	76	4.3	98
9/1/2010	110	96	0.04	99
9/22/2010	182	170	202	100
11/3/2010	113	120	0.19	100
11/30/2010	83	53	2.2	99
3/25/2011	35	29	1.9	99
5/26/2011	99	70	20	99
6/2/2011	107	97	222	99
Banner Creek at M Rd.				
3/17/2009	17	0.4	0.89	40
3/24/2009	705	390	32	97
4/10/2009	1,000	490	12	99
4/27/2009	798	400	165	99
4/30/2009	758	440	64	98
6/9/2009	490	320	6.4	99
6/15/2009	755	430	20	95
8/10/2009	99	14	1.4	79
8/17/2009	565	350	12	96
9/2112009	73	33	2.3	55
10/1512009	49	1.8	1.4	9
10/22/2009	173	140	8.9	96
10/2212009	114	95	7.7	97
3/11/2010	114	69	17	93
3/24/2010	4,760	2,340	237	90
3/25/2010	289	110	25	94
4/22/2010	346	160	11	97
4/22/2010	595	260	37	95
4/23/2010	1,820	480	103	93
6/14/2010	226	94	18	94
9/1/2010	881	500	21	97
11/3/2010	4	0.4	1.2	68
3/24/2011	16	0.4	1.4	40
5/24/2011	241	130	6.8	99
5/25/2011	1,970	1,130	59	93
6/2/2011	3,020	880	241	74
Banner Creek Lake				
3/17/2009	9	2.5	0.88	76
3/24/2009	30	20	21	96
4/10/2009	23	6.9	30	74
4128/2009	27	17	240	88
7/17/2009	2	3.8	7.7	40
8/1112009	22	8.4	5.5	77
10/15/2009	6	7	<.01	84
3/25/2010	5	6.8	47	96
5/25/2010	15	5.3	25	96
6/14/2010	7	4.5	18	86
7/21/2010	4	5.2	5.9	86
9/1/2010	4	4.8	2.9	93

Table 4 (continued). Suspended-sediment concentration and percent silt/clay (< 63 µm diameter) from discrete samples collected from study sites during March 2009 through September 2011.

Sample Date	Suspended-sediment concentration (mg/L)	In-situ turbidity (FNU)	Streamflow (ft^3/s)	Percent silt/clay <63 µm
10/21/2010	10	8.9	2.2	87
1113/2010	15	12	1.9	97
11/29/2010	43	26	1.1	81
1/25/2011	4	0.1	0.15	77
3/24/2011	5	4.2	12	95
5/24/2011	10	5.4	2.9	93
5/26/2011	8	3.9	39	96
6/212011	16	3.1	133	95
Black Vermillion River above Centralia Lake				
3/17/2009	21	4.6	0.3	93
4/10/2009	1,090	460	23	99
4/27/2009	1,320	510	39	99
4/28/2009	210	96	7.6	98
4/30/2009	211	70	4.3	91
5/15/2009	85	21	1.5	73
6/212009	601	240	18	92
6/9/2009	2,320	1,020	24	9:8
7/1412009	408	200	2.2	98
8/17/2009	1,030	370	45	98
11/17/2009	173	110	18	99
3/11/2010	1,310	340	38	76
3/24/2010	5,060	1,200	210	96
3/24/2010	4,320	1,030	200	86
3/24/2010	2,250	600	202	85
3/25/2010	350	140	20	92
4/23/2010	313	140	13	99
9/1/2010	469	340	0.83	99
11/4/2010	40	3.3	0.05	100
3/24/2011	45	36	<0.01	90
5/25/2011	533	250	10	97
5/25/2011	2,530	1,090	670	95
Black Vermillion River below Centralia Lake				
3/17/2009	45	29	0.4	93
4/27/2009	26	7.3	68	81
4/30/2009	63	8.5	38	92
5/15/2009	23	9.7	5	98
6/2/2009	27	14	28	79
7/14/2009	31	30	0.6	93
11/17/2009	19	20	7.5	96
3/11/2010	38	11	44	94
3/25/2010	43	16	72	93
6/17/2010	36	25	32	81
9/1/2010	47	37	0.48	99
11/4/2010	13	38	0.02	89
3/24/2011	21	5.3	0.1	99
5/26/2011	118	141	139	97
6/3/2011	93	74	204	99

greatest streamflow at 99-percent exceedance was at Banner with 0.08 ft^3/s, as compared to Atchison and Centralia, which had 99-percent exceedance of 0.01 ft^3/s. This indicates that Banner, which was the largest watershed, had higher baseflow volumes during the period of the study, likely because of more contributions from groundwater. During the entire study period, frequencies of exceedance greater than 1 percent (approximately 9.3 days), accounted for 40 percent, 34 percent, and 50 percent of the total flows during the period of the study for Atchison Lake, Banner Lake, and Centralia Lake watersheds respectively. Distributions of 1-percent frequency of exceedance during each individual year (approximately 2 days for partial 2009, approximately 3.6 days for 2010 and 2011) for each watershed are 44, 32, and 44 percent for each year respectively at Atchison; 31, 27, and 41 percent for each year respectively at Banner; and 40, 41, and 66 percent for each year respectively at Centralia. The more gradual rise of the duration curve between 10- to 1-percent exceedances at Clear Creek (upstream from Atchison County Lake) compared with the other two sites could be because of upstream impoundments and tile retaining storm-flows and releasing them at more steady rates than if the watershed was without the impoundments.

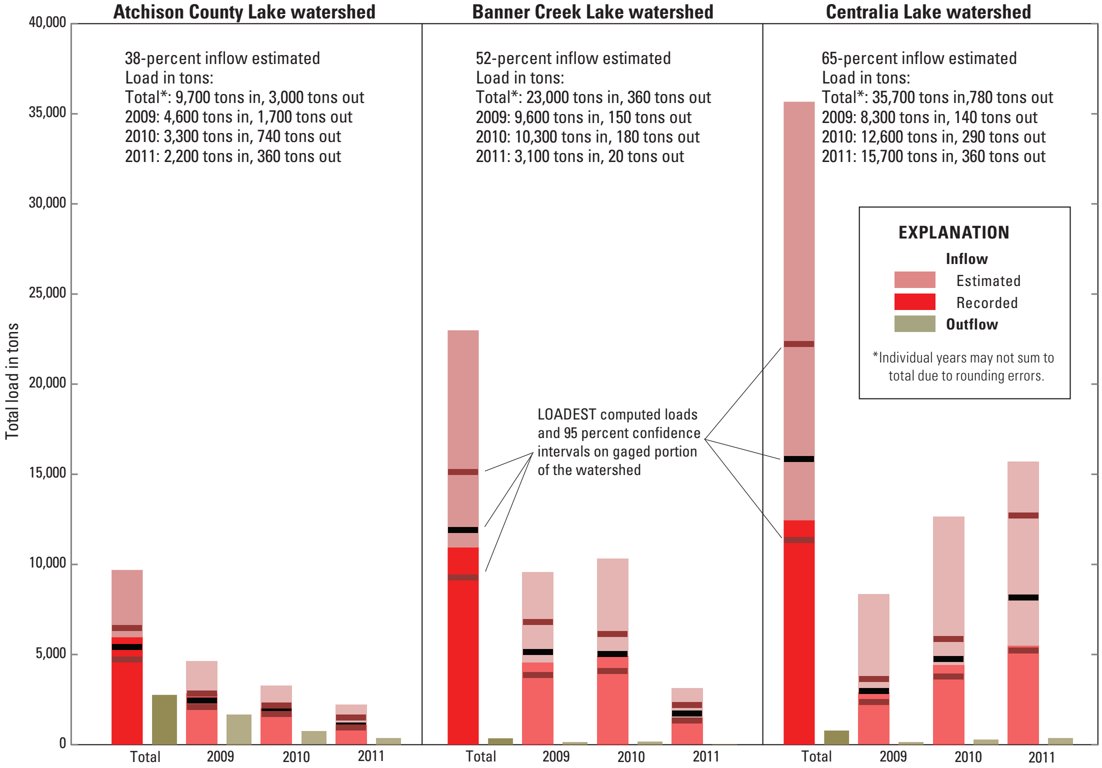


Figure 9. Computed and estimated sediment transport into and from each lake for study period during March 2009 through September 2011.

Sediment Transport. Sediment samples collected at study sites indicated most of the suspended-sediments were comprised of silts and clays (Table 4). Sediment transport into each of the three study watersheds during the study period, including the estimated ungaged parts, was 9,700; 23,000; and 35,700 tons at Atchison, Banner, and Centralia respectively (Figure 9). Transport from study impoundments was 3,000 tons from Atchison, 360 tons from Banner, and 780 tons from Centralia during the duration of the study.

To evaluate how sediment was transported, suspended-sediment duration curves were plotted for each upstream gaging site during the entire period of the study (Figure 10). Upstream from Atchison County, Banner Creek, and Centralia Lakes 73, 85, and 84 percent of the total load was transported during less than 1 percent (approximately 9 days) of the time (Figure 10). Upstream from Atchison County, Banner Creek, and Centralia Lakes 24, 38, and 32 percent of the total load was transported during less than 0.1 percent (approximately 0.9 days) of the time (Figure 10). Ninety-three percent of total transport at less than 1-percent exceedance occurred at Centralia during 2011, which was the year with the least annual precipitation. This large load was because of strong storms from May 24 to June 19, 2011 (field personnel noted the fields recently were planted throughout the watershed), which transported 11,200 tons, or 71 percent, of the 15,700 tons of sediment total for the year (31 percent of the sediment transport computed during the entire study). The same storm system

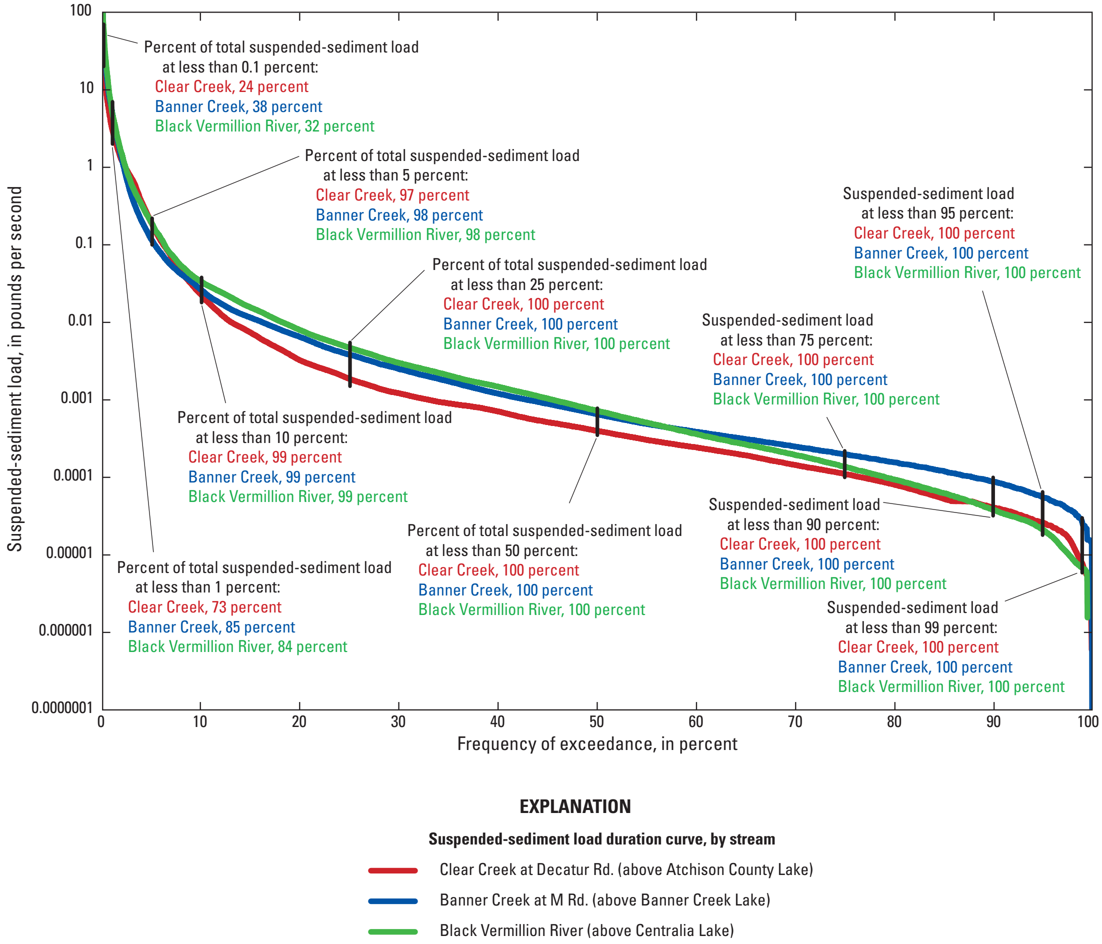


Figure 10. Suspended-sediment load duration curves for study sites upstream of lakes during March 2009 through September 2011.

at Banner transported 3,060 tons of the 3,140 tons of sediment total for 2011, or 97 percent (13 percent of the sediment transport computed during the entire study).

Sediment Yields. Total sediment yield at the upstream gage at Centralia (2,800 tons per square mile (tons/mi^2)) was about 2.7 times that computed at the Atchison (1,100 tons/mi^2) and Banner upstream gages (1,200 tons/mi^2) during the study period (Figure 11). Computed mean annual sediment yields (360 tons/mi^2/yr at Atchison, 400 tons/mi2/yr at Banner, and 970 tons/mi2/yr at Centralia) were less at all three watersheds than those estimated by Collins (1965), who estimated between 2,000 and 5,000 tons/mi^2/yr for this area of Kansas. The difference between the results in this study and those of Collins are likely a combination of the use of more accurate techniques in this study and the difference in scale between the studies, Collins examined and averaged much larger regions while this study examined small headwater watersheds. Streamflow yield did not vary substantially between the three watersheds during the same period (Figure 11), with the largest total streamflow yield computed at Atchison, 1,700 acre feet per square mile (acre-ft/

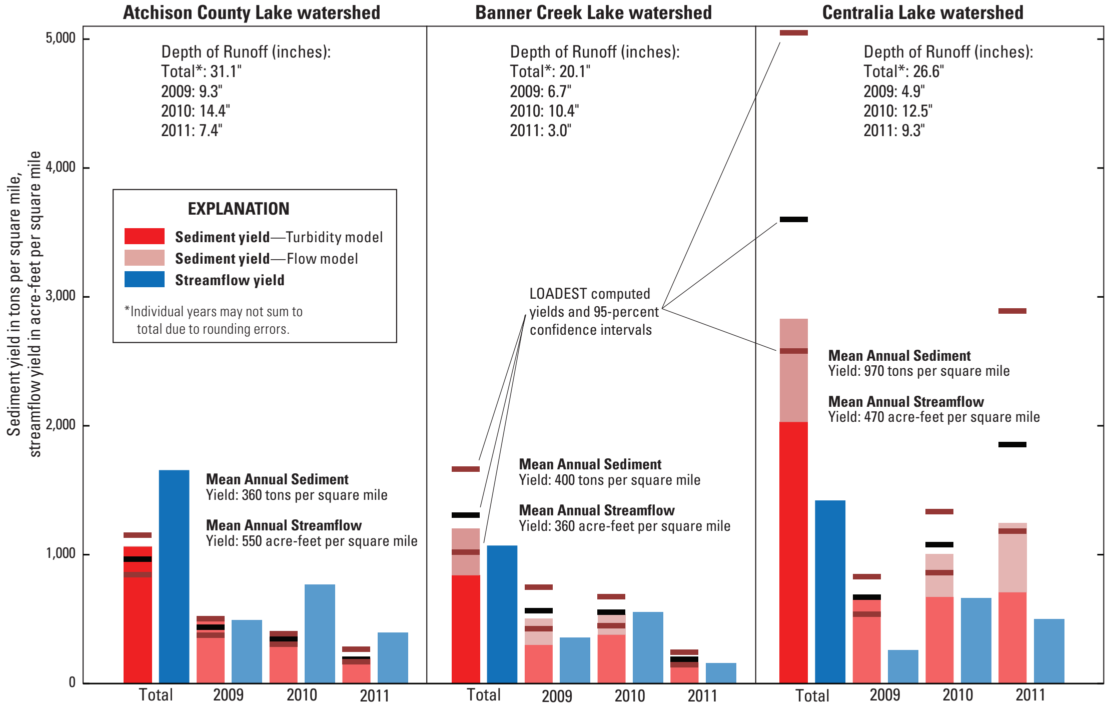


Figure 11. Total and mean annual sediment yield and streamflow and corresponding depth of runoff for study period during March 2009 through September 2011.

mi^2), which equals a depth of runoff of 31.1 inches. Although more water was transported per unit area at Atchison, which has similar land use to Centralia, less sediment was transported (per unit area) from Atchison than Centralia. Atchison yields were similar to Banner, which represented the reference grassland condition for the purposes of this study (Kansas Water Office, 2009). Despite an incomplete understanding of all the factors affecting sediment yields in Atchison (no complete survey of tile drains, riparian areas, and channelization), these results indicated that a cultivated watershed can carry yields similar to those observed under the assumed reference (or natural) condition.

Sediment transport at Banner may not represent a true reference condition if the streams were still adjusting to best management practices implemented from 1997 through 2007. These practices included 36 acres of agricultural land restored to native grass, an unspecified number of acres of brome grassland reseeded, and a reduction in the number of cattle crossings (U.S. Environmental Protection Agency, 2009). All of these practices may decrease sediment yields; however, not enough data were collected during this or previous studies to confirm this. Streambank sediment erosion was determined to be the highest at Banner (0.45 tons/foot/year) by a 2010 survey led by The Watershed Institute (TWI) as compared to Atchison (0.26 tons/foot/year) and Centralia (0.05 tons/foot/year) (The Watershed Institute and Gulf South Research Corporation, 2010). This streambank sediment erosion could be a factor in each watershed, under base-flow conditions, with Banner Creek having higher erosion and greater baseflow, resulting in greater low streamflow trans-

port and causing an increase in subsequent estimated yields. Additionally, Juracek (2007) determined that channel-bank sources were the largest source of sediment to Banner Lake based on analysis of cesium-137 determined in sediment cores taken in the lake. Based on the high rates of erosion observed by TWI, and the corresponding information from Juracek, sediments in Banner Creek likely have a substantial streambank source.

Sediment loads extrapolated from streambank surveys varied widely in comparison to sediment loads computed at downstream USGS monitoring sites. Average streambank sediment erosion estimates computed by TWI (2010) were multiplied by the length of the main stem above the three upstream sampling sites, and then multiplied by the 3 years of the study. Because precipitation conditions during the period of study represent average conditions (Figure 9) mean annual estimates of streambank erosion should approximate conditions observed during the study period. Streambank contributions from the main stem of Banner Creek are three times more than the sediment load observed at Banner Creek at M. Rd., 2.6 times more than the sediment load observed at Clear Creek at Decator Rd. (upstream from Atchison County Lake), and are 22 percent of the load computed at the Black Vermillion River above Centralia Lake. Substantially larger estimates of sediment contributions from only a portion of the streams in the Banner and Atchison County watersheds indicate that the extrapolation of average streambank-erosion rates from discrete, nonrandomized surveys can misrepresent the relative importance of streambanks when compiling sediment budgets. These survey-based estimations directly contradict the results found by the continuous monitoring and regression model methods used for this study, and indicate the best quantification methods are needed to determine the effectiveness of best management practices.

The larger sediment yield in 2011 at the Centralia Lake watershed, a year with lower precipitation, can be explained by a large storm that transported 890 tons/mi^2 during a 27-day period. This large storm occurred while fields were observed to be recently plowed throughout the watershed, which would have exposed and loosened field topsoils. Despite less streamflow in 2011, greater sediment loads indicate that not all storm events transport the same amount of sediment; larger, extreme storms during the spring may transport much larger sediment loads in small Kansas watersheds. Seasonal comparisons between fall and spring are problematic because of the dry fall seasons observed during the study period; however, mean sediment yields and mean runoff depths during spring were 200 tons/mi^2 (4.8 inches runoff depth) at Atchison, 260 tons/mi^2 (3.7 inches runoff depth) at Banner, and 560 tons/mi^2 (5.4 inches runoff depth) at Centralia, whereas mean fall sediment yields were 46 tons/mi^2 (1.7 inches runoff depth) at Atchison, 2 tons/mi^2 (0.5 inches runoff depth) at Banner, and 10 tons/mi^2 (0.5 inches runoff depth) at Centralia. These estimates do indicate greater yields during spring, which typically has greater precipitation and cultivation, as opposed to the post-harvest fall season, which has less rainfall and field topsoil that could be protected by leaf litter or are more compacted and less easily transported.

Table 5. Stormflows, sediment transport, trapping efficiencies, and sediment yields for study ponds Little Delaware Mission Dam (LDMD) 5 and LDMD 17 (rainfall totals recorded by National Weather Service Weather Station at Horton, Kansas) from April through August 2011.

			LDMD 5						
Storm	**Dates**	**Precipitation (inches)**	**Peak inflow (ft^3/s)**	**Flow IN (AF)**	**Flow OUT (AF)**	**Load IN (tons)**	**Load OUT (tons)**	**Trapping efficiency (%)**	**Sediment yield (tons/mi^2)**
1	May 25 to May 26	2.3	38	13	7.8	3.8	1.2	68	4.8
2	May 31 to June 6	2.5	59	37	27	9.7	6.1	37	12
3	June 25 to June 29	2.5	84	42	32	8.5	8.6	-0.1	11
4	July 3 to July 5	0.3	18	7.0	2.6	0.5	0.3	27	0.6
5	July 7 to July 9	2.0	99	39	32	7.8	7.2	8	10
			Totals	139*	101*	30*	23*	23*	39*
								Average	

		LDMD 17						
Storm	**Dates**	**Peak inflow (ft^3/s)**	**Flow IN (AF)**	**Flow OUT (AF)**	**Load IN (tons)**	**Load OUT (tons)**	**Trapping efficiency (%)**	**Sediment yield (tons/mi^2)**
1	May 25 to May 26	39	28	16	12	3.6	69	15
2	May 31 to June 6	53	36	34	18	9.2	49	23
3	June 25 to June 29	85	51	47	43	25	42	56
4	July 3 to July 5	33	10	9.0	6.5	4.2	36	8.4
5	July 7 to July 9	148	57	56	24	30	-24	31
		Totals	182*	161*	103*	72*	30*	134*
							Average	

*Sum of individual columns might not match total due to rounding errors.

[LDMD, Little Delaware Mission Dam; ft^3/s, cubic foot per second; AF, acre-feet; %, percentage; tons/mi^2, ton per square mile)

Stream channels in Centralia have been straightened (The Watershed Institute and Gulf South Research Corporation, 2010), which causes incision and increased transport because of channel adjustment resulting from increased stream velocities. Atchison County Lake and Banner Creek Lake watersheds had some vegetated riparian buffer along upstream banks (The Watershed Institute and Gulf South Research Corporation, 2010) which may increase the stability of streambanks, potentially decreasing downstream sediment transport (Sheridan and others, 1999, Zaimes and others, 2004). The presence of more tile drains in Atchison as compared to Centralia, 41 and 22 percent respectively (Table 2), may decrease sediment yields, because tile drains have been indicated to decrease sediment erosion from fields (Istok & Kling, 1983; Food and Agricultural Policy Research Institute, 2008). The difference in sediment yield between the Centralia Lake watershed and the other two study watersheds could also be related to increased channel adjustment, fewer riparian buffers, increased agricultural land use, and fewer upstream sub-impoundments relative to Banner Creek Lake watershed, and the potential for increased channel adjustment, fewer small upstream sub-impoundments, less tile drains, and less vegetated riparian buffers on upstream tributaries relative to Atchison County lake watershed (Figure 2; Table 2). To quantify the effects of sub-impoundments (ponds) on watershed sediment yields, streamflow and sediment transport were computed at two small NID listed ponds in the Atchison watershed during April through August 2011.

Effect of Ponds on Total Watershed Sediment Yield

Storms. Five storms occurred during the study period, which resulted in flow through the Atchison ponds. Rainfall depths for each storm were recorded at the NWS weather station at Horton, Kansas (Table 5). For both ponds, outflow volumes were less than inflow volumes for all of these storms because some of the inflow remained stored in the ponds.

Little Delaware Mission Dam 5. Stormflow, sediment transport, yields, and trapping efficiency for LDMD 5 are indicated in Table 5. Graphs of estimated discharge and SSC are indicated in igure 12 (*A*, *B*, *C*, *D*, and *E*). Computed inflow discharges ranged from 18 to 99 ft^3/s, and storm loads ("load in" on Table 8) ranged from 0.5 to 9.7 tons. Trapping efficiencies, by storm, ranged from 68 percent during storm 1 to -1 percent (the negative implying resuspension of previously deposited sediment, as a result of the age of the ponds indicating they are mostly silted in) estimated during storm 3. Average trapping efficiency during the five observed storms was 23 percent.

Little Delaware Mission Dam 17. Stormflow, loads, yields, and trapping efficiency for LDMD 17 are indicated in Table 8. Graphs of estimated discharge and SSC are indicated in Figure 12 (*F*, *G*, *H*, *I*, and *J*). Computed inflow discharges ranged from 33 to 148 ft^3/s, and storm loads ("load in" on Table 8) ranged from 6.5 to 43 tons. Trapping efficiencies, by storm, ranged from 69 percent during storm 1 to -24 percent (the negative implying resuspension of previously deposited sediment, as a result of the age of the ponds indicating they are mostly silted in) estimated during storm 5. Average trapping efficiency during the five observed storms was 30 percent.

Comparison of Results Between Ponds

Inflow SSC was larger at LDMD 17 than those at LDMD 5 (Figure 12). Initial storm sediment loads were typically high, and were followed by a more gradual increase in sediment outflows (Figure 12). Sediment inflows at LDMD 5 were much less than at LDMD 17 and subsequent sediment outflows were steady during the period of the storm (Figure 12). Sediment transport at LDMD 17 experienced more fluctuation (Table 5) leaving the pond, and similar to much higher sediment loading into that site. Given similar channel slopes, land use, and management practices in both ponds, the presence of an established grass buffer at LDMD 5 may be the most important factor contributing

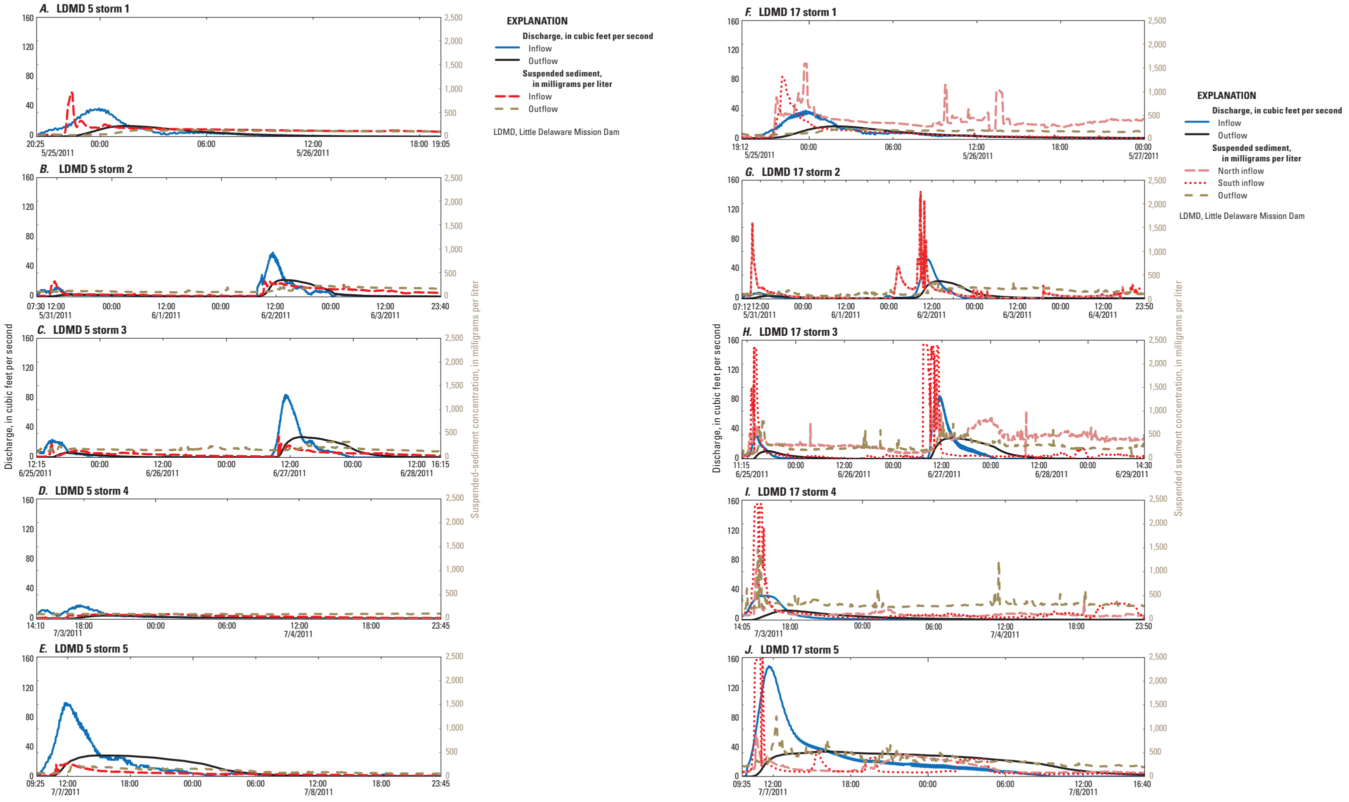


Figure 12. Stream discharge and Suspended Sediment Concentration Hydrographs for LDMD 5 and LDMD 17 for each storm (Rainfall totals recorded by NWS Weather Station at Horton, Kansas), April through August 2011.

to smaller sediment loads entering the pond.

Two factors may influence variation in sediment trapping among the 5 storms observed at LDMD 5 and 17. First, sediment trapping generally decreased through time at both sites, possibly indicating that sediments stayed suspended after storms only to be flushed out by subsequent storms. Second, sediment trapping efficiencies are smallest during the highest flow events, implying that sediments are transported through, or resuspended from these ponds. This second factor implies that during the largest storms (which previously were shown to transport the majority of sediments at baseline sites) small farm ponds may not serve as sinks for sediments transported from upstream fields.

