Kansas Water Resources Research Institute
Annual Technical Report
FY 2012

Introduction

The Kansas Water Resources Institute (KWRI) is part of a national network of water resources research institutes in every state and territory of the U.S. established by law in the Water Resources Research Act of 1964. The network is funded by a combination of federal funds through the U.S. Department of the Interior/Geological Survey (USGS) and non-federal funds from state and other sources.

KWRI is administered by the Kansas Center for Agricultural Resources and the Environment (KCARE) at Kansas State University. An Administrative Council comprised of representatives from participating higher education or research institutions, state agencies, and federal agencies assists in policy making.

The mission of KWRI is to: 1) develop and support research on high priority water resource problems and objectives, as identified through the state water planning process; 2) facilitate effective communications among water resource professionals; and 3) foster the dissemination and application of research results.

We work towards this mission by: 1) providing and facilitating a communications network among professionals working on water resources research and education, through electronic means, newsletters, and conferences; and 2) supporting research and dissemination of results on high priority topics, as identified by the Kansas State Water Plan, through a competitive grants program.

Research Program Introduction

Our mission is partially accomplished through our competitive research program. We encourage the following through the research that we support: interdisciplinary approaches; interagency collaboration; scientific innovation; support of students and new young scientists; cost-effectiveness; relevance to present and future water resource issues/problems as identified by the State Water Plan; and dissemination and interpretation of results to appropriate audiences.

In implementing our research program, KWRI desires to: 1) be proactive rather that reactive in addressing water resource problems of the state; 2) involve the many water resources stakeholders in identifying and prioritizing the water resource research needs of the state; 3) foster collaboration among state agencies, federal agencies, and institutions of higher education in the state on water resource issues; 4) leverage additional financial support from state, private, and other federal sources; and 5) be recognized in Kansas as a major institution to go to for water resources research.

Sediment Baseline Assessment

Basic Information

Title:	Sediment Baseline Assessment
Project Number:	2009KS71B
Start Date:	3/1/2010
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	2nd
Research Category:	Climate and Hydrologic Processes
Focus Category:	Sediments, Water Quality, None
Descriptors:	
Principal Investigators:	Dan Devlin, Will Boyer, Brock Emmert, Bruce McEnroe, DeAnn Presley, C. Bryan Young

Publications

There are no publications.

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

Mark Jakubauskas, Frank R. deNoyelles, Jr., Edward A. Martinko, Paul Liechti, and Scott Campbell. Kansas Biological Survey, University of Kansas, Lawrence, KS.

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).

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 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 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.

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 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.

Literature Cited

Hilton, J., Lishman, P., and Millington, A. 1986. A comparison of some rapid techniques for the measurement of density in soft sediments. *Sedimentology* (33):777-781.

Ketterer, M.E., Hafer, K.M., Jones, V.J., Appleby, P.G. 2004. Rapid dating of recent sediments in Loch Ness: Inductively coupled plasma mass spectrometric measurements of global fallout plutonium. *The Science of the Total Environment*, 322, 221-229.

Ketterer, M.E., Watson, B.R., Matisoff, G., and Wilson, C.G. 2006. Rapid dating of recent aquatic sediments using Pu activities and 240Pu/239Pu as determined by quadrupole inductively coupled plasma mass spectrometry. *Environmental Science & Technology* 36:(6), 1307-1311.

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	1055.4
Banner	480	7395	14.7	36.6	1078.1
Centralia	374	4006	10.3	27.4	1265.5

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			

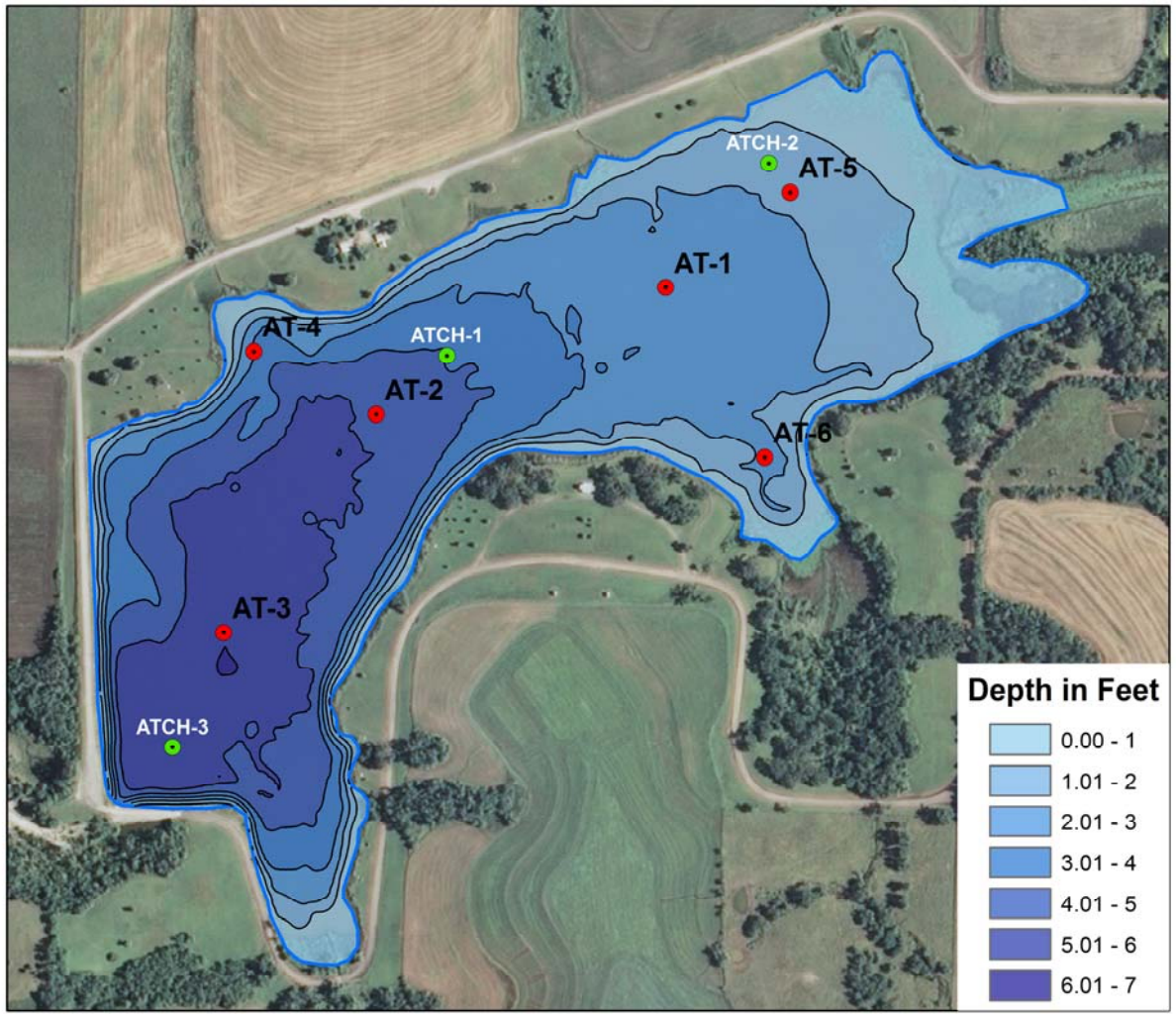

Figure 1. Depth map and coring locations for Atchison County Lake.

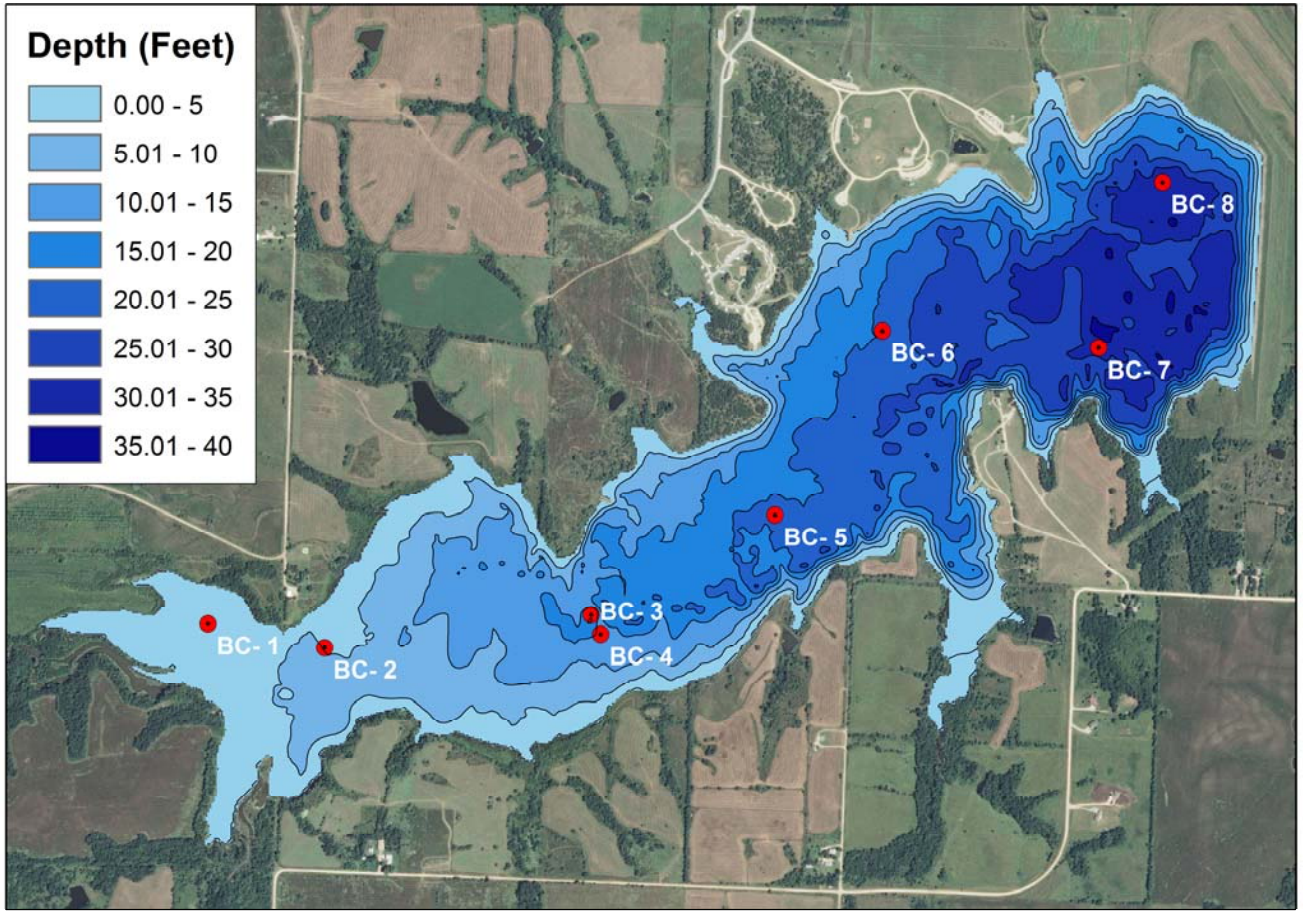

Figure 2. Depth map and coring locations for Banner Creek Reservoir.

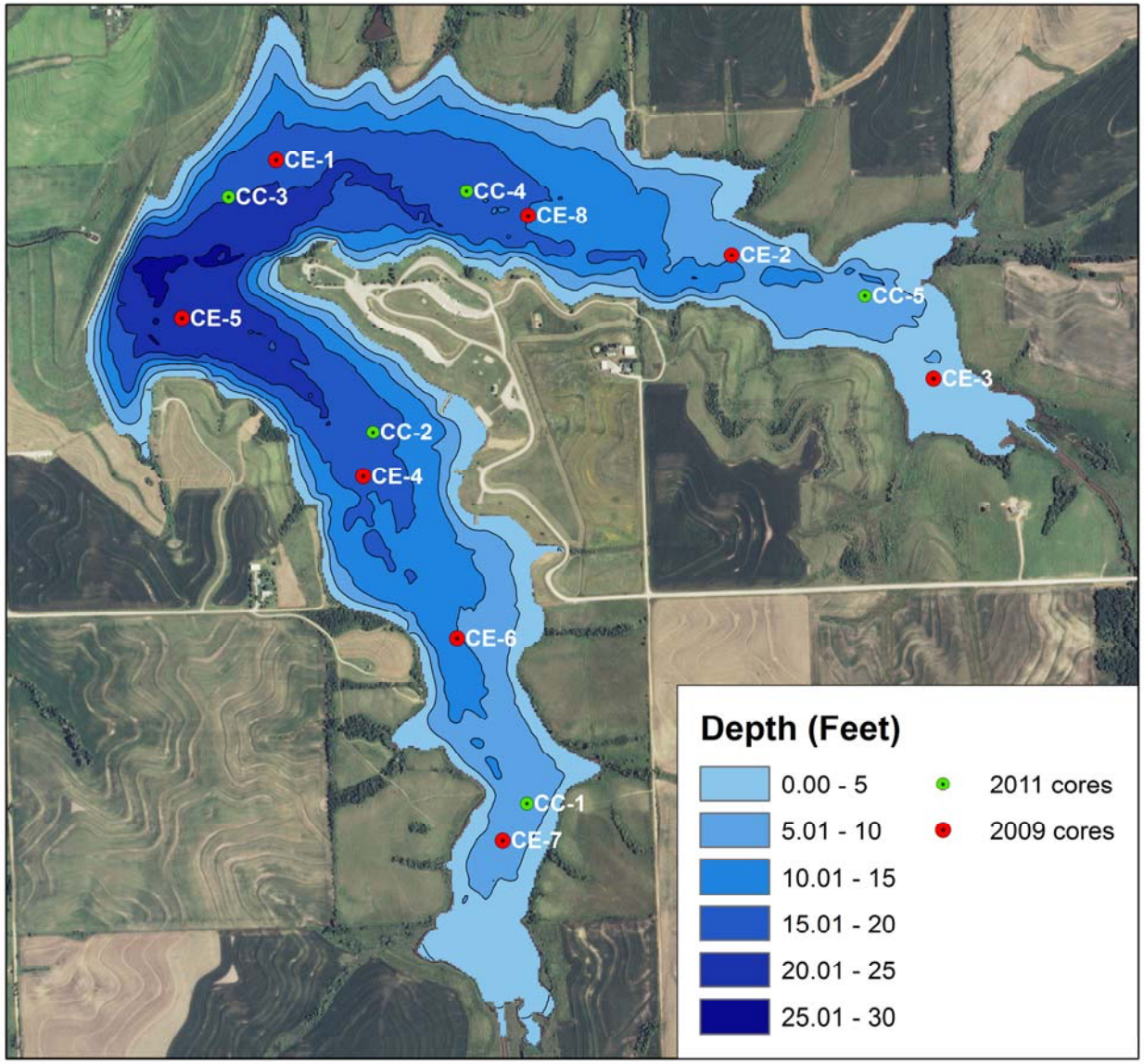

Figure 3. Depth map and coring locations for Centralia City Lake.

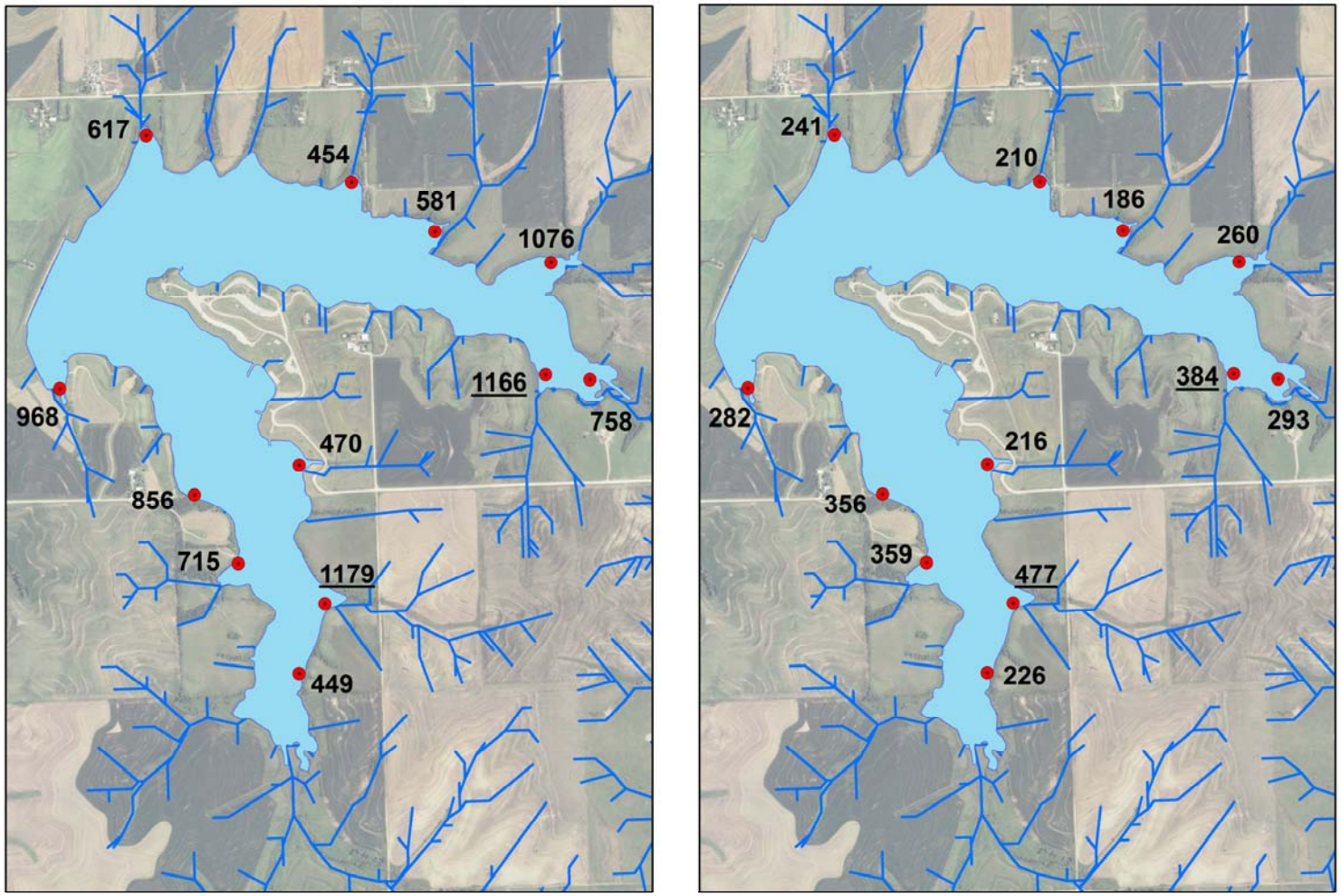

Figure 4. Nutrient data at spot sample locations in Centralia City Lake. Left: Total nitrogen in parts per million (ppm). Right: Total phosphorus in ppm.

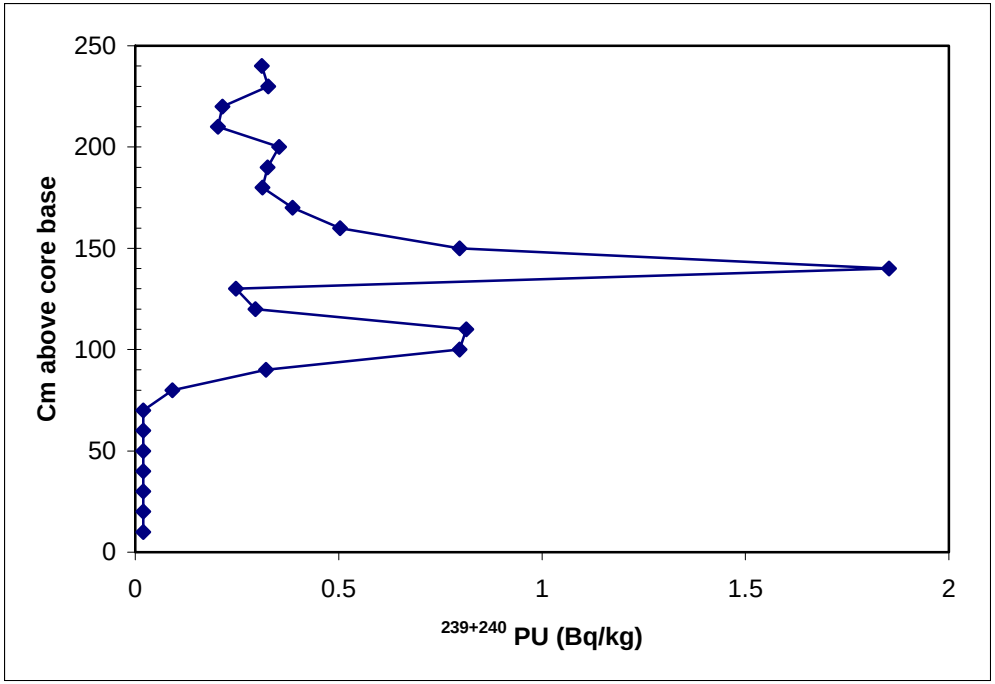

Figure 5. Radionuclide levels ($^{239+240}$Pu) in 10-cm slices of core AT-2 from Atchison County Lake.
Figure 6.