Trapping efficiency decreased to a net loss of sediment at LDMD 17 over each individual storm event, the average trapping efficiency over all five storm events was 30 percent. Loss of trapping efficiency is expected as pond volume decreases due to sediment deposition; however, causes for this decrease were not readily apparent in the streamflow or turbidity data. Steady SSC at the outflow during storms (Figure 12), after the initial sediment inflow passed through, can be explained by resuspended sediment or algae growth, data errors, or some combination of these factors. One possible cause of the trapping efficiency decrease is that sediment flushed into the ponds from earlier storms stayed suspended, allowing it to be flushed with the initial inflow of the next storms flow. Short intervals occurred between storms 1 and 2, and storms 4 and 5, and trapping efficiency decreases between these two events dropped considerably (Table 5).

Because this study only spanned 4 months and five storms, these results could indicate that during periods with low flows, such as winter, sediments may fall out or become compacted, and are thus less likely to stay suspended or be resuspended by subsequent flows. During periods when storm events are more closely spaced, trapping efficiency becomes less changed to almost unchanged. Because most of the suspended load was composed of silts and clays (94 percent average less than 63 micrometers, Table 4), long suspension times can be expected. By Stokes law (Daugherty and Ingersoll, 1954), a computation of the settling rates of silts and clays range from 9.02 × 10^{-3} to 2.62 × 10^{-4} feet per second. Days of moderate to high winds would assist in maintaining suspension, and may cause resuspension of previously deposited sediments. The relatively short interval between the final two storms was likely a factor in the flushing of previously suspended sediments. In addition, negative and small sediment trapping efficiencies were estimated in each pond during storm 5, the largest storm in terms of peak and total flow at both sites. High flows may resuspend previously deposited sediments, and thus trapping efficiency of ponds of this age may remain unchanged (or even contribute sediments to downstream loads) during large storms.

Comparison of Pond Results to Flow and Loads at Clear Creek at Decatur Rd. (upstream of Atchison Lake)

Although the studied farm ponds comprised 22 percent of the drainage upstream from the Clear Creek (upstream from Atchison County Lake) site, flow from these ponds during the 5 storms comprised 28 percent of the flow observed at the Clear Creek (upstream from Atchison County Lake) site. Increased downstream flows may be because of uneven distribution of rainfall, agricultural diversions, tile drains draining groundwater, or stream losses to groundwater.

Table 6. Comparison of sediment loads between small study ponds LDMD 5, LDMD 17 and Clear Creek at Decator Rd. (upstream of Atchison Lake) during April through August 2011.

	Load observed entering ponds (tons)	Load trapped in study ponds (tons)	Load passing Clear Creek gage (tons)	Percent of total load trapped (tons)
Storm 1	16	11	73	12
Storm 2	28	13	104	10
Storm 3	51	18	125	10
Storm 4	7.0	2.5	8.9	16
Storm 5	32	-5.3	105	-4
Totals	134*	38*	416*	8*
				Percent of total load (trapped/ (load entered+load passed))

*Sum of individual columns might not match total due to rounding errors.

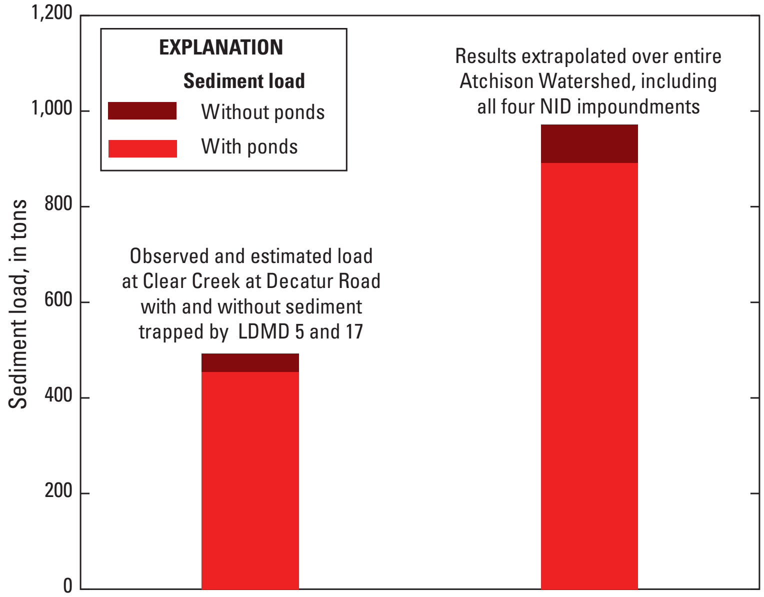


Figure 13. Difference in sediment loads with and without the two small study ponds on total watershed sediment transport (over the five observed storms), and extrapolated over entire watershed and all four NID listed ponds during April through August 2011.

For these five storm events, a total of 416 tons of sediment passed by the Clear Creek streamgage at Decatur Rd. (upstream from Atchison County Lake) (Table 6). It is estimated that 38 tons of sediment were trapped in the two study ponds during the study period, amounting to 8 percent of the load upstream from the Clear Creek at Decatur Rd. (upstream from Atchison County Lake) gage during the five observed storm events. Sediment inflow during periods when the pond elevation was below the outflow structure was not estimated, and would increase the amount of sediment trapped (assuming all inflows carry some sediment). There are two more NID listed ponds in the Atchison watershed, and numerous non-listed smaller ponds likely trap sediment in the same manner as LDMD 5 and LDMD 17. By extrapolating these results to the other two NID listed impoundments in the Atchison watershed, which drain 26 percent of the watershed, about 9 percent of total watershed sediment loads (including the ungaged drainage area) could be retained by these impoundments (Figure 13). These results do not explain the large difference in yields between Atchison County Lake watershed and Centralia Lake watershed, implying that differences in factors, such as riparian buffers, stream channelization, or the extent of tile drains, may better explain differences in sediment loading.

Trapping Efficiencies

Trapping efficiencies for each of the three study lakes range from 72 percent at Atchison County Lake and 98 percent for Banner Creek and Centralia Lakes during the entire study (Figure 14). Trapping efficiencies remained at 98 percent or greater for Banner Creek and Centralia Lakes each year recorded. These lakes are large relative to watershed drainage area and because outlet discharge is small, sediment remains in the lake longer (longer residence time) and settles to the lake bottom. Flow through Banner Creek and Centralia Lakes was constrained by the outlet structure over the duration of the study. Flow at Atchison County Lake was primarily through a small outlet structure, but during high flow events flow was diverted over an emergency spillway, which greatly increased the outflow discharge. At the maximum observed lake volumes (Kansas Biological Survey, 2010a, b, c) with corresponding maximum computed outlet discharges, residence times were approximately 6 hours at Atchison, 14 days at Banner, and 11 days at Centralia. Atchison County Lake, built in 1935, besides having been built with a smaller volume than Banner Creek and Centralia Lakes, has mostly silted in, resulting in a smaller volume and lower residence times

* Individual years may not sum to total due to rounding errors

Figure 14. Total and mean annual trapping efficiencies and loads into and from each study lake during March 2009 through September 2011.

as discussed in "Streamflow." Trapping efficiencies range from 64 to 84 percent for each year during the study period (Figure 14), with the greatest trapping efficiency during 2011, which corresponds to the year with the lowest annual flow volume, and fewer high flow events that topped the emergency spillway.

Conclusions

The U.S. Geological Survey, in cooperation with the Kansas Water Office, investigated sediment transport to and from three small impoundments in northeast Kansas from March 2009 through September 2011. Streamgages and turbidity sensors collected continuous 15-minute data upstream and downstream from Atchison County, Banner Creek, and Centralia Lakes in northeast Kansas. These sites were selected for study because they differed with respect to the extent or management of upstream agricultural activities. The Atchison County Lake and Centralia Lake watersheds have extensive agricultural activity, but both are similar with regard to installation of terraces and implementation of reduced and no tillage. However Atchison has more farms ponds, more tile drainage, and has more streams with riparian buffers. The Centralia Lake watershed is less tile drained, and streams are generally more channelized and have less riparian buffer. The Banner Creek Lake watershed is primarily grassland and pasture, has stream channels with riparian buffers, and has many farm ponds. Data from sampling sites were used to estimate sediment transport to and from each reservoir, and to characterize how natural factors and agricultural practices affect sediment transport in small watersheds in northeast Kansas.

The vast majority of sediment was transported to studied reservoirs during high flow conditions. Seventy-three to eighty-five percent of sediment loads were transported past headwater monitoring stations 1 percent of the time. Computed mean annual sediment yields (360 tons/mi^2/yr at Atchison, 400 tons/mi^2/yr at Banner, and 970 tons/mi^2/yr at Centralia) were less at all three watersheds than those estimated by Collins (1965), who estimated between 2,000 and 5,000 tons/mi^2/yr for this area of Kansas. Although small yields from Banner Creek were expected because of little agricultural activity, sediment yields at heavily cultivated Atchison County site were less than expected relative to Banner Creek or Centralia sites. These results also indicated that a cultivated watershed can carry yields similar to those observed under the assumed reference (or natural) condition. Data collected at two farm ponds upstream from Atchison County Lake in 2010 indicated average trapping efficiencies of 23 to 30 percent during five storms, but only 8 percent of the total load upstream from the Clear Creek at Decatur Rd. (upstream from Atchison County Lake) streamgage. Extrapolation of these results across the basin indicated that sediment trapping in farm ponds likely explain little of the difference in sediment yields observed among the three monitoring sites. Farm pond data indicate that less sediment is trapped during large storms and when sediments may remain in suspension when multiple storms occur within weeks or months.

Differences in sediment yields among Atchison and Centralia watersheds may be attributed to some combination of increased channelization, lack of riparian buffers, and less tile drainage in the Centralia basin. Equivalent sediment yields among the Atchison County and Banner Creek watersheds indicate that reference-like sediment yields may be observed in heavily agricultural watersheds through a combination of field-scale management activities and stream channel protection. When computing loads using published erosion rates obtained by single-point survey methodology, streambank contributions from the main stem of Banner Creek are three times more than the sediment load observed by this study at the sediment sampling site at Banner Creek, 2.6 times more than the sediment load observed by this study at the sediment sampling site at Clear Creek (upstream from Atchison County Lake), and are 22 percent of the load observed by this study at the sediment sampling site at Black Vermillion River above Centralia Lake. Comparisons of study sites to similarly sized urban and urbanizing watersheds in Johnson County, Kansas indicated that sediment yields from the Centralia watershed were similar to those in construction-affected watersheds, while much smaller sediment yields in the Atchison County and Banner Creek watersheds were comparable to stable, heavily urbanized watersheds. Comparisons of study sites to larger watersheds upstream from Tuttle Creek Lake indicate the Black Vermillion River watershed continues to have high sediment yields despite 98 percent of sediment from the Centralia watershed (a headwater of the Black Vermillion River) being trapped in Centralia Lake.

In comparison to upstream data, sediment loading data collected downstream from each impoundment indicated sediment trapping efficiencies of 72, 98, and 98 percent in Atchison, Banner, and Centralia Lakes, respectively. This is because storage volume of Atchison County Lake is less than that of Banner and Centralia Lakes relative to the size of upstream drainage area.

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Surveying Land Use and Agricultural Management Practices in Atchison County Lake, Banner Creek Lake and Centralia City Lake Watersheds

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Interpretative Summary

Major sources of sediment in Kansas watersheds are generally cropland fields, grazing lands, streambeds and streambanks. The goals of this project were to determine current land use and crop and grazing land management practices within Atchison County Lake (ACL), Banner Creek Lake (BCL) and Centralia City Lake (CCL) Watersheds. Field surveys were conducted of each watershed that involved inputting georeferenced field data into tablet computers. Inputted information included land use (crop land and grasslands), crop rotations, current conservation practices (i.e. terraces, terrace condition, waterways and tillage practices), grassland conditions (and whether grazed or hayed) and other relevant information. Terrace condition (excellent, average, or needs rebuilding) and grassland condition (excellent, fair to good, or poor) were qualitative ratings. This survey/evaluation was done on every cropland field and grassland field visible from public access roads. Approximately 90% of the total land area was accessible and evaluated. Photographs were also collected of conditions within the watersheds.

The watersheds have distinct differences in land use, which would be expected to result in differences in rates of erosion and sediment loading. The landscapes in ACL and CCL were predominately used for crop production, while BCL was mostly in pasture/grassland. Therefore, from land use alone, it is likely to expect higher sediment loading in ACL and CCL than in BCL. Soybeans were the most common crop grown in the three watersheds with corn being the second most prevalent. No tillage and reduced tillage cropping practices were prevalent in ACL and CCL. The improved tillage practices were used on a higher percentage of cropland acreage in ACL than in CCL, which may result in less erosion and sediment loading in ACL. Terraces with waterways or tile outlets were extensively used in cropland fields in all three watersheds, which should result in fewer ephemeral gullies and reduce sediment loading to water bodies. At least four watershed dams/lakes are present in ACL watershed, controlling the runoff from approximately 30% of the acreage in the watershed while watershed dams/lakes were not noted in CCL or in BCL.

From land use and land management practices in the three watersheds, we conclude that sediment loading would

Photo 1. Close up of stream showing sediment load following a rainfall event in May 2009.

likely be greatest in CCL, than ACL and least in BCL. The land use in BCL was mostly grassland, which should lead to the least upland erosion and sediment loading. ACL is expected to have less sediment loading than does CCL due to greater implementation of no tillage and reduced tillage practices and terraces and also the four waterways dams/lakes that would control significant amounts of sediment from upland fields in the ACL.

Photo 2. Conventionally tilled field in Centralia City Lake Watershed showing a tile emptying a tile outlet terrace system.

Photo 3. A series of terraces showing a tile inlet following a rain event in the Centralia City Late Watershed, 2010.

Introduction

In Kansas watersheds, the main sources of sediment are cropland fields, grazing lands, streambeds, and streambanks. Runoff also occurs from livestock confinement operations, roads and roadway ditches, forest lands, and rural and urban areas. As most Kansas landscapes are used for agricultural enterprises – either in crop or livestock production – it is expected that land management decisions by those land managers have a major impact on sediment movement to Kansas lakes, rivers and streams.

Implementation of best management practices and strategies have been shown to minimize erosion from crop fields and from grazing lands and reduce sediment loading to streams. These strategies and practices can be divided into two general categories. conservation structures and management practices. Examples of conservation structures include:

- Terraces
- Grass waterways
- Wetlands
- Vegetative and riparian buffers/filters
- Grade stabilization structures
- Water and sediment control structures

Management practices are generally related to agronomic practices and typically do not require an engineering design. Examples of management practices include:

- No-till
- Reduced or minimum tillage
- Contour farming
- Crop rotations

Some strategies reduce soil erosion; others trap sediment in the fields. A system that combines conservation structures and management practices would be most effective at reducing soil erosion and sediment yield.

We expect those agricultural watersheds with higher grazing lands/grasslands acreages compared to crop land acreages would have lower rates of sediment loading into streams and lakes. Also, those watersheds with higher implementation rates of conservation structures and practices should have lower sediment loading.

The goals of this project were to determine current land use and crop and grazing land management practices within Atchison County Lake (AKL), Banner Creek Lake (BCL) and Centralia City Lake (CCL) Watersheds. The information collected was than used for watershed modeling and also to help determine the reasons for the differences in sediment delivery to streams and lakes within each of the watersheds.

Procedures

GIS databases were collected from the following sources. Data Access & Support Center (DASC), USDA-NRCS, USDA-FSA, USDA-NASS and USGS. Data collected include digital orthophotos, soils data (SSURGO), digital elevation (DEM), land use, and cover and crop information. In May and June of 2009 (ACL, BCL and CCL) and 2010 (ACL and CCL), field surveys were conducted that involved inputting georeferenced field data into tablet computers. Inputted information included: land use (crop land and grasslands), crop rotations, current conservation practices (i.e. terraces, terrace condition and waterways), management practices, grassland conditions (and whether grazed or hayed) and other relevant information. Terrace condition (excellent, average, or needs rebuilding) and grassland condition (excellent, fair to good, or poor) were qualitative ratings by the authors. This survey/evaluation was done on every cropland field and grassland field that was visible from public access roads. Approximately 90% of the total land area was accessible and evaluated.

Photo 4. A conventionally tilled corn field just following a rainfall in 2009 showing sheet and reel erosion.

Photo 5. Unimproved roads were prevalent in all three watersheds and may be significant sources of sediment.

Photographs were also collected of conditions within the watersheds.

Results

The watersheds have distinct differences in land use. The landscapes in ACL (66.2% and 69.6% in 2009 and 2010, respectively) and CCL (60.4% in 2009 and 2010) were predominately used for crop production, while only 3.8% of BCL was devoted to crop production. Only 5.0% and 7.1%, in 2009 and 2010, respectively, of ACL and 15.7%, in 2009 and 2010, of CCL were in grasslands while 72.1% of BCL in 2009 were in grasslands and either hayed or grazed. From the small acreage of tilled lands in BCL, it is expected that little sediment loading in the watershed would result from crop production.


Photo 6. Ephemeral gully erosion in Centralia City Lake Watershed, 2010.


Photo 7. Stream in Centralia City Lake Watershed following a large storm. Note lack of riparian buffer/border between crop field and stream.

Soybeans were the most common crop grown on cropland in all three watersheds (approximately 60% in ACL, 50% in CCL, and 61% in BCL). Corn was grown on approximately 40% of the cropland in both ACL and CCL and wheat was grown on approximately 1% of the cropland in ACL, 13% in CCL, and 17% of BCL. Typically, soybean residue is not expected to provide as much erosion protection compared to corn or wheat residue so higher soybean acreage in ACL may result in greater watershed erosion and sediment loading than in CCL.

No tillage and reduced tillage cropping practices are among the most effective practices for reducing soil erosion from crop fields. When compared to conventional tillage practices, no tillage and reduced tillage would be expected to reduce soil erosion and sediment loading to streams and lakes. In ACL and CCL, no tillage and reduced tillage practices were implemented on about 88% and 75% of the cropland, respectively. No tillage and reduced tillage cropping practices were used infrequently on crop fields in BCL. However, since cropland was just a minor land use in BCL (3.8%), implementing improved management practices on cropland would be expected to have little impact on sediment loading into water bodies.

Terraces with waterways or tile outlets were extensively used in cropland fields in all three watersheds (approximately

90% in ACL and BCL and 70% in CCL). Fields without terraces generally had greater incidence of ephemeral gullies and would be expected to have greater soil erosion and contribute more to sediment loading to water bodies. In ACL, terrace outlets were more often tiles (47%) than waterways (42%) while in CCL and BCL, terrace outlets were generally waterways (70%), with the reminder being tile outlet terraces. Several fields in CCL were being converted from waterway outlets to tile outlet terrace systems.

At least four watershed dams/lakes are present in ACL watershed (Figure 4). These lakes are expected to control the runoff from approximately 30% of the acreage in the watershed and would be expected to significantly reduce sediment loading in to Atchison County Lake.

Conclusions

The watersheds have distinct differences in land use, which would be expected to result in differences in rates of erosion and sediment loading. The landscapes in ACL and CCL were predominately used for crop production, while BCL was mostly in grassland used for haying and grazing. Therefore, from land use alone it is likely to expect higher sediment loading in ACL and CCL than in BCL. Soybeans were the most common crop grown in the three watersheds with corn being the second most prevalent. A small amount of winter wheat was also grown in the watersheds. Typically, soybean residue is not expected to provide as much erosion protection compared to corn or wheat residue so higher soybean acreage in ACL may result in greater watershed erosion and sediment loading than in CCL. No tillage and reduced tillage cropping practices were prevalent on most cropland fields in ACL and CCL. The improved tillage practices were used on a higher percentage of cropland acreage in ACL than in CCL, which may result in less erosion and sediment loading in ACL. Terraces with waterways or tile outlets were extensively used in cropland fields in all three watersheds, which should result in fewer ephemeral gullies and reduce sediment loading to water bodies. At least four watershed dams/lakes are present in ACL watershed, controlling the runoff from approximately 30% of the acreage in the watershed.

From land use and land management practices in the three watersheds, we conclude that sediment loading would likely be greatest in CCL, than ACL and least in BCL. The land use in BCL was mostly grassland, which should lead to the least upland erosion and sediment loading. ACL should have less sediment loading than does CCL due to greater implementation of no tillage and reduced tillage practices and terraces and also the four waterways dams/lakes that would control significant amounts of sediment from upland fields in the ACL.

Photo 8. No-till planted soybeans in Atchison County Lake Watershed, 2010.

Recommendations

- Survey more watersheds, particularly, those containing watershed dams/lakes and/or wetlands.
- Survey watersheds that contain significantly greater amounts of CRP.
- Study the impact of watershed dams/lakes on sediment delivery.
- Develop a better understanding of the impact of conservation practices on sediment delivery.

Table 1. Summary of 2009 survey of land use, tillage practices, terraces (and terrace condition), and grassland conditions in Atchison County Lake Watershed, Banner Creek Watershed and Centralia Lake Watershed, by percent of acres in watershed.

		Atchison County Lake	Banner Creek Lake	Centralia City Lake
Acres in Cropland in the Watershed (% of total acreage)		3,835 (66.2%)	459 (3.8%)	5,425 (60.4%)
		Percentage of the Cropland within the Watershed		
Crop Grown	Soybeans	55.5	61.0	52.5
	Corn	44.1	16.3	33.7
	Wheat	0.3	16.7	11.2
	Other	None	None	2.7
		Percentage of Cropland within the Watershed		
Tillage Practice	No till	81.0	14.9	61.6
	Reduced till	7.8	None	11.6
	Conventional till	10.2	67.3	22.2
	Not determined	0.9	17.7	4.7
		Percentage of Cropland within the Watershed		
Terrace Type	Terraced with waterways	41.5	52.1	71.9
	Terraced with tiles	46.8	15.7	19.3
	No terraces	3.5	26.8	2.6
	Not determined	8.1	5.4	6.1
		Percentage of Cropland within Watershed		
Terrace Condition	Excellent	32.1	70.9	37.9
	Average	66.8	4.1	47.5
	Needs Rebuilding	1.1	None	13.3
	Not determined	None	25.0	1.4
		Atchison County Lake	**Banner Creek Lake**	**Centralia City Lake**
Acres in Grassland (%)		290 (5.0%)	8,815 (72.1%)	1,405 (15.7%)
		Percentage of Grassland within Watershed		
Grassland	Grazed	75.8	67.5	73.3
	Hayed	15.8	27.4	7.2
	CRP	0	0.5	13.2
	Other	8.4	4.6	6.3
		Percentage of Grassland within Watershed		
Grassland Condition	Excellent	11.0	42.4	30.3
	Fair to Good	75.9	52.3	69.7
	Poor	13.0	5.3	None
		Atchison County Lake	**Banner Creek Lake**	**Centralia City Lake**
Acres in Other Uses (lake, ponds, roads, homesteads) (% of total acreage)		1,671 (28.8%)	2,956 (24.1%)	2,701 (30.1%)

Table 2. Summary of 2010 survey of land use, tillage practices, terraces (and terrace condition), and grassland conditions in Atchison County Lake Watershed and Centralia City Lake Watershed, by percent of acres in watershed.

		Atchison County Lake	**Centralia City Lake**
Acres in Cropland in the Watershed (% of total acreage)		4,164 (69.6%)	5,425 (60.4%)
		Percentage of the Cropland within the Watershed	
Crop Grow	Soybeans	60.8	47.6
	Corn	37.4	41.4
	Wheat	1.7	9.1
	Other	None	1.9
		Percentage of Cropland within the Watershed	
Tillage Practice	No till	85.9	71
	Reduced till	0.7	7
	Conventional till	13.4	22
	Not determined	0	0
		Percentage of Cropland within the Watershed	
Terrace Type	Terraced with waterways	41.5	71.9
	Terraced with tiles	46.8	19.3
	No terraces	3.5	2.6
	Not determined	8.1	6.1
		Percentage of Cropland within Watershed	
Terrace Condition	Excellent	32.1	37.9
	Average	66.8	47.5
	Needs Rebuilding	1.1	13.3
	Not determined	None	1.4
		Atchison County Lake	**Centralia City Lake**
Acres in Grassland (% of total acreage)		422 (7.1%)	1,268 (15.7%)
		Percentage of Grassland within Watershed	
Grassland	Grazed	82.0	72.7
	Hayed	2.8	0.3
	CRP	0	27.0
	Other	5.2	0
		Percentage of Grassland within Watershed	
Grassland Condition	Excellent	11.0	28.9
	Fair to Good	75.9	71.1
	Poor	13.0	None
Acres in Other Uses (lake, ponds, roads, homesteads) (% of total acreage)		**Atchison County Lake**	**Centralia City Lake**
		1,396 (23.3%)	2,148 (23.9%)

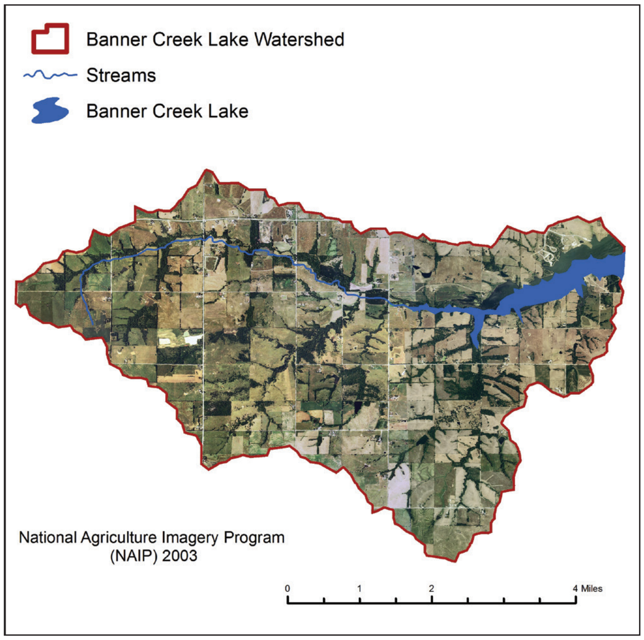

Figure 1. Aerial map of Banner Creek Lake Watershed.

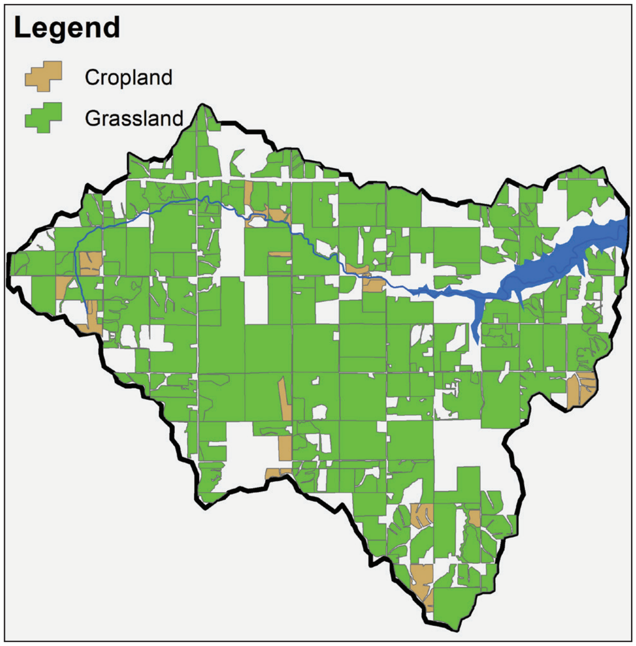

Figure 2. Land use in Banner Creek Lake Watershed, 2009.

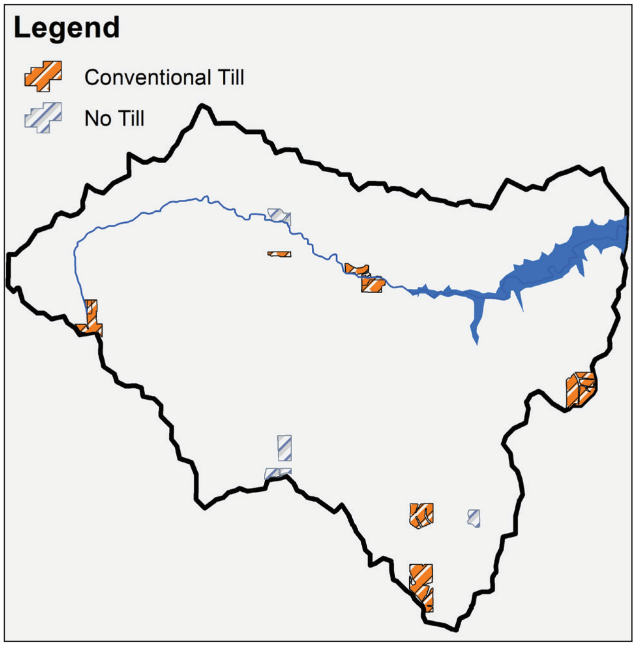

Figure 3. Tillage practices used in Banner Creek Lake Watershed, 2009.

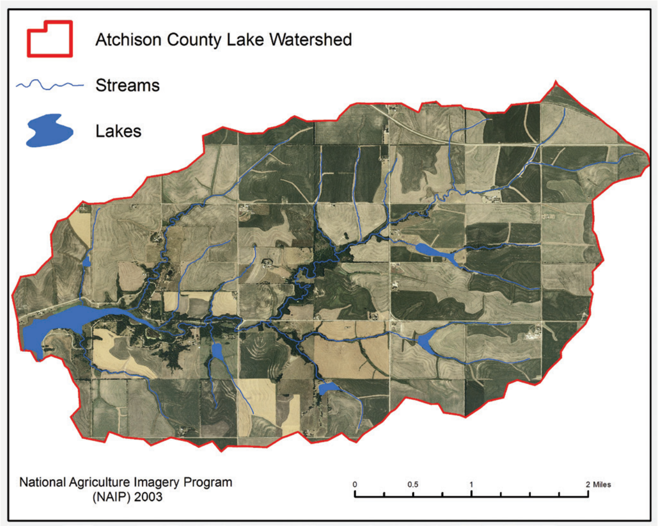

Figure 4. Aerial map of Atchison County Lake Watershed.

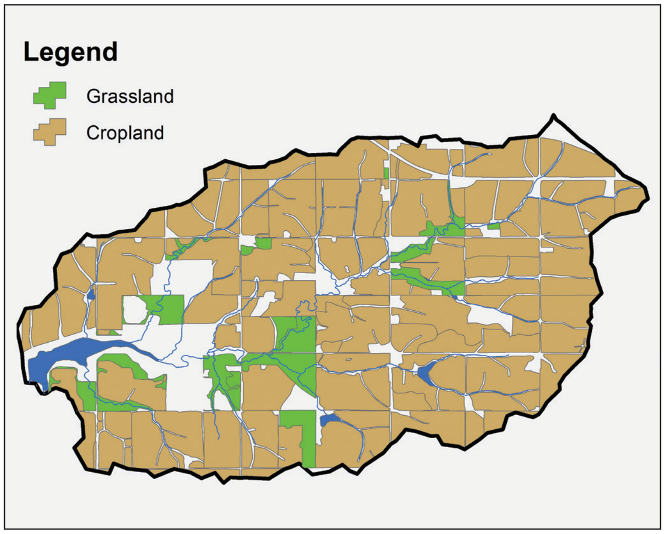

Figure 5. Land use in Atchison County Lake Watershed, 2010.

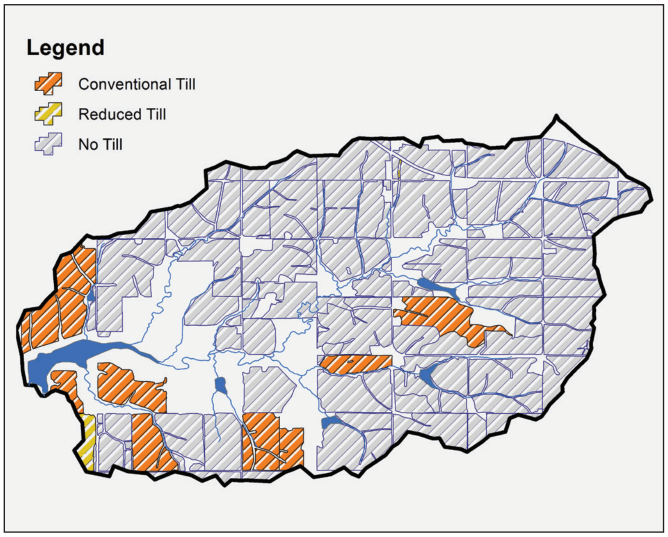

Figure 6. Tillage practices used in Atchison County Lake Watershed, 2010.

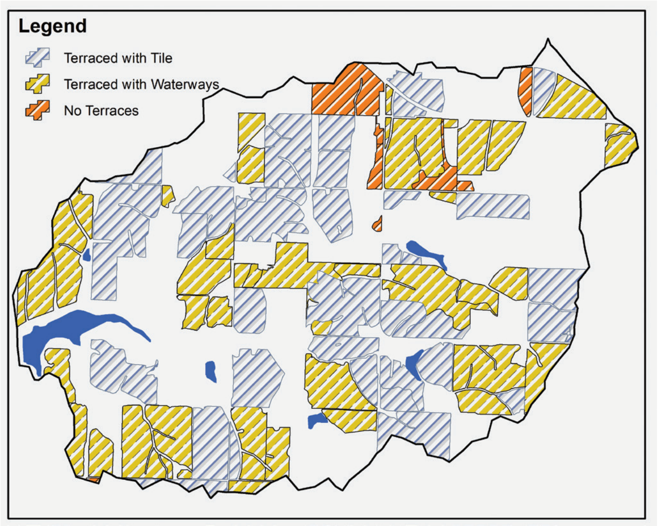

Figure 7. Terraced fields in Atchison State Lake Watershed, 2009.

Figure 8. Aerial map of Centralia City Lake Watershed.

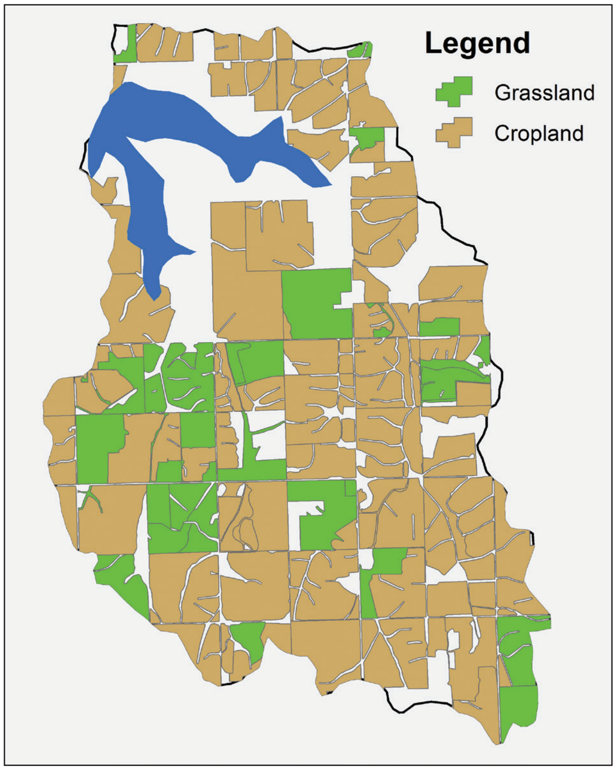

Figure 9. Land use in Centralia City Lake Watershed, 2010.

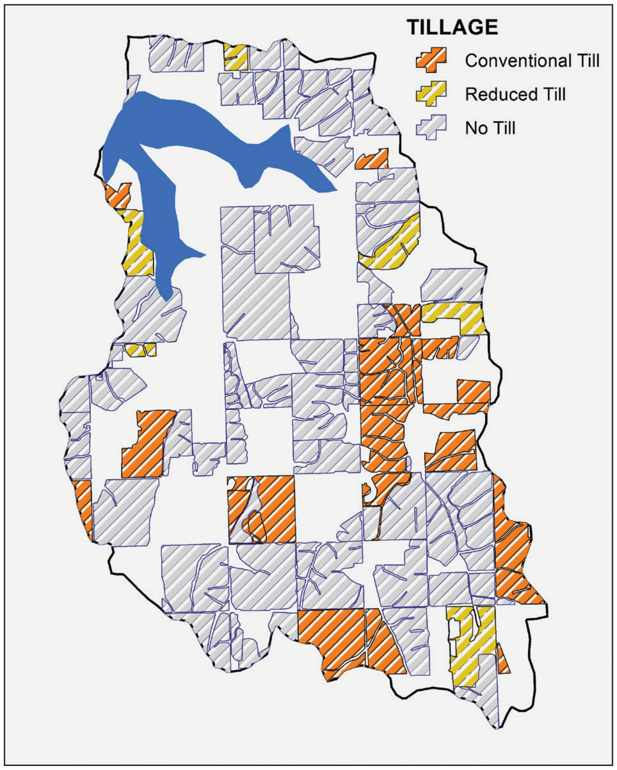

Figure 10. Tillage practices used in Centralia City Lake Watershed, 2010.

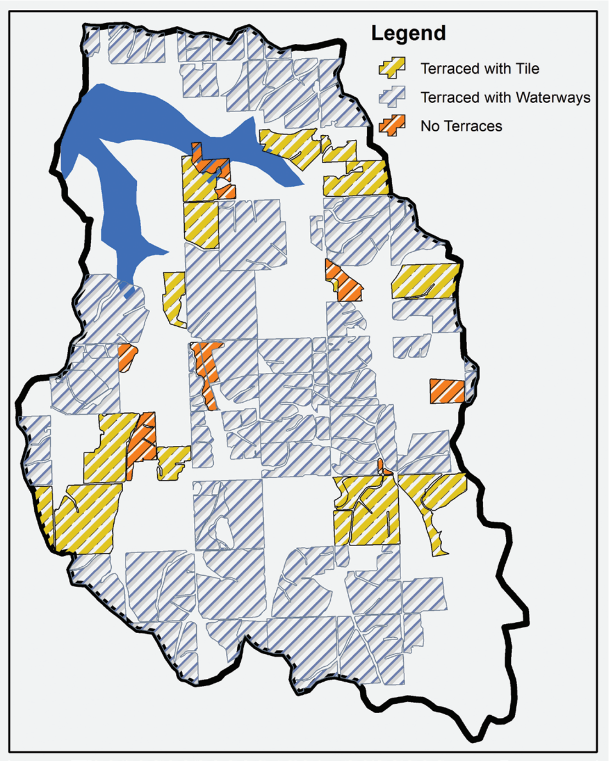

Figure 11. Terraced fields in Centralia City Lake Watershed, 2009.

Comparing Riparian Woodlands of Three Northeast Kansas Watersheds

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William Beck, *Kansas Forest Service*
Jeff Neal, *Blue Earth Consulting*

Interpretive Summary

Research in Kansas has documented the positive relationship that riparian forests have with water quality, most notably streambank stabilization (Geyer et al., 1997, 2003). The current study entailed comparing riparian forests within watersheds draining Atchison County Lake (Atchison), Banner Creek Lake (Banner), and Centralia City Lake (Centralia) in Northeast Kansas, to determine if there are correlations between observed sedimentation rates of these impoundments, and the functioning condition and extent of the riparian forests. Using a combination of GIS, remote sensing, and on-the-ground forest assessment and inventory plots, riparian forests in the three study watersheds were categorized into three functioning condition classes: forests in need of protection (i.e., properly functioning), forests in need of management (i.e., functioning at risk), and forests in need of establishment (i.e., non-functioning). Functioning condition class was assigned by examining the ratio of forest width (from top bank) to stream active channel width (ACW), and percent forest canopy coverage within the riparian area. Forest stand data and qualitative riparian area observations (e.g., invasive species presence, livestock use) were also collected from on-the-ground inventory plots within each watershed. Data and observations were used to validate GIS / remote sensing data, as well as provide guidance for future direction of voluntary forestry programs and technical assistance aimed at achieving the greatest water quality impact for the three lakes.

Riparian areas classified as “forests in need of establishment”, with no trees are expected to generate the highest amount of downstream sediment delivery to reservoirs, in comparison to the other two condition classes. These areas without riparian forests were found to be most prevalent within Centralia (76% of total riparian area), yet represented only 32%, and 16% of the total riparian area within Atchison and Banner, respectively. In addition to the inadequate width of riparian forest in many areas, all three watersheds exhibited a lack of sustainable forest management. This absence of management is evidenced by the current overstory forest species composition in all three watersheds, which was found to be dominated by lower-value species such as hackberry (*Celtis occidentalis*), honeylocust (*Gleditsia triacanthos*), and elm (*Ulmus spp*.). Regeneration composition of all three watersheds was similarly found to be dominated by these lower-value species. Tree species of high value (e.g., walnut (*Juglans nigra*), oak (*Quercus spp*.) represented no more than 10% of the total regeneration present within the study watersheds, again indicating an absence of management. Commonly observed threats to forest health/sustainability within on-the-ground riparian inventory plots included excessive livestock use, ice storm damage, and lack of sustainable forest management. Considering sedimentation rates, Banner exhibits a surprisingly high rate, despite having a grassland-dominated watershed. However, field observations made during riparian forest assessments indicated that Banner had the highest incidence of grazed riparian woodlands,

with 72% of the tracts surveyed showing evidence of cattle use, whereas Atchison and Centralia had cattle impacting only 25% and 21% of the tracts visited, respectively.

Introduction

Research along the Kansas River following the 1993 flood suggests that riparian forests outperform other landcover types (i.e., grass, row crop) in stabilizing streambanks and reducing downstream sediment delivery (Geyer, et al., 1997, 2003). Because of their correlation to reduced sediment loading, as well their ability to provide other ecological services such as stream shading/cooling, increased soil infiltration, flood attenuation, carbon sequestration, and wildlife habitat, properly functioning riparian forests are a critical component of the watersheds above Kansas' numerous reservoirs. In addition to ecological benefits, properly functioning riparian forests provide watershed landowners and residents with a wide variety of sustainable income sources (e.g., quality timber, fuelwood), increased recreational opportunities (e.g., hunting, wildlife viewing), and aesthetics. The goal of this study was to compare the extent, composition, and functioning condition of riparian forests within Atchison, Banner, and Centralia watersheds in Northeast Kansas. This information will be compiled into a GIS database that will be used by researchers, watershed stakeholders, and forestry professionals to determine policy, allocate resources, and guide forestry cost share and technical assistance programs, such as Environmental Quality Incentives Program (EQIP), and Continuous Conservation Reserve Program (CCPR), for water quality purposes.

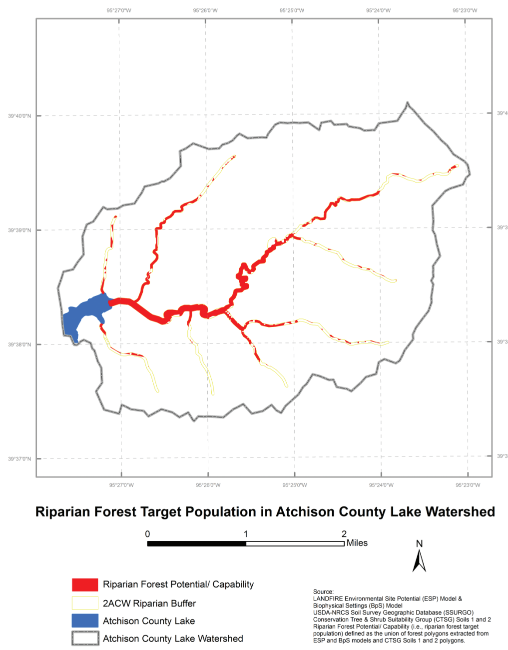
This study was undertaken simultaneously with an ongoing, U.S. Forest Service-funded project, entitled "Assessment of Riparian Forests to Reduce Sedimentation of Federal Reservoirs." This larger-scale study is using the same methodology as the current study, but is focusing on 7 additional HUC-12 sub-watersheds, as well as the main stem of the Delaware River, within the Delaware River HUC-8 watershed above Perry Reservoir.

Procedures (GIS and Remote Sensing)

Target Population Identification

The riparian forest target population was identified as the union of:

- *Riparian width* equal to twice the active channel width (ACW) based on "Stream Visual Assessment Protocol v.2" (SVAP2, USDA-NRCS 2009) and the "Riparian Area Management: Process for Assessing Proper Functioning Condition" guidance (PFC, USDI-BLM 1998).
- Estimation of ACW (i.e., bankfull width) based on regression equation: $\mathit{Drainage\ Area} = 22.37 * \mathit{ACW}^{0.2734}$ (drainage area in miles^2 and ACW is expressed in feet). The R^2 for the regression equation was 0.97, and was derived from surveys of nine reference streams in Northeast Kansas (Tetra Tech and SCC 2005).
- Soils indexed to Conservation Tree and Shrub Groups (CTSG) 1 and 2 based on the Soil Survey Geographic Database (SSURGO) for Kansas (USDA-NRCS 2009).



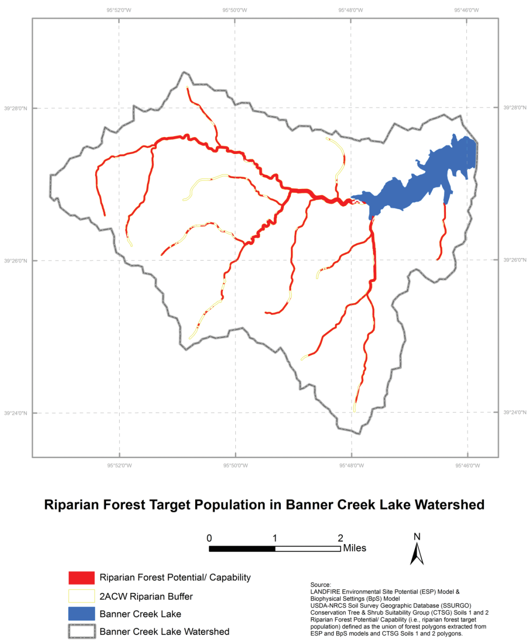
Source:
LANDFIRE Environmental Site Potential (ESP) Model &
Biophysical Settings (BpS) Model
USDA-NRCS Soil Survey Geographic Database (SSURGO)
Conservation Tree & Shrub Suitability Group (CTSG) Soils 1 and 2
Riparian Forest Potential/ Capability (i.e., riparian forest target population) defined as the union of forest polygons extracted from ESP and BpS models and CTSG Soils 1 and 2 polygons.

Figure 1. Atchison riparian forest target population.

- Extent of pre-settlement and potential riparian forest conditions using a biophysical settings (BpS) model and environmental site potential (ESP) model developed by the LANDFIRE program (www.landfire.gov).

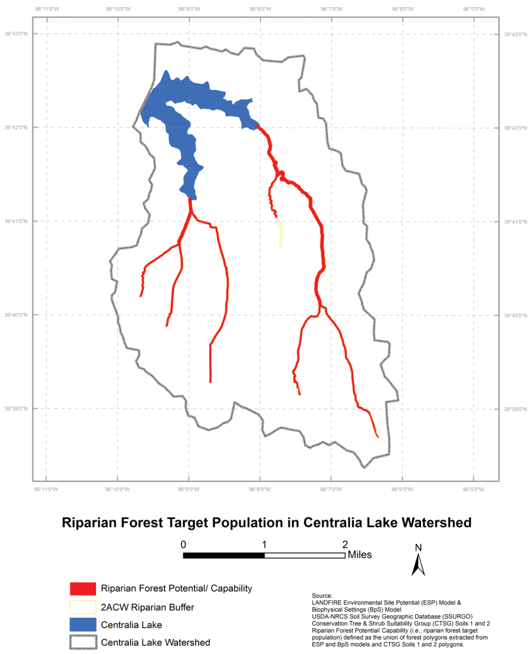
The riparian forest target populations for the three study watersheds are displayed in Figures 1-3.

We used two ACW (2ACW) as an input to define the riparian forest target population. In the three study watersheds, 2ACW riparian forests were not very prevalent, so 1ACW and 0.5ACW buffers were also calculated to evaluate riparian functional categories by extent. Field methods focused on 1ACW surveys, but field notes for land use extending beyond 1ACW were also recorded.



Source:
LANDFIRE Environmental Site Potential (ESP) Model &
Biophysical Settings (BpS) Model
USDA-NRCS Soil Survey Geographic Database (SSURGO)
Conservation Tree & Shrub Suitability Group (CTSG) Soils 1 and 2
Riparian Forest Potential/ Capability (i.e., riparian forest target population) defined as the union of forest polygons extracted from ESP and BpS models and CTSG Soils 1 and 2 polygons.

Figure 2. Banner riparian forest target population.



Source:
LANDFIRE Environmental Site Potential (ESP) Model &
Biophysical Settings (BpS) Model
USDA-NRCS Soil Survey Geographic Database (SSURGO)
Conservation Tree & Shrub Suitability Group (CTSG) Soils 1 and 2
Riparian Forest Potential/ Capability (i.e., riparian forest target population) defined as the union of forest polygons extracted from ESP and BpS models and CTSG Soils 1 and 2 polygons.

Figure 3. Centralia riparian forest target population.

The mean drainage area by stream order was used in the regression equation to approximate 0.5ACW, 1ACW, and 2ACW buffers of flow lines, while also accounting for the ACW of the streams themselves. Stream flow lines and Strahler stream order were defined by the National Hydrography Dataset Plus (NHDPlus, USEPA) for the three study watersheds.

Soil Data Viewer was used to extract the extent of CTSG 1 and 2 soils from the SSURGO database. CTSG soils 1 and 2 were selected as likely to support riparian forest species due to their favorable landscape positions for receiving beneficial moisture and the seasonal high water tables associated with these soils during the growing season. Grasslands or upland tree species are more likely to occur on CTSG soil types other than 1 and 2 (i.e., outside the target population).

Riparian Forest Land Use

All forest located within the 2ACW target population was identified using an object-based classification of four-band, 2008 NAIP imagery with ENVI software. After segmentation into polygons using a supervised classification, forest polygon boundaries were overlaid on Bing Maps imagery and edited to match observable boundary edges.


Photo 1. An example of an "area in need of establishment". These areas, which lack woody riparian vegetation, are expected to generate the highest amount of downstream sediment delivery, in comparison to the other two condition classes. The "establishment" condition class was most prevalent in the Centralia watershed.

LANDFIRE Existing Vegetation Type (EVT) data was used to identify land use other than forest which occurred within the 2ACW target population. Since riparian forest delineation was the goal of this project, only areas misidentified by EVT as forest were edited and assigned the correct land use (e.g., pasture rather than forest). EVT was allowed to stand-alone for non-forested areas.

Cover classes of riparian forest were approximated using the Normalized Difference Vegetation Index (NDVI). NDVI was calculated from the red and near infrared bands (NIR) of 2008 NAIP imagery according to the equation: NDVI = (NIR – Red) / (NIR + Red). The lowest values of NDVI were considered to represent "no cover" or "very low greenness" values ranging to high values that were considered to be "high cover" or "high greenness" values. NDVI was only calculated for the forest polygons extracted from object-based classification.

Riparian Forest Functioning Condition Class

The riparian forest target population was classified into three functioning condition classes for the 0.5 ACW, 1ACW, and 2ACW extents. The 3 classes were: areas in need of establishment, areas in need of management, and areas in need of protection.

Areas in need of establishment were cropland, developed areas (e.g., roads), pastures, native grasslands, bare patches, or "no cover" or "very low greenness" forest NDVI values that occurred where riparian forest should or could occur, according to intersection of data inputs (Photo 1). Areas in need of management were "less dense" or "low to low-medium cover" forest NDVI values, and generally were comprised of stands of shrubs and seedlings, less dense forest, or the outside perimeters of riparian forests along pastures or crop fields (Photo 2). Finally, areas in need of protection represented "medium to high cover" forest NDVI values and corresponded with more densely wooded riparian areas (Photo 3). Within forest stands, water and sand bars associated with the river were sometimes classified as areas in need of establishment. Water and wetland values from the EVT layer were not classified into a functional category.

Riparian land use located outside the riparian forest target population was also identified to make comparisons, to report grassland management areas, and to document alternative BMP locations (e.g., potential grass buffers or waterways in cropped riparian areas).

Results (GIS and Remote Sensing)

Target Population

Riparian buffer extents for 0.5ACW, 1ACW, and 2ACW and their union with CTSG 1 and 2 soils, BpS, and ESP models in the three study watersheds are presented. Potential for riparian forest buffers existed for 59.9% of 2ACW in Atchison, 82.5% of 2ACW in Banner, and 96.2% of 2ACW in Centralia. The potential natural vegetation of the 2ACW extent beyond the target population would likely be native grassland and wetlands, and this is also true of the 0.5ACW and 1ACW extent beyond the target population.

Photo 2. Riparian areas with sparse forest cover were classified as "areas in need of management", and represented relatively low acreage within study watersheds.

Photo 3. Riparian areas with a significant amount of forest cover were classified as "areas in need of protection", and were most prevalent within the Banner Creek watershed.

Riparian Forest Land Use

Riparian forest comprised 64.5% of the 2ACW target population in Atchison, 82.1% in Banner, and only 21.4% in Centralia. Some riparian forest existed in the 2ACW buffer beyond the target population, with 16.2% more forest in Atchison, 53.7% more in Banner, and 0.3% in Centralia. Overall, Banner had the most acreage and highest % of riparian forest, Atchison had moderate values, and Centralia had low values both in the target population and the buffer region beyond it.

Riparian Forest Functioning Condition Class

Riparian forest was categorized by functioning condition class to provide an estimate of the types of BMPs or protective measures that are necessary to improve riparian area function within the target population (Table 1; Figures 4-6). NDVI was used to further characterize riparian forest components of the target population and discriminate between forests that need to be managed (low to medium cover) and protected (medium to high cover), and areas that will require tree establishment (e.g., along crop fields). Additionally, land use that was not identified as forest but that existed within the 2ACW target population was by definition an area in need of forest

Table 1. Riparian landuse composition, including functioning condition class, within target population.

2ACW Target Population	**25 ft or 0.5ACW**		**50 ft or 1ACW**		**2ACW**	
Atchison County Lake	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**
Establishment	23.9	28.5	40.0	33.0	53.4	32.2
Management	6.5	7.7	9.1	7.5	11.8	7.1
Protection	51.6	61.5	68.6	56.6	93.4	56.4
Herbaceous Wetlands	1.6	1.9	3.1	2.5	6.1	3.7
Water	0.4	0.5	0.5	0.4	0.9	0.5
Total	83.9	100.0	121.3	100.0	165.6	100.0
Banner Creek Lake	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**
Establishment	28.2	13.4	49.8	14.9	66.3	16.4
Management	11.8	5.6	19.0	5.7	21.4	5.3
Protection	164.7	78.2	256.3	76.7	306.1	75.9
Herbaceous Wetlands	0.0	0.0	0.0	0.0	0.0	0.0
Water	5.8	2.8	9.0	2.7	9.6	2.4
Total	210.5	100.0	334.1	100.0	403.4	100.0
Centralia City Lake	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**
Establishment	79.8	69.7	138.3	75.6	165.1	76.4
Management	1.8	1.5	2.0	1.1	2.1	1.0
Protection	30.5	26.7	39.2	21.4	44.0	20.3
Herbaceous Wetlands	0.9	0.8	1.4	0.7	2.0	0.9
Water	1.5	1.3	2.1	1.2	3.0	1.4
Total	114.4	100.0	183.0	100.0	216.2	100.0

establishment. Centralia had the highest percentage and acres of riparian forest in need of establishment. Banner had the lowest percentage of forest in need of establishment and by far the greatest acreage in need of protection. Atchison had intermediate values for protection and establishment. Management acreage was relatively low in all watersheds.

Field Methods

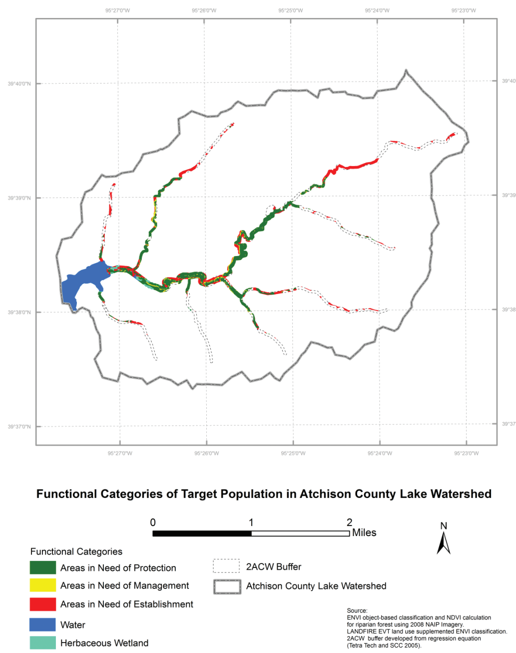
Sampling Design

To collect the field data a selected representative sample design was used. The GIS data had already estimated the coverage of riparian woodlands in the three watersheds, and placed the areas of interest, (riparian zone of one active channel width) into three classes, forests in need of protection, management, or establishment. Areas in need of protection represented "medium to high cover" forest NDVI values and corresponded with more densely wooded riparian areas.

Field data collection involved cross referencing these areas with landownership and contact information, to gain access to these sites. The number of plots varied roughly with the overall size of the watershed: Atchison 9.3 mi^2; 12 plots,

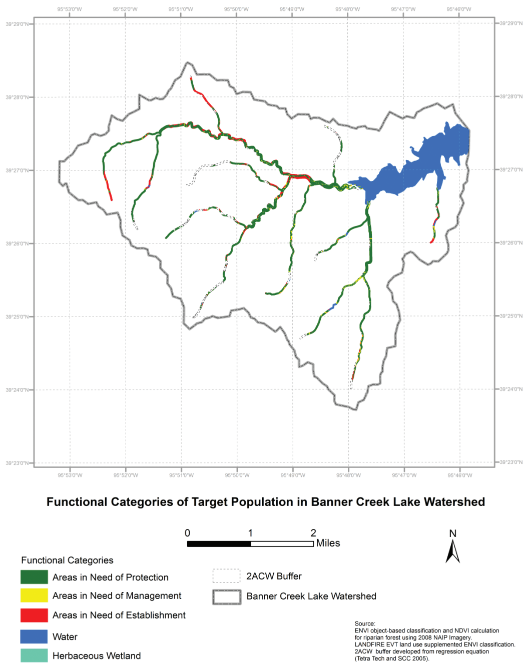
Table 2. Riparian landuse composition beyond target population.

Beyond Target Population	**25 ft or 0.5ACW**		**50 ft or 1ACW**		**2ACW**	
Atchison County Lake	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**
Water	6.4	10.5	10.3	10.2	10.7	9.6
Riparian Forest	10.0	16.4	14.8	14.7	18.0	16.2
Herbaceous Wetland	0.0	0.0	0.0	0.0	0.0	0.0
Grassland	18.8	31.0	31.6	31.3	34.6	31.1
Cropland	24.2	39.8	41.7	41.3	45.1	40.6
Developed	1.5	2.4	2.6	2.6	2.8	2.5
TOTAL	60.8	100.0	101.0	100.0	111.1	100.0
Banner Creek Lake	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**
Water	4.3	9.5	6.7	9.8	7.6	8.8
Riparian Forest	25.6	56.7	41.9	61.0	46.1	53.7
Herbaceous Wetland	0.0	0.0	0.0	0.0	0.0	0.0
Grassland	14.6	32.3	28.1	41.0	30.6	35.7
Cropland	0.0	0.0	0.0	0.0	0.0	0.0
Developed	0.7	1.5	1.3	1.9	1.5	1.7
TOTAL	45.1	100.0	78.0	113.7	85.7	100.0
Centralia City Lake	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**
Water	0.1	2.1	0.2	2.2	0.2	2.2
Riparian Forest	0.0	0.2	0.0	0.3	0.0	0.3
Herbaceous Wetland	0.0	0.0	0.0	0.0	0.0	0.0
Grassland	1.7	40.8	3.2	40.5	3.5	40.7
Cropland	2.1	52.3	4.2	53.2	4.5	53.0
Developed	0.2	4.5	0.3	3.8	0.3	3.8
TOTAL	4.1	100.0	8.0	100.0	8.5	100.0



Source:
ENVI object-based classification and NDVI calculation for riparian forest using 2008 NAIP Imagery.
LANDFIRE EVT land use supplemented ENVI classification.
2ACW buffer developed from regression equation (Tetra Tech and SCC 2005).