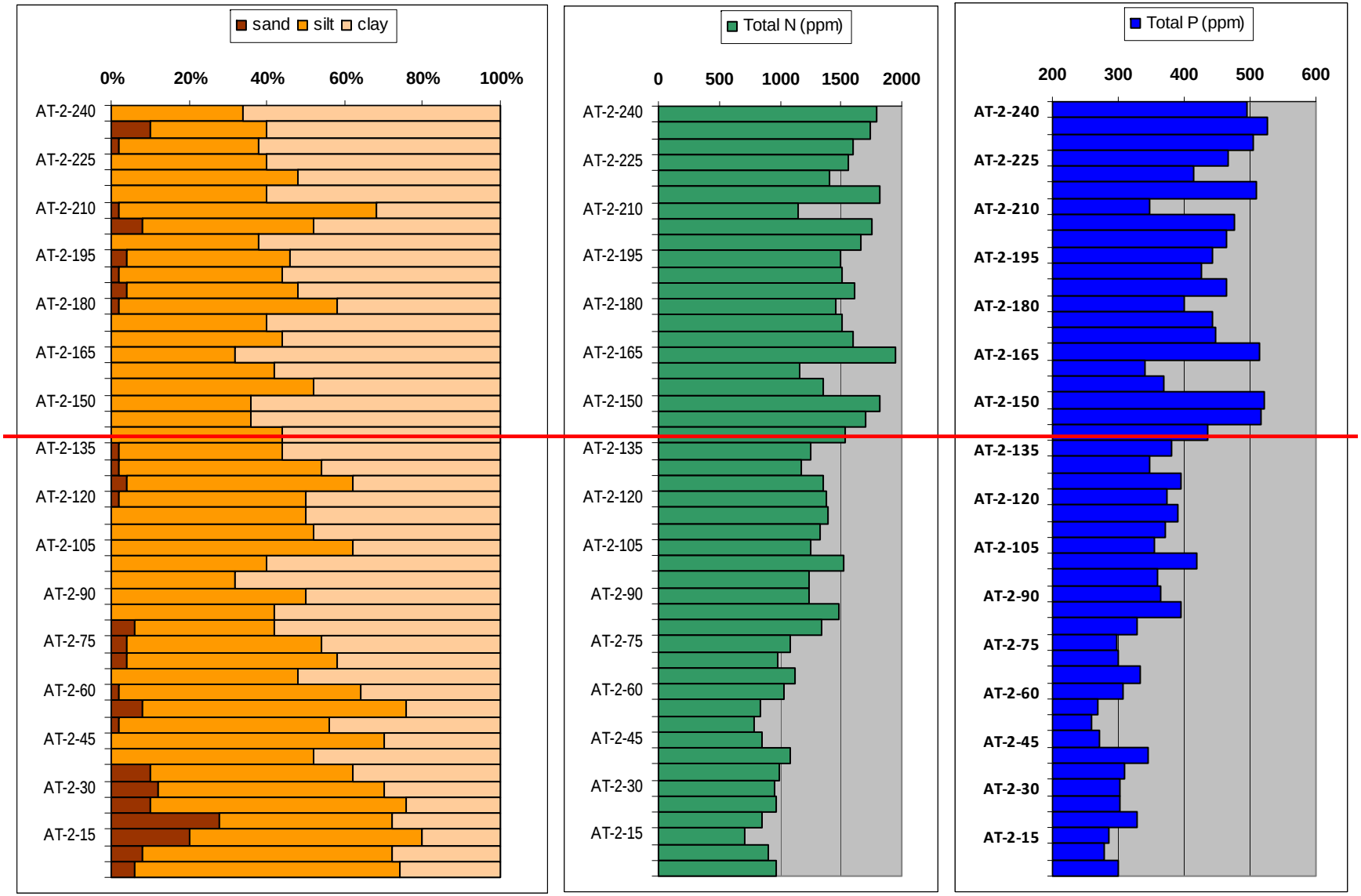

Figure 6. Texture analysis, total nitrogen (ppm), and total phosphorus (ppm) in 10-cm sections of core AT-2, Atchison County Lake.

ASSESSING THE BASELINE STREAMFLOW AND SEDIMENT CONTRIBUTION IN THREE WATERSHEDS OF NORTHEAST KANSAS WITH SWAT

Aleksey Y. Sheshukov[1], Kyle R. Douglas-Mankin[2], Daniel L. Devlin[3]

1. 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 5,795 to 12,447acres 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 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.

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2. INTRODUCTION

The Great Plains streams and ecosystems, integral parts of the diminishing North American 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" sediment load 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 of non-point source pollution 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.

3. MATERIALS AND METHODS

3.1. 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).

3.1.1. 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 according to the classification used in Devlin and Boyer (2012). 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.

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.

3.1.2. 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. Several 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 north-west of the USGS station and at elevation 1030 m (NCDC, 2010).

3.1.3. 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).

3.2. SWAT MODELS

3.2.1. 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 simulated 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):

$$SED = R_{MUSLE} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG$$

where $R_{MUSLE} = 11.8(RO \cdot q_{PEAK} \cdot A_{HRU})^{0.56}$ is the daily runoff factor, q_{PEAK} 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 soil surface erosion to be simulated on a daily basis. Additional sources of channelized overland 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 of stream flow and pollutant loads (Neitsch et al., 2004, 2005).

3.2.2. 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). The 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).

The 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.

3.2.3. 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 (R^2), 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.

3.3. 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):

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

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 R^2>98%) was selected for the SWAT simulation.

4. 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 overall difference in annual water yield averaged over less than 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). The presence of dams in several lakes/ponds within the ACLW that was not accounted in the SWAT model might improve the comparison and force a reduction in sediment yields.

There is another important factor that can increase sediment yield in agricultural watersheds and was not fully accounted in SWAT: 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 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 subwatershed 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, tile drainage, and crop rotations among others.

5. 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, 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).

6. RECOMMENDATIONS FOR FUTURE RESEARCH

- 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.
- Continue sediment (turbidity) monitoring for longer time periods for better understanding of sediment sources in a watershed 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.
- Survey watersheds for existence of ponds and incorporate pond outlet flows in the SWAT model.

7. REFERENCES

Arnold, J. G., R. Srinivasan, R. S. Muttiah, and J. R. Williams. 1998. Large-area hydrologic modeling and assessment: Part I. Model development. J. American Water Resour. Assoc. 34(1): 73-89.

BASINS. 2010. Better Assessment Science Integrating point and Non-point Sources (BASINS). EPA. Available at: http://water.epa.gov/scitech/datait/models/basins/index.cfm.

Brunsell, N. A., A. R. Jones, T. L. Jackson, and J. J. Feddema. 2010. Seasonal trends in air temperature and precipitation in IPCC AR4 GCM output for Kansas, USA: evaluation and implications. International J. Climatology 30: 1178-1193.

Chow, V. T., D. R., Maidment, and L. W. Mays. 1988. Applied Hydrology. McGraw-Hill, Inc. USA

Daggupati, P., K. R. Douglas-Mankin, A. Y. Sheshukov, P. L. Barnes, and D. L. Devlin. 2011. Field-Level Targeting using SWAT: Mapping Output from HRUs to Fields and Assessing Limitations of GIS Input Data. Trans. ASABE 54(2): 501-514.

Devlin, D. and W. Boyer. 2012. Surveying land use and agricultural management practices in Atchison County Lake, Banner Creek Lake and Centralia City Lake watersheds. (this report publication).

Devlin, D. L., W. L. Hargrove, J. C. Leatherman, K. R. Mankin, and R. M. Wilson. 2005. Using WRAPS to implement TMDLs in Kansas. In Proc. 3rd Conf. Watershed Mgmt. to Meet Water Quality Standards and Emerging TMDL. ASABE Paper No. 701P0105. St. Joseph, Mich.: ASABE.

Dodds, W. K., K. Gido, M. R. Whiles, K. M. Fritz, and W. J. Matthews. 2004. Life on the Edge: The Ecology of Great Plains Prairie Streams. BioScience. 54(3): 205-216.

Douglas-Mankin, K. R., R. Srinivasan, and J. G. Arnold. 2010. Soil and Water Assessment Tool (SWAT) model: Current developments and applications. Trans. ASABE 53(5): 1423-1431.

Douglas-Mankin, K. R., P. Daggupati, A. Y. Sheshukov, and P. L. Barnes. 2012. Paying for sediment: Field-scale conservation practice targeting, funding, and assessment using SWAT. J. Soil Water Conserv. (accepted)

Gassman, P. W., M. R. Reyes, C. H. Green, and J. G. Arnold. 2007. The Soil and Water Assessment Tool: Historical development, applications, and future research directions. Trans. ASABE 50(4): 1211-1250.

IPCC. 2000. Special Report on Emission Scenarios. Cambridge University Press, UK: Intergovernmental Panel on Climate Change.

IPCC. 2007. Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland.

Karl, T. R., J. M. Melillo, and T. C. Peterson, (eds.). 2009. Global Climate Change Impacts in the United States. Cambridge University Press.

KDHE, 2010. Jefferson, Nemaha, Jackson, and Brown Counties Land use/Land cover Survey Data. Kansas Department of Health and Environment, Kansas.

Lee C. and G. Foster. 2010. Kansas Baseline Sediment Project Update Report, USGS Report, Presented Sept. 28, 2010. Available at: http://www.kwo.org/reservoirs/SedimentGroup/ppt_USGS_Flow_Suspended_Sediment_Project_Update_092310.pdf

Moriasi, D. N., J. G. Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel, and T. L. Veith. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans. ASABE 50(3): 885-900.

NCDC. 2010. Climate-radar data inventories. Asheville, N.C.: National Climatic Data Center. Available at: www.ncdc.noaa.gov/oa/ncdc.html

Neitsch, S. L., J. G. Arnold, J. R. Kiniry, R. Srinivasan, and J. R. Williams. 2004. Soil and Water Assessment Tool Input/Output File Documentation, Version 2005. Temple, Tex.: USDA-ARS Grassland, Soil and Water Research Laboratory.

Neitsch, S. L., J. G. Arnold, J. R. Kiniry, and J. R. Williams. 2005. Soil and Water Assessment Tool Theoretical Documentation, Version 2005. Temple, Tex.: USDA-ARS Grassland, Soil and Water Research Laboratory, and Blackland Research and Extension Center.

Nejadhashemi, A. P., S. A. Woznicki, and K. R. Douglas-Mankin. 2011. Comparison of four models (STEPL, PLOAD, L-THIA, SWAT) in simulating sediment, nitrogen, and phosphorus loads and pollutant source areas. Trans. ASABE 54(3): 875-890.

Richardson, C. W. 1981. Stochastic simulation of daily precipitation, temperature and solar radiation. Water Resources Research, Vol. 17(1): 182-190.

Sheshukov, A. Y., C. B. Siebenmorgen, C. B., and K. R. Douglas-Mankin. 2011. Seasonal and annual impacts of climate change on watershed response using an ensemble of global climate models. Trans. ASABE 54(6): 2209-2218.

Siebenmorgen, C. B., A. Y Sheshukov, and K. R. Douglas-Mankin. 2010. Impacts of climate change on hydrologic indices in a northeast Kansas watershed. In Proc. 5th Conf. on Watershed Mgmt. to Meet Water Quality Standards and Emerging TMDLs. St. Joseph, Mich.: ASABE.

Singh, V. P. 1995. Computer Models of Watershed Hydrology. Highlands Ranch, CO: Water Resources Publications.

USDA-NRCS. 2004. National Engineering Handbook. Part 630 Hydrology. Chapter 10. Estimation of Direct Runoff from Storm Rainfall, USDA Natural Resources Conservation Service. Available at: ftp://ftp.wcc.nrcs.usda.gov/wntsc/H&H/NEHhydrology/ch10.pdf.

USDA-NRCS. 2005. Soil data mart. Washington, D.C.: USDA Natural Resources Conservation Service. Available at: http://soildatamart.nrcs.usda.gov.

USDA-NRCS. 2010. Geospatial data gateway. Washington, D.C.: Natural Resources Conservation Service. Available at: http://datagateway.nrcs.usda.gov.

USGS. 2011. Daily streamflow for the nation. Washington, D.C.: U.S. Geological Survey. Available at: http://nwis.waterdata.usgs.gov/nwis.

White, M. J., D. E. Storm, P. R. Busteed, S. H. Stoodley, and S. J. Phillips. 2009. Evaluating Nonpoint Source Critical Source Area Contributions at the Watershed Scale. J. Environ. Qual. 38:1654–1663.

Williams, J. R. 1975. Sediment routing for agricultural watersheds. Water. Resour. Bull. 11(5): 965-974.

Wilson, B. N., A. Y. Sheshukov, and R. Pulley. 2006. Erosion risk assessment tool for construction sites, Minnesota Department of Transportation, Report MN/RC-2006-27, 72 pp. Available at: http://www.lrrb.org/pdf/200627.pdf.

Wischmeier, W. H. and D. D. Smith. 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. Agriculture Handbook No. 537. USDA/Science and Education Administration, US Govt. Printing Office, Washington, DC. 58 pp.

WRAPS. 2011. Kansas Watershed Restoration and Protection Strategies. Topeka, KS. Available at http://www.kswraps.org/

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)

Table 2. Land use classification used in SWAT modeling.

	Land use	Tillage		Terrace	Watershed (% of total)		
		No-till	Conv		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

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

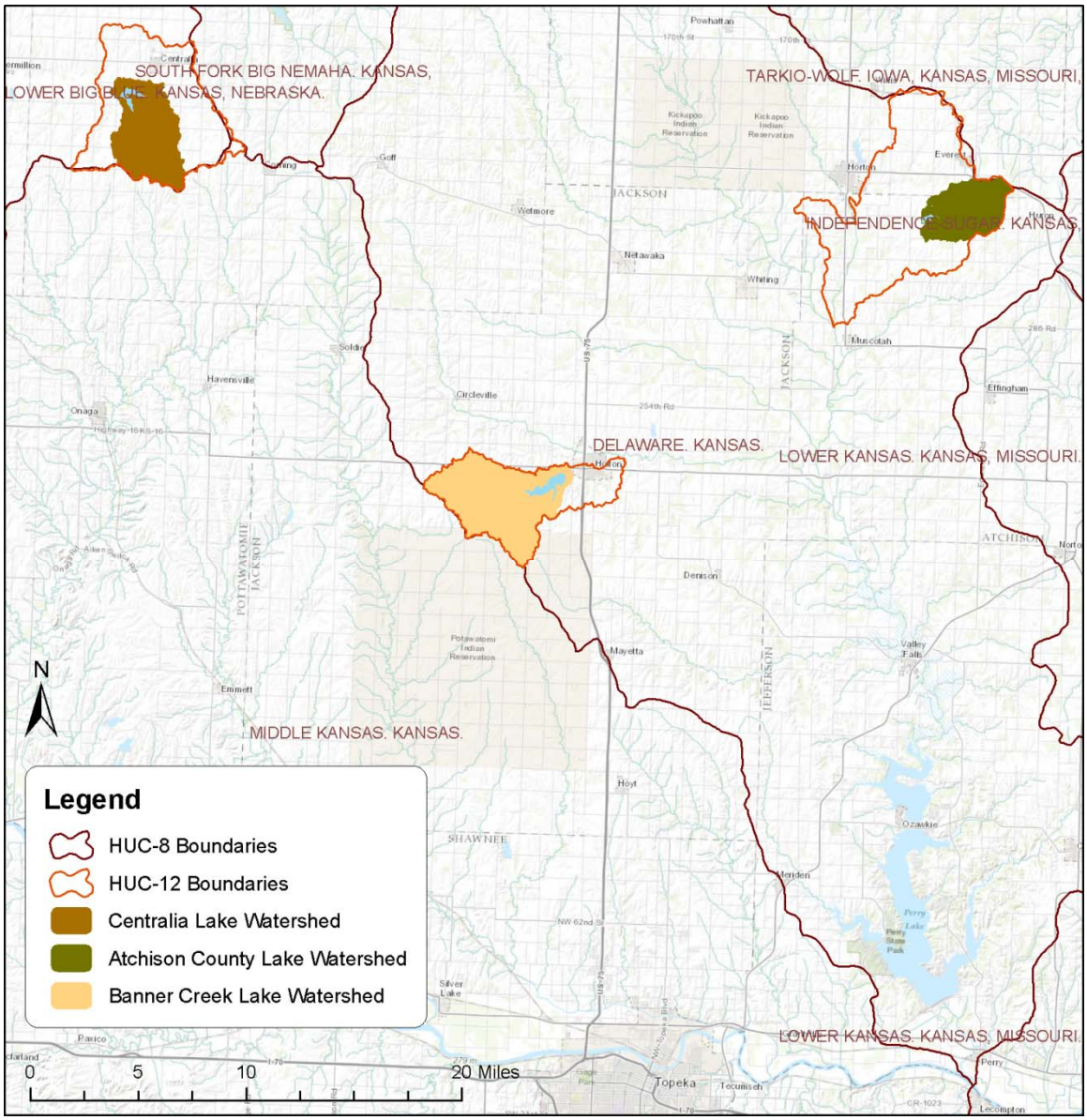
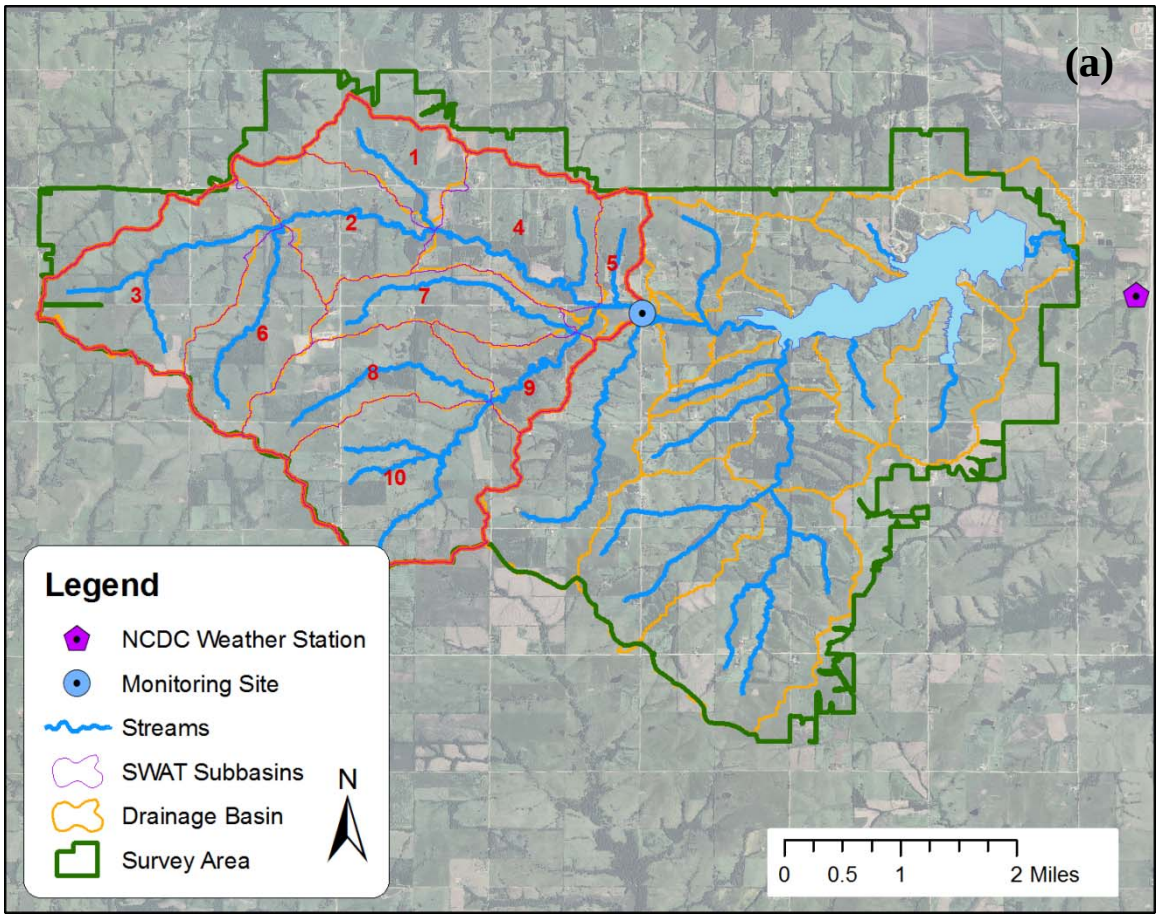
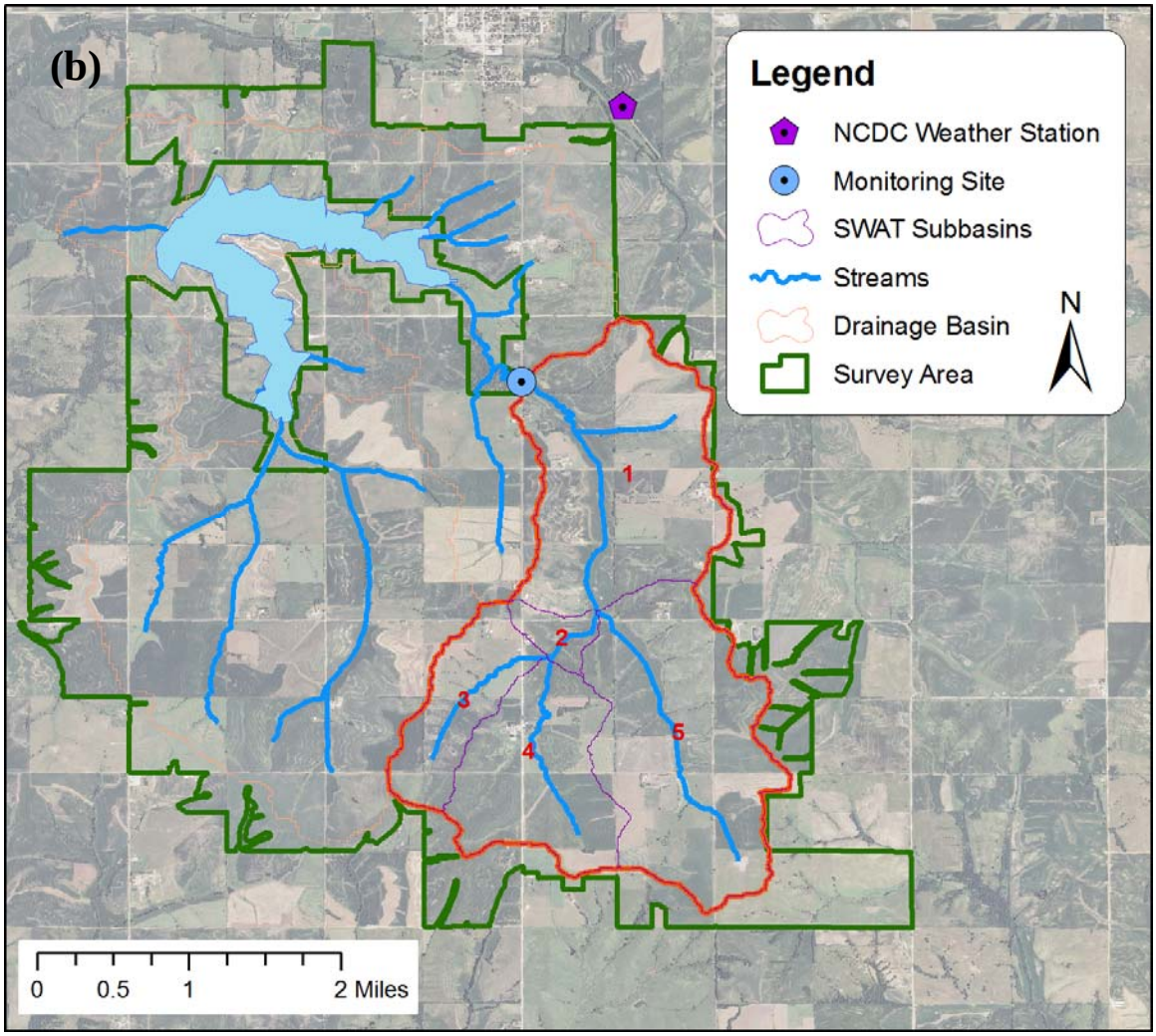