Figure 4. Atchison target population functioning condition class composition.



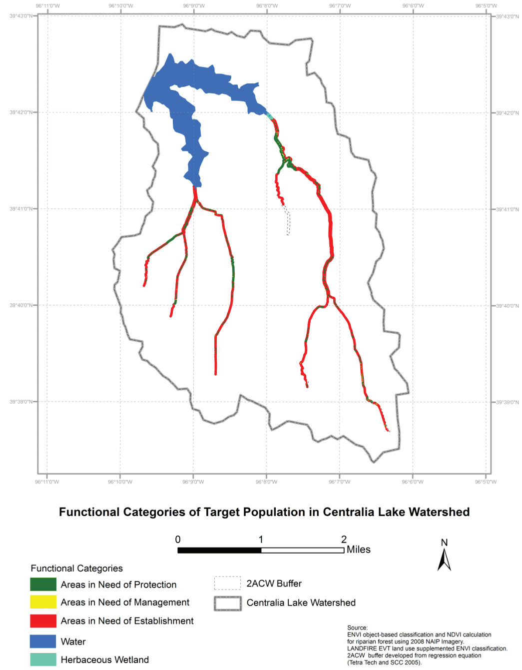
Source:
ENVI object-based classification and NDVI calculation for riparian forest using 2008 NAIP Imagery.
LANDFIRE EVT land use supplemented ENVI classification.
2ACW buffer developed from regression equation (Tetra Tech and SCC 2005).

Figure 5. Banner target population functioning condition class composition.

Banner 19 mi^2, 18 plots; Centralia 12 mi^2, 14 plots. Field data was recorded to determine the structure and composition of riparian woodlands in the three watersheds.

Plot Layout and Field Data Collection

Rectangular plots were established with a long axis perpendicular to the stream of 50’ or one ACW, whichever was greater, (Figure 7). The width of the plot was 30’, resulting in a plot area of at least 1,500 ft^2. Within this plot a number of observations and measurements were recorded, including diameter breast height (DBH), crown class and height of each tree by species. Stream active channel width, forest width from the top of the bank, and forest canopy coverage were recorded as well. Qualitative data was also recorded, such as



Source:
ENVI object-based classification and NDVI calculation for riparian forest using 2008 NAIP Imagery.
LANDFIRE EVT land use supplemented ENVI classification.
2ACW buffer developed from regression equation (Tetra Tech and SCC 2005).

Figure 6. Centralia target population functioning condition class composition.

evidence of evidence of woodland management (marking, harvesting, or planting trees) (Photo 4), livestock use (Photo 5) and dominant groundcover (grassy, broad-leaved herbaceous, brushy, woody debris). The second ACW beyond the plots was also visually classified as either forest, grass, or crop field.

Seedling and sapling regeneration was recorded from two circular plots with a radius of 5.3 feet, with a stratified random location within the half of the plot nearest the stream, and the half of the plot furthest from the stream. Seedlings were classified as any small specimens of tree species present up to 4.5 feet tall and having a diameter of less than one inch. Saplings were recorded in the plots if they were more than 1 inch but less than 5 inches in DBH.

Calculations

Basal area per acre of a species is a key measure of dominance, and defined as the cross-sectional area at breast height and is computed through the formula by Avery and Burkhart (1994):

$$\mathrm{BA}(\mathrm{ft}^2) = \frac{\pi \mathrm{dbh}^2}{4(144)} = 0.005454\ \mathrm{dbh}^2$$

where *BA* is the basal area of the tree, *dbh* is the diameter at breast height, and is the mathematical constant 3.14159.

Then, the basal area per acre was calculated by the summation of the total basal area per tree species multiplied by the expansion factor (29.04) for the 1,500 ft^2 plots, to yield *BA* per acre. The same expansion factor of 29.04 was also used to calculate estimates of trees per acre.

Photo 4. Evidence of riparian forest management, such as harvesting, was recorded within field plots. The Atchison watershed exhibited the highest occurrence of management evidence.

Photo 5. Evidence of livestock presence within riparian areas was most prevalent within the Banner Creek watershed.

Field Results

Centralia watershed had the highest basal area (BA ft^2) per acre with 155, while Atchison and Banner watersheds were both 120 square feet per acre (Figure 8). Number of trees per acre exhibited the opposite trend, with Centralia having the lowest trees per acre (TPA) at 135, Banner with 177 TPA and Atchison with 187 TPA (Figure 8).

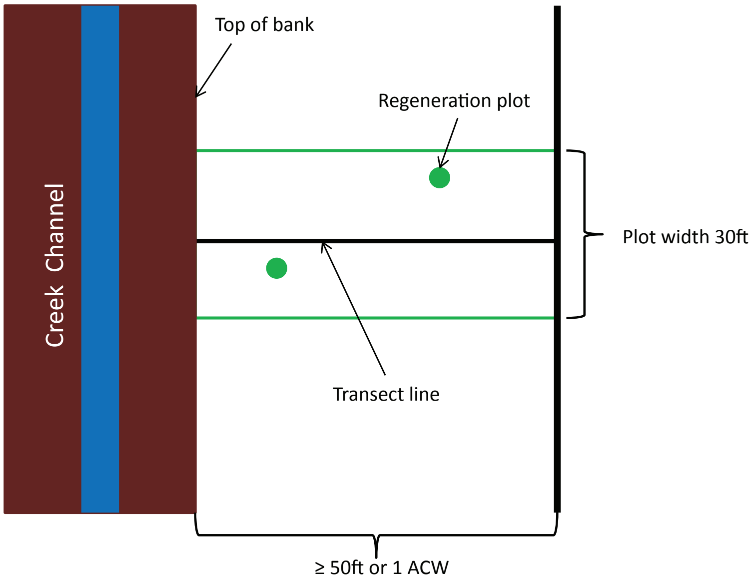


Figure 7. Riparian forest inventory plot schematic.

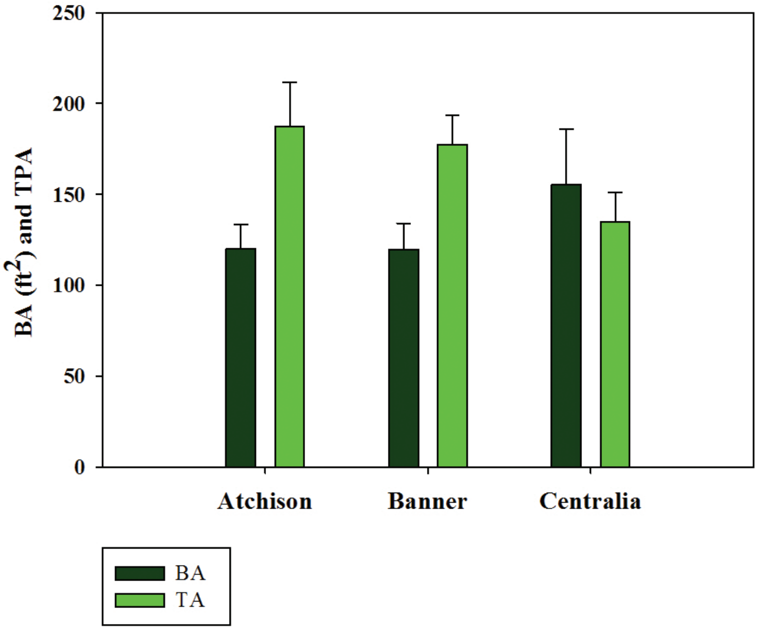


Figure 8. Comparison of basal area (BA) per acre and trees per acre (TPA) in Atchison, Banner, and Centralia watersheds.

Several species of oaks were found in the assessed watersheds, but bur oak (*Quercus macrocarpa*) was the most predominant, with lesser amounts northern red oak (*Q. rubra*), black oak (*Q. velutina*), and chinkapin oak (*Q.muehlenbergii*) also being recorded. The tree species with the highest basal area (BA) per acre in Atchison was honeylocust (*Gleditsia triacanthos*) which represented 29% of the total, in Banner was oak species which represented 24%, and in Centralia was cottonwood (*Populus deltoides*) with 41% (Figure 10). In the Atchison watershed, honeylocust, black walnut *(Juglans nigra)*, and bur oak accounted for over 50% of the BA. Whereas in the Banner watershed, oaks (bur, black, and chinkapin), hackberry (*Celtis occidentalis*), and walnut accounted for over 50% the BA of the trees. Unlike Atchison and Banner, Centralia was clearly dominated by just two species, with cottonwood and honeylocust accounting for 73% of the BA.

The TPA data also showed strong differences between the watersheds, with a high value species, black walnut, being the most numerous in Atchison, whereas much lower value species were most numerous in Banner (elm) and Centralia (honeylocust) (Table 3).

The quadratic mean diameter (QMD) is defined as the diameter of the tree that has the mean basal area for the watershed. The quadratic mean diameter (QMD) instead of the simple arithmetic mean is commonly used in forest surveys because it assigns a greater weight to larger trees.

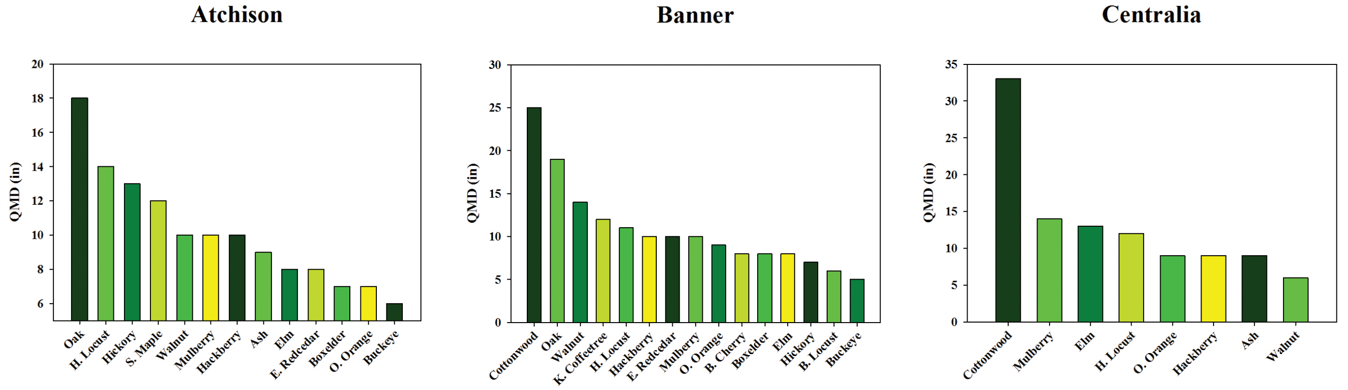


Figure 9. Quadratic mean diameter of tree species in Atchison, Banner, and Centralia watersheds.

Table 3. Average trees per acre (TPA) by species in the three watersheds.

Atchison		Banner		Centralia	
Species	**Avg. TPA**	**Species**	**Avg. TPA**	**Species**	**Avg. TPA**
Honeylocust	32	Elm	38	Honeylocust	62
Walnut	25	Hackberry	33	Hackberry	19
Ash	24	Hickory	22	O. Orange	17
Boxelder	22	O. Orange	21	Mulberry	12
Hackberry	17	Walnut	15	Cottonwood	10
Elm	17	Oak	12	Elm	6
Hickory	15	Honeylocust	10	Ash	4
O. Orange	9	K. Coffeetree	10	Walnut	2
Buckeye	7	Mulberry	5		
Oak	7	Buckeye	3		
Mulberry	5	E. Redcedar	3		
S. Maple	2	B. Cherry	2		
E. Redcedar	2	Boxelder	2		
		B. Locust	2		
		Cottonwood	1		

In Atchison, oaks, honeylocust, and hickory had the highest QMD (Figure 9). Cottonwood, oaks, and walnut were the species with the highest QMD in Banner watershed, whereas in Centralia cottonwood, mulberry and elm represented the highest three QMD species. In the three watersheds, Centralia had trees with the highest QMD (33 in) followed by Banner (25 in).

In all three riparian woodlands, the dominant seedling regeneration was hackberry which represented 35, 28, and 88% of the regeneration in Atchison, Banner, and Centralia, respectively (Figure 11). Hackberry and Ash (*Fraxinus americana and F. pennsylvanica*) accounted for over 50% of the seedling regeneration in the Atchison watershed. Within the Banner watershed, the two species with the highest seedling regeneration was hackberry and hickory (*Carya cordiformis and C. tomentosa*) which together accounted 53% of the total. Since hackberry represented one of the most common species in the overstory,

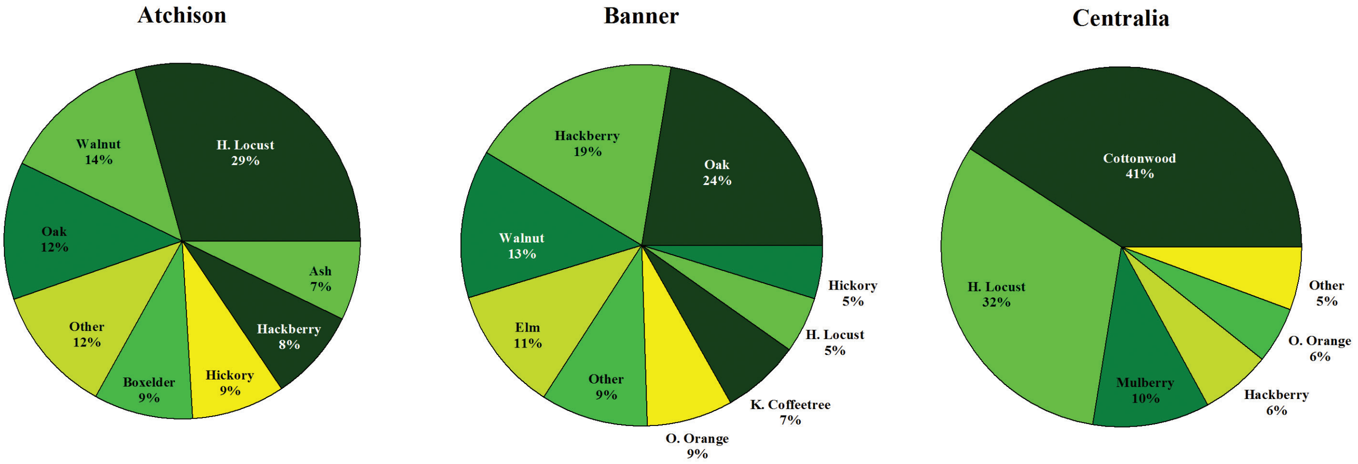


Figure 10. Comparison of the riparian forest basal area (BA) composition between and within watersheds.

and is quite shade tolerant, it was not a surprise to find that near 90% of seedling regeneration within the Centralia watershed was comprised of hackberry.

In addition, hackberry also dominated the sapling regeneration of Atchison and Centralia riparian woodlands; while bitternut hickory was the prevailing species in Banner (Figure 11). Centralia had the lowest amount of regeneration diversity. Only 8 different species of seedlings and 3 different species of saplings were found in the Centralia watershed.

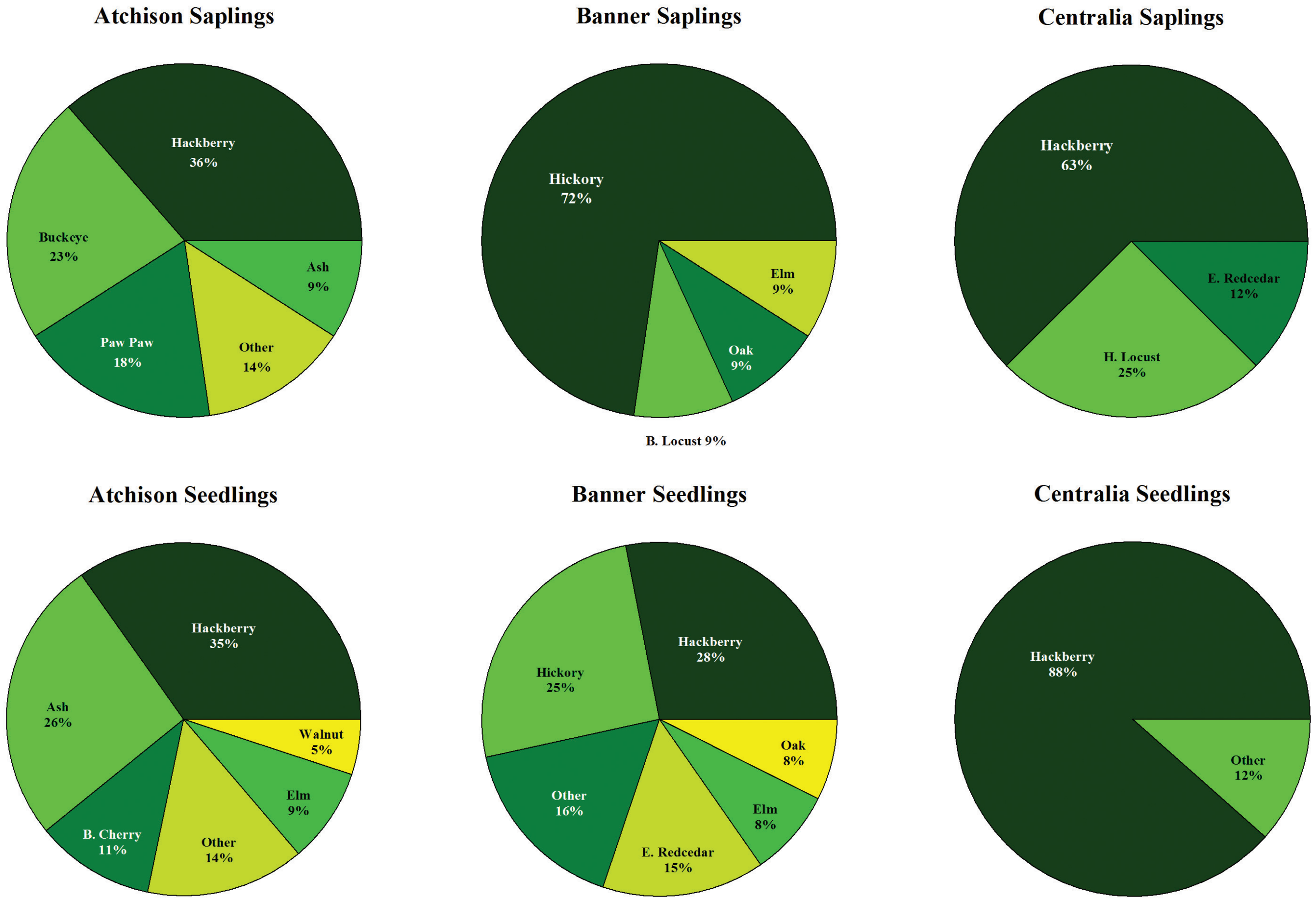
Categorization of Overstory Species According to Timber Value

It was important to consider tree species composition from a commercial perspective, because of the need for landowners to value riparian forests within the watersheds. Therefore, in consultation with the Kansas Forest Service district forester (David Bruton, personal communication) the species found in the assessed watersheds were categorized into 3 groups, based on the timber market value. Group 1 (high dollar value) was composed of all oaks and walnut. Group 2 (moderate dollar value) was composed of ash, black cherry, cottonwood, hackberry, hickory, and silver maple. Group 3 (low dollar value) was composed of all other species.

Atchison and Banner had significantly higher BA and TPA in Group 1 than Centralia (Figures 12 and 13). Group 2 trees had the highest BA in Centralia. Other differences between watersheds were not significant.

Categorization of Regeneration Species According to Timber Value

In all the watersheds assessed, seedlings were the prevalent form of regeneration. A high number of seedlings per acre (near 2,000) were found in all three watersheds (Figure 14), with species in Group 2 (predominately hackberry) being the most common. Group 2 species represented over 90% the total regeneration in Centralia. In all 3 watersheds the the



Atchison Saplings

Banner Saplings

Centralia Saplings

Atchison Seedlings

Banner Seedlings

Centralia Seedlings

Figure 11. Comparison of the seedling and sapling regeneration between and within watersheds.

dominant seedling regeneration was in species Groups 2 and 3.

In all three of the watersheds sapling regeneration per acre was very low, relative to seedling regeneration. In Atchison and Centralia watersheds, Group 1 sapling regeneration was absent (Figure 15). However, Atchison had the highest total sapling regeneration per acre in comparison with Banner and Centralia watersheds. Atchison had an average of 229 saplings per acre of species in Group 2, whereas Banner and Centralia watersheds had an average of 111 and 89 saplings per acre, respectively. Atchison also had the highest Group 3 sapling totals, with 229 saplings per acre.

When seedlings and saplings regeneration were combined, Atchison watershed still had the highest regeneration (approximately 3300 trees/acre) (Figure 16). Species in Group 2 had the highest regeneration in all three watersheds.

Banner had the highest number of plots with seedling regeneration present, at 92% (Table 4). For plot sapling presence, Atchison was highest with saplings found in about 50% of its total plots. In addition, Atchison had the highest number of plots where both seedlings and saplings were present.

In Banner, 72% of plots showed evidence of livestock use and only 11% showed

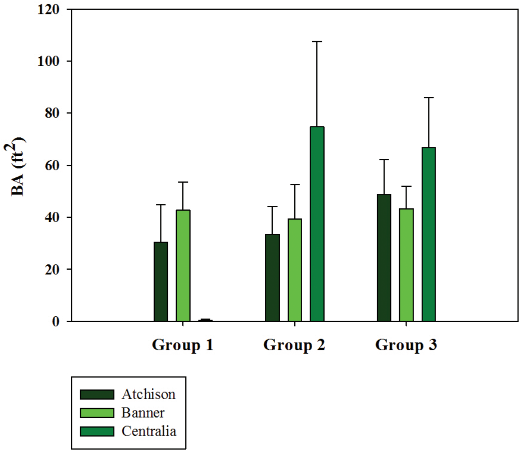


Figure 12. Overstory basal area (BA) per acre by species group for each watershed.

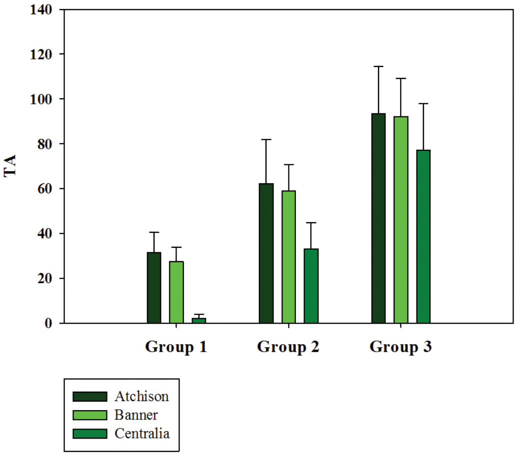


Figure 13. Overstory trees per acre (TPA) by species group for each watershed.

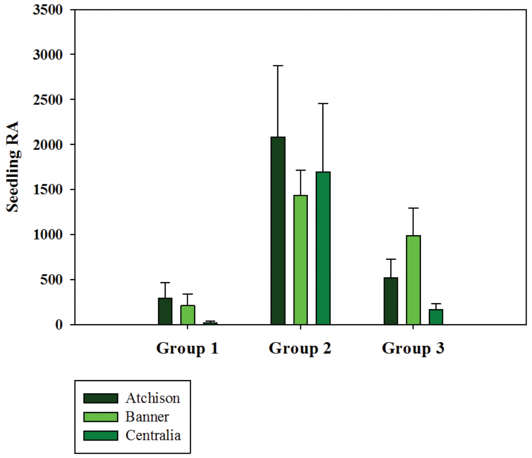


Figure 14. Seedling regeneration per acre by species group.

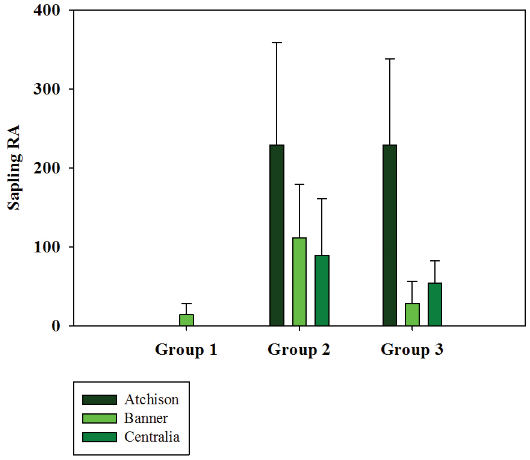


Figure 15. Sapling regeneration per acre by species group.

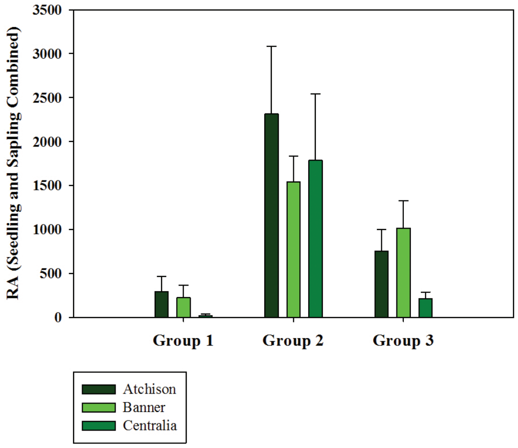


Figure 16. Seedling and sapling regeneration per acre by species group.

Table 4. Percentage of plots in each watershed that had seedlings and saplings regeneration.

	Atchison	Banner	Centralia
Plots		%	
Plots that had seedlings	92	94	79
Plots that had saplings	50	22	29
Plots with both seedlings and saplings	42	22	21

Table 5. Plot livestock presence, forest management presence, and 2nd ACW characteristics by watershed.

		% Plots with		2nd. Active Channel Width (ACW)		
Watershed	**Total Plots**	**Livestock**	**Management**	**Forest**	**Grass**	**Crop**
					%	
Atchison	12	25	25	92	0	8
Banner	18	72	11	72	28	0
Centralia	14	21	0	64	29	7

evidence of forest management. However, in Atchison only 25% of its plots showed evidence of livestock use, with a similar number of plots with evidence of forest management. In case of Centralia watershed, 21% of plots showed evidence of livestock use, but none of the plots showed evidence of forest management (Table 5). In the Atchison watershed, 92% of plots had a second ACW occupied by forest, while the remaining 8% were occupied by row crop. In Banner however, a lower number of plots were adjacent to forest (72%) and 28% were occupied by grass. The distribution of land use in the second ACW in Centralia watershed was higher for forest (64%) followed by grass (29%) and finally crop (7%)

Conclusions

Due to the differing extent and composition of riparian woodlands in the three study watersheds, customized approaches could be used to promote improved riparian area management, to reduce sedimentation. Centralia has the highest amount (76.4%) of 2ACW riparian area classified as "In need of establishment" (i.e., non-functioning), thus a riparian buffer and tree planting initiative has plenty of area to make improvements on. Centralia also had the highest amount of over-mature stands of cottonwood. Harvesting of the declining large cottonwoods should be promoted concurrently with the establishment of a more diverse, valuable and longer-lived mixture of species.

Atchison and Banner had much lower amounts of 2ACW riparian area classified "In need of establishment," 32.2% and 16.4% respectively, thus a major riparian buffer establishment program is not called for in these watersheds. However, they did have substantial amounts of the more valuable oak and walnut timber, with Atchison BA of 26%and Banner BA of 37% in these Group1 species. The management and economic value of these species should be highlighted to promote the idea that riparian forests have economic as well as environmental value. Thinning and crop tree release, to allow the oaks and walnuts to grow more quickly following the removal of competing species, would be an excellent practice to promote. With the oaks showing a


Photo 6. Involved, passionate, landowners that are willing to act as spokespersons, are critical for promoting proper riparian management within watersheds.

QMD of 18-19 inches, they are close to reaching maturity, while the walnuts are in the slightly smaller size class, with a QMD of 10” in Atchison, and 14” in Banner, which would respond well to a release from competition. Demonstration sites should be established on a willing landowner in each watershed, to show how these treatments are conducted, and data collected to document the effect (Photo 6).

The dominate species of tree seedlings recorded in all 3 watersheds was hackberry, which raises some concerns. Hackberry is very shade tolerant, and high numbers of seedlings can build up over time. Unfortunately, hackberry is a moderate to lower-value species. Education and management should seek to reduce the prevalence of hackberry in the understory following harvest, and the promotion of a more diverse species mixture when planting. Species with higher values for timber and wildlife include bur and northern red oak, black walnut, silver maple, hickory, and black cherry.

Considering sedimentation rates, Banner exhibits a surprisingly high rate, despite having a grassland-dominated watershed. In addition, Banner’s 2ACW riparian area had the lowest amount of acres classified as “in need of establishment”, as compared to the other two watersheds. However, observations made during the riparian forest assessment indicated that Banner also had the highest incidence of grazed riparian woodlands, with 72% of the tracts surveyed showing evidence of cattle use, whereas Atchison only had cattle using 25% of the tracts visited. This was a surprising finding, considering that the only riparian woodland sites assessed were the ones that were classified as “In need of protection”, with GIS data indicating that a well-established, mature stand of trees was present in the riparian zone. Reducing the impact of cattle use in Banner Creek riparian areas, with riparian fencing, hardened stream access points, alternative water sources and moving feeding/loafing areas away from riparian areas will improve both forest health and water quality.

Recommendations

Future research should be focused on increasing the adoption and success of riparian forestry practices, such as forest buffers, within Eastern Kansas. Increased success of riparian plantings will lead to increased adoption of these practices. Therefore, research into site preparation, planting, and maintenance techniques is recommended.

Because lower-value timber species dominated both the forest canopy as well as forest regeneration within study watersheds, research into market development and alternative uses for these species is recommended. Revenue from the removal/harvest of lower-value species would increase revenue generated from forest management, thus increasing incentives for watershed landowners to actively manage their woodland.

Combining newly available LiDAR datasets with NVDI information could result in accurate, remotely sensed assessments of riparian forests, with reduced need for extensive field work. LiDAR will also facilitate more accurate mapping of the channel, providing better information on parameters such as ACW.

Quantifying the ability of various types of riparian vegetation to stabilize streambanks is recommended. This may assist in quantifying watershed-scale sediment load reductions resulting from the implementation of riparian forest buffers. Developing policy that places value on riparian forests and promotes their protection, management, and establishment is a key component to reducing sedimentation rates of our federal reservoirs.

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An Assessment of the Lithostratigraphy and Erodibility of Holocene Alluvial Fills in the Watersheds of Atchison County Lake, Banner Creek Lake And Centralia Lake

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Introduction

The significance of streambanks as sediment sources has long been recognized (e.g., Thorne, 1982; Trimble, 1997), especially with regard to constructing accurate sediment budgets for watersheds (e.g., Dietrich et al., 1982; Trimble, 1983). Many studies have demonstrated that streambank erosion contributes a large portion of the annual sediment yield in a drainage system. For example, over 90 percent of the total suspended sediment yield during bankfull discharge of a snowmelt runoff event on the West Fork of the Madison River, Montana was a product unstable streambanks and channel instability (Rosgen 1973, 1976). Simon (1989) reported lateral bank erosion rates of 1.5 m/yr in the Forked Deer River system of West Tennessee and estimated that bank erosion contributed 82 percent of the 10 million tons of sediment delivered to the drainage basin each year. Streambank erosion rates of 14 m/yr were recorded in the Cimarron River in southwestern Kansas (Schumm and Lichty, 1963), and Simon (1992) determined that streambanks in the Gila River of Arizona were retreating at a rate of 50 m/yr.

Streambanks in the Midwest have been shown to contribute as much as 80% of total watershed sediment yield (e.g., Simon et al., 2000). In the Banner Creek watershed of northeastern Kansas, streambank sources are considered the largest source of sediment to Banner Lake (Juracek and Ziegler, 2007). In general, however, while considerable effort has been made to reduce upland erosion, sediment contributions from streambanks have been relatively ignored.

Streambank erosion is a natural process that occurs when the forces exerted by flowing water exceed the resisting forces of bank materials and vegetation. Although a complex process, streambank erosion is ultimately controlled by two variables: streambank characteristics (erodibility) and hydraulic/gravitational forces (Rosgen, 2001). Our study focused on the lithology of streambank materials, especially alluvium, as a measure of bank erodibilty. The lithology of streambank materials is a description of its physical characteristics visible in an outcrop or in a core and includes color, texture (grain-size distribution), degree of melanization (darkening from organic matter) and weathering features. The lithology of alluvium is largely controlled by sediment source and weathering history.

Deposits of fine-grained Holocene alluvium comprising streambanks in northeastern Kansas are members of the DeForest Formation, a formal lithostratigraphic unit originally defined in western Iowa and subsequently recognized in most of the Eastern Plains (Bettis, 1995; Mandel and Bettis, 2001). In Kansas the DeForest Formation consists of five formal members: the Camp Creek, Roberts Creek, Honey Creek, Gunder and Corrington. Because the different members have different lithologies, it is likely that their erodibility varies. In other words, one member will be more resistant to erosion than another member when all other variables are the same. Hence, determining their distribution in a drainage basin is important to the identification of areas that are prone to streambank erosion and, therefore, the identification of sediment sources.

The primary objectives of our study were to measure the erodibility of the different members of the DeForest Formation and to map them along streams that flow into Banner Creek Lake, Centralia Lake, and Atchison County Lake. The stratigraphic (vertical) relationships of the members also were determined in the watersheds above the lakes. In addition to alluvial fills, the erodibility of glacial till was measured as these deposits commonly comprise the bank material in low order tributaries and may provide an important sediment source to axial channels. The results of our investigation shed new light on the relationship between the lithology of bank materials and streambank erosion in the project area and, more broadly, the Midwest.

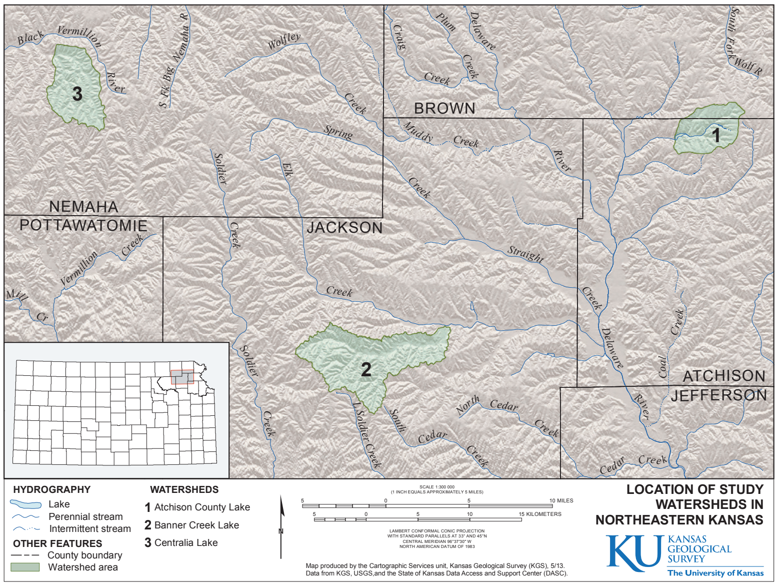

Figure 1. Location of study watersheds in northeastern Kansas

Study Area

Physiography and Bedrock Geology

The project area (Figure 1) is located in the Glaciated Region of Fenneman's (1931) Central Lowland physiographic province. The Glaciated Region is limited to the northeast corner of Kansas and is bordered on the south by the Kansas River and on the west by the Flint Hills. During the Pre-Illinoian glacial episodes of the Pleistocene, a continental ice sheet that extended slightly beyond the Kansas River in places and overlapped portions of the Flint Hills covered this area. The ice sheet buried pre-glacial stream valleys, cut new valley segments, and leveled the uplands (Mandel and Bettis, 2001). Streams subsequently dissected the drift plain that was left by the ice sheet, leaving glacial deposits high in the landscape. Hence, this region is referred to as the Dissected Till Plain (Schoewe, 1949). Interstream areas, or divides, are characterized by smooth, broad, gently rolling hills. Approaching the valleys of large rivers, the land becomes more dissected and the hills have steep convex slopes.

Pennsylvanian and Permian marine and near-marine rocks crop out and significantly influence landscape form and processes in the project area. Exposed rocks in the area are primarily limestone and shale of the Shawnee, Wabaunsee and Admire (Upper Pennsylvanian) and Council Grove (Permian) groups (Merriam, 1963). Cyclic sedimentation, produced by marine regressions and transgressions, is well expressed in these rocks. Bedrock geology in the project area is complicated by structure associated with the Humboldt Fault Zone, a complex zone of faults and steep dips that has been active since the Paleozoic (Steeples et al., 1979).

Quaternary Geology

The Pleistocene stratigraphy of the Dissected Till Plain beyond the Wisconsin and Illinoian glacial limits is based on a framework of Pre-Illinoian glacial tills and intercalated volcanic ashes, and younger loesses. These deposits are regional in extent and thus provide references to which more localized fluvial and colluvial units can be stratigraphically related.

Deposits associated with at least two and as many as five Pre-Illinoian glacial episodes have been described from localities in northeastern Kansas (Frye and Leonard, 1952; Dort, 1966, 1985; Bayne et al., 1971; Aber, 1988, 1991; Mandel and Bettis 2001). Aber (1991) assigned all of these glacial deposits to the Independence Formation. The available evidence constrains the Independence Formation tills and associated stratified glacial outwash deposits to the period between about 0.62 and 0.78 million years B.P., during marine oxygen isotope stages 16-18 (Mandel and Bettis 2001). In the project area, glacial tills comprising the Independence Formation are generally calcareous, loamy, matrix-supported diamictons; that is, finer grained matrix material constitutes the greatest volume and surrounds individual pebbles and larger rocks in the diamicton. At some localities the presence of a weathering profile in the lower diamicton indicates a minimum of two Pre-Illinoian glaciations separated by nonglacial conditions during which the weathering profile developed.

The interfluves and Pleistocene terraces in northeastern Kansas are mantled by late-Quaternary loess. At least three stratigraphically superposed loesses occur in the region: the Loveland, Gilman Canyon, and Peoria. The combined thickness of loess deposits in the project area is generally less than 4 m, and in many areas, the Loveland and Gilman Canyon loesses have been eroded from the uplands and only a thin mantle (< 2 m) of Peoria Loess remains. The Peoria Loess is typically a calcareous, massive, light yellowish tan to brown colored silt loam. A large body of radiocarbon and luminescence ages (TL, IRSL, and OSL) indicates that Peoria Loess began to accumulate near its source areas around 23,000 years before present (B.P.) and continued to accumulate across the Eastern Plains until about 12,000 B.P. (Bettis et al., 2003; Mason et al., 2006).

Mandel and Bettis (2001) recently established the Severance Formation, a lithostratigraphic unit comprised of colluvium and alluvium underlying the Peoria Loess on slopes and alluvial terraces in northeastern Kansas and southeastern Nebraska. The type locality for the Severance Formation is in the Wolf River valley immediately west of the community of Severance in Doniphan County, northeastern Kansas. The upper 3-4 m of the Severance Formation are oxidized and have two or more paleosols forming a pedocomplex developed in them. Radiocarbon ages determined on organic carbon from the paleosols range from ca. 25,000 to 15,000 B.P., with most clustering between 24,000 and 18,000 B.P.

Holocene deposits in northeastern Kansas mostly consist of alluvium and colluvium. There are also a few local deposits of

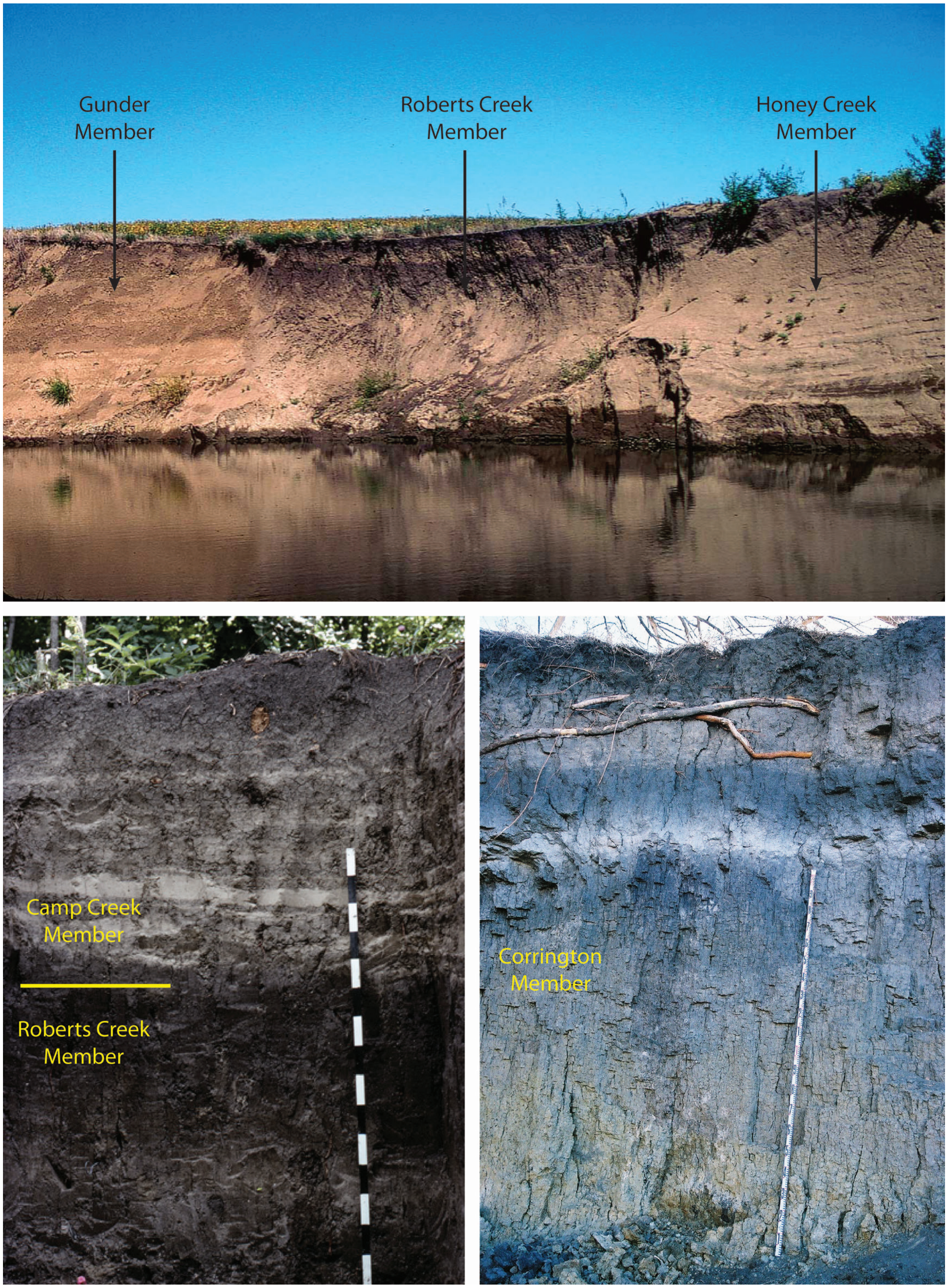

Figure 2. Outcrop examples of members of the DeForest Formation typically found in Midwestern streams.

eolian sand that date to the Holocene. All deposits of fine-grained Holocene alluvium and colluvium in northeastern Kansas have been assigned to a single lithostratigraphic unit: the DeForest Formation (Mandel and Bettis 2001). Daniels et al. (1963) originally identified the DeForest Formation upon observing a consistent sequence of alluvial fills in the Loess Hills of western Iowa. Subsequent studies of drainage basins in Iowa and adjacent states have led to expansion and revision of the formation (e.g., Bettis, 1990, 1995; Mandel et al., 1991; Fosha and Mandel, 1991; Dillon, 1992; Mandel and Bettis, 1992, 2001, 2003; Mandel, 1994a, 1994b, 1996; Bettis et al., 1996; Dillon and Mandel, 2008). The DeForest Formation consists of eight formal members, one of which, the Honey Creek Member is new (Dillon and Mandel, 2008). Five members of the formation – the Camp Creek, Roberts Creek, Honey Creek, Gunder, and Corrington (Figure 2) – occur in the project area.

The Camp Creek Member encompasses deposits that were formerly and informally referred to as “post-settlement alluvium.” This member usually consists of stratified, calcareous to noncalcareous, very dark gray to brown silt loam to clay loam, though some deposits may consist of coarser sediment. It is inset into or unconformably overlies the Gunder, Corrington, Honey Creek, and Roberts Creek members, depending on the geomorphic setting and history of land use (Bettis, 1990). The thickness of the Camp Creek Member is variable in the project area, ranging from a few centimeters to more than 2 m. Surface soils developed in the Camp Creek Member are Entisols with thin A horizons grading to stratified parent materials (C horizons). The Camp Creek Member includes sediment that accumulated after about 500 B.P. (Bettis, 1990, 1995; Mandel and Bettis, 1992, 2001).

The Roberts Creek Member consists of dark-colored, clayey, silty, and loamy alluvium. This member can overlie a wide variety of deposits, including the Gunder and Corrington members, coarse-grained older alluvium, loess, and glacial till (Bettis, 1990, 1995). Roberts Creek Member deposits usually occur as channel fills on floodplains and low terraces (T-1), although it sometimes comprises flood drapes. The Roberts Creek Member is separated from younger DeForest Formation deposits (Camp Creek Member) by either a fluvial erosion surface or an unconformity marked by a buried soil. Weakly developed buried soils with A-C or A-Bw profiles are common in the Roberts Creek Member, but they are rarely traceable from one valley to another. Surface soils developed into the Roberts Creek Member are thick, dark-colored Mollisols. These soils are morphologically less well expressed and have darker colored B and C horizons than soils developed in the Honey Creek, Gunder, and Corrington members. In large valleys the Roberts Creek Member ranges in age from ca. 3000 to 500 B.P. (Bettis, 1990, 1995; Mandel and Bettis, 1992, 2001).

The Gunder Member consists of oxidized, dominantly silty and loamy alluvium lacking a loess cover. Lower parts of this member may be reduced and/or coarse grained. Gunder Member deposits unconformably overlie coarse-grained and often organic-rich older alluvium, loess, glacial till, or bedrock (Bettis, 1990, 1995). Overlying younger members of the formation are separated from the Gunder Member by a fluvial erosion surface or an

unconformity marked by a buried soil. Surface soils developed in the Gunder Member are thick Mollisols with brown or yellowish brown Bw or Bt horizons. Buried soils have been documented within the Gunder Member, but they are not widely traceable. In large valleys, the Gunder Member ranges in age from about 10,500 B.P. at its base to about 4000 B.P. at its surface (Bettis, 1990, 1995; Mandel and Bettis 2001), and it is often represented in two separate fills: a strongly oxidized fill that probably dates from ca. 10,500 B.P. at its base to ca. 6000 B.P. at its surface (early Gunder), and a moderately oxidized fill dating from ca. 6000 B.P. at its base to ca. 4000 B.P. at its surface (late Gunder) (Mandel and Bettis, 2001). The late Gunder Member is inset against and topographically-lower than the early Gunder Member where both units are present.

The Honey Creek Member is composed of grayish brown silt loam overbank facies coarsening downward to a gravelly channel facies with prominent, large-scale trough cross-bedding (Dillon and Mandel, 2008). A prominent, cumulic soil with A-Bw horizonation is formed in the upper portions of the fill, and buried soils with A-AC and/or A-Bw profiles are common. Also, multiple entrenched channel fills with abrupt, concave lower boundaries often occur within the Honey Creek Member. However, these channel fills exhibit the same sequence of facies and colors as the unit as a whole. The Honey Creek Member may be draped over or laterally inset against the Gunder Member. In northeastern Kansas, the Camp Creek Member often mantles the Honey Creek Member. The stratigraphic relationship between the Roberts Creek and Honey Creek members, however, is not clearly understood. The Honey Creek Member consistently yields late Holocene ages (ca. 3700-600 B.P.) within drainage basins across the eastern Plains.

Corrington Member deposits are restricted to alluvial fans and colluvial aprons along the margins of valley floors. The alluvial fans are located where small streams (first- through third-order) enter large valleys. The Corrington Member is the most internally variable unit of the DeForest Formation and consists of very dark brown to yellowish brown oxidized loam and clay loam with interbedded lenses of sand and gravel (Bettis, 1990, 1995; Mandel and Bettis, 2001). The unit is stratified and often contains multiple buried soils. Surface soils developed into this unit are thick Mollisols with argillic (Bt) horizons. The Corrington Member buries coarse-grained older alluvium, glacial till, loess, or bedrock, and can grade laterally into Gunder Member deposits. Radiocarbon ages indicate that sediment composing the Corrington Member accumulated between ca. 9000 and 2500 B.P. (Bettis, 1990, 1995; Mandel and Bettis, 1992, 2001).

Climate

The climate of northeastern Kansas is continental; summers are very hot, and winters are very cold. There also are extremes in precipitation, with years of drought sometimes followed by periods of excessive annual rainfall. Mean annual precipitation ranges from 90.42 cm at Holton, Kansas to 89.91 cm at Atchison, Kansas (High Plains Regional Climate Center, 2013a, 2013b). June and January are normally the wettest and driest months, respectively. Approximately 75 percent of the precipitation falls during the six months of the growing season, April through September, largely due to frontal activity. Pacific and polar air masses that flow into the central Plains during spring and summer usually converge with warm, moist maritime-tropical air flowing north from the Gulf of Mexico. The collision of these air masses often produces intense rainfall of short duration along the zone of convergence. During late summer, convectional thunderstorms also can produce heavy rainfalls. Periodic intensification of westerly (zonal) airflow, however, prevents moist Gulf air from penetrating the central Plains. This condition and the development of strong anticyclonic (high-pressure) activity in the upper atmosphere over the midcontinent tend to cause drought in the region (Borchert, 1950; Bryson and Hare, 1974; Namias, 1982).

Vegetation

The natural vegetation of the region is tall grass prairie interspersed with deciduous forests (Küchler, 1964). The prairies are dominated by big bluestem (Andropogon gerardii), little bluestem (Andropogon scoparius), Indian grass (Sorghastrum nutans), and switch grass (Panicum virgatum). Upland deciduous forest are dominated by black walnut (Juglans nigra), bur oak (Quercus macrocarpa), white oak (Q. alba), black oar (Q. velutina), shagbark hickory (Carya ovata.), bitternut hickory (C. cordiformis), and green ash (Fraxinus pennsylvanica). Cottonwood (Populus deltoides), black willow (Salix nigra), hackberry (Celtis occidentalis), and American elm (Ulmus americana) dominate gallery forests along streams.

Background

As previously noted, streambanks are the primary source of sediment in Midwestern watersheds. The delivery of bank material to the stream channel typically occurs by a combination of hydraulic forces acting on the channel boundary (i.e. fluvial erosion) and gravitational forces acting on the channel banks (i.e. mass-wasting) (e.g., Thorne, 1982; Osman and Thorne, 1988; Simon et al., 2000). Alluvial sediments erode when the shear stress, exerted by flowing water, at the channel boundary (τ_0) exceeds the critical shear stress (τ_c) of the bank material. The critical shear stress (τ_c) is defined as the shear stress at which sediment detachment begins. Whether sediment is entrained is a function of fluid properties and the physical properties of the sediment. A basic distinction is typically made between non-cohesive sediments (i.e. sand and gravel) and cohesive sediments (i.e. silt and clay), with entrainment of the latter being complicated by the nature of electrochemical bonds. In the Midwest, streambanks are typically composed of cohesive sediments.

Studies investigating the erodibility of cohesive materials have reported that numerous soil properties influence resistance to erosion, including soil moisture, clay content and mineralogy, density, structure, organic content and water chemistry (Grissinger, 1982). The erodibility characteristics of a soil are typically parameterized as a coefficient, k. As k is dependent on the physio-chemical parameters that determine inter-particle forces (Parchure and Metha, 1985), it provides a good estimation of the resistance of cohesive sediments to erosion. However, k and τ_c are difficult to estimate due to the range of soil properties that influence resistance to erosion. One method that has shown success in accurately measuring these parameters is the *in situ* submerged jet-test device. This device was developed by Hanson (1990) based on the knowledge of the hydraulic characteristics of a submerged jet and the erodibility characteristics of soil.

Several studies have successfully employed submerged jet-test devices to determine the erodibility of alluvial sediments (e.g., Hanson and Simon, 2001; Shugar et al., 2007; Thoman and Niezgoda 2008; Simon et al., 2010). Hanson and Simon (2001) conducted 83 tests on cohesive streambeds in southeastern Nebraska, southwestern Iowa and north-central Mississippi. They observed a wide variation in the erosion resistance of streambeds, spanning six orders of magnitude for τ_c (0.003-400 Pa) and four orders of magnitude for k (0.001-3.75 cm^3/Ns). In general, the most erodible sediments were in Iowa and Nebraska where beds consist of loess-derived alluvium. An inverse relationship between τ_c and k was observed where:

$$k = 0.2\ \tau_c^{-0.5} \qquad (1)$$

This relationship was recently updated using 702 tests from 16 states (Simon et al., 2010):

$$k = 1.42\ \tau_c^{-0.824} \qquad (2)$$

Other studies have also noted a large variation in τ_c and k. For example, Shugar et al. (2007) report six orders of magnitude variation for τ_c but only one order of magnitude for k from 10 jet-tests conducted on till in southern Ontario, Canada. Thoman and Niezgoda (2008) report ranges of 0.11-15.35 Pa for τ_c and 0.27-2.38 cm^3/Ns for k from cohesive materials in the Powder River Basin, Wyoming. The variability observed in these studies is typically attributed to varying degrees of subaerial exposure.

Methodology

Field Methods

Prior to fieldwork, a GIS basemap was prepared for each of the three watersheds that were designated for study. The maps included U.S. Geological Survey (USGS) topographic data and Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) data (Figures 5, 9 and 13). All GIS data were downloaded from the Kansas Data Access and Support Center (DASC) at the Kansas Geological Survey. The GIS basemaps were used to identify landform sediment assemblages comprising valley floors. In addition, because specific soil series tend to be associated with the different members of the DeForest Formation, the SSURGO data were used to prepare preliminary maps showing the spatial patterns of the members (Figures 6, 10 and 14). Ground testing was subsequently used to confirm the relationship between the soil series and members comprising surface deposits.

In order to determine the character of alluvial sediments in the study area, 15 cores (5.0 cm in diameter) were collected from 13 sites with a Giddings Hydraulic Soil Probe. Fourteen cores were collected from alluvial valley fills and one core on an alluvial fan. In addition, one cutbank profile was described to determine the characteristics of glacial till. Surfaces of alluvial landforms in the project area were numbered consecutively from stream level upward, with floodplain and terrace surfaces designated as T-0 and T-1, respectively.

Detailed descriptions of the litho- and soil-stratigraphy were prepared using standard procedures and terminology outlined by Soil Survey Staff (1993) and Birkeland (1999). Each soil horizon was described in terms of its Munsell matrix color and mottling, texture, structure, consistency and boundary. Where present, clay films, roots, pores, and secondary carbonate and iron-oxide forms were described. In addition, sedimentary features in C horizons were described where preserved.

Based on the stratigraphy described from the 13 sites in the three watersheds, six sites were selected for testing the erodibility of streambanks. Site selection was also determined by the availability of sufficient water in the channel to conduct erodibility testing. Testing was performed using a modified, portable version of the submerged jet-test device (a "mini" jet-test) originally developed by Hanson (1990) (Figure 3). This device consists of a 12 cm diameter base ring that is driven into the bank-face. Water is pumped directly into the device, filling the submergence tank and creating a 3.2 mm diameter jet that impinges on the alluvial sediments at 90°. The pressure of the jet is measured with a pressure gauge and changes in scour depth are measured at regular intervals during the test with a point gauge. As the depth of scour increases over time the applied shear stress decreases due to the increasing dissipation of energy (Stein and Nett, 1997). Erosion is initially high and asymptotically approaches zero as the shear stress generated by the jet approaches the critical shear stress of the bank material. Hanson and Cook (1997) developed analytical procedures for estimating τ_c and *k* from submerged jet-test results. τ_c is determined by fitting a hyperbolic logarithmic equation developed by Blaisdell et al. (1981) to the scour results. The coefficient *k* is determined by fitting the scour measurements to the excess shear stress equation developed by Parteniades (1965). For this study, each bank face was cleaned with a shovel before installing the jet-test. Tests were then conducted at varying elevations on the bank face depending on the litho- and soil-stratigraphy. We were unable to test all soil horizons at a given site because (i) the A horizons tended to be very friable and were susceptible to scour around the base of the jet-test device, and (ii) deep horizons, described from cores, were often covered with slumped bank toe material.

Laboratory Methods

Soil and sediment samples were collected from select representative cores and from all jet-test locations for laboratory analysis. Soils were sampled by horizon using standard procedures (Soil Survey Staff, 1993). Samples were air-dried or oven-dried at 40°C and ground to pass through a 2 mm sieve. Prepared samples were then analyzed for particle-size distribution by the pipette method (Soil Survey Staff, 1982).

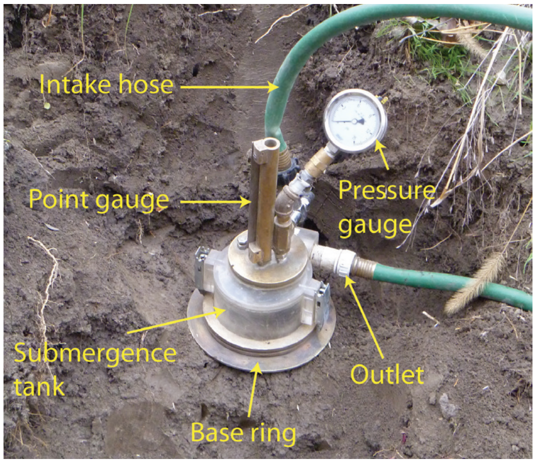

Figure 3. Portable "mini" jet test device used to test erodibility.

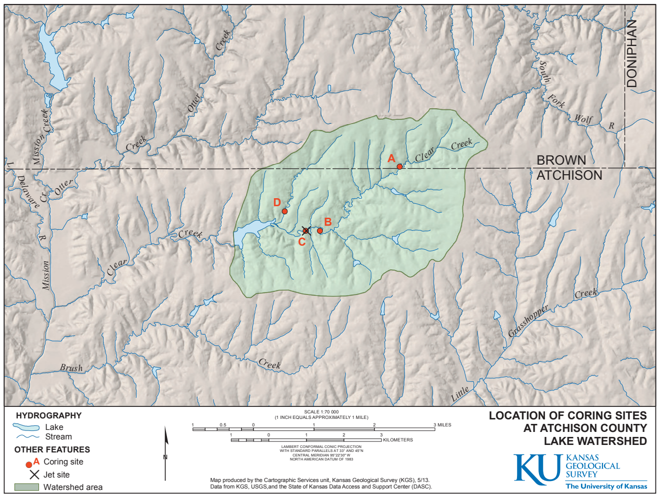

Figure 4. Location of coring sites at Atchison County Lake.

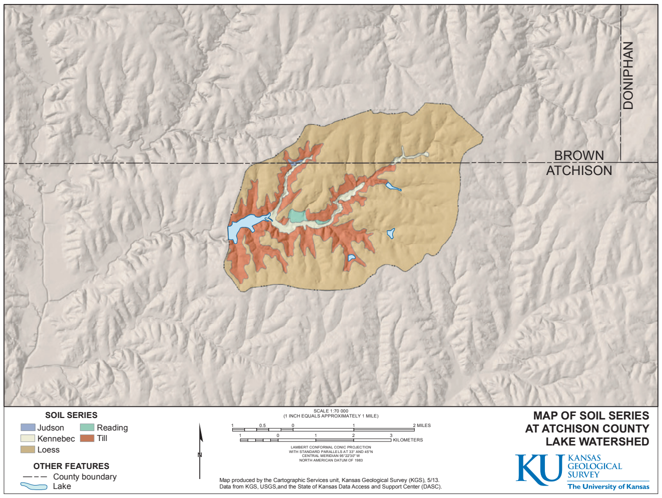

Figure 5. Map of soil series at Atchison County Lake.