Figure 1. Map of the three studied watersheds located north of Topeka, Kansas.


(a)
1
2
3
4
5
6
7
8
9
10
Legend
NCDC Weather Station
Monitoring Site
Streams
SWAT Subbasins
Drainage Basin
Survey Area
N
0
0.5
1
2 Miles


(b)
Legend
NCDC Weather Station
Monitoring Site
SWAT Subbasins
Streams
Drainage Basin
Survey Area
N
1
2
3
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0
0.5
1
2 Miles

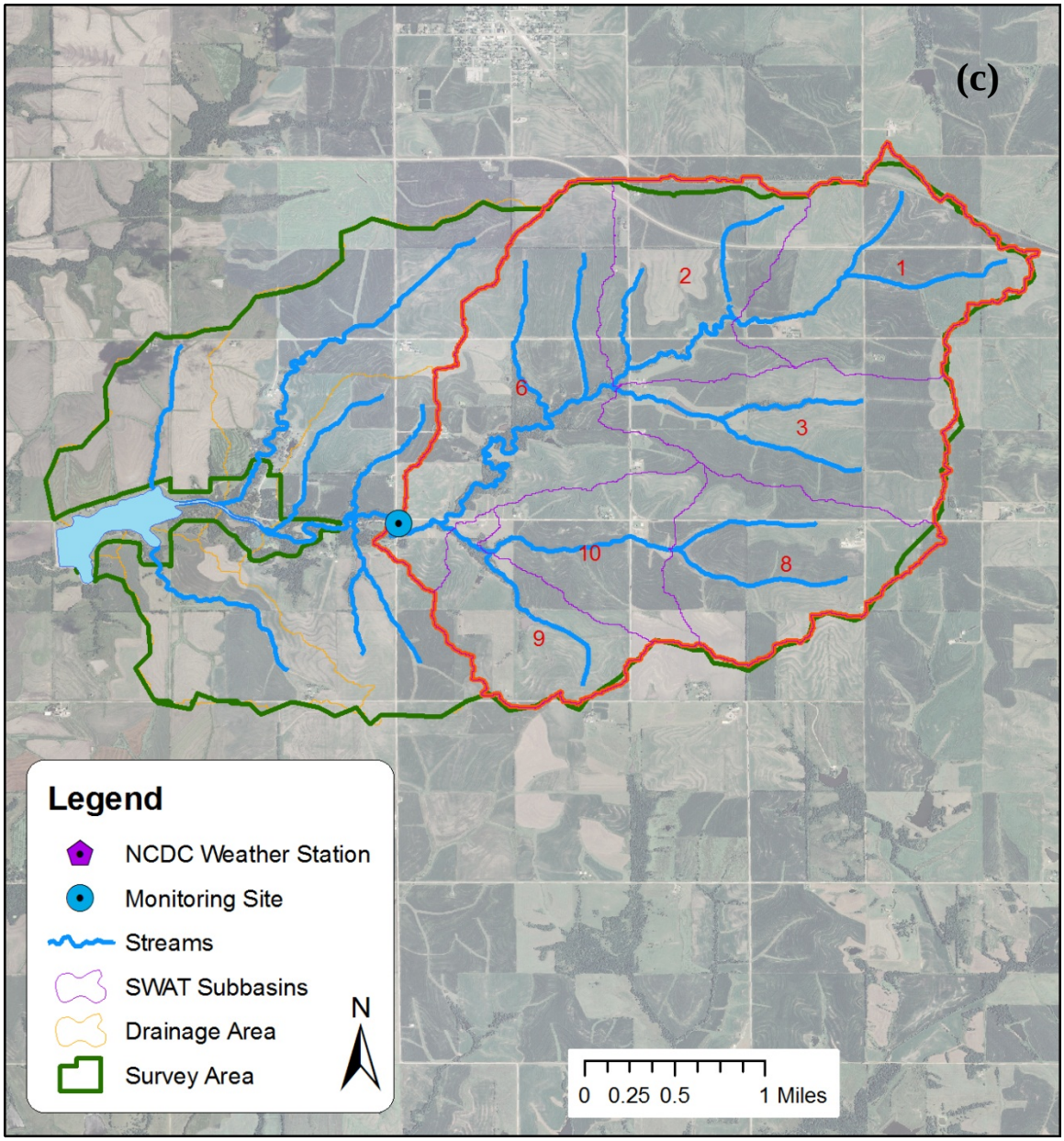
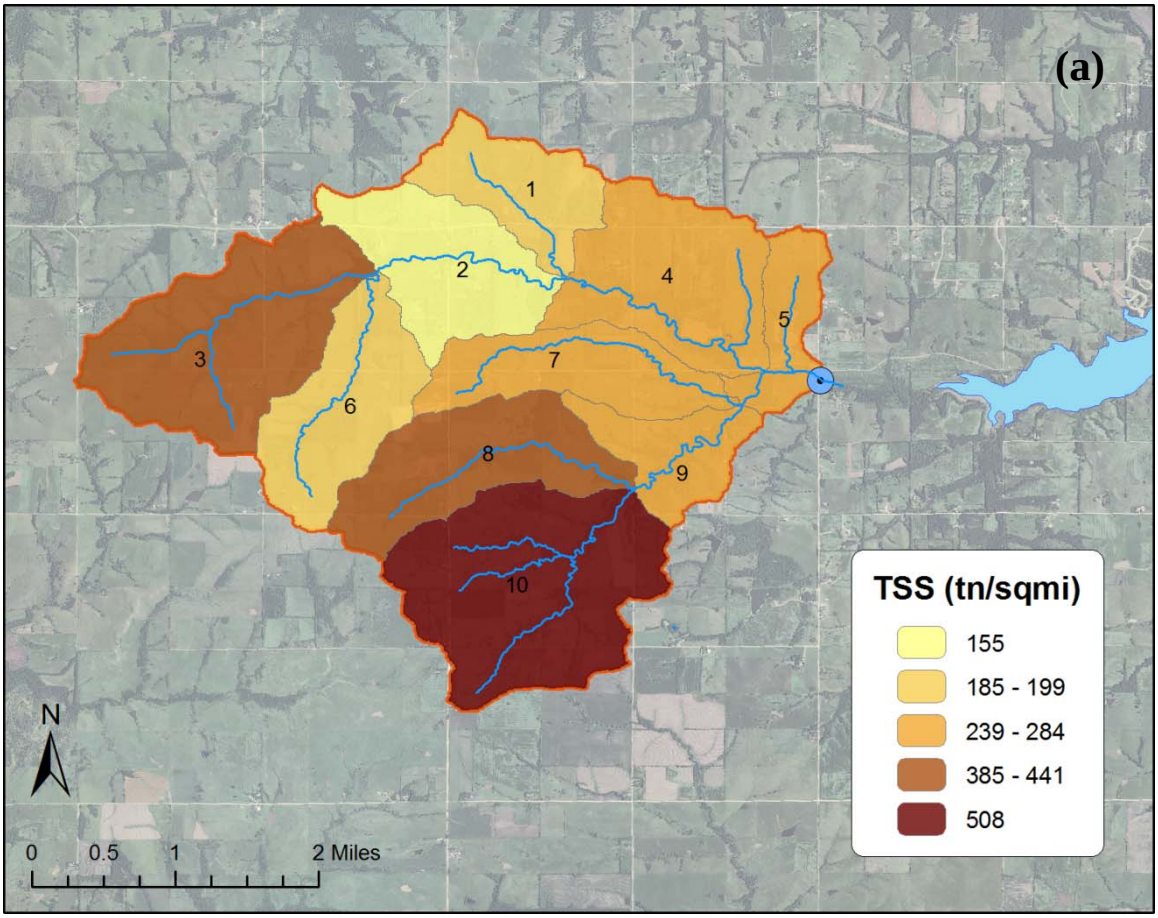
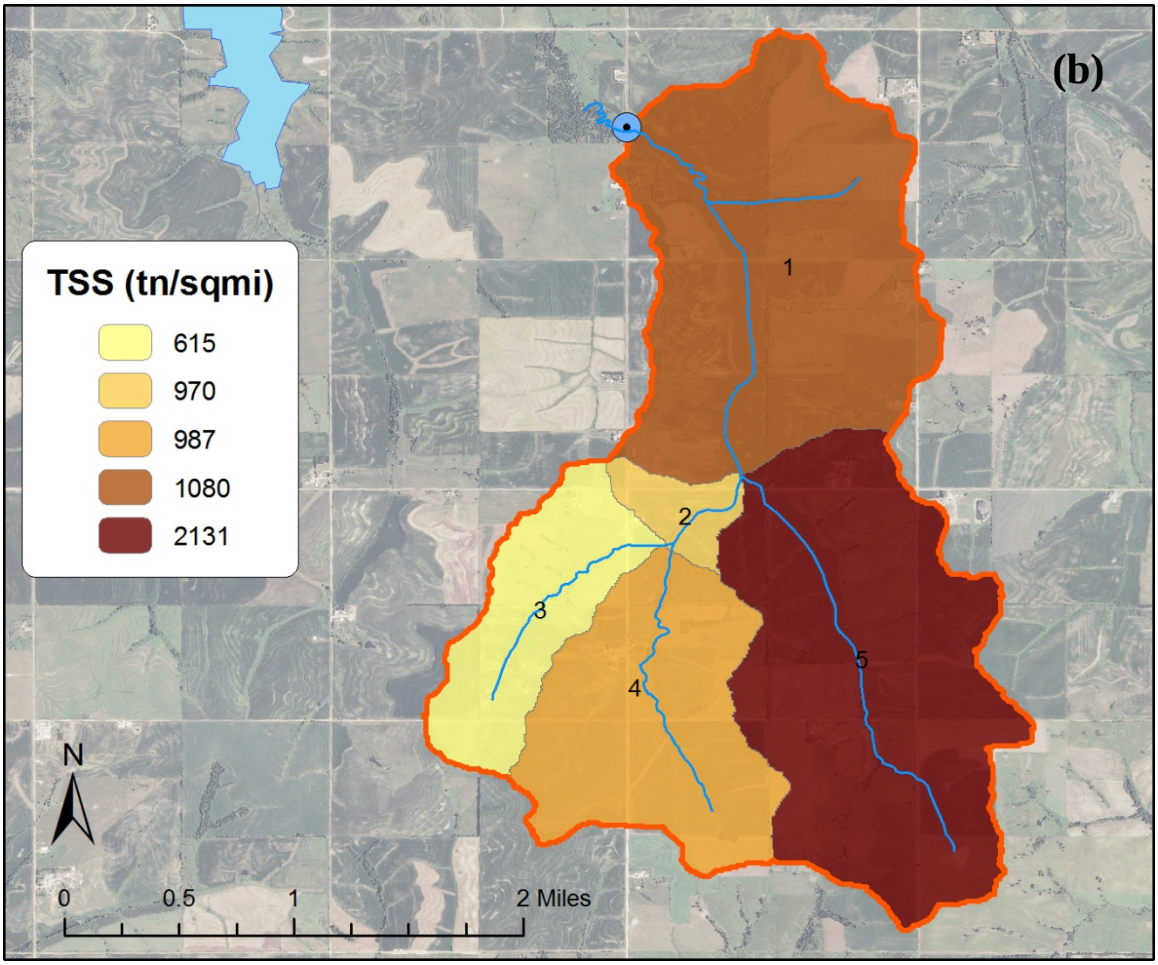


Figure 2. Surveyed and delineated areas of (a) Banner Creek Lake Watershed, (b) Centralia City Lake Watershed, and (c) Atchison County Lake Watershed. The surveyed area (Devlin and Boyer, 2012) is outlined by the green line, while the drainage basin for the USGS gage station is outlined by the red line.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


(a)
1
2
3
4
5
6
7
8
9
10
TSS (tn/sqmi)
155
185 - 199
239 - 284
385 - 441
508
N
0
0.5
1
2 Miles


(b)
TSS (tn/sqmi)
615
970
987
1080
2131
1
2
3
4
5
N
0
0.5
1
2 Miles

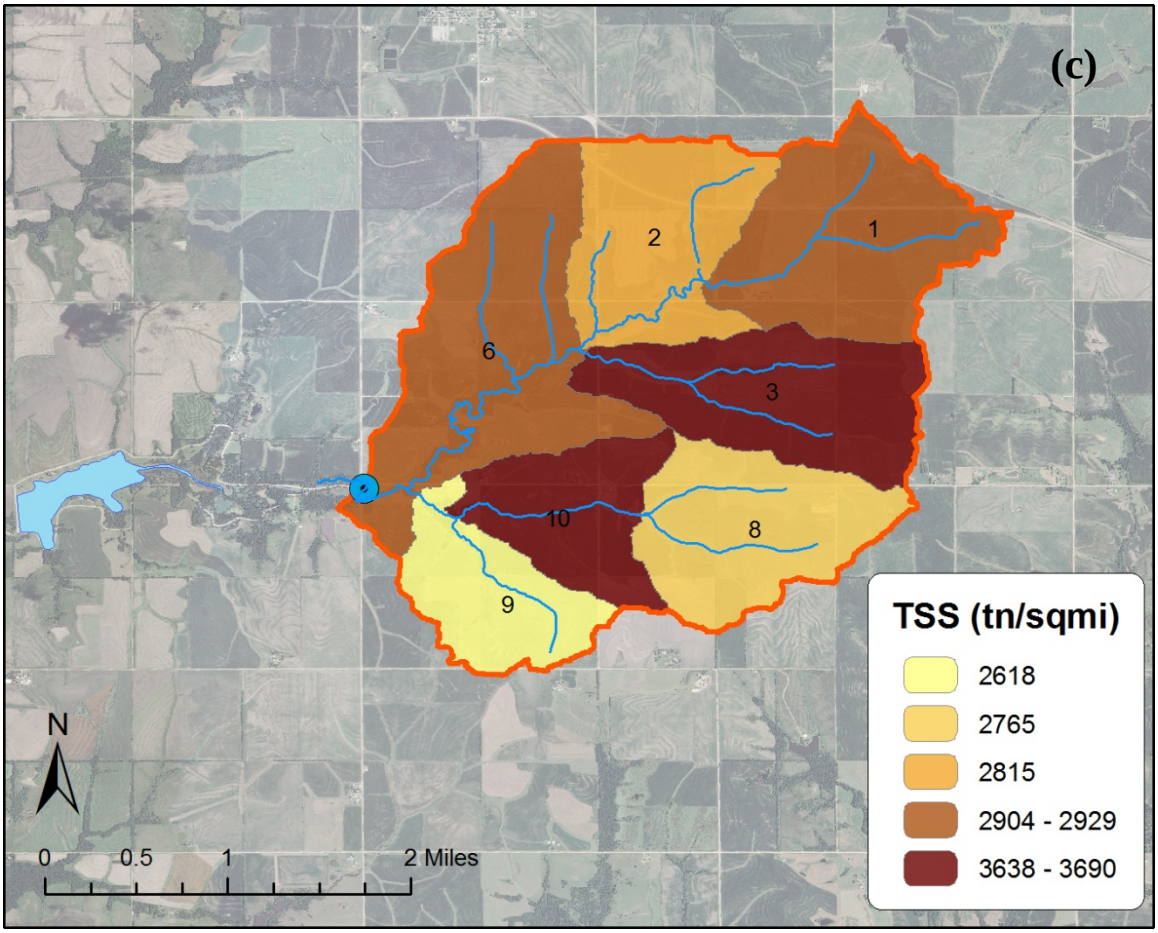


Figure 3. A subwatershed map of the annual average total suspended sediment yield for the USGS gage station drainage areas of: (a) Banner Creek Lake Watershed, (b) Centralia City Lake Watershed, and (c) Atchison County Lake Watershed. The darker the color, the higher the average annual suspended sediment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

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

1. 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 (see Chapter ??). 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%.