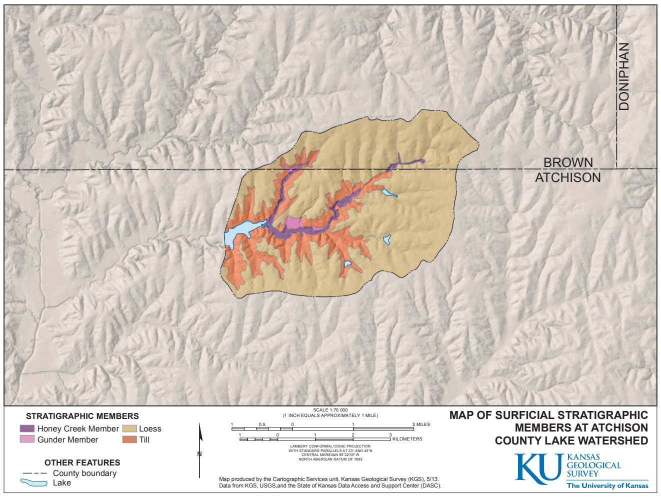

Figure 6. Map of surficial stratigraphic members at Atchison County Lake.

Results

Stratigraphy

Atchison County Lake Watershed.

Four cores were taken on the T-0 surface in the Atchison County Lake watershed (Figure 4). The surface soil at each coring site is mapped as the Kennebec series (Figure 5). In cores A, B and C, the surface soil is developed in the Honey Creek Member of the DeForest Formation (Figures 6 and 7). The Honey Creek Member comprises the upper 1-2+ m of T-0 fill and consists of silty clay loam, silt loam and loam (Table 1). The color of unweathered sediment (C horizons) is dark gray (10YR 4/1, dry) and grayish brown (10YR 5/2, dry). Some yellowish red (5YR 5/8) mottles occur in the subsoil in core A.

Sediments of the Honey Creek Member have been moderately modified by pedogenesis and typically exhibit A-Bw horizonation. The matrix color of the soil comprising A and Bw horizons is typically dark grayish brown (10YR 4/2, dry) and brown (10YR 5/3, dry). The Bw horizons are approximately 30 cm thick and have weak to moderate, sub-angular blocky structure and friable consistence (Table 1). Core A contains a weakly developed buried soil (soil 2) 95 cm below the surface (Figure 7). Grain-size data for the Honey Creek Member in core A differs from core C, with core A containing less sand (4 to 27%) than core C (23 to 42%) (Table 2). The total sand fraction in both cores indicates a fining-upward sequence within the Honey Creek Member.

In cores B and C, the soils and sediments of the Honey Creek Member overlie deposits of the Roberts Creek Member (Figure 8; Table 1). Because of its higher organic matter content, the Roberts Creek Member is typically darker than the Honey Creek Member. Matrix colors of soils developed in the Roberts Creek Member range from dark gray (10YR 4/1, dry) to dark grayish brown (10YR 4/2, dry) and gray (10YR 5/1, dry) in the Roberts Creek Member. Buried soils developed in the Roberts Creek Member have A-C or A-AC-C horizonation and the A horizon is typically overthickened (>1 m thick). Grain-size distributions for the Roberts Creek and Honey Creek Members are similar (Table 2).

Although the surface soil at each coring site in the Atchison County Lake watershed is mapped as the Kennebec series, the soils and sediments at locality D differ from the other localities. The upper 45 cm of core D comprises overbank facies of the Camp Creek Member (Figure 7; Table 1). Minimal soil development in the Camp Creek Member distinguishes it from the Honey Creek Member. The surface soil (soil 1) developed in the Camp Creek Member has a weakly expressed Ap-A-C profile (Table 1). Grain-size data indicate higher silt content (75 to 85% silt) in the Camp Creek Member compared to other members of the DeForest Formation (Table 2).

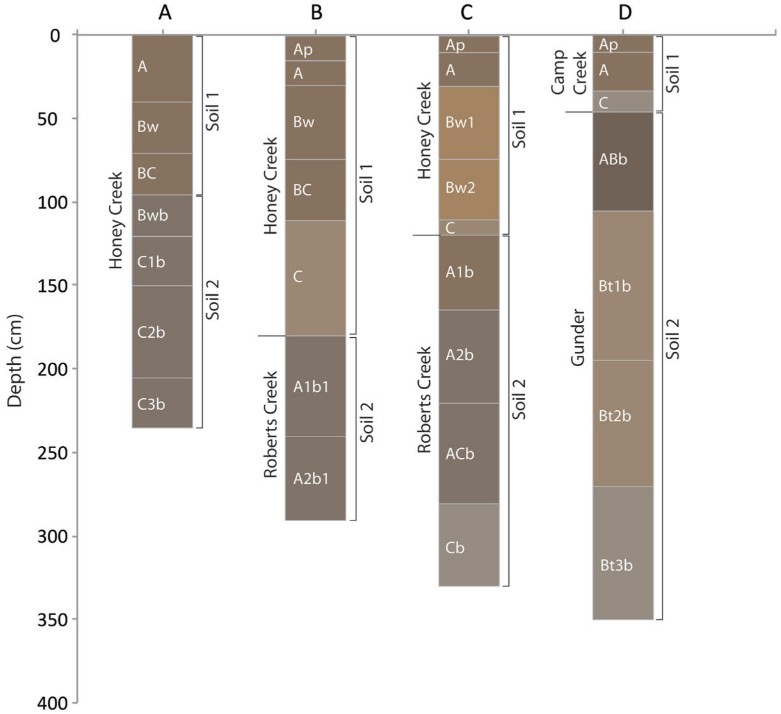

Figure 7. Stratigraphy at Atchison County Lake. Munsell colors (dry) of horizons are shown.

In core D, the Camp Creek Member mantles fine-grained facies of the Gunder Member that have been strongly modified by pedogenesis. The soil developed in the Gunder Member (soil 2) is over 3 m thick and has a well-expressed AB-Bt profile (Figure 7; Table 1). The matrix colors of the Btb horizon are grayish brown (10YR 5/2, dry) and gray (10YR 5/1, dry), and prominent yellowish red (5YR 5/8) mottles are common. Compared to the other members of the DeForest Formation, the Gunder Member has high clay content (33 to 44%) (Table 2). Evidence for clay illuviation is present in the form of many prominent black (10YR 2/1) clay films and clay flows on ped faces and in macropores, respectively (Table 1).

Banner Creek Lake Watershed. In the Banner Creek watershed, two cores (B and C-1) were taken on the T-0 surface and three cores (A, C-2 and D-1) were taken on the T-1 surface (Figure 8). In addition, one core (D-2) was taken on an alluvial fan that grades to the T-1 surface.

The surface soil on the T-0 surface is mapped as the Kennebec series (Figure 9). In cores B and C-1, this surface soil (soil 1) is developed in the Camp Creek Member (Figures 10 and 11). Soils formed in the Camp Creek Member have weakly expressed Ap-A-AC-C profiles, weak granular and sub-angular blocky structure, and

Table 1. Core descriptions from Atchison County Lake Watershed.

Locality	Member	Horizon	Depth (cm)	Color		Texture[1]	Structure[2]	Consistence[3]	Clay Films[4]	Boundary[5]	Pores[6]	Roots[6]	Notes
				Moist	Dry								
A	Honey Cr	A	0-40	10YR 3/2	10YR 4/2	SiL	1 f sbk	vfr	---	g	3f 2vf	3f 3vf	Parts to 1 f gr
		Bw	40-70	10YR 3/2	10YR 4/2	SiCL	1 f sbk	fr	---	a	2f 3vf	3f 3vf	Parts to 2 f gr
		BC	70-95	10YR 3/2	10YR 4/2	SiCL	2 f sbk	fr	---	a	1m 3f 3vf	3f 3vf	Parts to 1 f gr; Common fine laminae, Si, 10YR 5/2
		Bwb	95-120	10YR 3/1	10YR 4/1	SiCL	2 m sbk	fr	---	g	3f 2vf	2f 3vf	Parts to 1 f sbk
		C1b	120-150	10YR 3/1	10YR 4/1	SiCL	1 f gr	vfr	---	g	1f 2vf	2vf	Mottling[7] 2 m p, 5YR 5/8; some clasts 1-3mm
		C2b	150-205	10YR 3/1	10YR 4/1	SiCL	2 f gr	vfr	---	g	2f 1vf	---	Mottling[7] 1 f p, 5YR 5/8
		C3b	205-235	10YR 3/1	10YR 4/1	SiL	3 f gr	vfr	---	---	2f 2vf	---	Some clasts 1-2mm
B	Honey Cr	Ap	0-15	10YR 3/2	10YR 4/2	SiL	1 vf gr	vfr	---	g	2f 2vf	1m 2f 3vf	
		A	15-30	10YR 3/2	10YR 4/2	SiL	1 vf sbk	fr	---	g	2f 1vf	2f 3vf	Common wormcasts filling pores
		Bw	30-74	10YR 3/2	10YR 4/2	SiL	2 f sbk	fr, sh	---	a	1f 3vf	3vf	Parts to 1vf sbk; Common wormcasts filling pores
		BC	74-110	10YR 3/2	10YR 4/2	SiL	1 f sbk	fr	---	g	1m 2f 3vf	2vf	Parts to 1 f gr; Common wormcasts filling pores; Few fine laminae, Si, 10YR 5/2
		C	110-180	10YR 4/2	10YR 5/2	SiL	1 f gr	vfr	---	a	2m 2f 3vf	1f 2vf	Common fine laminae, Si, 10YR 5/2
	Roberts Cr	A1b1	180-240	10YR 2/1	10YR 4/1	SiCL	1 f pl	fr	---	a	2vf	---	Few fine laminae, Si, 10YR 5/2
		A2b1	240-290	10YR 2/1	10YR 4/1	SiCL	2 m gr	vfr	---	---	2f 2vf	---	
C	Honey Cr	Ap	0-10	10YR 3/2	10YR 4/2	SiL	2 f gr	vfr	---	g	1m 1f 2vf	2f 3vf	
		A	10-30	10YR 3/2	10YR 4/2	L	1 vf sbk	vfr	---	g	2f 2vf	2vf	Parts to 1 f gr
		Bw1	30-75	10YR	10YR	L	2 f sbk	fr	---	g	3f 2vf	1vf	Parts to 2 f gr

Table 1. Core descriptions from Atchison County Lake Watershed. (continued)

Locality	Member	Horizon	Depth (cm)	Color		Texture[1]	Structure[2]	Consistence[3]	Clay Films[4]	Boundary[5]	Pores[6]	Roots[6]	Notes
				Moist	Dry								
				4/3	5/3								
		Bw2	75-110	10YR 4/3	10YR 5/3	L	2 f sbk	fr	---	a	2f 3vf	1vf	Parts to 1 f gr
		C	110-118	10YR 4/3	10YR 5/2	L	1 f gr	vfr	---	a	2f 3vf	1vf	Common fine laminae, Si, 10YR 5/2
	Roberts Cr	A1b	118-165	10YR 2/2	10YR 4/2	SiL	1 f sbk	vfr	---	g	3f 3vf	1f 1vf	Parts to 2 m gr
		A2b	165-220	10YR 2/1	10YR 4/1	SiL	2 m gr	vfr	---	g	2f 3vf	---	
		ACb	220-280	10YR 2/1	10YR 4/1	SiL	1 f gr	vfr	---	g	1f 2vf	---	
		Cb	280-330	10YR 3/1	10YR 5/1	L	1 f gr	vfr	---	---	1f 2vf	---	
D	Camp Cr	Ap	0-10	10YR 3/2	10YR 4/2	L	1 f gr	vfr	---	g	3f 3vf	3vf	
		A	10-33	10YR 3/2	10YR 4/2	L	1 f sbk	vfr	---	a	1m 2f 3vf	3vf	Parts to 1 f gr
		C	33-45	10YR 3/1	10YR 5/1	L	1 vf gr	vfr	---	a	1m 2f 3vf	1vf	
	Gunder	ABb	45-105	10YR 2/1	10YR 3/1	SiC	2 f pr	fi, h	---	g	1f 3vf	1vf	Parts to 2 m sbk
		Bt1b	105-195	10YR 4/2	10YR 5/2	SiCL	2 f pr	fi, h	3 p pf/po	g	1f 3vf	1f	Parts to 2 m abk; Continuous clay films, 10YR 2/1
		Bt2b	195-270	10YR 4/2	10YR 5/2	SiCL	2 f pr	fr, h	3 p pf/po	g	3f 3vf	1f	Parts to 2 f sbk; Discontinuous clay films, 10YR 2/1; Mottling[7] 1 c p, 5YR 6/8
		Bt3b	270-350	10YR 4/1	10YR 5/1	SiCL	1 f pr	fr, h	3 p po	---	3f 3vf	---	Clay flows in macropores, 10YR 2/1; Mottling[7] 2 m p, 5YR 6/8

1Texture: C – Clay, CL – Clay Loam, SiCL – Silty Clay Loam, SiC – Silty Clay, L – Loam, SiL – Silty Loam, LS – Loamy Sand

2Structure: 1 – weak, 2 – moderate, 3 – strong, m – massive, sg – single grain; f – fine, m – medium, c- coarse; abk – angular blocks, sbk – subangular blocks, pl – plates

3Consistence: so – soft, sh – slightly hard, h – hard, vh – very hard; lo – loose, vfr – very friable, fr – friable, fi – firm; vfi – very firm

4Clay Films: 1 – few, 2 – common, 3 – many; d – distinct, p – prominent; pf – ped faces, po – pores

5Boundaries: a – abrupt, c – clear, g – gradual

6Roots and pores: 1 – few, 2 – common, 3 – many; vf – very fine, f – fine, m – medium, c- coarse

7Mottling: 1 – few, 2 – common, 3 – many; f – fine, m – medium, c- coarse; d – distinct; p – prominent

Table 2. Laboratory data for Atchison County Lake watershed.

				Particle Size Distribution (%)							
		Soil	Depth	Sand	Silt[1]				Clay[2]		
Locality	Member	Horizon	(cm)	Total	C	M	F	Total	C	F	Total
A	Honey Cr	A	0-40	4	35	31	5	71	10	15	25
		Bw	40-70	8	29	27	6	62	11	19	30
		BC	70-95	10	26	28	5	59	12	19	31
		Bwb	95-120	12	29	27	4	60	11	17	28
		C1b	120-150	19	23	26	5	54	11	16	27
		C2b	150-205	14	27	26	5	58	10	18	28
		C3b	205-235	27	24	22	4	50	9	14	23
C	Honey Cr	Ap	0-10	23	33	22	3	58	9	10	19
		A	10-30	35	24	20	3	47	7	11	18
		Bw1	30-75	38	27	17	3	47	5	10	15
		Bw2	75-110	42	23	15	2	40	7	11	18
		C	110-118	41	26	15	2	43	6	10	16
	Roberts Cr	A1b	118-165	17	34	25	4	63	8	12	20
		A2b	165-220	13	30	27	5	62	11	14	25
		ACb	220-280	21	25	26	4	55	9	15	24
		Cb	280-330	46	17	15	3	35	7	12	19
D	Camp Cr	Ap	0-10	10	33	36	9	78	8	4	12
		A	10-33	4	34	36	9	79	10	7	17
		C	33-45	2	29	39	7	75	10	13	23
	Gunder	ABb	45-105	2	12	37	7	56	11	31	42
		Bt1b	105-195	4	26	32	5	63	10	23	33
		Bt2b	195-270	5	22	35	4	61	11	23	34
		Bt3b	270-350	3	26	32	5	63	11	23	34

[1] Silt fractions: C = Coarse (50-20μm); M = Medium (20-5μm); F = Fine (5-2μm)

[2] Clay fractions: C = Coarse (2-0.2μm); F = Fine (<0.2μm)

friable consistence (Table 3). Soil profiles are between 75 cm and 115 cm thick and consist of very dark grayish brown (10YR 3/2, dry), dark grayish brown (10YR 4/2, dry) and brown (10YR 4/3, dry), silty loam and loam. Fine, brown (10YR 5/3) and pale brown (10YR 6/3) silty laminae are common in C horizons.

In cores B and C-1, the Camp Creek Member mantles the Honey Creek Member and the Gunder Member, respectively (Figure 11; Table 3). Core B contains two buried soils (soils 2 and 3) developed in the Honey Creek Member. Soils 2 and 3 are moderately developed and are morphologically similar to soils developed in the Honey Creek Member at Atchison County Lake. Buried Bw horizons are approximately 30 cm thick and consist of dark grayish brown (10YR 4/2, dry) and dark gray (10YR 4/1, dry) silty loam with moderate, sub-angular blocky structure and friable consistence (Table 3). Grain-size is fairly uniform throughout the Honey Creek Member in core B, with clay contents ranging from 24% and 31% and silt contents ranging from 49% to 57%.

Surface soils on the T-1 surface are mapped as the Reading and Chase soil series (Figure 9). Cores A, C-2 and D-1 indicate that these surface soils are developed in the Gunder Member (Figures 10 and 11). The Gunder Member also occurs in core C-1, but is buried beneath the Camp Creek Member (Figure 11). Soils developed in the Gunder Member are similar to each other, typically consisting of well-expressed A-Bt-BCt profiles with thick Bt horizons (77 cm to over 3 m) that have moderate, prismatic and blocky structure, firm to very firm moist consistence, and hard to very hard dry consistence (Table 3). Clay illuviation is also evident in the form of dark grayish brown (10YR 4/2) continuous and discontinuous clay films on ped faces and black (10YR 2/1) clay flows in macropores. The Bt horizon is typically a brown (10YR 4/3 and 5/3, dry) or yellowish brown (10YR 5/4, dry) silt loam or silty clay loam. The matrix colors (10YR 4/1 and 10YR 4/2, dry) of the Bt horizon in core A are darker than the Bt horizons in the other cores. Also, prominent yellowish brown (10YR 5/6) mottles occur in the C horizon in core A. This feature is indicative of somewhat poorly drained conditions and is consistent with the mapped soil series (Chase) at the core A location.

The clay content of the Bt horizon in cores A and C-2 is higher (31-39%) than the clay content of other members of the DeForest Formation (Table 4) and similar to soils developed in the Gunder Member at Atchison County Lake. However, grain-size data for core C-1 indicate lower clay content (23-27%) and higher sand content (15-26%) in the Bt hori-

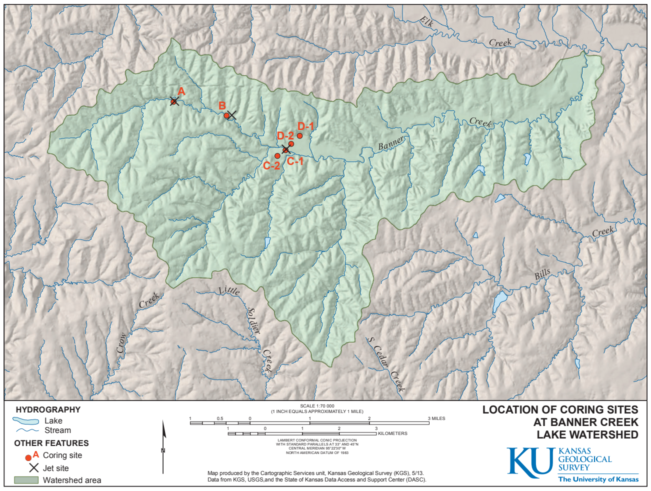

Figure 8. Location of coring sites at Banner Creek Lake.

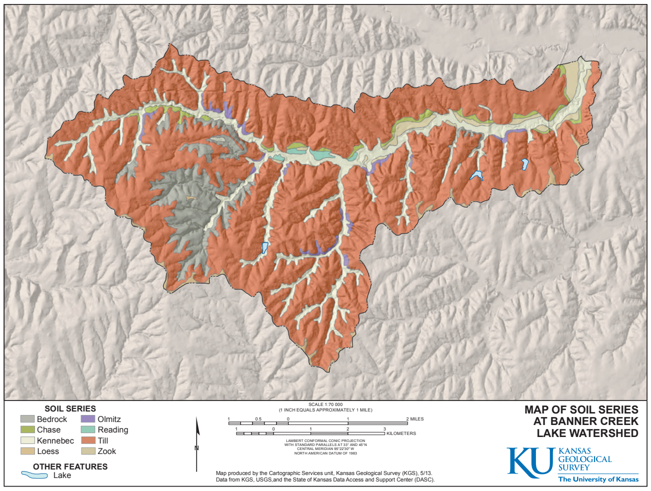

Figure 9. Map of soil series at Banner Creek Lake.

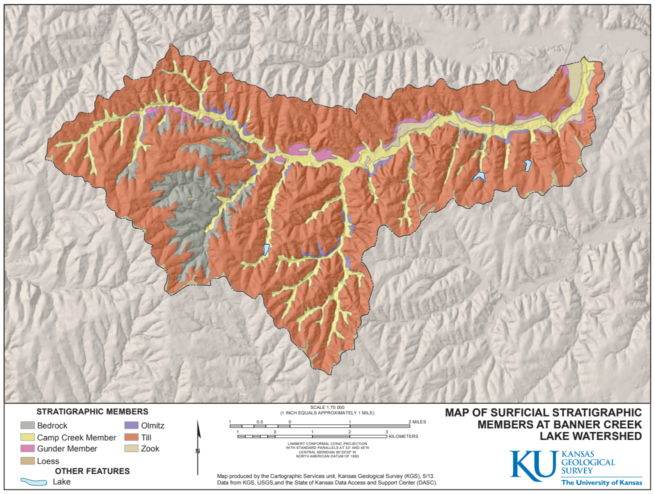

Figure 10. Map of surficial stratigraphic members at Banner Creek Lake.

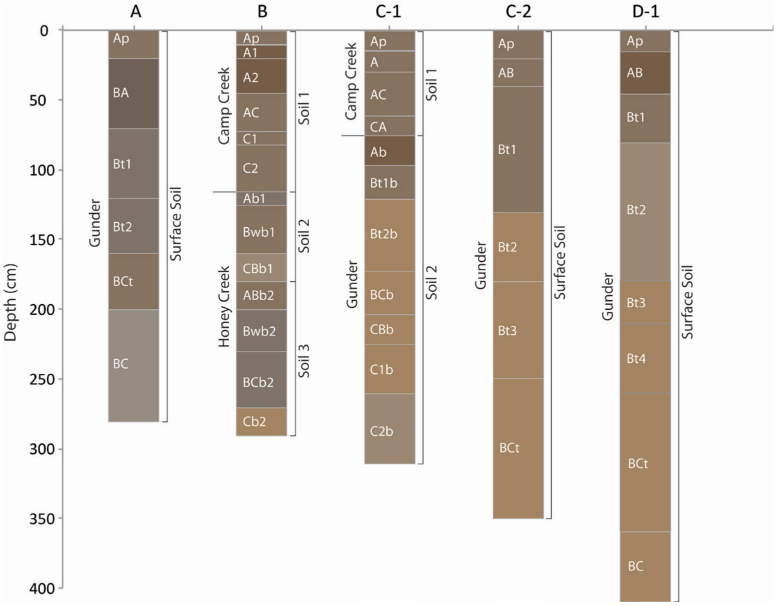

Figure 11. Stratigraphy at Banner Creek Lake. Munsell colors (dry) of horizons are shown.

zon compared to cores A and C-2. Clay content typically peaks in the uppermost Bt horizon.

Core D-2 was taken from an alluvial fan that grades to the T-1 terrace. The surface soil on the fan is mapped as the Chase series (Figure 9) and is developed in the Corrington Member of the DeForest Formation. Soil development in the fan is similar to that described for the Gunder Member in other cores. The surface soil is over 1 m thick and has a well-expressed Bt horizon with dark grayish brown (10YR 4/2, dry) and grayish brown (10YR 5/2, dry) colors and moderate, prismatic structure (Table 3). Prominent, continuous clay films are common on ped faces in the Bt horizon. Also, Core D-2 contains a well-developed buried soil at a depth of 185 cm. The buried soil consists of yellowish brown (10YR 5/4, dry) sandy loam with a thick (> 1 m) Bt horizon. The Btb horizon has moderate to strong prismatic structure and many prominent clay films on ped faces. Prominent yellowish red (5YR 5/6) mottles occur throughout the buried soil.

Centralia Lake Watershed. Five cores were taken at Centralia Lake, all on the T-0 surface (Figure 12). Surface soils on T-0 are mapped as the Kennebec series (Figure 13). The cores reveal that the Kennebec soil (soil 1) is developed in the Camp Creek Member (Figures 14 and 15). The Camp Creek Member is typically 60-80 cm thick and has surface soils with Ap-A-AC horizonation (cores A, C and D) (Table 5). However, in core B the soil is only 30 cm thick and is represented by an AC horizon. In core E, the Camp Creek Member is thicker (140 cm) and has multiple buried soils (soils 2 and 3). Overall, soils developed in the Camp Creek Member in the watershed above Centralia Lake have weakly expressed profiles, though some A horizons have moderate, blocky and prismatic structure. Such structure probably is a product of the fine-grained parent material instead of pedogenesis. As Birkeland (1999) noted, clay content is an important factor in the formation of blocky structure. In the watershed above Centralia Lake, field textures (Table 5) indicate that the Camp Creek Member typically consists of a silty clay loam compared to loam and silt loam in the other watersheds. Furthermore, grain-size data for core A at Centralia Lake indicates that the clay content is relatively high (31-39 %) (Table 6), which explains the formation of moderate, subangular and angular blocky structure in the A horizon of the surface soil at this location.

The Camp Creek Member mantles other members of the DeForest Formation in all cores (Figure 15). In core A, Camp Creek alluvium overlies the Roberts Creek Member. The Roberts Creek Member is similar

Table 3. Core descriptions from Banner Lake watershed.

Locality	Member	Horizon	Depth (cm)	Color		Texture[1]	Structure[2]	Consistence[3]	Clay Films[4]	Boundary[5]	Pores[6]	Roots[6]	Notes
				Moist	Dry								
A	Gunder	Ap	0-20	10YR 3/2	10YR 4/2	SiCL	1 f sbk	fr, h	---	g	3vf	3f 3vf	Parts to 2 f gr
		B	20-70	10YR 2/1	10YR 3/1	SiC	1 f sbk	fi, h	---	g	2vf	3 vf	Parts to 2 f sbk
		Bt1	70-120	10YR 3/1	10YR 4/1	SiCL	2 f sbk	vfi, vh	3 p pf/po	g	2vf	2vf	Parts to 2 f abk; Continuous clay films, 10YR 4/2
		Bt2	120-160	10YR 3/1	10YR 4/1	SiCL	2 m sbk	vfi, vh	2 p pf	g	3vf	3vf	Parts to 2 f abk
		BCt	160-200	10YR 3/1	10YR 4/2	SiCL	1 f gr	fr	2 p po	g	2f 3vf	---	Parts to 2 m gr; clay flows in macropores, 10YR 2/1
		BC	200-280	10YR 4/1	10YR 5/1	SiCL	2 f gr	fr	---	---	2f 3vf	---	Parts to 2 f gr; Mottling[7] 2 f p, 10YR 5/6
B	Camp Cr	Ap	0-10	10YR 3/2	10YR 4/2	L	1 f gr	fr	---	a	2f 2vf	2f 3vf	
		A1	10-20	10YR 3/1	10YR 3/2	L	2 f abk	fr	---	g	2vf	1vf	Parts to 2 f gr
		A2	20-45	10YR 3/1	10YR 3/2	SiL	1 f sbk	fr	---	a	2vf	1f 2vf	Parts to 2 f gr; common wormcasts
		AC	45-72	10YR 3/2	10YR 4/2	L	1 f sbk	fr, so	---	a	2f 2vf	1m 1vf	Parts to 1 f gr; Few fine laminae, Si, 10YR 6/3
		C1	72-82	10YR 3/2	10YR 4/2	L	1 f gr	vfr, so	---	a	2f 2vf	1vf	Common fine laminae, Si, 10YR 5/3
		C2	82-115	10YR 3/2	10YR 4/2	SiL	1 f sbk	fr, so	---	a	2f 2vf	1vf	Few fine laminae, Si, 10YR 5/3
	Honey Cr	Ab1	115-125	10YR 3/1	10YR 4/1	SiL	1 f sbk	fr	---	g	2f 2vf	1vf	Parts to 2 f gr; common wormcasts
		Bwb1	125-160	10YR 3/2	10YR 4/2	L	2 m sbk	fr	---	g	2f 2vf	1vf	Parts to 2 m gr; common wormcasts
		CBb1	160-180	10YR 3/2	10YR 5/2	SiL	1 f sbk	fr, sh	---	a	1m 2f 3vf	1f	Parts to 1 f gr; few fine laminae, Si, 10YR 5/3
		Ab2	180-200	10YR 3/2	10YR 4/2	SiL	1 f sbk	fr	---	g	3f 3vf	2f 3vf	Parts to 1 f gr
		Bwb2	200-230	10YR 3/2	10YR 4/1	SiL	2 m sbk	fr	---	g	2f, 3vf	2vf	

Table 3. Core descriptions from Banner Lake watershed. (continued)