2. 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.

3. Procedures

3.1 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.

3.1.1 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.

3.1.2 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.

3.1.3 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 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.

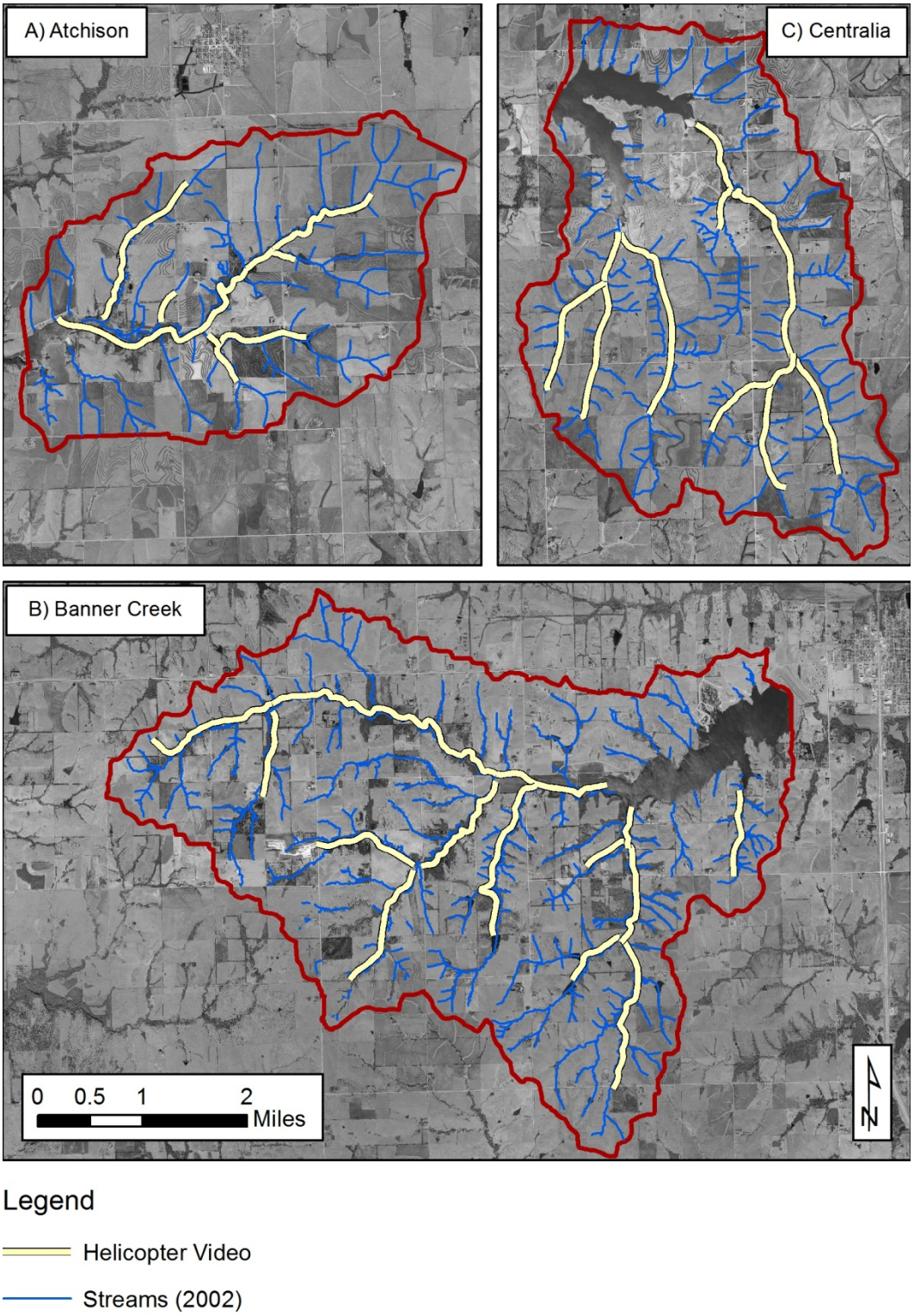


Figure 1. Map of Helicopter Path for Video Collection

As mentioned previously, helicopter videography has been successfully employed in Western Iowa (Reference) 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.

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

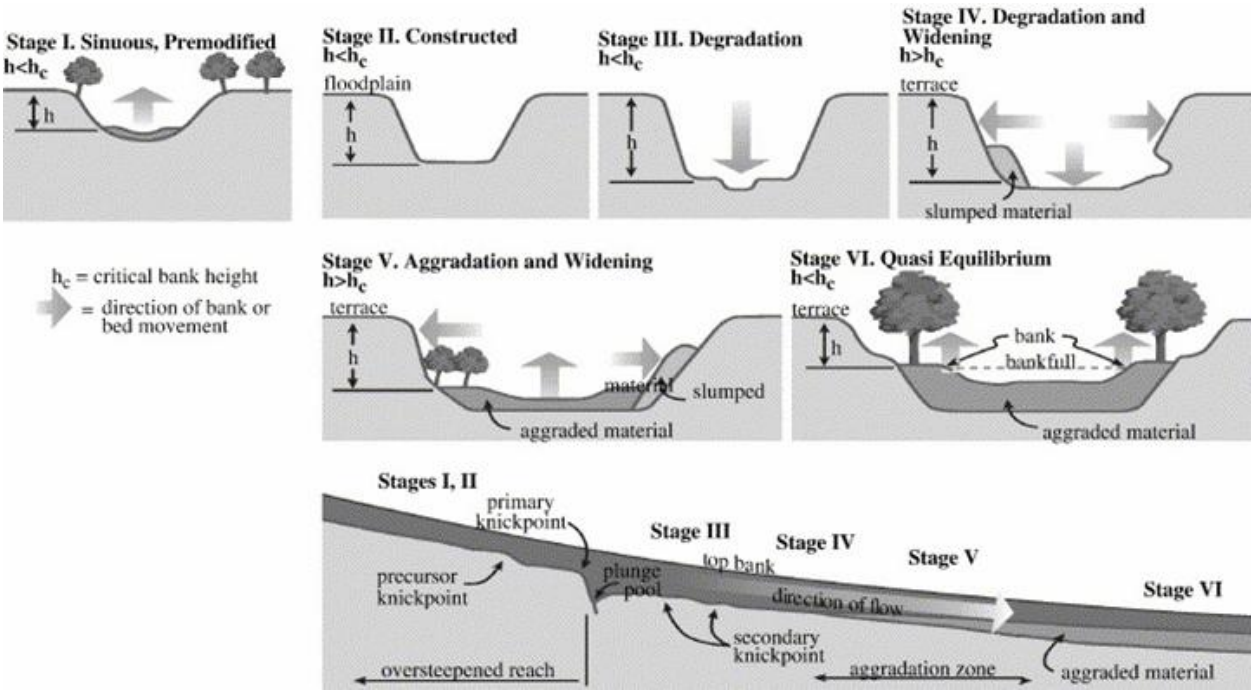


Figure 2. Six-Stage Channel Evolution Model. Figure from (Simon and Rinaldi 2006).

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.

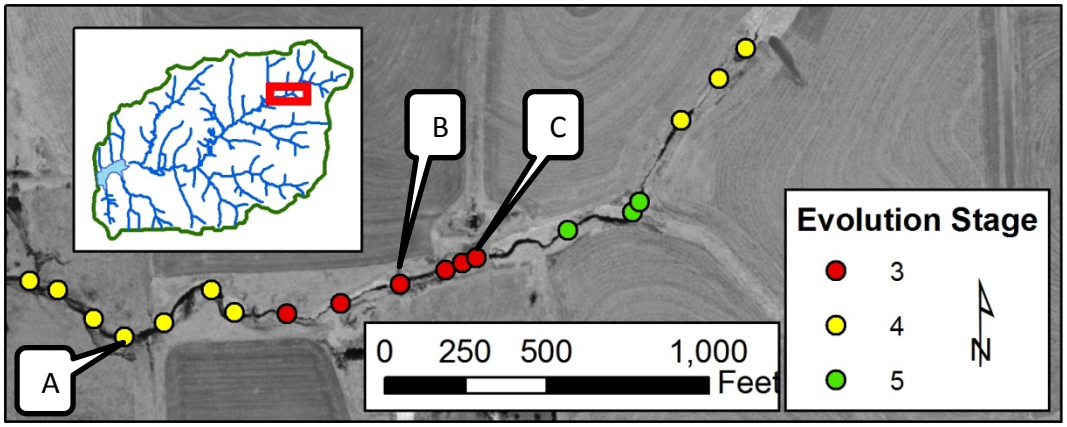
In addition, it is unusual to see many streams that fall in Stage II, as a channel will almost immediately move from Stage II to Stage III. As a result, all of the streams classified for the three watersheds in this study fall into Stages III through V. Although some streams may have reached Stage VI, 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 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.

3.1.4 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.



Stage 4: Channel appears to be widening after incision.

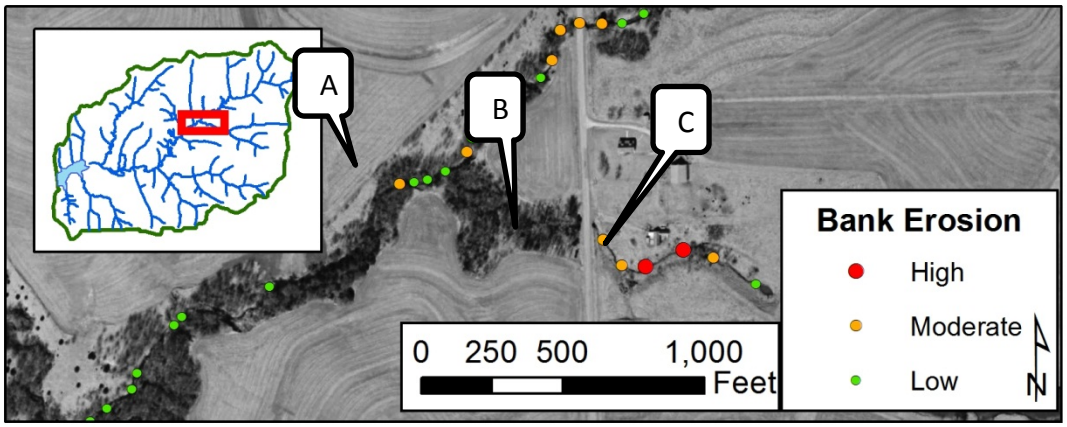
Stage 3: Channel appears to be incising. A nickpoint is visible in upper right corner of

Stage 5: The channel u/s of the grade control structure appears to be relatively stable.

Figure 3. Stream Classification -- Sample Photographs

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

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

3.2 Historical Aerial Photography

3.2.1 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.

3.2.2 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.

3.2.3 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.

3.2.4 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.

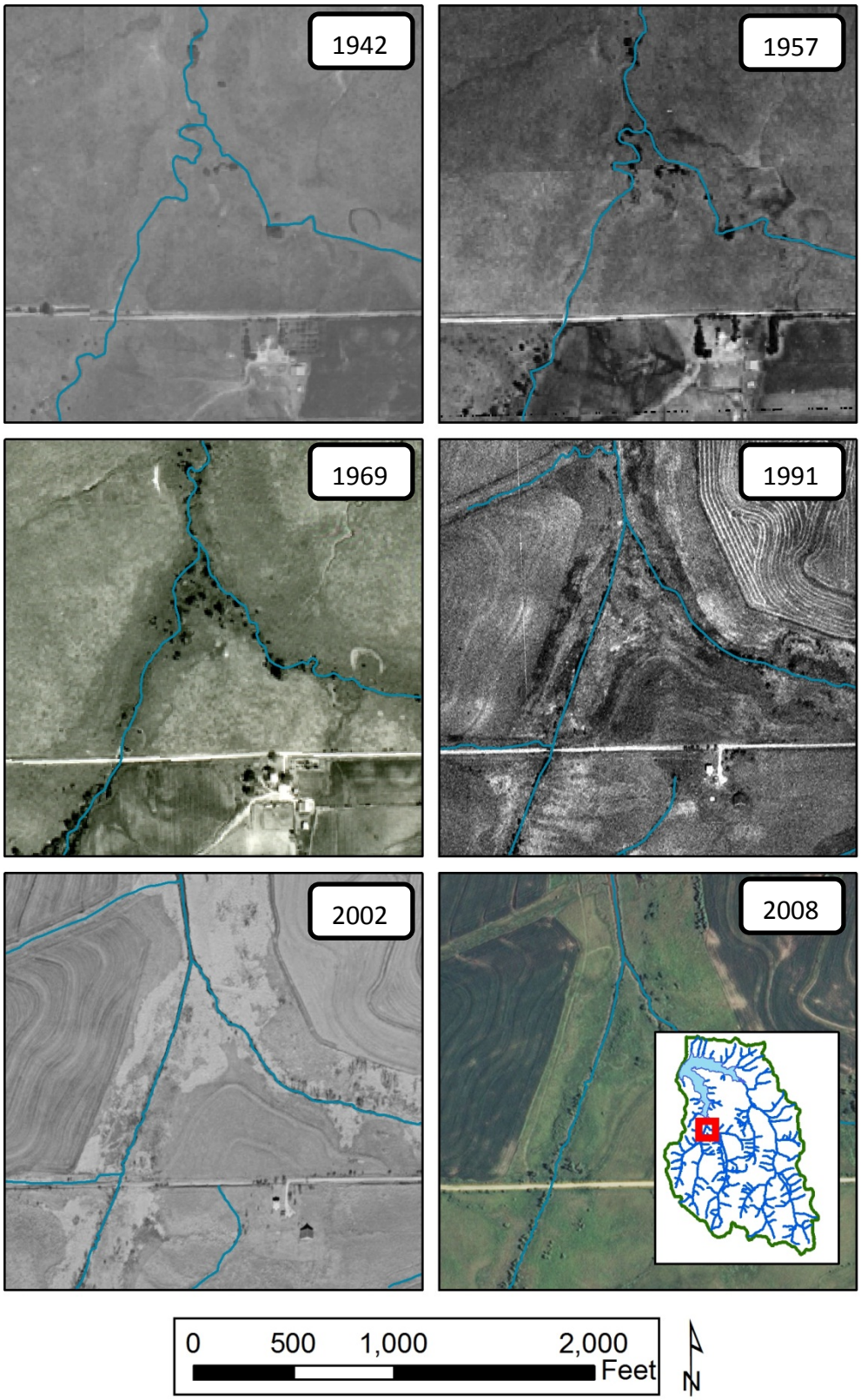


Figure 5. Aerial Photographs Dating from 1942 – 2008

4. Results

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

4.1.1 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.

Table 3. Stream Visibility for Helicopter Photographs

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

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.

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

4.2 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 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 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 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	1261	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	1223	846

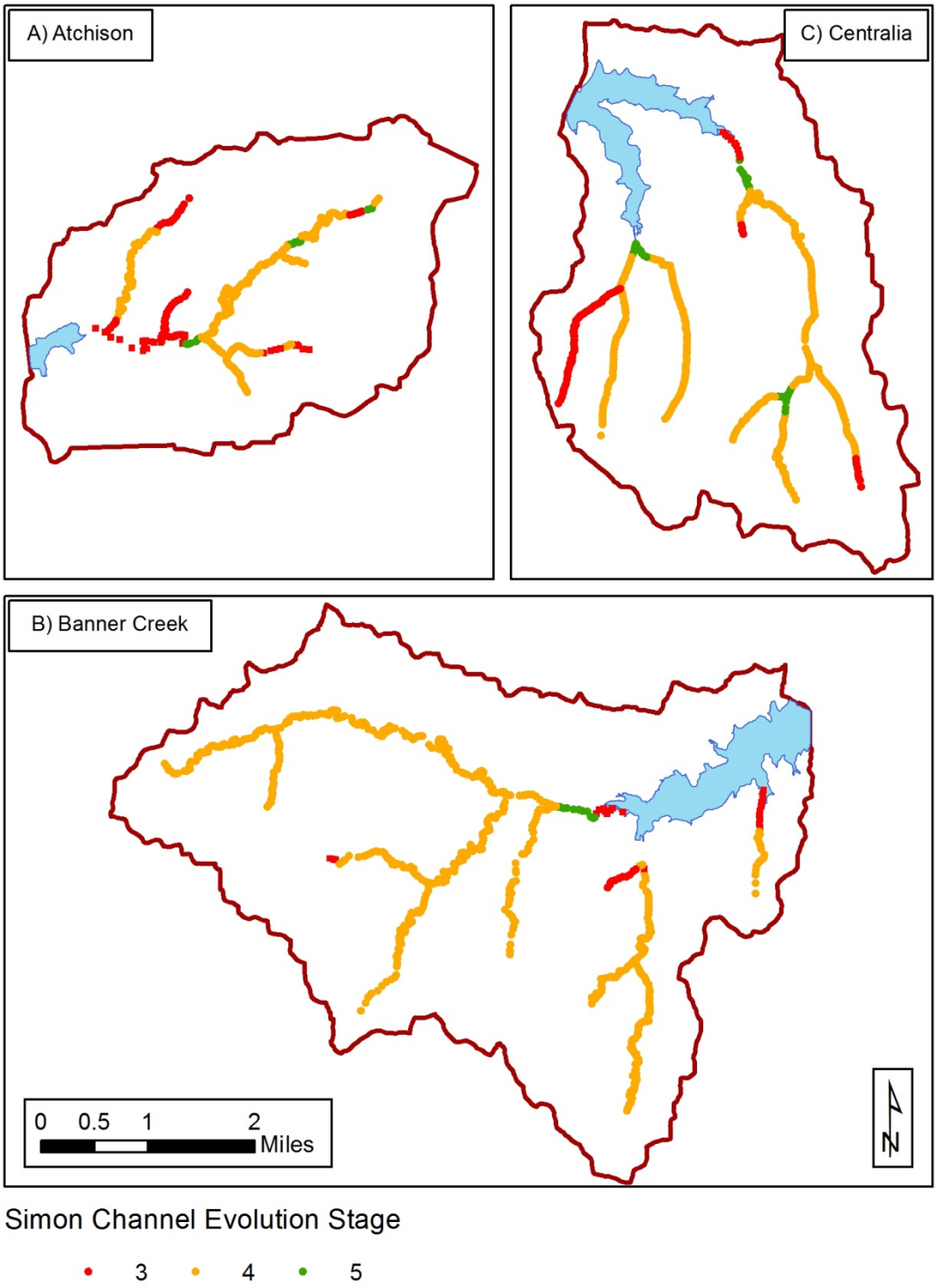


Figure 6. Channel Evolution Stage

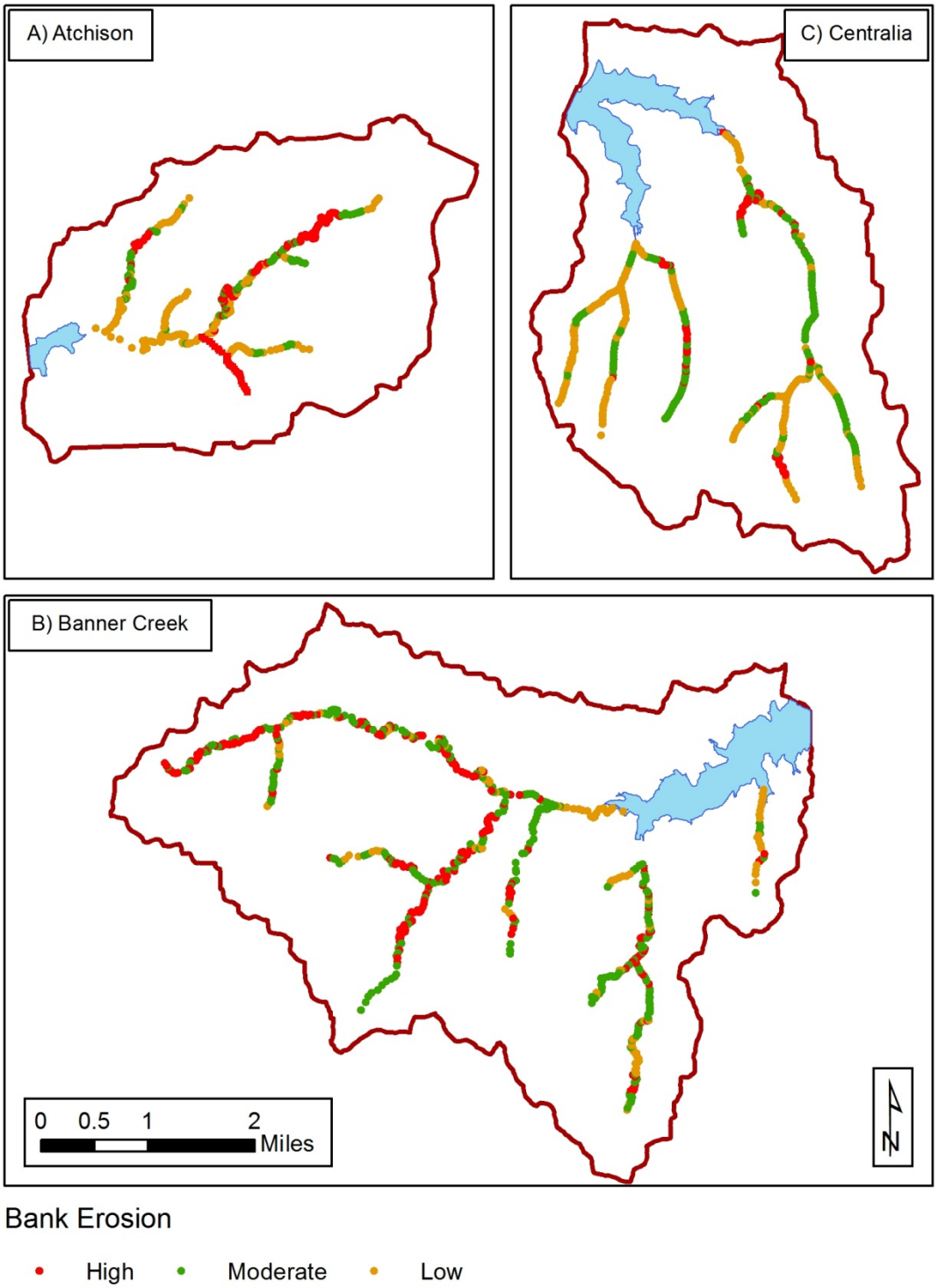


Figure 7. Map of Channel Erosion Assessment

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 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 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.

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 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.

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

4.3 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 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 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 (mi^2)		
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%

4.4 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.

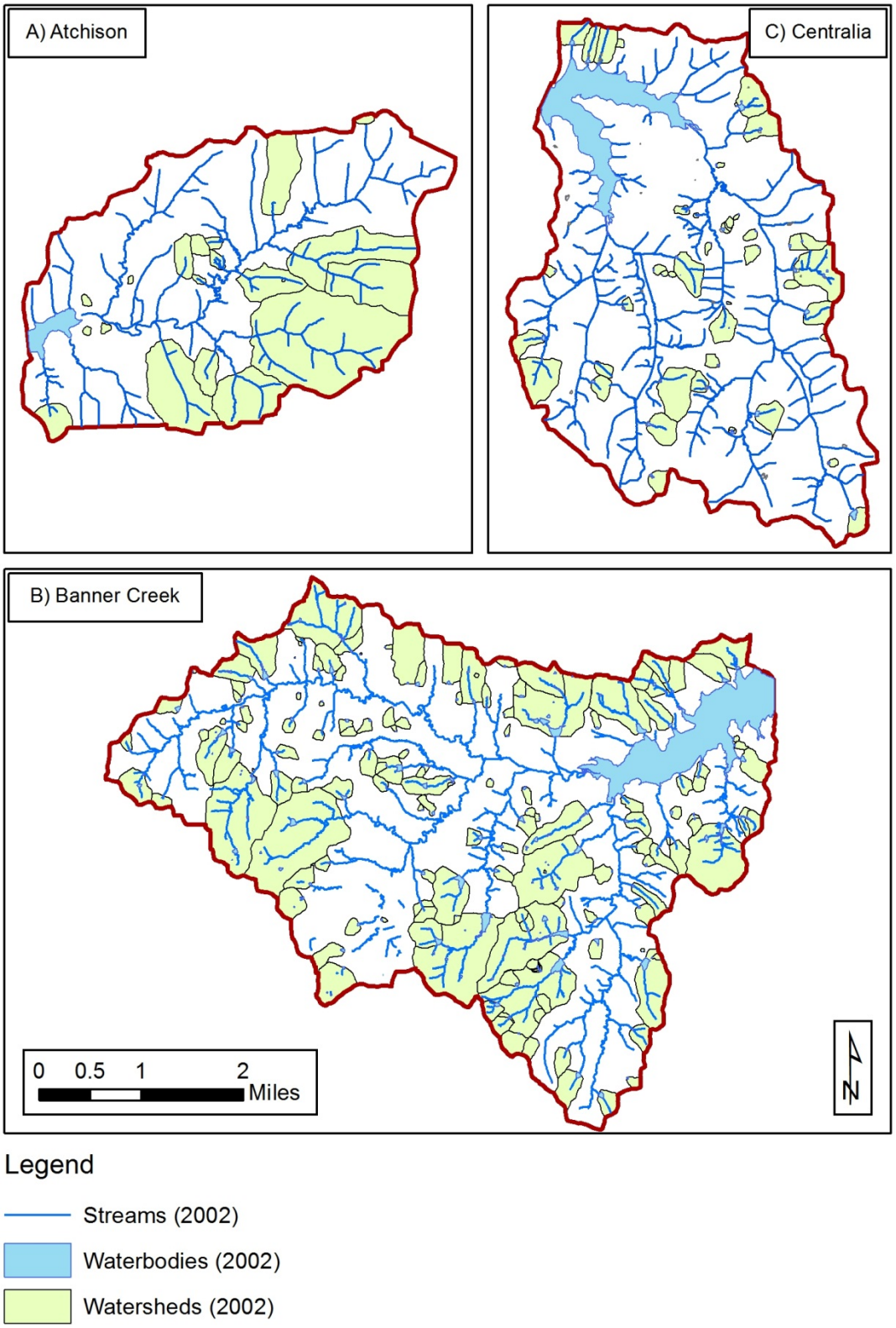


Figure 8. Ponds and Lakes from 2002 Aerial Photography

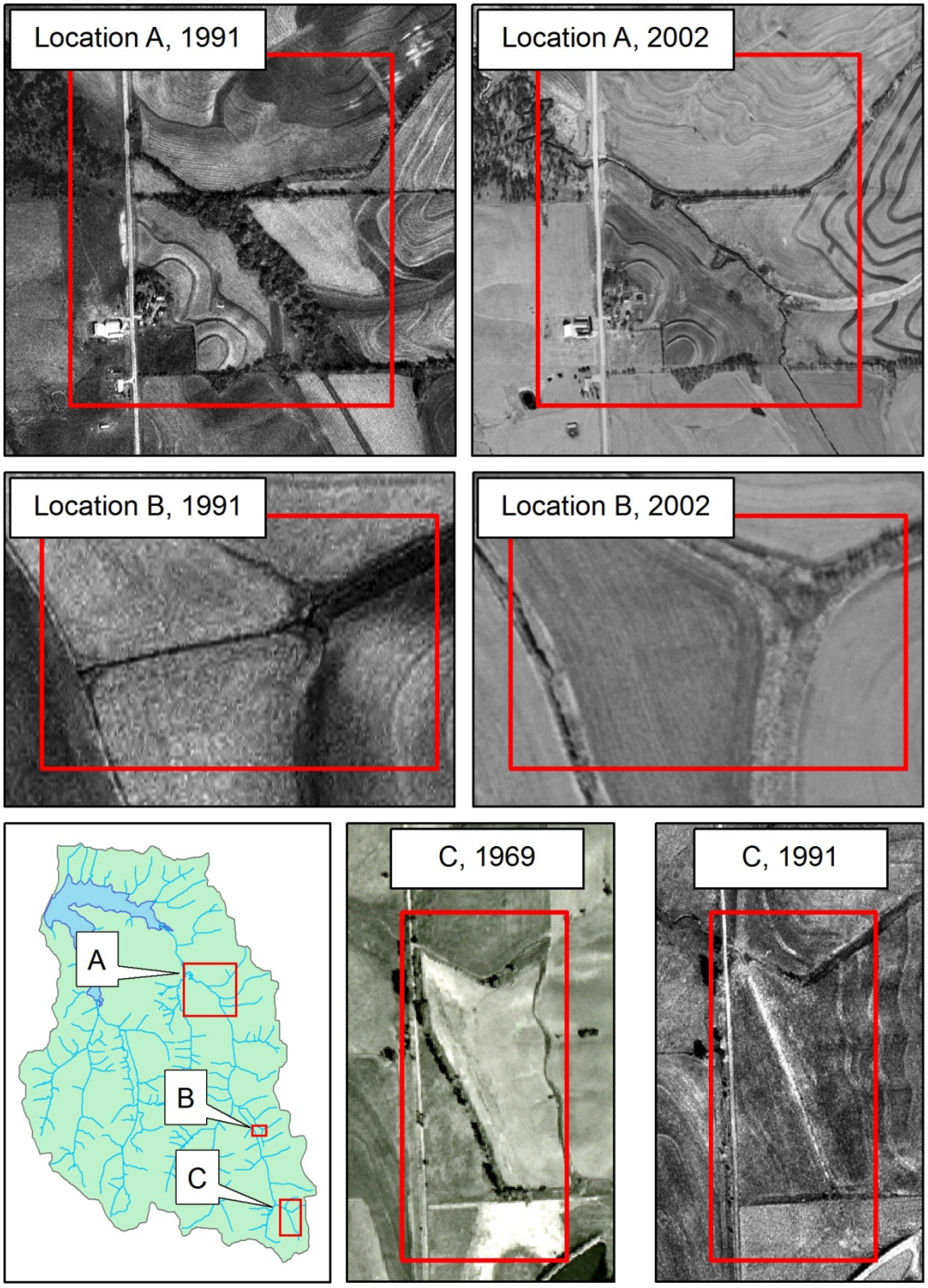


Figure 9. Examples of Channel Changes in Centralia

5. 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 (see Chapter ??). 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%.

6. Recommendations for Future Research

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.

7. Literature Cited

Foster, G. (2011). "Effects of small impoundments on total watershed sediment yield in northeast Kansas, April through August 2011." M.S. Thesis, University of Kansas, Lawrence, KS.

Kansas Geological Survey (2012). "State of Kansas GIS Data Access & Support Center." <http://www.kansasgis.org >. (9/30/2012, 2012).

Simon, A., and Rinaldi, M. (2006). "Disturbance, stream incision, and channel evolution: The roles of excess transport capacity and boundary materials in controlling channel response." *Geomorphology*, 79(3-4), 361-383.

Thomas, J. (2009). "Hungry Canyons Alliance: Streambed Stabilization in Western Iowa." *Proc., World Environmental and Water Resources Congress 2009*, ASCE, 17-21.

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

Daniel Devlin[1] and Will Boyer[2]

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 was conducted of each watershed and data collected and then georeferenced field data was inputted into tablet computers on land use (crop land and grasslands, crop rotations, current conservation (primarily terraces, terrace condition and 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 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 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 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

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waterways dams/lakes that would control significant amounts of sediment from upland fields in the ACL.

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 grazinglands/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_ortho imagery, 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 was conducted of each watershed and data collected and then georeferenced field data was inputted into tablet computers on land use (crop land and grasslands, crop rotations, current conservation (primarily terraces, terrace condition and 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 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. 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.

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 and compared to conventional tillage practices 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 in that watershed would be expected to have little impact on sediment loading into water bodies in the watershed.

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. Watershed dams/lakes were not noted in CCL or in BCL.

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 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 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.

Recommendations for Future Research Needs

1. Survey more watersheds, particularly, those containing watershed dams/lakes and/or wetlands.
2. Survey watersheds that contain significantly greater amounts of CRP.

3. Study the impact of watershed dams/lakes on sediment delivery.
4. Develop a better understanding of the impact of conservation practices on sediment delivery.

		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	Soybeans	55.5	61.0	52.5

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.

Grown	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

Acres in Grassland (%)		Atchison County Lake 290 (5.0%)	Banner Creek Lake 8,815 (72.1%)	Centralia City Lake 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 acreaage)		**4,164 (69.6%)**	**5,425 (60.4%)**
Percentage of the Cropland within the Watershed			
Crop Grown	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

Acres in Grassland (% of total acreage)		Atchison County Lake 422 (7.1%)	Centralia City Lake 1,268 (15.7%)
Percentage of Grassland within Watershed			
Grassland	Grazed	82.0	72.7
	Hayed	2.8	.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

	Atchison County Lake	Centralia City Lake
Acres in Other Uses (lake, ponds, roads, homesteads) (% of total acreage)	1,396 (23.3%)	2,148 (23.9%)

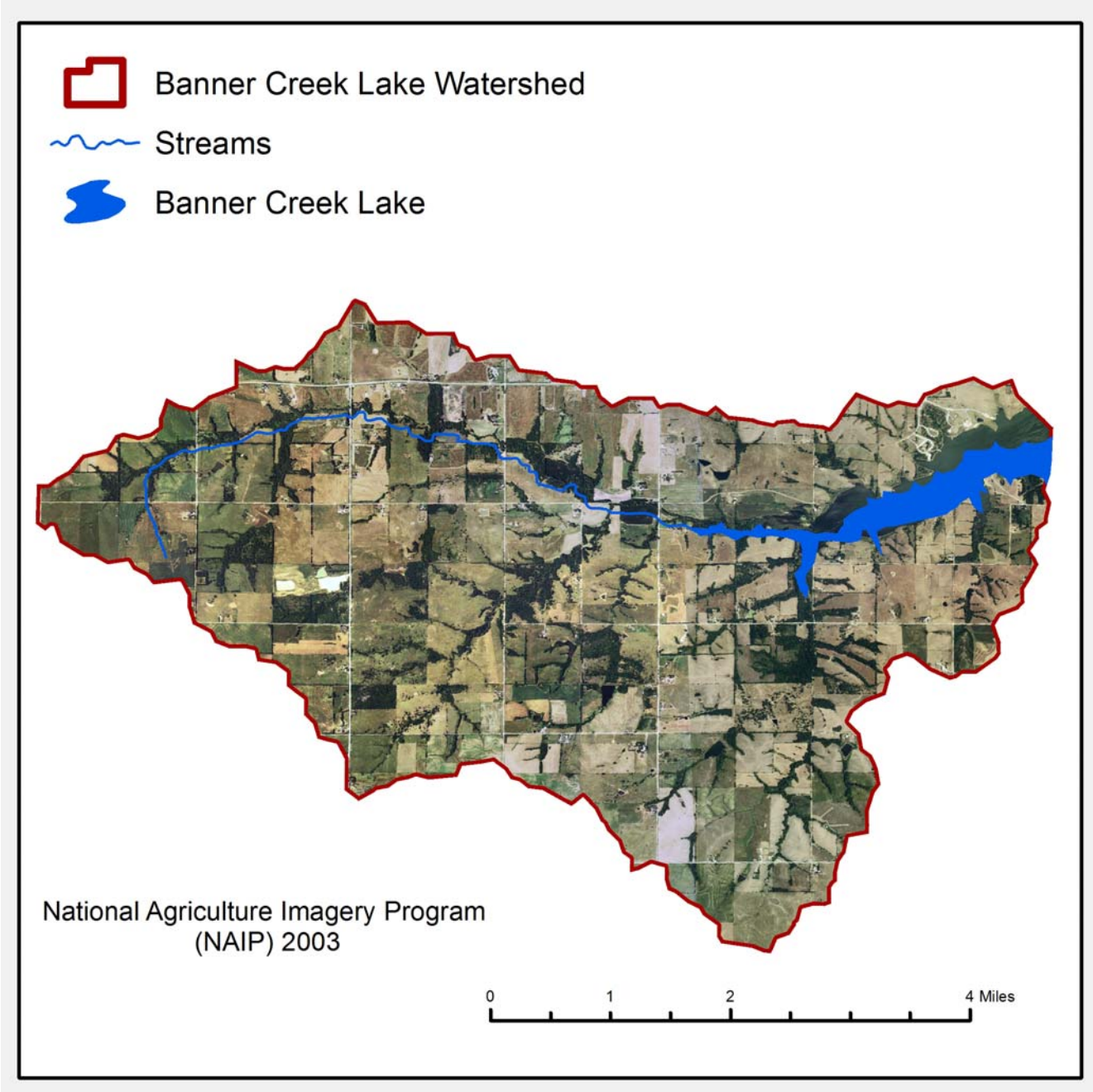

Figure 1. Aerial map of Banner Creek Lake Watershed.

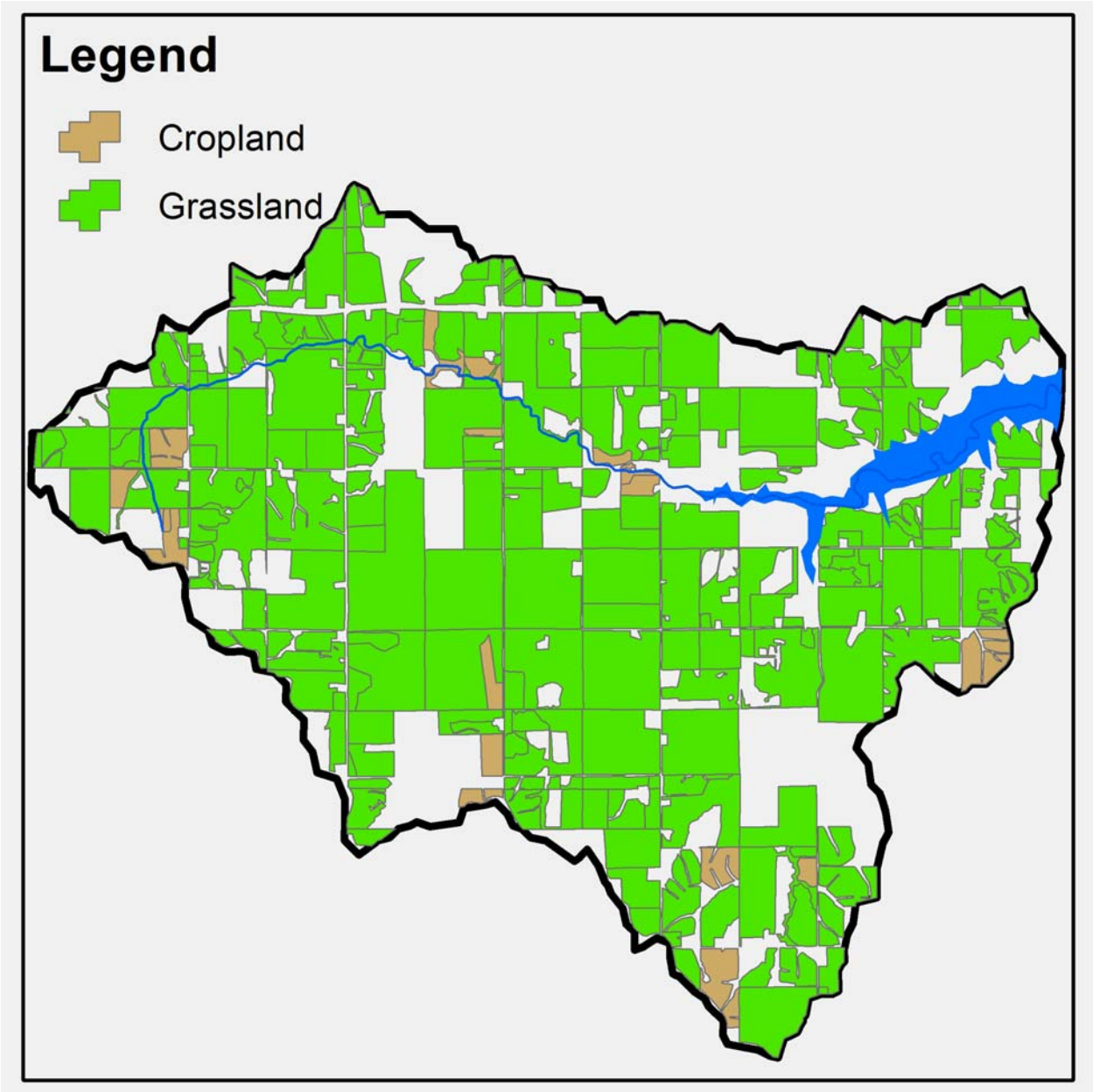

Figure 2. Land use in Banner Creek Lake Watershed, 2009.