Locality	Member	Horizon	Depth (cm)	Color		Texture[1]	Structure[2]	Consistence[3]	Clay Films[4]	Boundary[5]	Pores[6]	Roots[6]	Notes
				Moist	Dry								
		BCb2	230-270	10YR 3/1	10YR 4/1	SiCL	2 f sbk	fr	---	g	3vf	1c	Parts to 2 f gr
		Cb2	270-290	10YR 5/3	10YR 5/4	SiCL	m	fi, h	---	---	2vf	---	Color 50% 10YR 3/1 moist, 10YR 4/1 dry
C-1	Camp Cr	Ap	0-15	10YR 3/2	10YR 4/2	SiL	1 f gr	vfr	---	g	2f 2vf	2f 2vf	
		A	15-30	10YR 3/2	10YR 4/2	L	1 f gr	vfr	---	g	2f 2vf	2f 2vf	Common wormcasts
		AC	30-62	10YR 3/3	10YR 4/3	SiL	1 f gr	fr	---	g	2vf	2f 2vf	Many wormcasts; Very few, very fine, laminae, SiL, 10YR 5/3
		C	62-75	10YR 3/3	10YR 4/3	SiL	1 f gr	fr	---	a	2f 2vf	2f 2vf	Common wormcasts; Common fine laminae, SiL, 10YR 7/3
	Gunder	Ab	75-96	10YR 3/1	10YR 3/2	SiL	1 f sbk	fr, h	---	a	2m 3f 3vf	3f 3vf	Parts to 2 m gr
		Bt1b	96-120	10YR 3/3	10YR 4/3	SiCL	2 m pr	fi, h	3 d pf	g	1m 3f 3vf	1m 3f 3vf	Parts to 2 f sbk; Continuous clay films, 10YR 4/2; Many wormcasts and burrows
		Bt2b	120-173	10YR 4/3	10YR 5/3	SiL	2 m pr	fi, h	2 d pf	g	1m 3f 3vf	2f 2vf	Parts to 2 f sbk; Discontinuous clay films, 10YR 4/2; Many wormcasts
		BCb	173-204	10YR 4/3	10YR 5/3	SiL	1 m pr	fi, sh	---	g	1m 3f 3vf	1vf	Parts to 1 f sbk; few wormcasts
		CBb	204-225	10YR 4/3	10YR 5/3	L	1 f gr	fr, so	---	a	2f 2vf	1vf	Few wormcasts; Few very fine laminae, 10YR 7/3
		C1b	225-260	10YR 4/3	10YR 5/3	SL	m	lo, so	---	a	---	1vf	Parts to sg
		C2b	260-310	10YR 4/2	10YR 5/2	L	m	fi, h	---	---	2m 2f 3vf	---	Few fine laminae, 10YR 6/3
C-2	Gunder	Ap	0-20	10YR 3/2	10YR 4/2	SiCL	1 f sbk	vfr	---	a	2f 3vf	1vf	Parts to 1 f gr
		AB	20-40	10YR 3/2	10YR 4/2	SiCL	2 m sbk	fr	---	g	1f 3vf	---	Parts to 2 m gr
		Bt1	40-130	10YR 3/3	10YR 4/3	SiCL	2 m pr	vfi, vh	3 p pf/po	g	1f 3vf	2vf	Parts to 2 m abk; Continuous clay films, 10YR 4/2

Table 3. Core descriptions from Banner Lake watershed. (continued)

				Color									
Locality	Member	Horizon	Depth (cm)	Moist	Dry	Texture[1]	Structure[2]	Consistence[3]	Clay Films[4]	Boundary[5]	Pores[6]	Roots[6]	Notes
		Bt2	130-180	10YR 4/4	10YR 5/4	SiCL	2 m pr	vfi, vh	2 p pf/po	g	2f 3vf	1vf	Parts to 2 m abk; Continuous clay films 10YR 4/2
		Bt3	180-250	10YR 4/3	10YR 5/3	SiCL	1 f pr	fr, h	2 p po	g	1m 3f 3vf	---	Parts to 2 f sbk; clay flows in macropores, 10YR 2/1
		BCt	250-350	10YR 4/3	10YR 5/3	SiCL	1 f pr	vfr	1 p po	---	3f 3vf	---	Parts to 1 f gr; clay flows in macropores, 10YR 2/1
D-1	Gunder	Ap	0-15	10YR 3/2	10YR 4/2	SiL	1 f sbk	fr	---	g	3f 2vf	1f 2vf	Parts to 1 f gr
		AB	15-45	10YR 3/1	10YR 3/2	SiL	2 f sbk	fi	---	g	1f 3vf	2vf	Parts to 2 f gr
		Bt1	45-80	10YR 3/2	10YR 4/2	SiL	2 m pr	fi, h	2 p pf	g	1f 3vf	1f 2vf	Parts to 2 f sbk
		Bt2	80-180	10YR 4/2	10YR 5/2	SiCL	3 m pr	vfi, vh	3 p pf	g	2f 3vf	1vf	Parts to 2 m abk; Continuous clay films 10YR 3/2
		Bt3	180-210	10YR 4/4	10YR 5/4	SiCL	2 m pr	vfi, vh	2 p pf/po	g	1f 3vf	---	Parts to 2 f sbk; Discontinuous clay films, 10YR 3/2
		Bt4	210-260	10YR 4/4	10YR 5/4	SiCL	1 f pr	fi, h	1 p po	g	2f 3vf	---	Parts to 2 f gr; 10YR 3/2 clay films
		BCt	260-360	10YR 4/3	10YR 5/3	CL	1 m sbk	fr, h	1 p po	g	2f 3vf	---	Parts to 1 m gr
		BC	360-420	10YR 4/3	10YR 5/3	CL	1 m sbk	fr, h	---	---	1f 3vf	---	Parts to 1 m gr
D-2	Corrington	Ap	0-10	10YR 3/2	10YR 4/2	SiL	1 f sbk	fr	---	a	2f 3vf	3f 3vf	Parts to 1 f gr
		A	10-50	10YR 2/1	10YR 3/1	L	1 f sbk	fr	---	g	1f 3vf	1f 2vf	Parts to 1 f gr
		ABt	50-80	10YR 3/2	10YR 4/2	L	2 f sbk	fr, h	1 d pf	g	1f 3vf	2f 2vf	Parts to 2 m gr; Discontinuous clay films, 10YR 3/2

Table 3. Core descriptions from Banner Lake watershed. (continued)

Locality	Member	Horizon	Depth (cm)	Color		Texture[1]	Structure[2]	Consistence[3]	Clay Films[4]	Boundary[5]	Pores[6]	Roots[6]	Notes
				Moist	Dry								
		Bt1	80-120	10YR	10YR	L	2 m pr	fi, h	2 p pf	g	2f 3vf	1vf	Parts to 1 f sbk; Continuous
				3/2	4/2								clay films 10YR 3/2
		Bt2	120-150	10YR	10YR	L	2 m pr	fi, h	2 p pf	g	3f 3vf	1vf	Parts to 2 f sbk; Continuous
				4/1	5/2								clay films, 10YR 3/2
		Bt3	150-185	10YR	10YR	L	2 m pr	fi, h	2 p pf	a	3f 2vf	---	Parts to 2 f sbk; Continuous
				4/1	5/2								clay films, 10YR 3/2; Mottling[7] 1 m d, 10YR 5/3
		Bt1b	185-225	10YR	10YR	SL	3 c pr	vfi, vh	3 p pf	g	3f 3vf	---	Parts to 3 m abk;
				4/4	5/4								Continuous clay films, 10YR 3/1; Mottling[7] 1 m p,
													5YR 5/6
		Bt2b	225-290	10YR	10YR	SL	2 m pr	fr, sh	3 p pf	g	2f 3vf	---	Parts to 2 m agr; Continuous
				4/4	5/4								clay films, 10YR 3/1;
													Mottling[7] 2 m p, 5YR 5/6
		BCtb	290-350	10YR	10YR	SL	2 f gr	fr, sh	---	---	3f 2vf	---	Mottling[7] 2 m p, 5YR 5/6
				4/4	5/4								

1Texture: C – Clay, CL – Clay Loam, SiCL – Silty Clay Loam, SiC – Silty Clay, L – Loam, SiL – Silty Loam, LS – Loamy Sand
2Structure: 1 – weak, 2 – moderate, 3 – strong, m – massive, sg – single grain; f – fine, m – medium, c- coarse; abk – angular blocks, sbk – subangular blocks, pl – plates
3Consistence: so – soft, sh – slightly hard, h – hard, vh – very hard; lo – loose, vfr – very friable, fr – friable, fi – firm; vfi – very firm
4Clay Films: 1 – few, 2 – common, 3 – many; d – distinct, p – prominent; pf – ped faces, po – pores
5Boundaries: a – abrupt, c – clear, g – gradual
6Roots and pores: 1 – few, 2 – common, 3 – many; vf – very fine, f – fine, m – medium, c- coarse
7Mottling: 1 – few, 2 – common, 3 – many; f – fine, m – medium, c- coarse; d – distinct; p – prominent

Table 4. Laboratory data for Banner Lake watershed

Locality	Member/ Unit	Soil Horizon	Depth (cm)	Sand Total	Particle Size Distribution (%)						
					Silt[1]				Clay[2]		
					C	M	F	Total	C	F	Total
A	Gunder	Ap	0-20	4	21	35	7	**63**	15	18	33
		B	20-70	3	19	27	7	**53**	13	31	44
		Bt1	70-120	3	25	27	6	**58**	12	27	39
		Bt2	120-160	5	27	29	5	61	10	24	34
		BCt	160-200	7	30	28	4	62	9	22	31
		BC	200-280	2	22	34	6	62	11	25	36
B	Camp Cr	Ap	0-10	50	19	13	3	35	7	8	15
		A1	10-20	30	26	18	4	48	9	13	22
		A2	20-45	27	30	16	4	50	9	14	23
		AC	45-72	33	30	14	3	47	8	12	20
		C1	72-82	48	22	10	3	35	7	10	17
		C2	82-115	23	35	18	4	57	9	11	20
	Honey Cr	Ab1	115-125	25	25	21	5	51	10	14	24
		Bwb1	125-160	26	21	24	4	49	10	15	25
		CBb1	160-180	19	32	20	4	56	10	15	25
		ABb2	180-200	18	31	22	4	57	9	16	25
		Bwb2	200-230	18	29	23	4	56	10	16	26
		BCb2	230-270	14	24	27	5	56	11	19	30
		Cb2	270-290	17	20	27	5	52	11	20	31
C-1	Camp Cr	Ap	0-15	26	22	22	6	50	11	13	24
		A	15-30	32	24	19	4	47	9	12	21
		AC	30-62	25	28	20	4	52	10	13	23
		C	62-75	20	29	23	3	55	12	13	25
	Gunder	Ab	75-96	23	23	23	5	51	12	14	26
		Bt1b	96-120	15	26	26	6	58	12	15	27
		Bt2b	120-173	26	28	19	4	51	10	13	23
		BCb	173-204	24	28	19	5	52	10	14	24
		CBb	204-225	42	18	14	4	36	9	13	22
		C1b	225-260	61	12	10	3	25	6	8	14
		C2b	260-310	31	22	19	5	46	9	14	23
C-2	Gunder	Ap	0-20	3	27	37	6	70	12	15	27
		AB	20-40	2	24	33	6	63	10	25	35
		Bt1	40-130	1	23	34	5	62	12	25	37
		Bt2	130-180	2	28	32	5	65	11	22	33
		Bt3	180-250	2	23	36	6	65	13	20	33
		BCt	250-350	11	28	27	7	62	12	15	27

[1] Silt fractions: C = Coarse (50-20μm); M = Medium (20-5μm); F = Fine (5-2μm)
[2] Clay fractions: C = Coarse (2-0.2μm); F = Fine (<0.2μm)

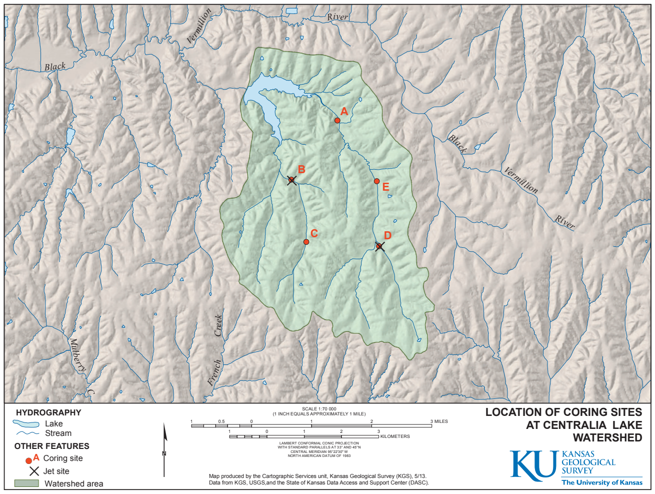

Figure 12. Location of coring sites at Centralia Lake.

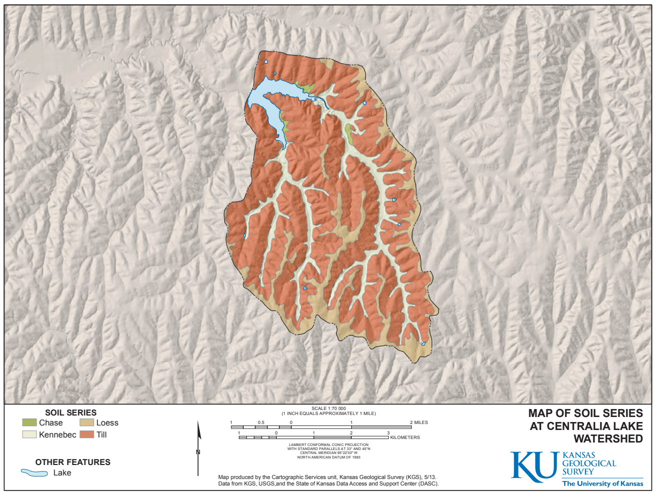

Figure 13. Map of soil series at Centralia Lake.

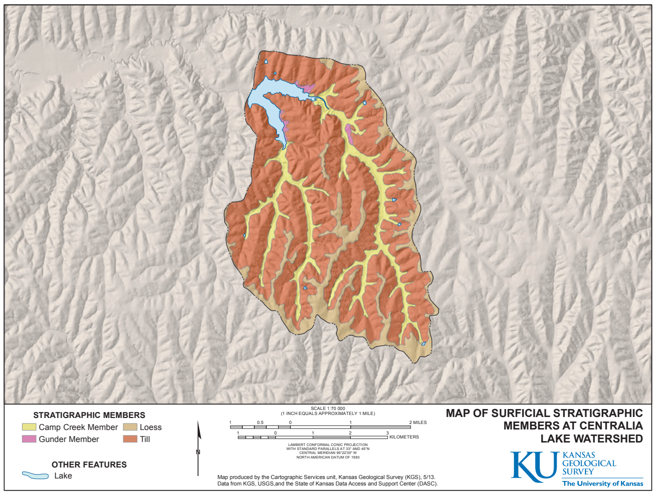

Figure 14. Map of surficial stratigraphic members at Centralia Lake.

to that described at Atchison County Lake. A prominent dark gray (10 YR 4/1, dry) cumulic soil (soil 2), with a 2 m-thick A horizon and an A-AC-C profile occurs (Table 5; Figure 15). This soil has a silt loam to silty clay loam texture and weak granular and sub-angular blocky structure.

In cores B, C and E the Camp Creek Member overlies the Gunder Member (Figure 15). The Gunder Member also occurs in core D, buried by both Honey Creek and Camp Creek alluvium. Soils developed in the Gunder Member have strongly expressed A-Bt profiles with similar morphologies to those described in other watersheds. The Bt horizons are 60 cm to 120 cm thick and have weak to moderate prismatic structure, firm and hard consistence, and are typically brown (10YR 4/2, dry) and grayish brown (10YR 5/2, dry) silty clay loams (Table 5). The darker color of the Bt horizon in core D (dark gray and gray) was similar to core A at Banner Creek, which is mapped as the Chase series. Also, clay films in the Bt horizon were less prominent in core A compared to the other cores. Grain-size data for the Gunder Member is similar to the Gunder in the other watersheds, with clay peaks in the uppermost Bt horizon and relatively high clay contents (31-37%) (Table 6).

In core D, the Honey Creek Member is between the Camp Creek Member and the Gunder Member (Figure 15). The soil developed in the Honey Creek Member at the core D locality is similar to soils developed in the Honey Creek Member in the other watersheds. In core D the surface soil has a moderately expressed A-Bw-BC profile. The Bw horizon is 23 cm thick and consists of dark grayish brown (10YR

4/2, dry) silt loam with moderate, subangular blocky structure (Table 5).

In addition to the five cores, an outcrop of glacial till was described in the Centralia Lake watershed. The outcrop was located 100 m upstream of the core B site. The till is a clay loam with a well-developed soil over 2 m thick (Table 7). The surface soil has a well-expressed Bt horizon with yellowish brown (10YR 5/4, dry) color, moderate prismatic structure and common, discontinuous clay films on ped faces. The Bk horizon is 1.2 m thick and has yellowish brown (10YR 5/4 and 10YR 5/8, dry) colors, moderate prismatic and angular blocky structure and common, fine soft carbonate masses. Grain-size is relatively uniform throughout the profile, with clay contents ranging from 26% and 32% and silt contents ranging from 38% to 41% (Table 6).

Erodibility

The results of 43 jet-tests are presented in Figure 16. Values of τ_c range from 0.04 to 19.0 Pa and k values range from 1.4 to 32.5 cm^3/Ns. As expected and noted in other studies, we observe an inverse relationship between τ_c and k (Figure 16A; R^2=0.61), where soils and sediments with low τ_c have high k values and vice versa. Sites with the lowest τ_c values (high k values) can be expected to erode at the highest rates. Based on this relationship, k can be estimated as a function of τ_c where:

$$k = 8.32\ \tau_c^{-0.47} \qquad (3)$$

This relationship is similar to that reported in other studies (equations 1 and 2). However, we obtained a much higher coefficient value of 8.32.

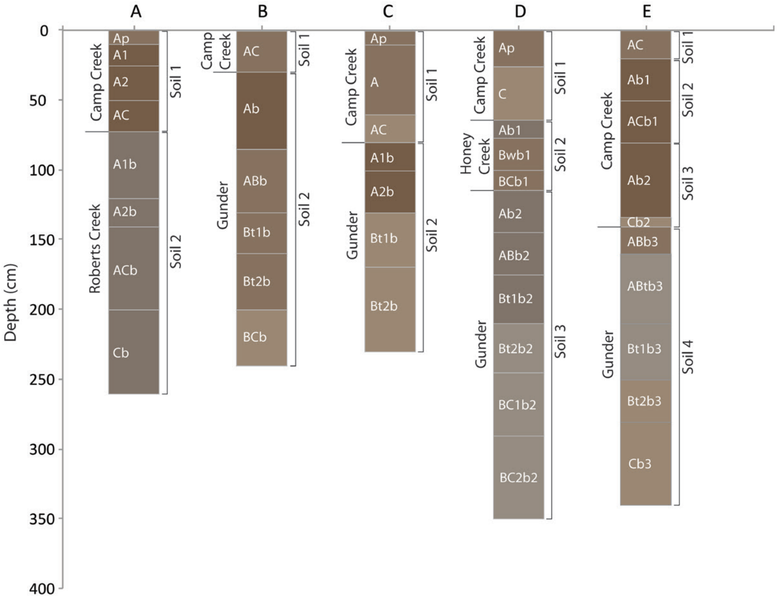

Figure 15. Stratigraphy at Centralia Lake. Munsell colors (dry) of horizons are shown.

We use a classification scheme similar to the one used by Thoman et al. (2008), based on Hanson and Simon (2001), to assess the relative erosion resistance of alluvium. The majority of bank materials tested in this study (72% of tests) were classed as erodible to moderately resistant (Figure 16B).

Figure 17 show the relative resistance to erosion for the various members of the DeForest Formation. Distinct differences in the susceptibility to fluvial erosion exist between the different members. The most erodible member is the Camp Creek Member, which consists of predominantly very erodible to erodible bank material (average τ_c = 1.0 Pa). The Honey Creek Member is mostly comprised of erodible to moderately resistant materials (average τ_c = 2.2 Pa). The most resistant member of the DeForest Formation is the Gunder Member, which consists of moderately resistant to resistant material (average τ_c = 10.4). Glacial till (average τ_c = 7.0 Pa) displayed a similar erosive resistance and

Table 5 - Core descriptions from Centralia Lake watershed.

Locality	Member	Horizon	Depth (cm)	Color		Texture^1	Structure^2	Consistence^3	Clay Films^4	Boundary^5	Pores^6	Roots^6	Notes
				Moist	Dry								
A	Camp Cr	Ap	0-10	10YR 3/2	10YR 4/2	SiCL	2 f gr	vfr	---	g	3f 3vf	1m 2f 3vf	
		A1	10-25	10YR 3/1	10YR 3/2	SiCL	2 f sbk	fr	---	g	2vf	1m 2f 2vf	Parts to 2 m gr
		A2	25-50	10YR 3/1	10YR 3/2	SiCL	2 f abk	fr, h	---	g	1f 2vf	1m 2f 3vf	Parts to 2 f sbk
		AC	50-72	10YR 3/1	10YR 3/2	SiCL	2 f sbk	fr	---	a	2f 3vf	1f 2vf	Parts to 2 m gr; Common fine laminae, 10YR 5/3
	Roberts Cr	Ab	72-120	10YR 2/1	10YR 4/1	SiL	1 f sbk	vfr	---	g	2f 2vf	2vf	Parts to 2 f gr
		A2b	120-140	10YR 2/1	10YR 4/1	SiCL	1 f sbk	fr	---	g	1f 2vf	---	Parts to 1 f gr
		ACb	140-200	10YR 2/1	10YR 4/1	SiCL	1 f gr	fr	---	g	2vf	---	
		Cb	200-260	10YR 3/1	10YR 4/1	SiCL	m	fi, h	---	---	1vf	---	Mottling^7 3 f d, 10YR 4/4
B	Camp Cr	AC	0-30	10YR 3/2	10YR 4/2	SiCL	1 f sbk	fr	---	a	2f 3vf	1m 3f 3vf	Parts to 2 f gr; Common wormcasts; Very few, very fine, SiL, laminae 10YR 5/3
	Gunder	Ab	30-85	10YR 3/1	10YR 3/2	SiL	2 m sbk	fi, h	---	c	2f 3vf	1f 2vf	Common wormcasts
		ABb	85-130	10YR 3/2	10YR 4/2	SiCL	2 m abk	vfi, h	---	g	2vf	1vf	Parts to 2 m gr
		Bt1b	130-160	10YR 3/2	10YR 4/2	SiCL	3 m pr	vfi, h	2 p pf/po	g	1f 2vf	1vf	Parts to 2 m sbk; Continuous clay films, 10YR 3/1
		Bt2b	160-200	10YR 3/2	10YR 4/2	SiCL	2 m pr	fi, h	2 p po	g	1f 3vf	---	Parts to 1 f gr; Discontinuous clay films, 10YR 3/1
		BCb	200-240	10YR 4/2	10YR 5/2	SL	1 f sbk	fi, h	---	---	2vf	---	
C	Camp Cr	Ap	0-10	10YR 3/2	10YR 4/2	SiCL	2 m pr	vfr	---	g	1f 3vf	1f 3vf	
		A	10-60	10YR 3/2	10YR 4/2	SiCL	2 f sbk	fr	---	g	2f 3vf	2vf	Parts to 1 f gr

Table 5 - Core descriptions from Centralia Lake watershed. (continued)

Locality	Member	Horizon	Depth (cm)	Color		Texture[1]	Structure[2]	Consistence[3]	Clay Films[4]	Boundary[5]	Pores[6]	Roots[6]	Notes
				Moist	Dry								
		AC	60-80	10YR 4/2	10YR 5/2	SiCL	2 f sbk	fr	---	a	1f 3vf	1f 2vf	Common fine laminae, Si, 10YR 5/3
	Gunder	A1b	80-100	10YR 3/1	10YR 3/2	SiL	2 f sbk	vfr	---	g	3vf	2vf	Parts to 1 f gr; Common wormcasts in macropores
		A2b	100-130	10YR 3/1	10YR 3/2	SiL	2 f sbk	fr	---	g	1f 3vf	1vf	Parts to 2 m gr
		Bt1b	130-170	10YR 4/2	10YR 5/2	SiCL	2 m pr	fi, h	3 p pf	g	2f 3vf	1vf	Parts to 2 f sbk; Continuous clay films, 10YR 3/2
		Bt2b	170-230	10YR 5/1	10YR 5/2	L	2 m pr	fr, h	3 p pf	---	3vf	---	Parts to 1 f sbk; Discontinuous clay films, 10YR 3/1; Hard carbonate masses; Mottling[7] 1 f d, 10YR 5/6
D	Camp Cr	Ap	0-26	10YR 3/2	10YR 4/2	SiL	2 f abk	fr	---	a	2vf	1f 2vf	Parts to 2 f gr
		C	26-64	10YR 3/2	10YR 5/2	SiL	1 f gr	vfr	---	a	3vf	1f 1vf	Many fine laminae, Si, 10YR 6/3
	Honey Cr	Ab1	64-77	10YR 3/1	10YR 4/1	SiCL	1 f sbk	fr	---	g	2f 2vf	1f 2vf	Parts to 2 f gr; Common wormcasts
		Bwb1	77-100	10YR 3/2	10YR 4/2	SiL	2 f sbk	fr	---	g	2f 3vf	1f 2vf	Parts to 2 m gr
		BCb1	100-114	10YR 3/2	10YR 4/2	SiL	2 f sbk	vfr	---	a	3f 3vf	1vf	Parts to 2 m gr; Few fine laminae, Si, 10YR 6/3
	Gunder	Ab2	114-145	10YR 3/1	10YR 4/1	SiL	1 f gr	fr, so	---	g	3f 3vf	1vf	
		ABb2	145-175	10YR 3/1	10YR 4/1	SiCL	1 f sbk	fr, h	---	g	1f 3vf	---	Parts to 2 m gr; Common wormcasts
		Bt1b2	175-210	10YR 3/1	10YR 4/1	SiCL	2 m pr	fi, h	1 d pf/po	g	2vf	---	Discontinous clay films, 10YR 3/1
		Bt2b2	210-245	10YR 4/1	10YR 5/1	SiCL	2 m pr	fi, h	1 d pf/po	g	2vf	---	Patchy clay films, 10YR 3/1
		BC1b2	245-290	10YR 4/1	10YR 5/1	SiCL	1 c pr	fi, h	---	g	2vf	---	Parts to 1 m sbk
		BC2b2	290-350	10YR 4/1	10YR 5/1	SiCL	1 c pr	fi, h	---	---	1f 3vf	---	Mottling[7] 3 m p, 5YR 5/6

Table 5 - Core descriptions from Centralia Lake watershed. (continued)

Locality	Member	Horizon	Depth (cm)	Color		Texture[1]	Structure[2]	Consistence[3]	Clay Films[4]	Boundary[5]	Pores[6]	Roots[6]	Notes
				Moist	Dry								
E	Camp Cr	AC	0-20	10YR 3/2	10YR 4/2	SiL	2 f gr	vfr	---	g	1f 2vf	2vf	Few fine laminae, SiL, 10YR 6/3
		Ab1	20-50	10YR 3/1	10YR 3/2	SiCL	2 f sbk	fr	---	g	3vf	1vf	Parts to 1 f gr
		ACb1	50-80	10YR 3/1	10YR 3/2	SiCL	1 f sbk	fr	---	g	2f 3vf	2vf	Few fine laminae, SiL, 10YR 6/3
		Ab2	80-135	10YR 3/1	10YR 3/2	SiL	2 f sbk	fr	---	g	2f 3vf	1vf	Parts to 1 f gr; Common wormcasts
		Cb2	135-140	10YR 4/2	10YR 5/2	SiL	1 f gr	lo, so	---	g	3vf	---	
	Gunder	ABb3	140-160	10YR 3/2	10YR 4/2	SiL	1 m pr	fr	---	g	1f 3vf	---	Parts to 2 f gr
		ABtb3	160-210	10YR 4/1	10YR 5/1	SiCL	2 m pr	fr	2 d pf	g	2f 3vf	---	Parts to 2 f gr; Continuous clay films, 10YR 3/2; 2 f p mottles[7] lining pores, 2.5YR 4/6
		Bt1b3	210-250	10YR 4/1	10YR 5/1	SiCL	2 m pr	fi, h	2 d pf	g	1f 3vf	---	Parts to 2 m abk; Continuous clay films, 10YR 3/2; Mottling[7] 2 f p lining pores, 2.5YR 4/6
		Bt2b3	250-280	10YR 4/2	10YR 5/2	SiCL	2 m pr	fi, h	2 p pf/po	g	1f 2vf	---	Discontinuous clay films, 10YR 3/2; Mottling[7] 2 f p, 2.5YR 4/6
		Cb3	280-340	10YR 4/2	10YR 5/2	SiCL	m	fi, h	---	---	1f 2vf	---	

1Texture: C – Clay, CL – Clay Loam, SiCL – Silty Clay Loam, SiC – Silty Clay, L – Loam, SiL – Silty Loam, LS – Loamy Sand
2Structure: 1 – weak, 2 – moderate, 3 – strong, m – massive, sg – single grain; f – fine, m – medium, c- coarse; abk – angular blocks, sbk – subangular blocks, pl – plates
3Consistence: so – soft, sh – slightly hard, h – hard, vh – very hard; lo – loose, vfr – very friable, fr – friable, fi – firm; vfi – very firm
4Clay Films: 1 – few, 2 – common, 3 – many; d – distinct, p – prominent; pf – ped faces, po – pores
5Boundaries: a – abrupt, c – clear, g – gradual
6Roots and pores: 1 – few, 2 – common, 3 – many; vf – very fine, f – fine, m – medium, c- coarse
7Mottling: 1 – few, 2 – common, 3 – many; f – fine, m – medium, c- coarse; d – distinct; p – prominent

Table 6. Laboratory data for Centralia Lake watershed.