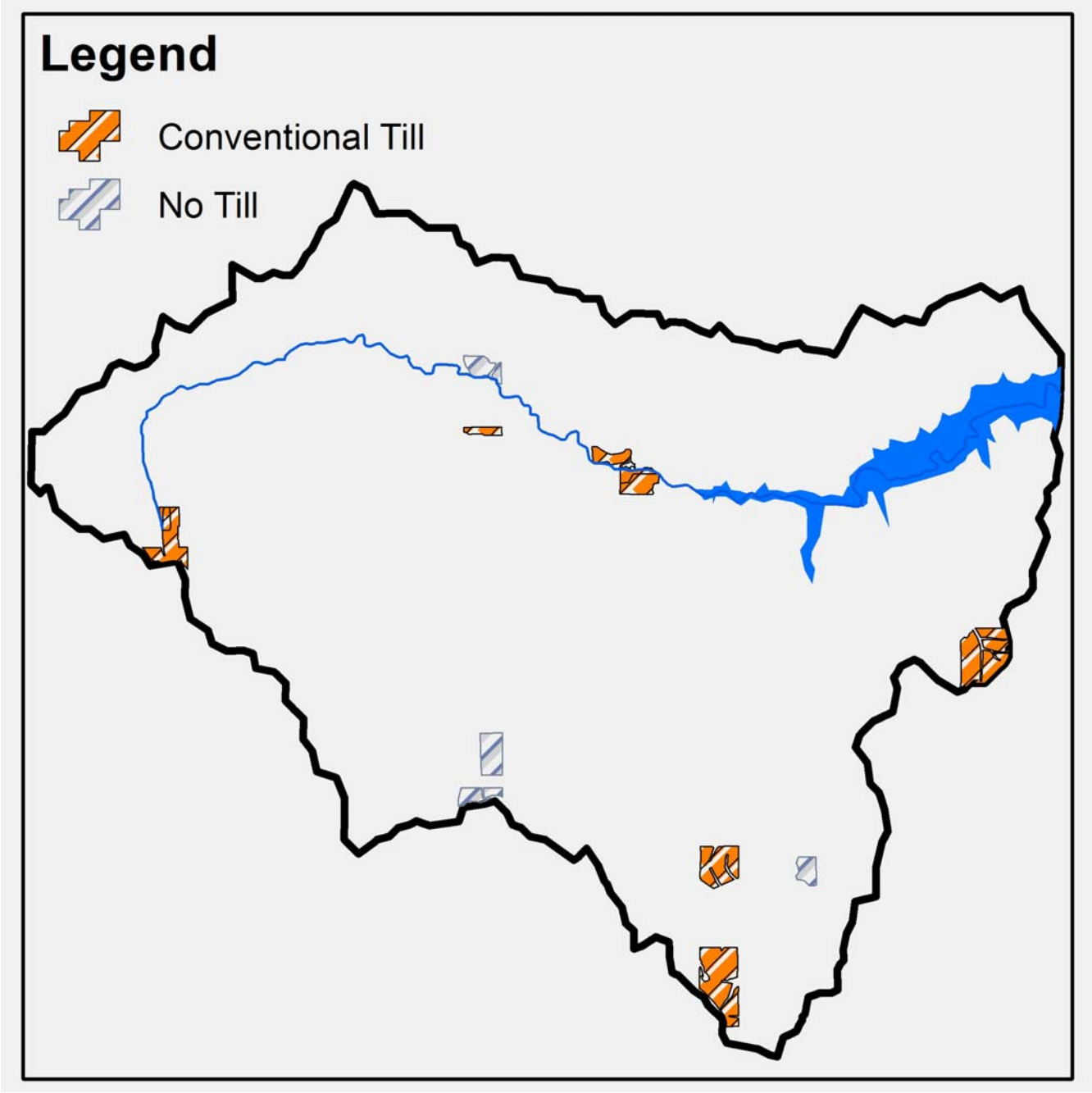

Figure 3. Tillage practices used in Banner Creek Lake Watershed, 2009.

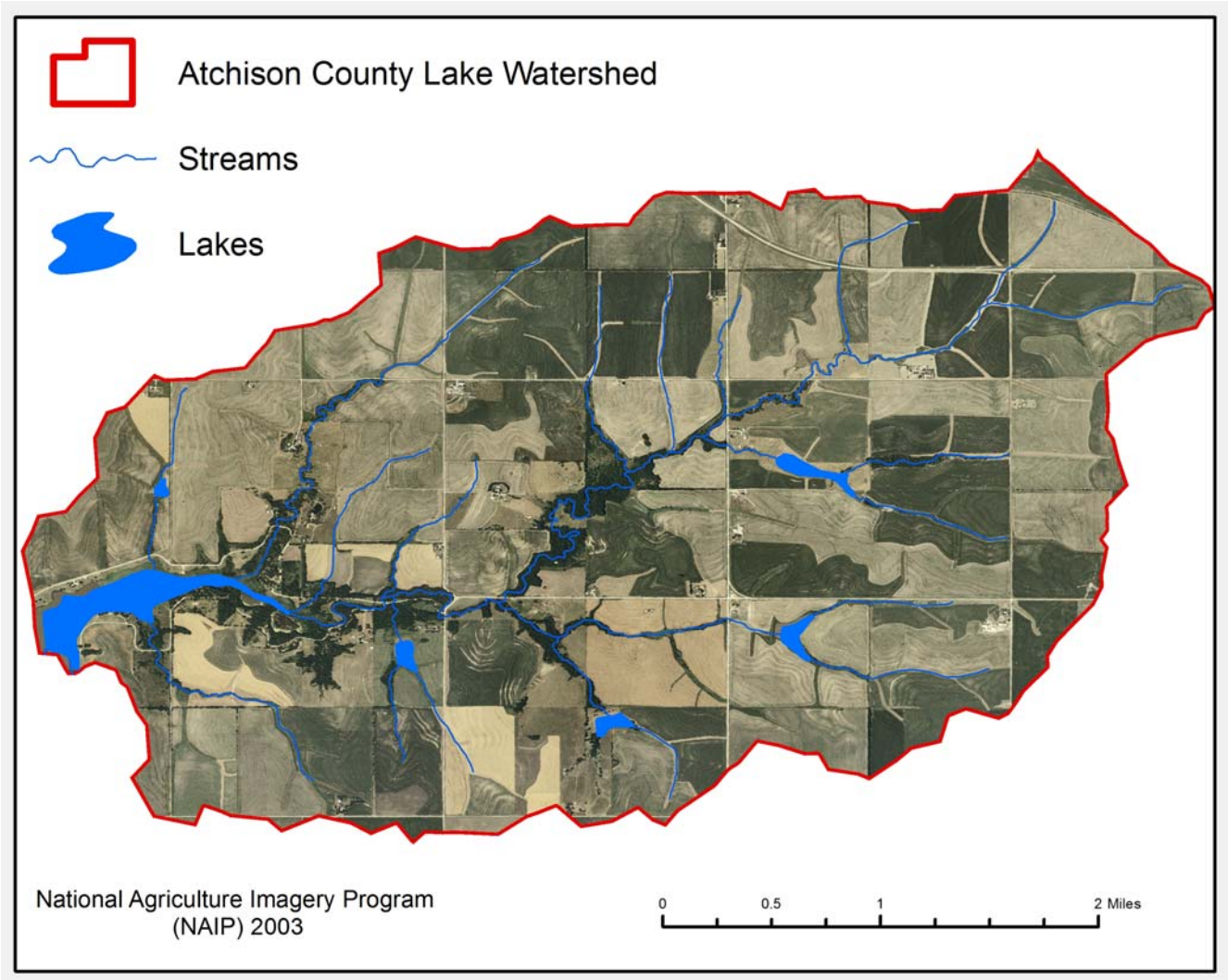

Figure 4. Aerial map of Atchison County Lake Watershed.

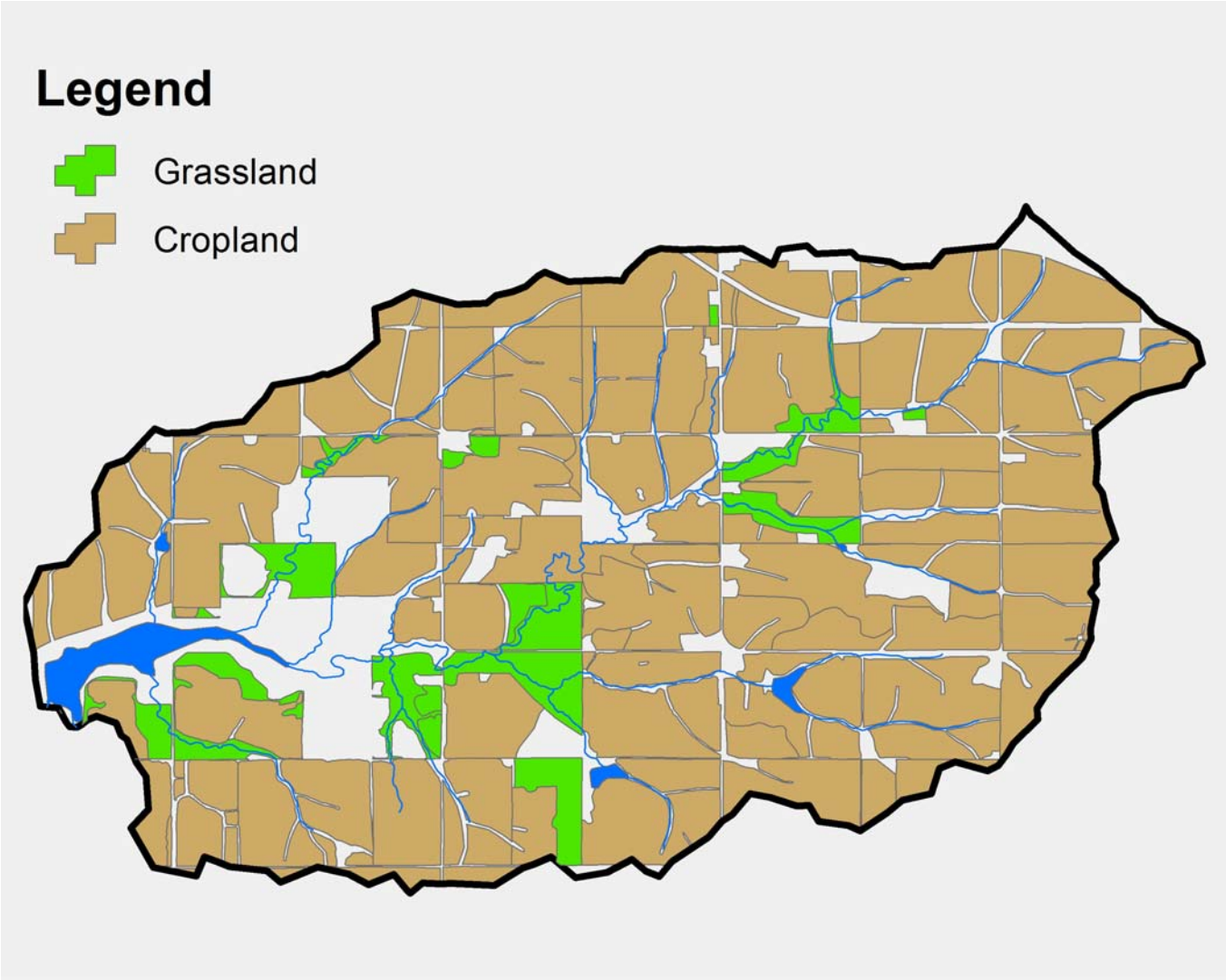

Figure 5. Land use in Atchison County Lake Watershed, 2010.

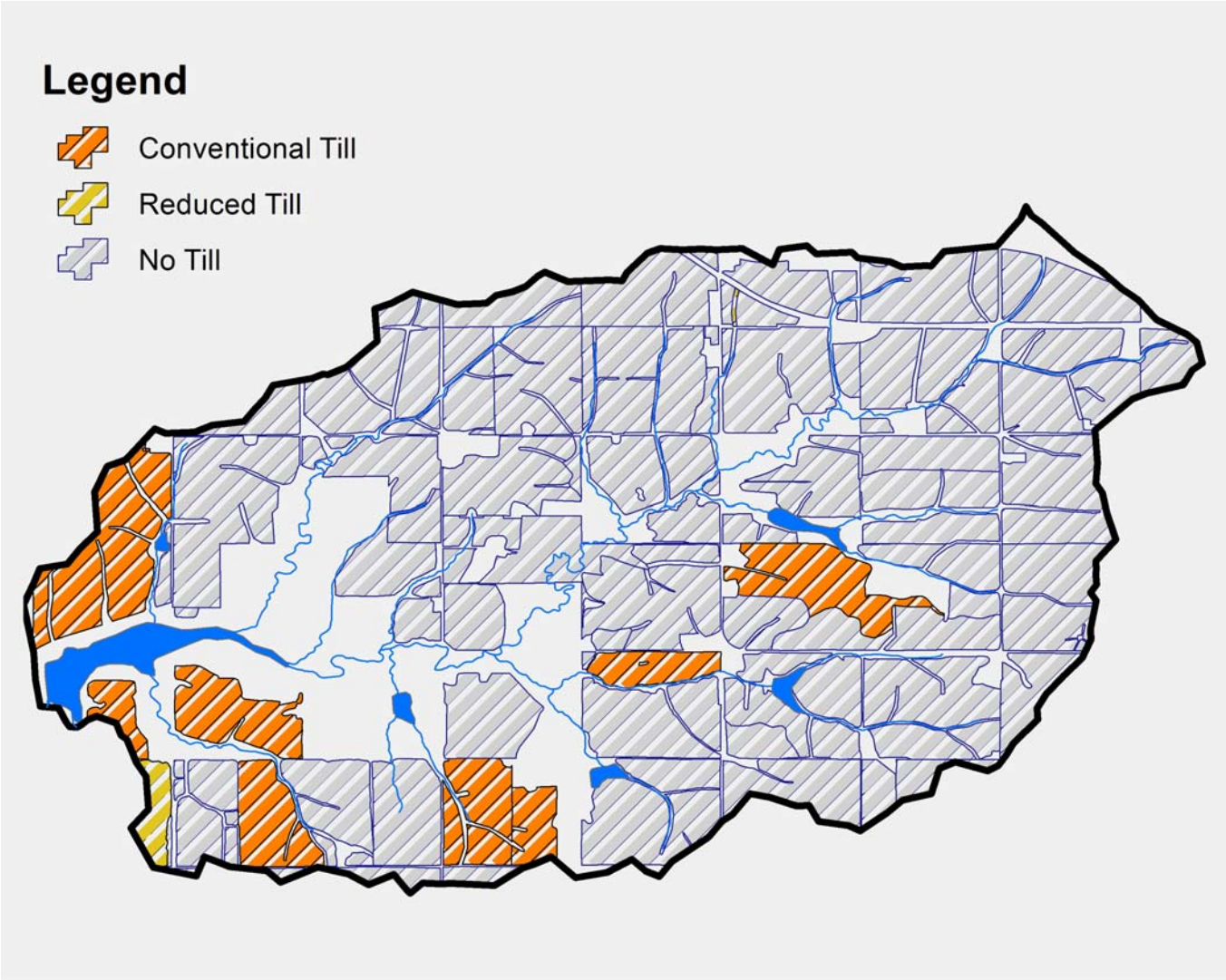

Figure 6. Tillage practices used in Atchison County Lake Watershed, 2010.

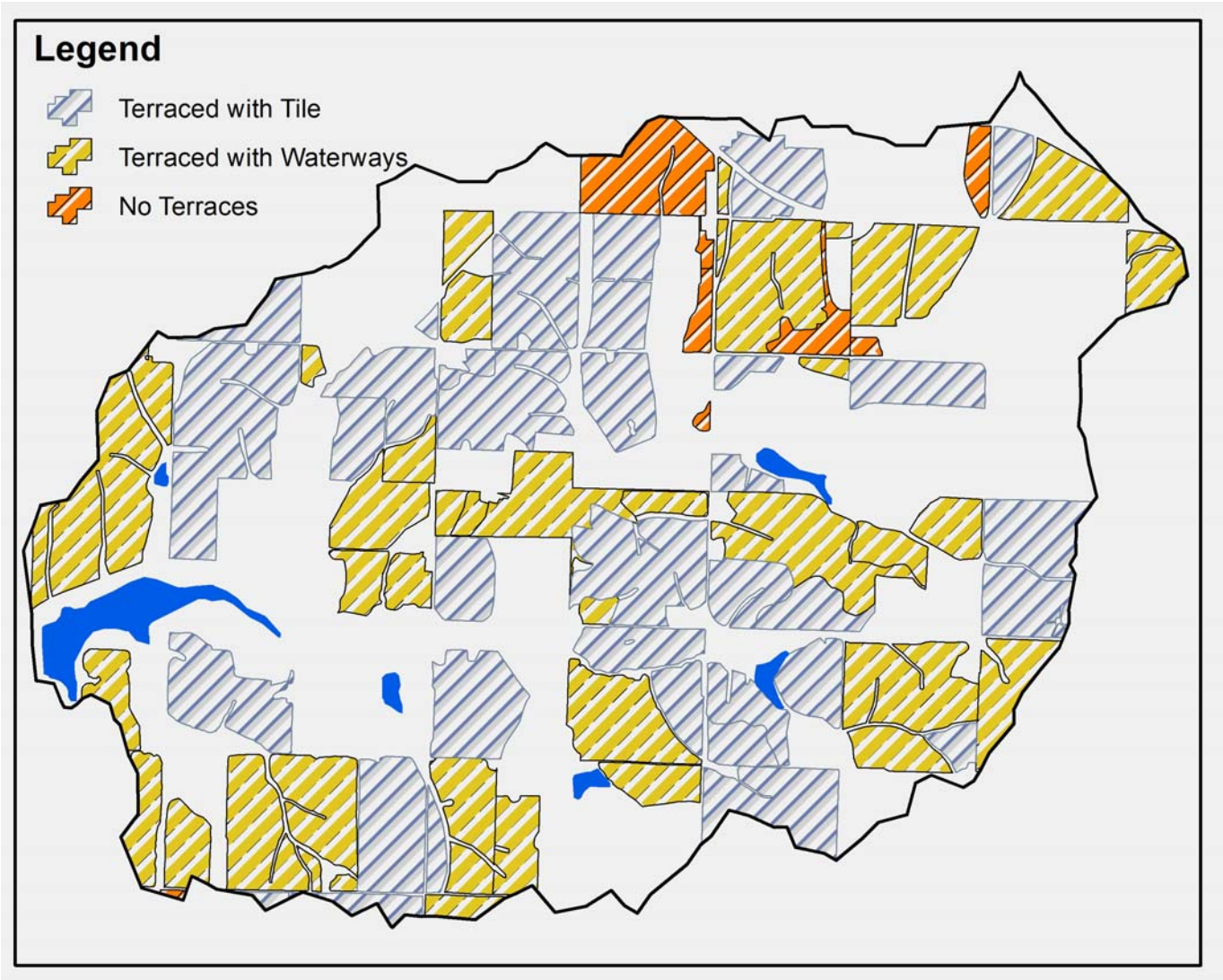

Figure 7. Terraced fields in Atchison State Lake Watershed, 2009.

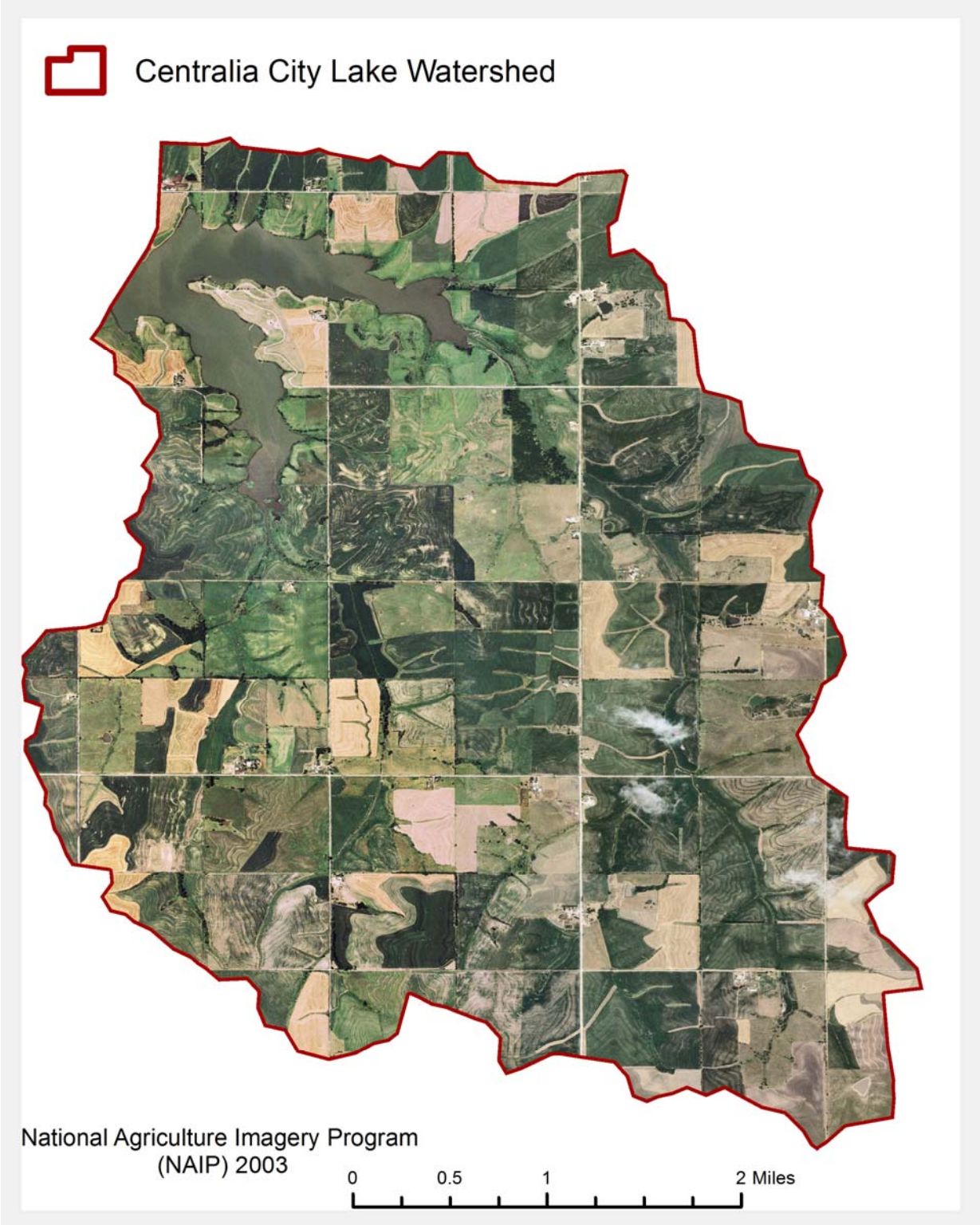

Figure 8. Aerial map of Centralia City Lake Watershed.

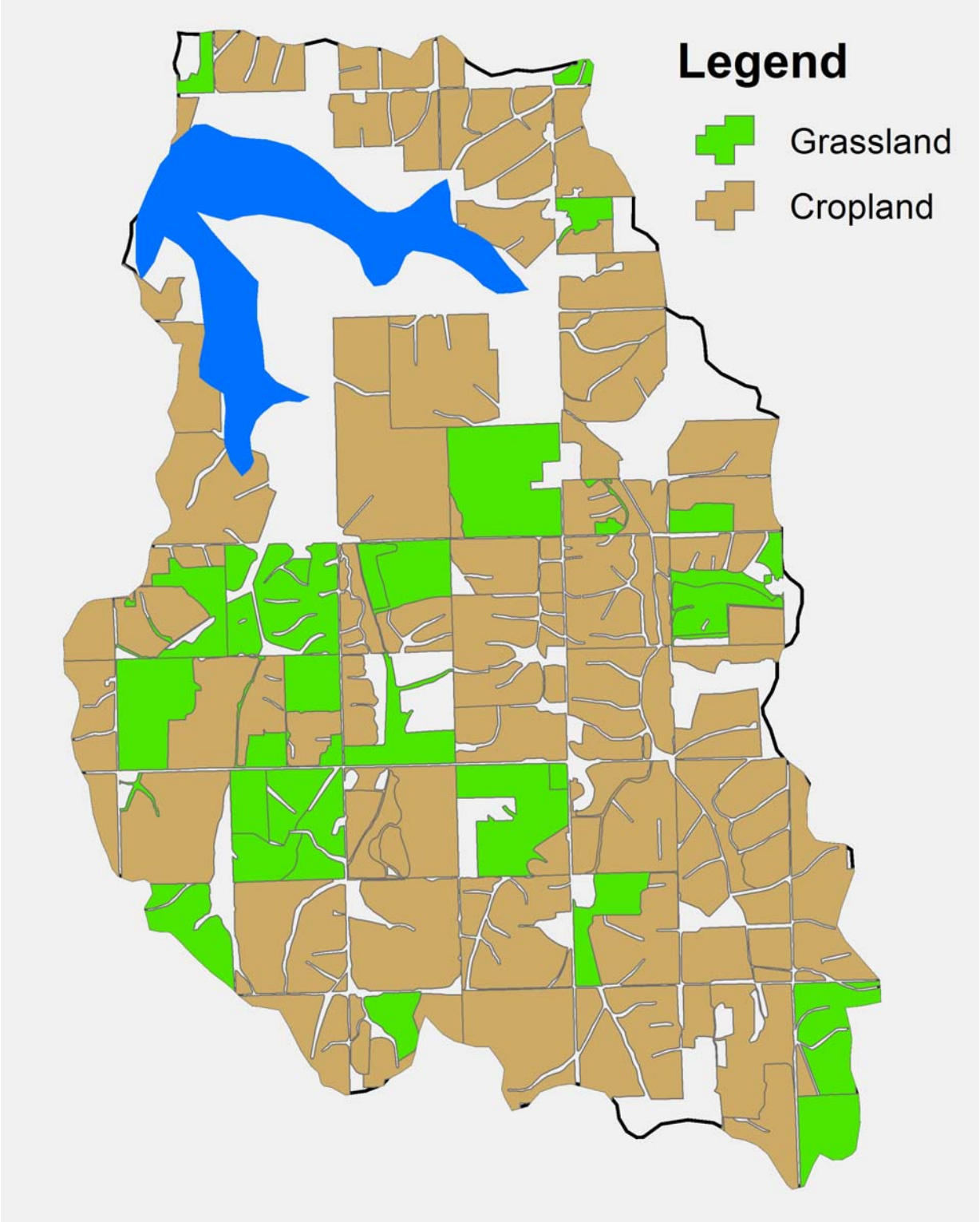

Figure 9. Land use in Centralia City Lake Watershed, 2010.

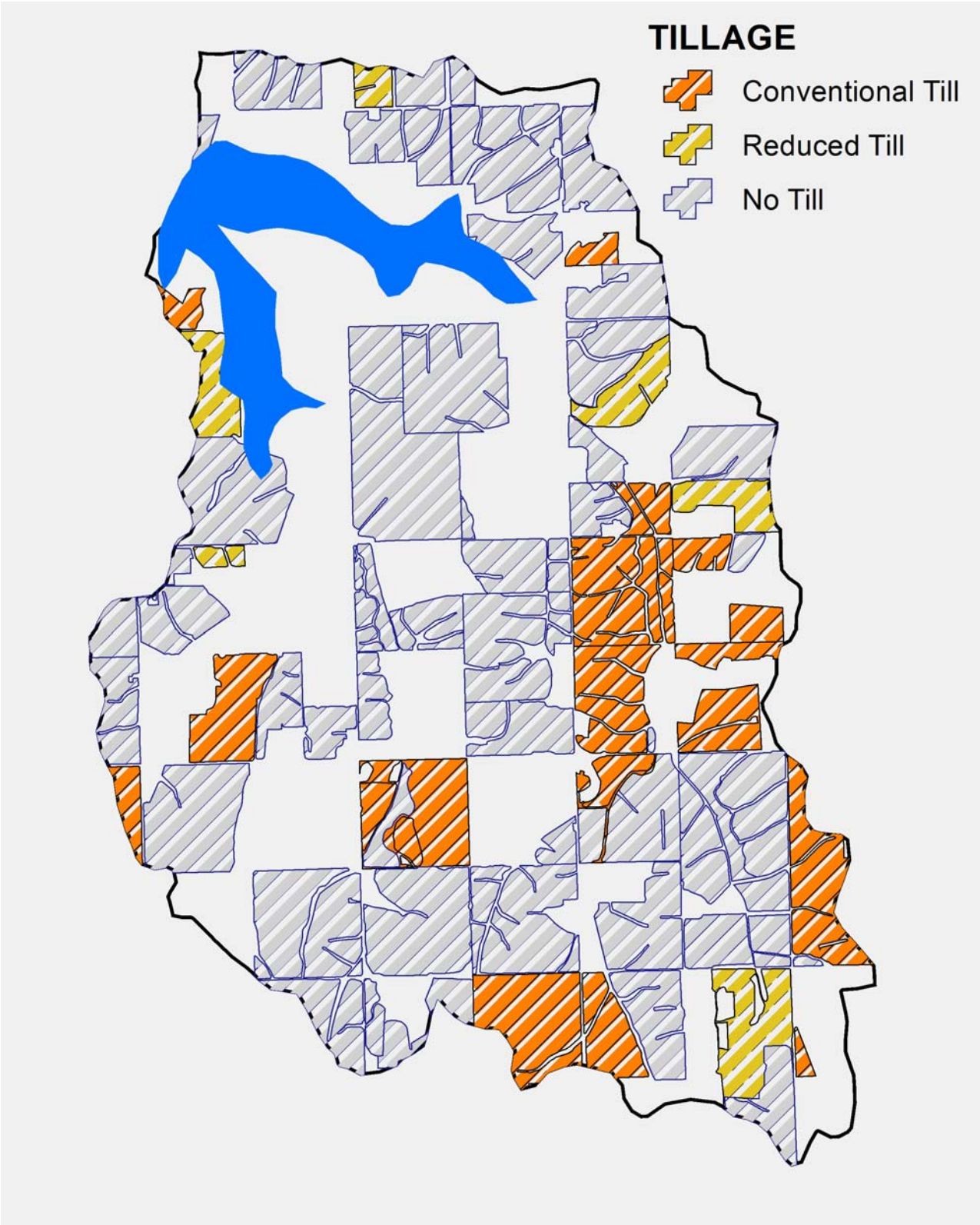

Figure 10. Tillage practices used in Centralia City Lake Watershed, 2010.

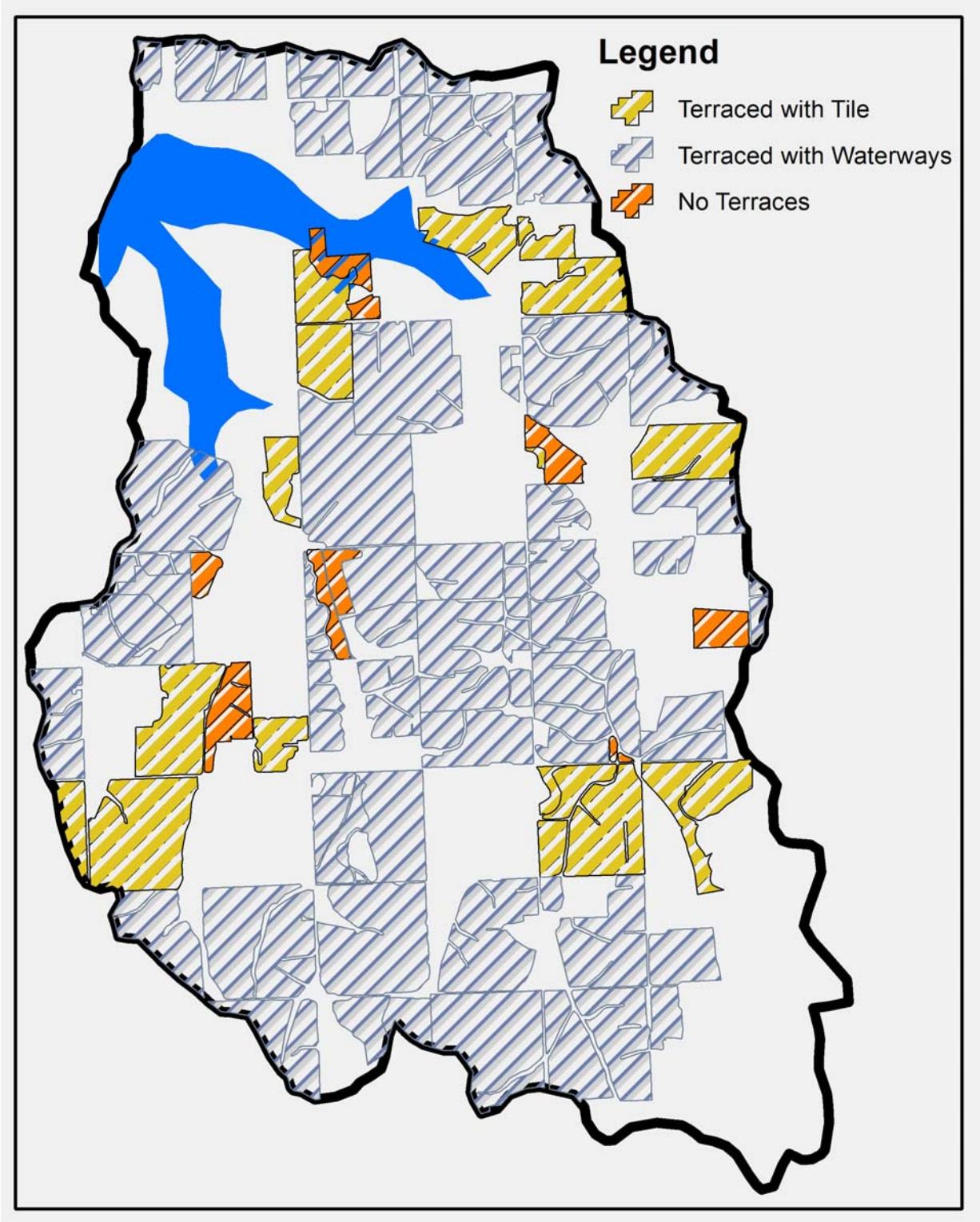

Figure 11. Terraced fields in Centralia City Lake Watershed, 2009.

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

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

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

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

Photo 5. A dirt road in Centralia City Lake Watershed. Dirt roads are prevalent in all three watersheds and may be a significant source of sediment loading to streams and lakes.

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

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

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

Effects of long-term management on near surface soil properties of upland soils in northeast Kansas

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EXECUTIVE SUMMARY

Sedimentation of lakes and reservoirs in Kansas is due to a combination of historic land use as well as from the 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 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 lead to infiltration and thus less 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 pastured. 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 thing to document. According to Olson et al. (2005a), as of 1991, there were 20 million acres of eroded Mollisols mapped in the USA, and 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 1840's to 1860's. The best agricultural land was either plowed for crops, or pasture for livestock. Starting in the 1950's, 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 1970's, 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 historical descriptions contained in soil surveys completed between ≈1950 and ≈1970.

Veenstra (2010) examined 82 representative pedons 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 27-71% 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 is 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, 1-3% 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 permission 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 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.

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.

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

REFERENCES

Amundson, R., Y. Guo, and P. Gong. 2003. Soil diversity and land use in the United States. Ecosystems 6:470-482.

Blake, G.R., and K.H. Hartge. 1986. Bulk Density. p. 364-367. *In* A. Klute (ed.) Methods of soil Analysis. Part 1. Ser. 5. SSSA, Madison, WI.

Grossman, R.B., and T.G. Reinsch. 2002. Bulk density and linear extensibility. p. 201–228. *In* J.H. Dane et al. (ed.) Methods of soil analysis. Part 4. SSSA Book Ser. 5. SSSA, Madison, WI.

Kemper, W.D. and R.C. Rosenau. 1986. Aggregate stability and size distribution. In Klute, A., (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI, pp. 425-442.

Kilmer, V.J., Alexander, L.T., 1949. Methods of making chemical analyses of soils. Soil Sci. 68, 15–24.

Kimble, J.M., R. Lal, and M. Mausbach. 1999. Erosion effects on soil organic carbon pools in soils of Iowa. Sustaining the global farm. 10th International Soil Conservation Organization Meeting pp. 472-475.

Leikam, D.F., R.E. Lamond, and D.B. Mengel. 2003. Soil Test Interpretations and Fertilizer Recommendations. Kansas State Research and Extension. Available online at http://www.ksre.ksu.edu/bookstore/pubs/mf2586.pdf Accessed [December 20, 2012].

Madsen MD, Chandler DG. 2007. Automation and use of Mini Disk Infiltrometers. Soil Science Society of American Journal 71:1469-1472.

Nelson, D., and L. Sommers. 1996. Total carbon, organic carbon, and organic matter: laboratory methods. *In*: Sparks, D et al. (eds.). Methods of soil analysis. Part 3. SSSA Book Ser. No. 5 SSSA and ASA, Madison, WI, pp. 961-1010.

Olson, K.R. T.E. Fenton, N.E. Smeck, R.D. Hammer, M.D. Ransom, C.W. Zanner, R.McLeese, and M.T. Sucik. 2005. Identification, mapping, classification, and interpretation of eroded Mollisols in the U.S. Midwest. Soil Survey Horizons 46:23-35.

Olson, K.R. T.E. Fenton, N.E. Smeck, R.D. Hammer, M.D. Ransom, C.W. Zanner, R.McLeese, and M.T. Sucik. 2005. Proposed modifications of mollic epipedon thickness criteria for eroded conditions and potential impacts on existing soil classifications. Soil Survey Horizons 46:39-47.

Presley, D.R. Kansas State University, Department of Agronomy. 2011. Tillage Practice Data. Available online at http://www.agronomy.ksu.edu/extension/tillage Accessed [July 29, 2011].

Schoeneberger, P.J., Wysocki, D.A. Benham, E.C., and Broderson. W.D. (ed.) 2002. Field book for describing and sampling soils, Version 2.0. NRCS, National Soil Survey Center, Lincoln, NE.

Soil Survey Laboratory Staff. 1996. Soil survey laboratory methods manual. Soil Survey Investigation Report No. 42 version 3.0. National Soil Survey Center, Lincoln, NE.

Soil Survey Staff[a]. Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions. Available online at http://soils.usda.gov/technical/classification/osd/index.html. Accessed [July 27, 2011].

Soil Survey Staff[b]. Natural Resources Conservation Service. United States Department of Agriculture. Web Soil Survey. Avallable online at http://websoilsurvey.nrcs.usda.gov Accessed [July 27, 2011].