Locality	Member/Unit	Soil Horizon	Depth (cm)	Particle Size Distribution (%)							
				Sand	Silt[1]				Clay[2]		
				Total	C	M	F	Total	C	F	Total
A	Camp Cr	Ap	0-10	12	23	25	9	57	16	15	31
		A1	10-25	16	23	21	8	52	14	18	32
		A2	25-50	4	17	29	11	57	17	22	39
		AC	50-72	2	22	33	8	63	15	20	35
	Roberts Cr	Ab	72-120	6	35	26	8	69	11	14	25
		A2b	120-140	6	34	28	5	67	10	17	27
		Acb	140-200	6	30	29	6	65	9	20	29
		Cb	200-260	13	26	24	4	54	10	23	33
B	Camp Cr	AC	0-30	4	34	28	5	67	13	16	29
	Gunder	Ab	30-85	9	35	26	7	68	12	11	23
		ABb	85-130	8	33	26	5	64	10	18	28
		Bt1b	130-160	6	30	26	4	60	10	24	34
		Bt2b	160-200	7	34	24	4	62	9	22	31
		BCb	200-240	11	30	24	5	59	9	21	30
B	Till	A	0-25	36	17	14	7	38	14	12	26
		A/B	25-35	35	15	16	8	39	14	12	26
		Bt	35-48	29	14	18	9	41	17	13	30
		Bk1	48-82	29	14	18	9	41	17	13	30
		Bk2	82-108	30	12	16	10	38	18	14	32
		Bk3	108-170	30	14	15	9	38	18	14	32
		BCk	170-220	30	14	18	8	40	17	13	30
D	Camp Cr	Ap	0-26	4	42	24	4	70	10	16	26
		C	26-64	7	46	21	3	70	8	15	23
	Honey Cr	Ab1	64-77	1	29	32	5	66	12	21	33
		Bwb1	77-100	3	39	28	4	71	10	16	26
		BCb1	100-114	3	42	28	4	74	10	13	23
	Gunder	Ab2	114-145	4	33	31	9	73	12	11	23
		ABb2	145-175	4	28	30	6	64	12	20	32
		Bt1b2	175-210	4	27	26	6	59	8	29	37
		Bt2b2	210-245	6	25	26	7	58	10	26	36
		BC1b2	245-290	5	24	29	6	59	11	25	36
		BC2b2	290-350	6	21	30	6	57	12	25	37
E	Camp Cr	AC	0-20	10	38	24	3	65	9	16	25
		Ab1	20-50	10	32	24	5	61	11	18	29
		ACb1	50-80	7	37	25	4	66	11	16	27
		Ab2	80-135	8	34	27	5	66	10	16	26
		Cb2	135-140	7	41	25	4	70	9	14	23
	Gunder	ABb3	140-160	7	36	27	5	68	9	16	25
		ABtb3	160-210	4	27	33	5	65	9	22	31
		Bt1b3	210-250	3	25	32	5	62	10	25	35
		Bt2b3	250-280	6	25	31	4	60	9	25	34
		Cb3	280-340	7	29	26	4	59	10	24	34

1 Silt fractions: C = Coarse (50-20µm); M = Medium (20-5µm); F = Fine (5-2µm)

2 Clay fractions: C = Coarse (2-0.2µm); F = Fine (<0.2µm)

Table 7 - Outcrop description of till from Centralia Lake watershed.

Locality	Unit	Horizon	Depth (cm)	Color		Texture[1]	Structure[2]	Consistence[3]	Clay Films[4]	Boundary[5]	Pores[6]	Roots[6]	Notes
				Moist	Dry								
B	Till	A	0-25	10YR 3/2	10YR 4/2	L	1 f sbk	fr, h	---	g	2f 3vf	1m 3f 3vf	Parts to 2 m gr; Common wormcasts
		A/B	25-35	10YR 3/2	10YR 4/2	L	1 f sbk	fr, h	---	g	2f 3vf	2f 3vf	60% A, 40% B; Parts to 2 m gr; Common wormcasts
		Bt	35-48	10YR 4/4	10YR 5/4	CL	2 m pr	fr, h	2 d pf	g	2f 3vf	2f 3vf	Parts to 2 f sbk; Discontinuous clay films, 10YR 4/2
		Bk1	48-82	10YR 4/4	10YR 5/4	CL	2 m pr	fr, h	---	g	2f 3vf	2f 2vf	Common 10YR 6/1 reduction zones; Parts to 2 f sbk; Common fine soft carbonate masses
		Bk2	82-108	10YR 4/6	10YR 5/8	CL	2 m abk	fr, h	---	g	2f 2 vf	2f 2vf	Many 10YR 6/1 reduction zones; Parts to 2 f sbk; Common fine soft carbonate masses
		Bk3	108-170	10YR 4/6	10YR 5/8	CL	2 m abk	fr, h	---	g	1f 1vf	1f 1vf	Few iron oxide segregations, slightly hard; Few coarse soft carbonate masses
		BCk	170-220	10YR 4/6	10YR 5/8	CL	1 f abk	fr, h	---	g	1f 1vf	---	Few iron oxide segregations, slightly hard; Very few fine soft carbonate masses

[1] Texture: C – Clay, CL – Clay Loam, SiCL – Silty Clay Loam, SiC – Silty Clay, L – Loam, SiL – Silty Loam, LS – Loamy Sand
[2] Structure: 1 – weak, 2 – moderate, 3 – strong, m – massive, sg – single grain; f – fine, m – medium, c- coarse; abk – angular blocks, sbk – subangular blocks, pl – plates
[3] Consistence: so – soft, sh – slightly hard, h – hard, vh – very hard; lo – loose, vfr – very friable, fr – friable, fi – firm; vfi – very firm
[4] Clay Films: 1 – few, 2 – common, 3 – many; d – distinct, p – prominent; pf – ped faces, po – pores
[5] Boundaries: a – abrupt, c – clear, g – gradual
[6] Roots and pores: 1 – few, 2 – common, 3 – many; vf – very fine, f – fine, m – medium, c- coarse

Table 8. Average and median critical shear stress (τc) and erodibility coefficient values (k) by stratigraphic member/unit.

Member/Unit	Average τc	Median τc	Average k	Median k
Camp Creek	1.0	0.8	18.5	15.0
Honey Creek	2.2	2.1	8.0	6.5
Gunder	10.4	9.3	3.2	2.3
Till	7.0	7.7	4.2	4.7

distribution of τ_c values to the Gunder Member. As the erodibility data are not normally distributed, median values (Table 8) may provide a better estimate of the central tendency of the data.

In general, we did not observe a significant difference in the erodibility of the members of the DeForest Formation in different watersheds.

Grain-size data from jet-tests locations indicates a weak positive correlation ($R^2 = 0.229$) between percent clay content and τ_c (Figure 18A). Overall, clay content and τ_c values for the Gunder Member were much higher compared to the Camp Creek and Honey Creek Members (Figure 18B). No clear relationship was observed between grain-size data and the erodibility coefficient, *k*.

Discussion

Soils and Stratigraphy

Surface soils on the T-0 surface in all watersheds were mapped as the Kennebec series (Figures 5, 9 and 13). The official Kennebec series consists of moderately well drained soils on floodplains (Soil Survey Staff, 2013). The typical pedon is described as a silt loam with an Ap-A-AC-C profile (Soil Survey Staff, 2013). Results indicate that in Banner Lake and Centralia Lake the surface soil is developed in Camp Creek Member alluvium. Atchison County soils are the exception, where in three of the four cores (A, B and C) surface soils are developed in the Honey Creek Member. The official description allows for the presence of a Bw horizon as found in soils developed in Honey Creek alluvium. However, this limits the usefulness of SSURGO data to identify the particular stratigraphic member on the basis of soil series.

Surface soils on T-1 surfaces are mapped as the Chase or Reading series (Figures 5, 9 and 13). The official Chase series consists of somewhat poorly drained and moderately well drained soils formed in alluvium on floodplains (Soil Survey Staff, 2013). Results confirm the somewhat poorly drained nature of Chase soils in the study area (i.e. darker Bt horizon colors). However, in the Banner Creek Lake watershed, mapping indicates that the Chase series soil was formed in T-1 terrace deposits not in floodplain alluvium. The Reading series consists of well drained or moderately well drained soils formed in alluvium on stream terraces (Soil Survey Staff, 2013). The typical pedon for the Chase and Reading series has a Ap-A-BA-Bt-BC-C and Ap-A-Bt-C profile, respectively. Results indicate that the Chase and Reading series accurately represent the Gunder Member of the DeForest Formation.

Erodibility

A wide range of variability in jet-test results (Figure 16A) has been observed in

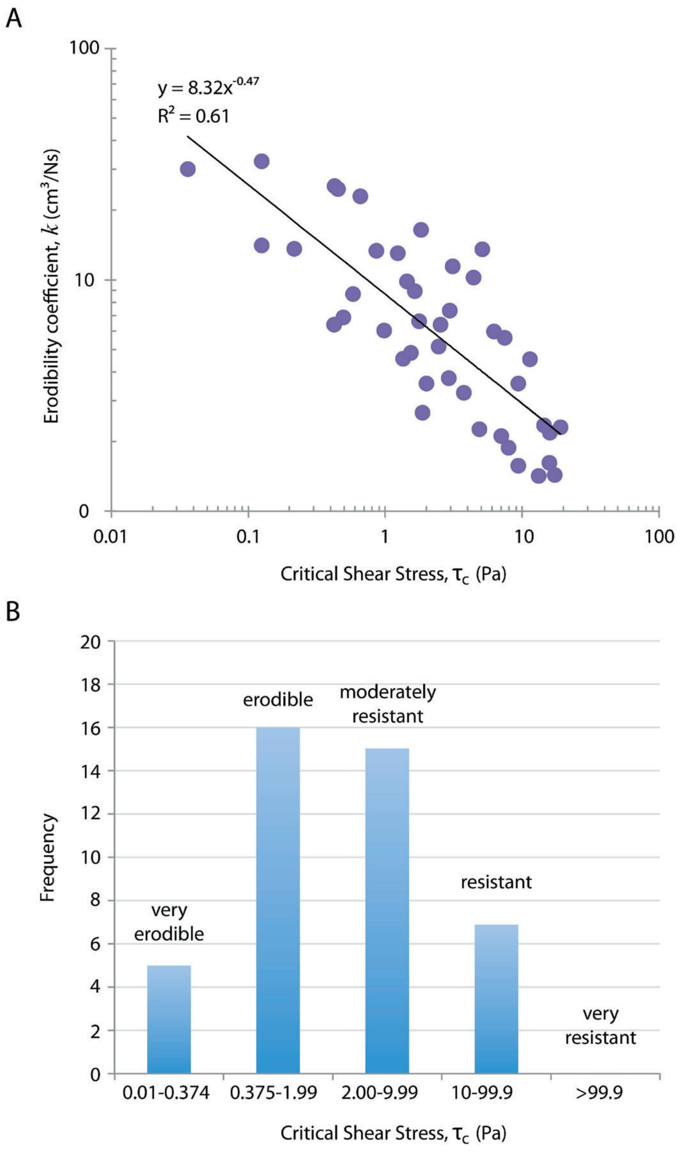

Figure 16. A) Relationship between critical shear stress and the erodibility coefficient; B) Frequency distribution of critical shear stress values from jet-test results.

other studies (e.g., Hanson and Simon, 2001; Shugar et al., 2007; Thoman and Niezgoda; 2008) and has typically been attributed to varying degrees of subaerial exposure. Subaerial processes, such as frost heave and soil desiccation, are climate controlled weathering phenomena that weaken the strength of bank material, making it more susceptible to erosion (e.g., Thorne, 1982). However, in our study each bank-face was cleaned before jet testing to remove bank material exposed to subaerial processes. Of greater importance is the recognition that each member of the DeForest Formation has a different weathering history, indicated by the different degrees of soil-formation (Tables 1, 3 and 5). Therefore, variability in the erodibility observed *within* each member (Figure 17A) can in part be attributed to different magnitudes of post-depositional soil-forming processes. For example, the average critical shear stress values for weathered (Bt horizon) versus unweathered sediments (C horizon) of the Gunder member are 5.0 Pa and 15.0 Pa, respectively. Similarly, average τ_c values for A horizons versus unweathered C horizons of the Camp Creek Member are 0.5 Pa and 1.4 Pa, respectively. The Bt horizons of the Gunder Member typically have prismatic structure that parts to blocky peds. The fracture planes along ped faces provide an avenue of weakness that may be exploited by flowing water compared to the more massive and cohesive C horizons tested in outcrop. The A horizons in the Camp Creek Member generally have extremely friable granular structure and numerous biogenic features that tend to loosen the soil matrix. In contrast, the C horizons of the Camp Creek Member are commonly stratified and have few biogenic features. Generally, the data suggest that soil-forming processes reduce the critical shear stress of fine-grained bank material.

Variability in the erosive resistance *within* each member can also be explained by the inherent variability of the alluvial parent material. For example, τ_c values for the unweathered C horizon of the Gunder Member range from 9.3 Pa to 19.0 Pa. Similarly, τ_c values for till deposits (all from the BCk horizon) range from 1.5 Pa to 11.3 Pa; likely as a result of the variability inherent in the glacial sediments. The intrinsic variability of the parent material can also been seen in the range of particle size distributions for unweathered (C horizon) DeForest Formation alluvium (Tables 2, 4 and 6).

Overall, we conclude that the wide variation in τ_c and *k* observed in this study (Figure 16) and the high coefficient in equation 3 reflects the strong lithologic and pedologic contrast *between* the various members of the DeForest Formation. Furthermore, the variability *within* members of the DeForest formation (Figure 17) can be attributed to the magnitude of weathering from pedogenic processes as well as the inherent variability in the alluvial and glacial parent material. Therefore, the nature of stratification is an important and often neglected consideration for accurately assessing streambank erodibility.

Erodibility results show a weak positive correlation ($R^2 = 0.229$) between percent clay content and τ_c (Figure 18A). This relationship therefore provides a useful tool for approximating the erodibility of streambanks based on grain-size data. Results also indicate that resistance to erosion by fluid flow (i.e. higher τ_c values) is significantly greater where clay contents exceed around 28%. Clay contents greater than 28% are typically indicative of the Gunder Member of the DeForest Formation (Figure 18B).

In this report we use two empirical equations to estimate τ_c based on grain-size data in order to evaluate jet-test results. Smerdon and Beasley (1961) developed an equation relating τ_c to percent clay (PC) based on flume experiments (equation 4). Julian and Torres (2006) used a third-order polynomial to generate an equation relating τ_c to percent silt-clay (SC) (equation 5).

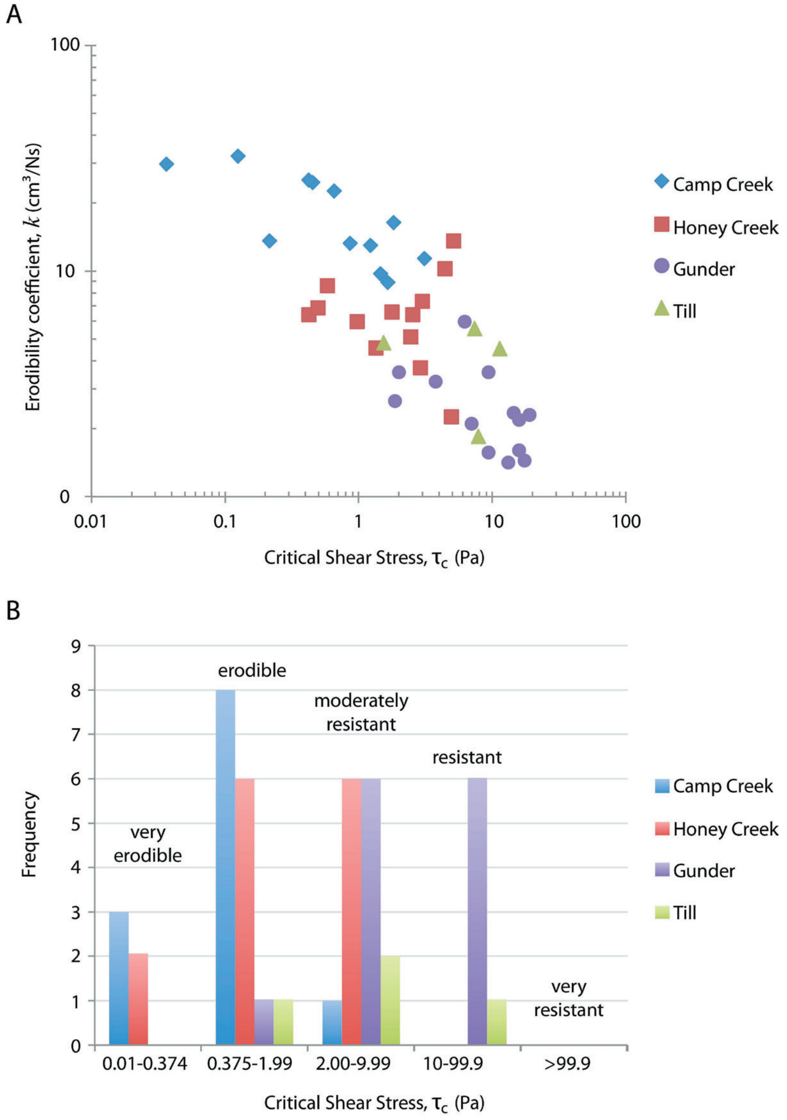

Figure 17. A) Relationship between critical shear stress and the erodibility coefficient (*k*) by stratigraphic member; B) Frequency distribution of critical shear stress values from jet-test results by stratigraphic member.

$$\tau_c = 0.493 \times 10^{0.0182\,PC} \qquad (4)$$

$$\tau_c = 0.1 + 0.1779(SC) + 0.0028(SC)^2 - 2.34E-5(SC)^3 \qquad (5)$$

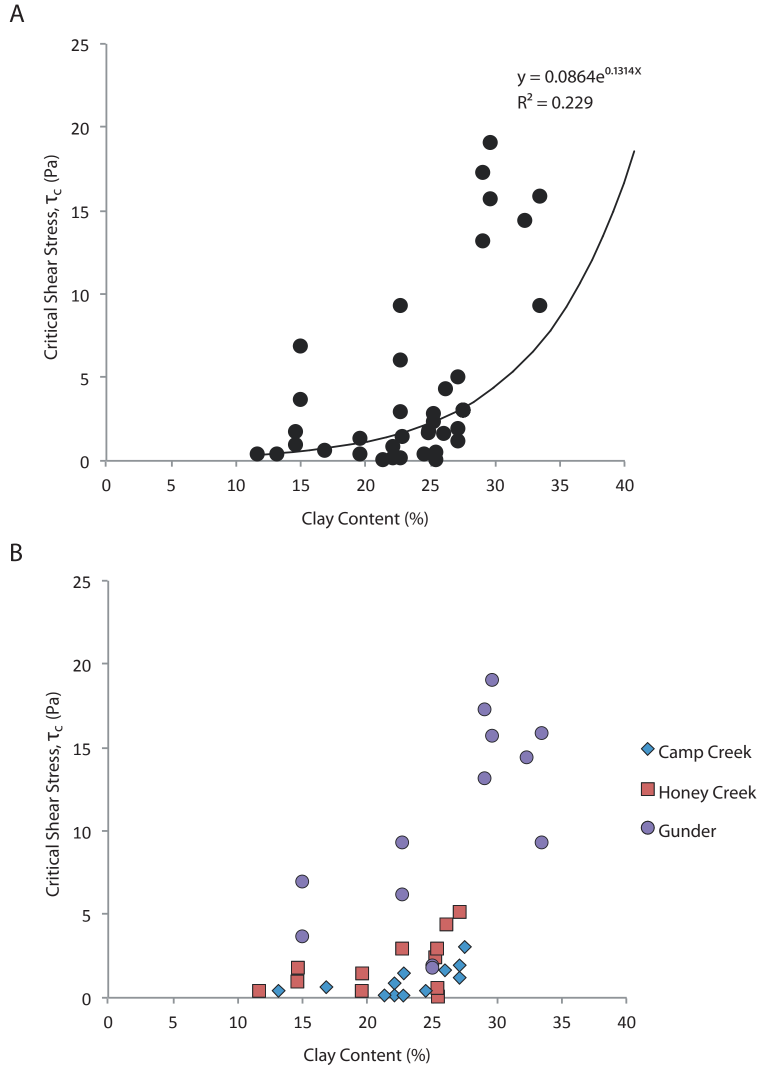

Figure 18. Relationship between clay content and critical shear stress.

Grain-size data (percent clay and percent silt-clay) from samples collected at each jet-test location were input into equations 4 and 5. Results indicate that estimates of τ_c from equation 4 were similar to the results of the jet-test device where percent clay was less than around 28% (Camp Creek and Honey Creek Members) (Figure 19). However, τ_c estimates from equation 4 were significantly lower than jet-test results where clay contents exceeded 28% (Gunder Member). The τ_c estimates from equation 5 are all significantly higher than those measured with the jet-test device and estimated with equation 4.

Clark and Wynn (2007) compared jet-test results from alluvial sediments in southwest Virginia with a variety of empirical equations developed for estimating τ_c, including equations 4 and 5. They found that the τ_c values from jet testing were as much as four orders of magnitude greater than those calculated by equation 4 but statistically lower than τ_c values based on equation 5. The differences between the empirical and jet-test results were attributed to the remolding and reconstitution of sediments used to develop the empirical equations, which likely altered sediment structure. Additionally, they note that these equations rely on a single soil parameter (particle size). In contrast, jet-test results better reflect the cumulative effects of texture, mineralogy, moisture content, and cohesion because the jet-test is conducted on *in-situ* material in the field.

A recent report and supplemental data provided by The Watershed Institute (TWI, 2013) provides cross-sectional profiles of streambanks and bankfull indicators for some of the sites investigated in this study. Bankfull stage corresponds to the discharge at which channel maintenance is the most effective and results in the average morphologic characteristics of a channel (Dunne and Leopold, 1978). Although extreme discharge events transport large quantities of sediment per event and smaller flows convey sediment more frequently, intermediate flow regimes (represented by bankfull discharges) typically transport the greatest quantity of sediment because of the higher frequency of occurrence for such events (Wolman and Miller, 1960). Bankfull discharges typically have a 1.5-year recurrence interval (Dunne and Leopold, 1978). In the study area, Foster et al. (2012) found that strong storms in May and June transported 97% and 71% of the annual sediment load for 2011 in the Banner Lake and Centralia Lake watersheds, respectively. The discharges associated with these storms likely represent bankfull events in these watersheds.

Bankfull stage elevations provided by The Watershed Institute are presented in Figure 20, where data were available. Although jet-test results indicate that the Camp Creek Member was the most erodible member of the DeForest Formation, it always occurs, stratigraphically, as the uppermost member. Bankfull stage data indicate that bankfull discharges rarely attain elevations sufficient to erode Camp Creek Member deposits. Therefore, other members of the DeForest Formation, particularly the more resistant Gunder Member, are able to exert some control on the rate of bank erosion.

Based upon the alluvial stratigraphy and results of jet-testing, the Atchison Lake watershed contains the most erodible sediments (predominantly Camp Creek and Honey Creek Members). We would therefore expect to see higher sediment yields from streambank sources in this watershed. However, recent reports by Foster et al. (2012) and TWI (2013) indicate that sediment yields are higher in the Centralia Lake watershed. Sediment yields from in-channel sources were estimated at 2,065 tons per square mile in Centralia Lake watershed and 943 tons per square mile in Atchison County Lake watershed (TWI, 2013). Measurements of sediment yields from USGS monitoring sites between March 2009 and September 2011 indicate that total sediment yields at Centralia were about 2.7 times that of Atchison and Banner (Foster et al., 2012).

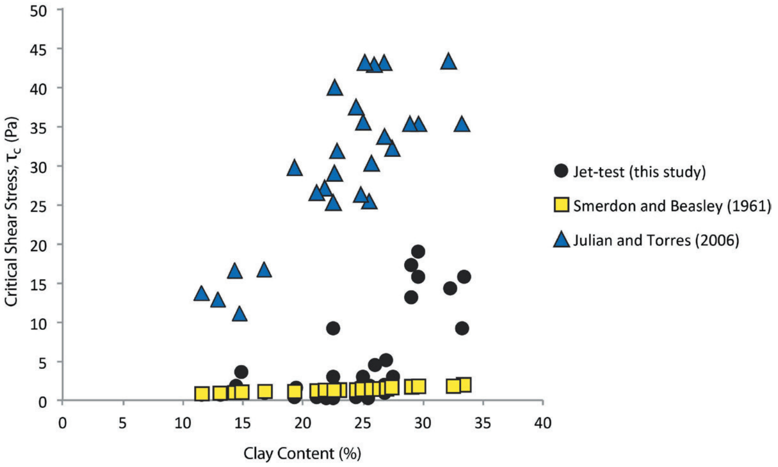

Figure 19. Comparison of jet-test results and estimates of critical shear stress from empirical equations. Note that although Julian and Torres (2006) use percent silt-clay data points are plotted based on percent clay in order to facilitate comparison.

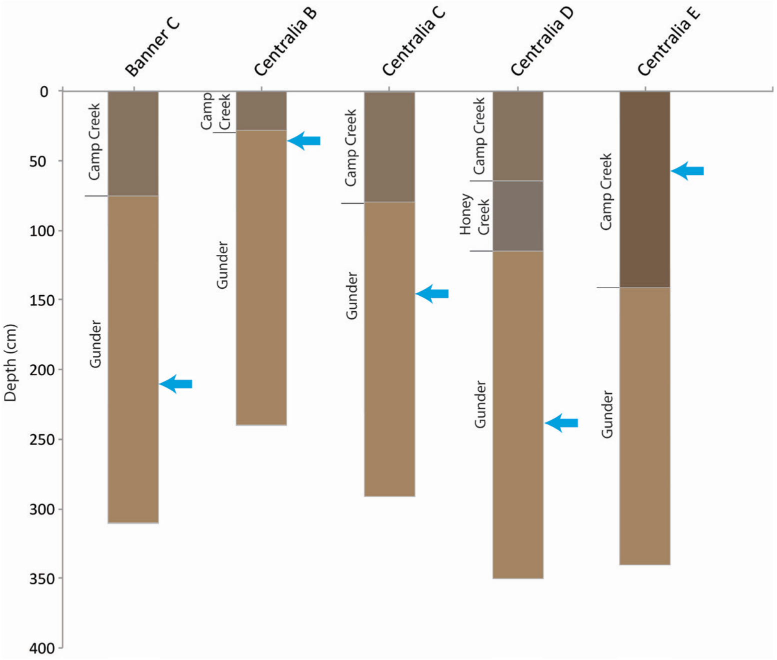

Figure 20. Bankfull stage elevations (blue arrows) at select sites in the study area watersheds.

Erodibility results (this study) together with the differences in measured and estimated sediment yields between Centralia and the other watersheds suggest that the entrainment of sediments from streambanks by flowing water (i.e. hydraulic forces) may not the primary process contributing to documented sediment yields. However, streambanks have still been shown to be a significant source of sediment in the study area (e.g., Juracek and Ziegler, 2007). Therefore, factors other than the entrainment of sediment by fluid flow should be considered. In particular, streambank failures due to mass-wasting processes (i.e. gravitational forces) contribute significant amounts of sediment to stream channels (see Thorne, 1982 and Simon et al., 2000). In the study area, numerous bank failures were observed, particularly in the Centralia Lake watershed. The erosion of sediments by fluvial processes typically increases the height and angle of the bank to the point where gravitational forces exceed the shear strength of the bank material, promoting streambank failure (Osman and Thorne, 1988). Centralia Lake has been shown to have deeper channels and greater stream power due to channelization (TWI, 2013), which increases the likelihood of streambank failures and consequently the amount of sediment contributed to the channel. Investigating the relationship between the erodibility of streambanks and the geotechnical strength of the bank material in Kansas' watersheds should be a focus of future study in order to better quantify sediment contributions from streambanks. Other causes of streambank failure include positive pore water pressure after rapid draw-down (Simon et al., 2000), groundwater seepage (Fox et al., 2007) and the formation of tension cracks (Thorne, 1982). Also, mass-wasting processes are driven by the degree of channel adjustment. For example, Simon and Rinaldi (2000) found that unstable stream channels in the Midwest are undergoing system-wide channel adjustment processes as a result of human modifications to drainage basins and stream channels. In particular, they identified mass-wasting processes as the dominant adjustment process. Similar human modifications have been identified in the study area. For example, Foster et al. (2012) highlight the degree of channel straightening, fewer riparian buffers, tile drainage and upstream sub-impoundments in the Centralia watershed.

Conclusions

The primary objectives of this study were to measure the erodibility of the different members of the DeForest Formation and to map their spatial distribution along streams that flow into Banner Creek, Centralia, and Atchison County lakes in northeastern Kansas. We tested whether particular soil series shown on county soil survey maps corresponded to particular members of the DeForest Formation. Surface soils on T-1 surfaces are mapped as the Chase or Reading series. Results of our investigation indicate that these soil series accurately represent the Gunder Member of the DeForest Formation. Surface soils on the T-0 surface are mapped as the Kennebec soil series. Results indicate that the Kennebec soil series accurately represents the Camp Creek Member of the DeForest Formation in the Banner and Centralia Lake watersheds. However, in the Atchison County Lake watershed the Kennebec surface soil is developed in the Honey Creek Member. Therefore, while soil maps can provide a reasonable first approximation of the horizontal distribution of members of the DeForest Formation at the surface, spatial relationships must be confirmed by field mapping. Of greater importance, however, is the documented complexity in the vertical relationships between the various members, which has important implications for streambank erodibility.

Distinct differences in erodibility were observed between the different members of the DeForest Formation, which has important implications for streambank erosion by fluid flow. The most erodible member is the Camp Creek Member, which largely consist of very erodible to erodible bank material. The Honey Creek Member is mostly comprised of erodible to moderately resistant materials. The most resistant member of the DeForest Formation is the Gunder Member, which consists of moderately resistant to resistant material. Glacial till displayed a similar erosive resistance and distribution of τ_c values to the Gunder Member.

Based on grain-size analysis, variability within members of the DeForest formation occurs. This variability is attributed to the magnitude of weathering from pedogenic processes as well as the inherent variability in the alluvial and glacial parent material, which highlights the importance of assessing litho- and soil-stratigraphic relationships in streambanks. Grain-size results also indicated a weak positive correlation between clay content and τ_c, that may provide a useful tool for approximating the erodibility of streambanks based on grain-size data. Resistance to erosion by fluid flow (i.e., higher τ_c values) was found to be significantly greater where clay contents exceed approximately 28%.

Although jet-test results indicate that the Camp Creek Member was the most erodible member of the DeForest Formation, it always occurs, stratigraphically, as the uppermost member. Bankfull stage data indicate that bankfull discharges rarely attain elevations sufficient to erode Camp Creek Member deposits. Therefore, other members of the DeForest Formation, particularly the more resistant Gunder Member, are able to exert some control on the rate of bank erosion. However, consideration of other mechanisms of bank erosion is important when assessing sediment contributions from streambanks. This study has shown that the erodibility of the different members of the DeForest Formation varies, and it is therefore likely that the susceptibility to mass wasting processes also varies between the different members. Investigating the relationship between the erodibility of streambanks and the geotechnical strength of the bank material, in the context of stratigraphic relationships, should be the focus of future study in order to better quantify sediment contributions from streambanks. Overall, determining the vertical relationships between the different members of the DeForest formation is important for accurately determining likely areas of streambank erosion in Midwestern streams.

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