Tabatabai, M.A., and J.M. Bremner. 1970. Use of the Leco automatic 70-second carbon analysis of soils. Soil Sci. Soc. Am. Proc., 34:608-610.

United States Department of Agriculture, Natural Resources Conservation Service. 2006. Land resource regions and major land resource areas of the United States, the Caribbean, and the Pacific Basin. U.S. Dept. of Ag. Handbook 296.

Veenstra, J.J. 2010. Fifty years of agricultural soil change in Iowa. Ph.D. diss. Iowa State University.

Recommendation for Future Research Needs

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

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%.

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)	SOC	Mehlich III Extractable P
		µm sec^{-1}	Mg ha^{-1}	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

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.

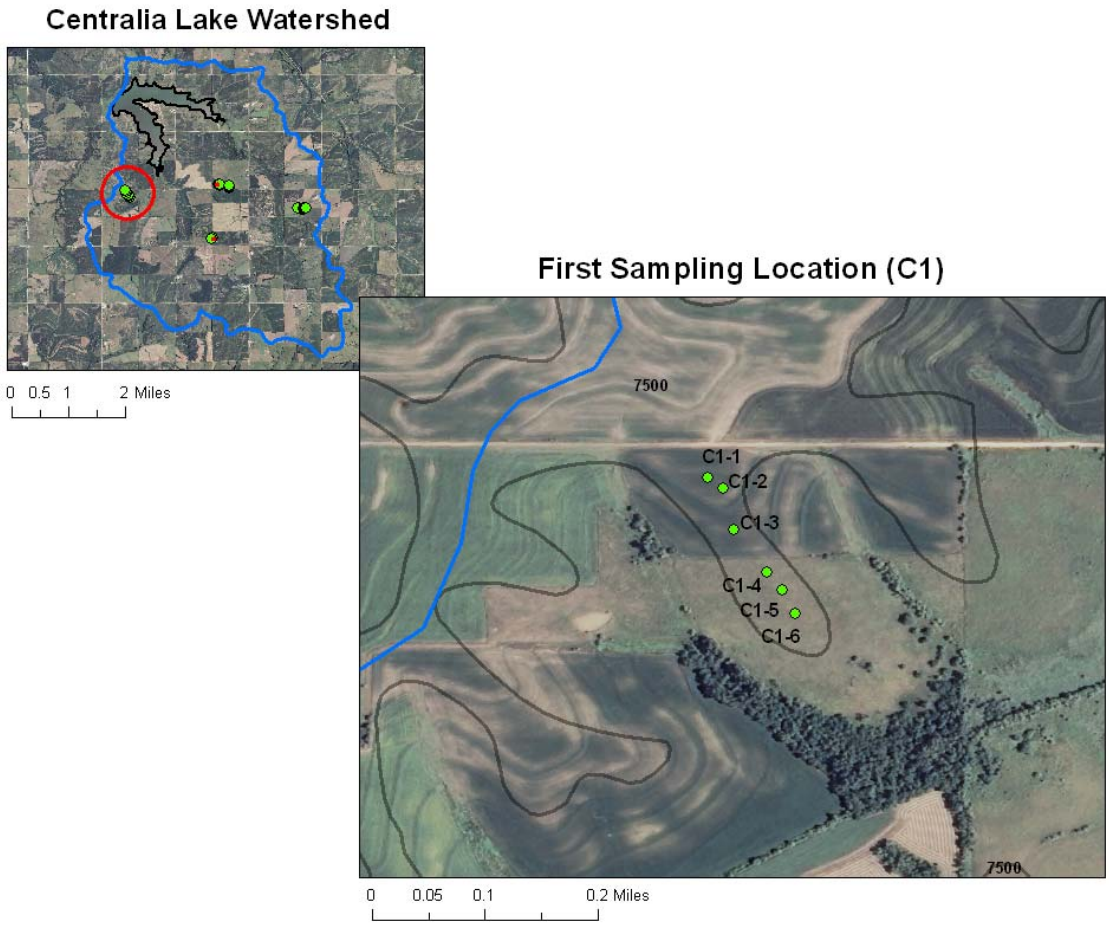


Figure 2. Soil sampling was completed by coring with a hydraulic truck-mounted soil probe, and infiltration measurements were collected using an automated mini disk infiltration network.

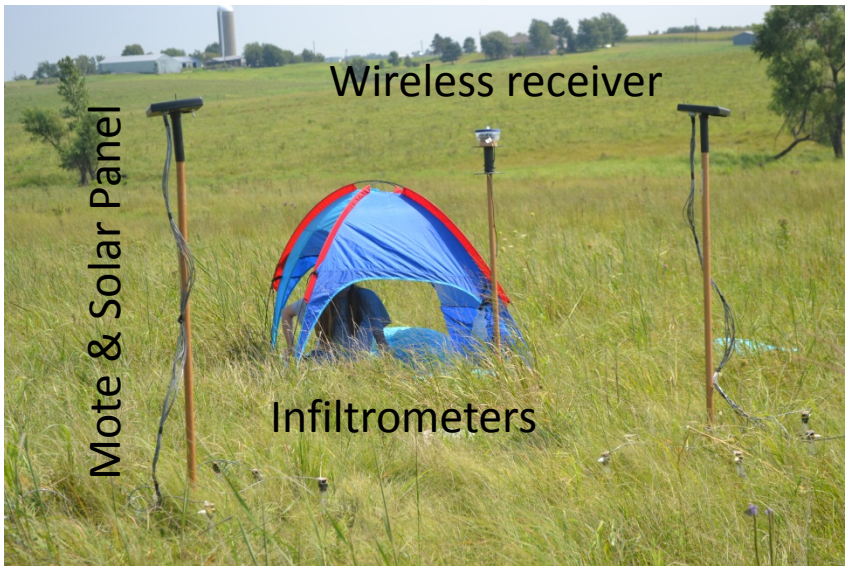


Figure 3. Typical ranges in saturated hydraulic conductivity (Ksat) for soils. The values recorded in this study are within the expected ranges. Source for the diagram: http://soils.usda.gov/technical/handbook/contents/part618ex.html

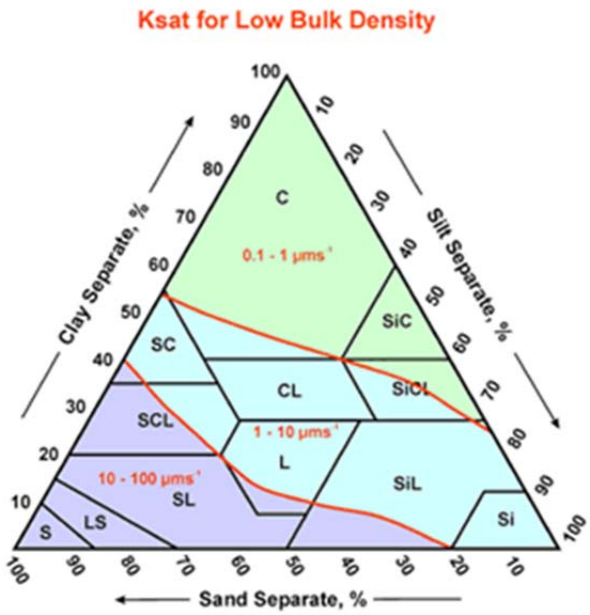
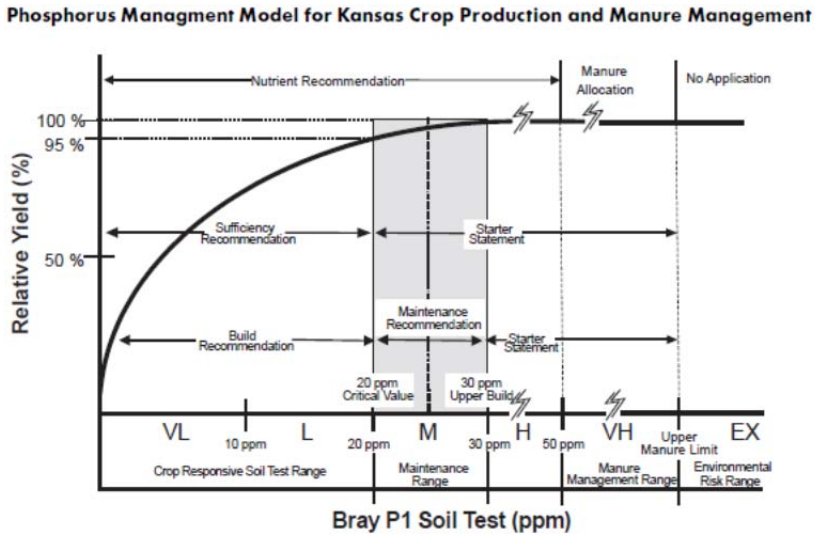


Figure 4. Phosphorus management recommendations for Kansas (Leikam et al., 2003).



FLUVIAL GEOMORPHOLOGY ASSESSMENT OF ATCHISON COUNTY LAKE, BANNER CREEK, AND CENTRALIA LAKE, WATERSHEDS

Brock Emmert[1]

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.

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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 for Centralia Lake and Atchison County Lake watersheds to compare with U.S. Geological Survey (USGS) sediment transport monitoring (March 2009 – September 2011). The predicted sediment yields from in-channel sources are 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 (Guy et al. 2012) were 2,800 tons per square mile at the Centralia Lake gage and 1,100 tons per square mile at the Atchison County gage during the monitoring period; suggesting in-channel sources are the primary sediment source. TWI did not compare Banner Creek watershed sediment yields with Atchison County and Centralia Lake watersheds as a result of differences in drainage density and topography. 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

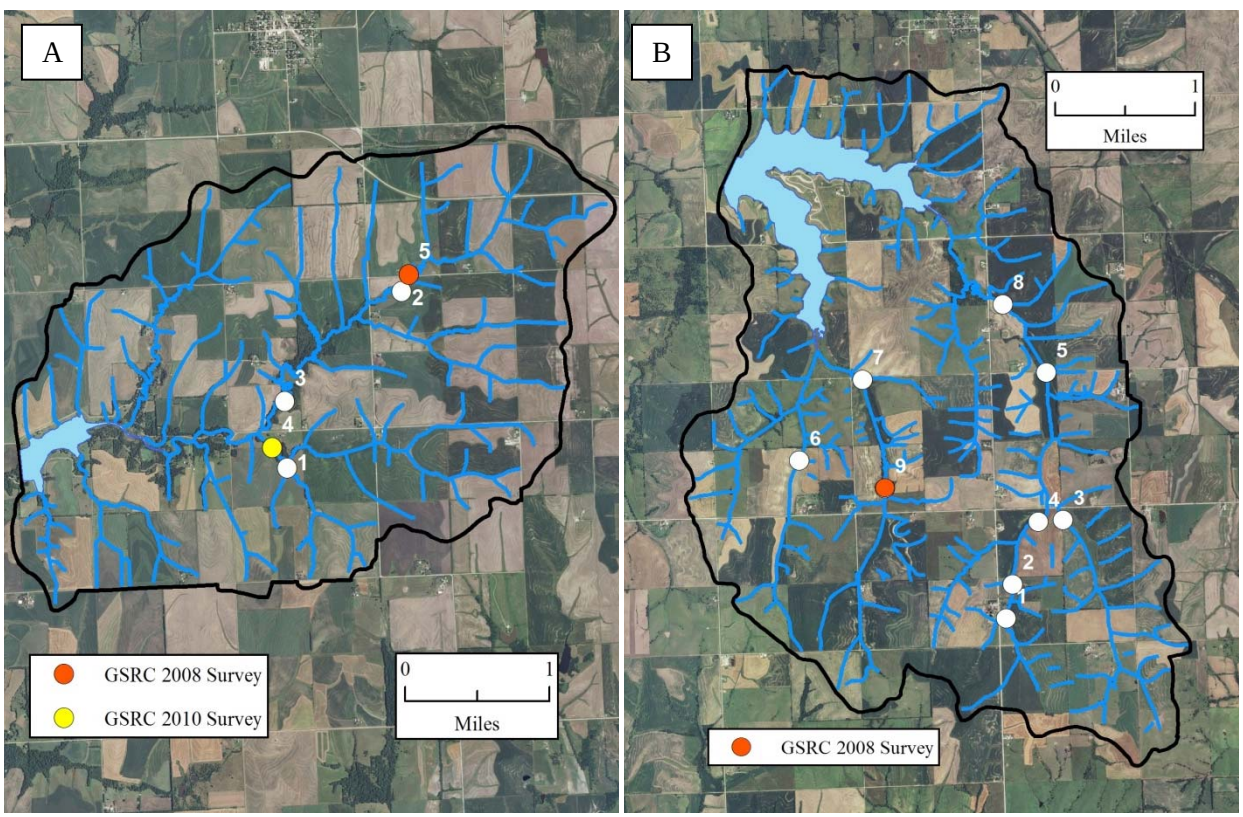
The Watershed Institute, Inc. (TWI) completed fluvial geomorphology assessments at selected channel reaches to document channel stability characteristics. Fluvial geomorphology assessments are one of seven watershed characteristics researched as part of this sediment baseline study. In-channel sediment 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.



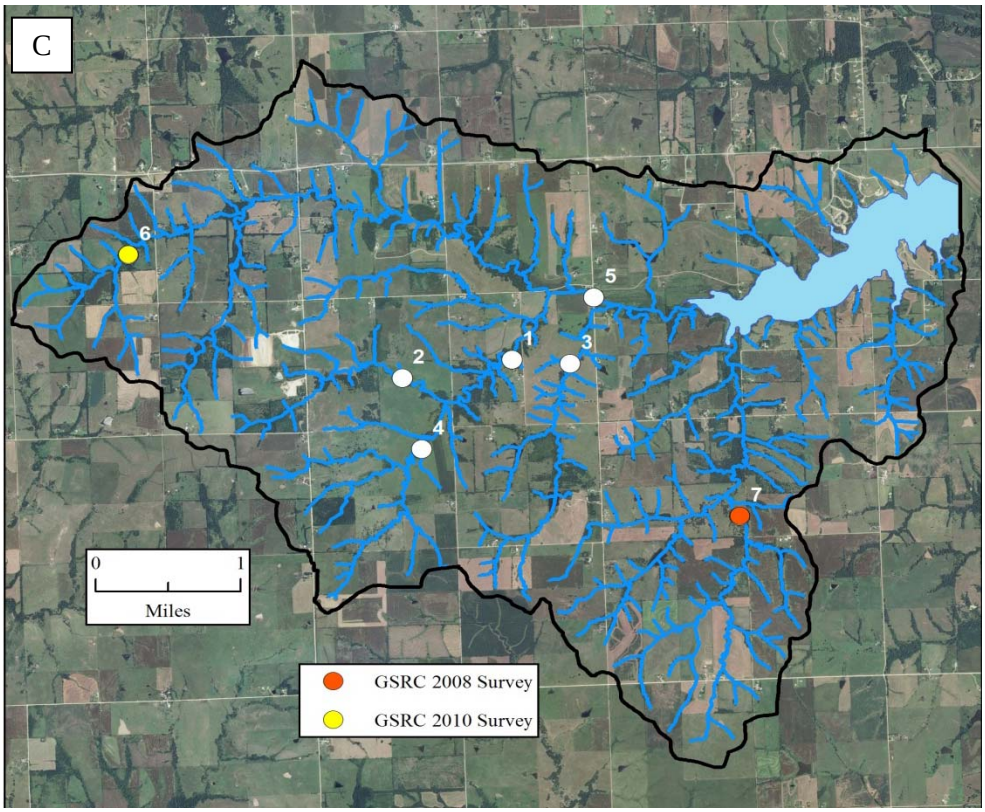


Figure 1: Fluvial Geomorphology Survey Locations for (A) Atchison County Lake, (B) Centralia Lake, and (C) Banner Creek Reservoir.

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

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.

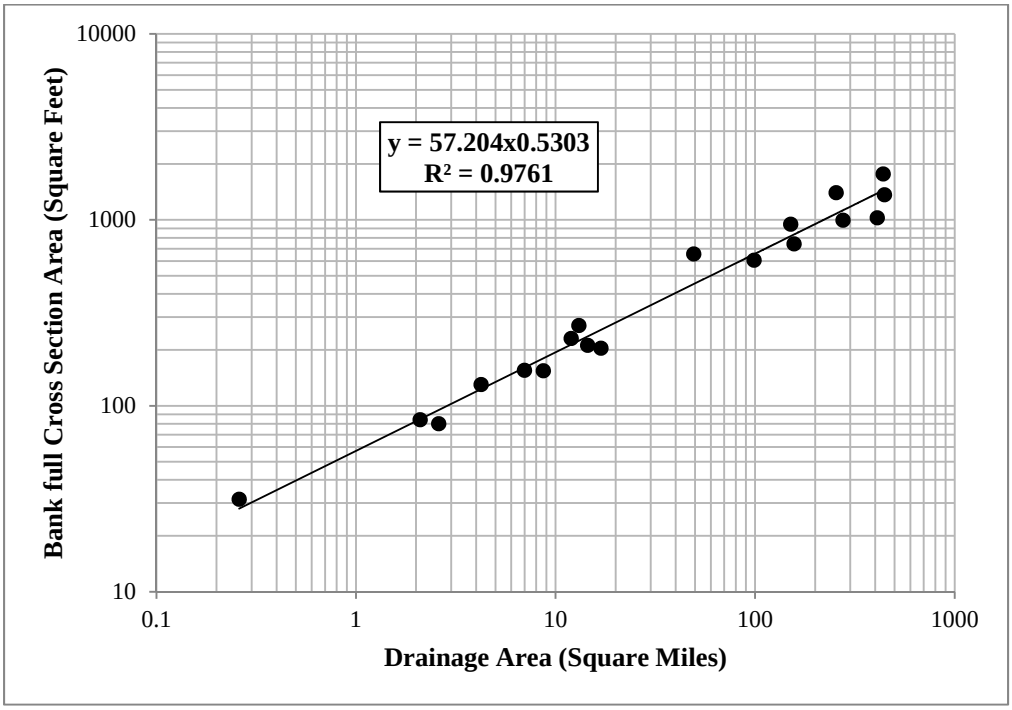


Figure 2: Drainage Area versus Cross Section Area of Northeast Kansas Streams (from Emmert and Hase 1998, TWI 2006, GSRC 2008, and GSRC 2010)

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.

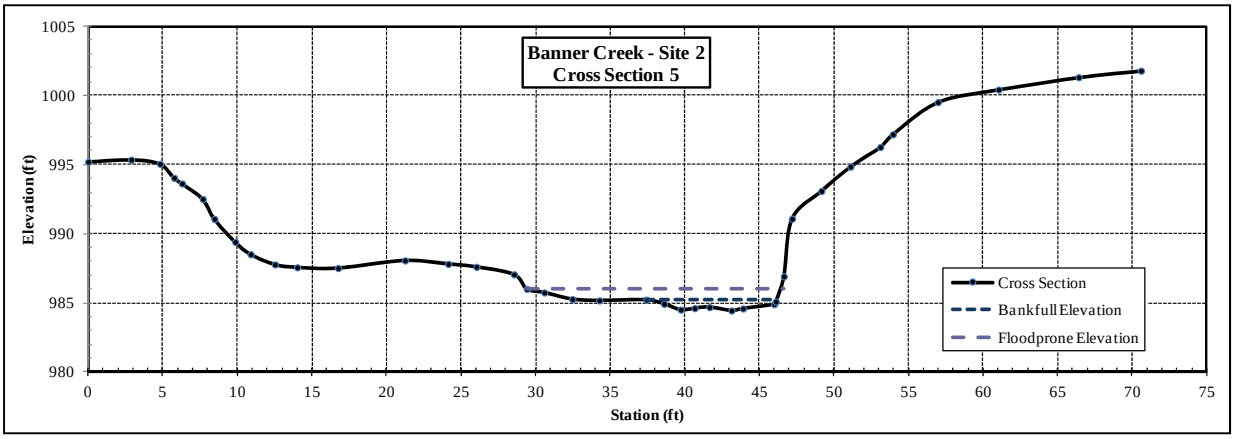


Figure 3: Formation of small floodplain at Banner Creek – Site 2.

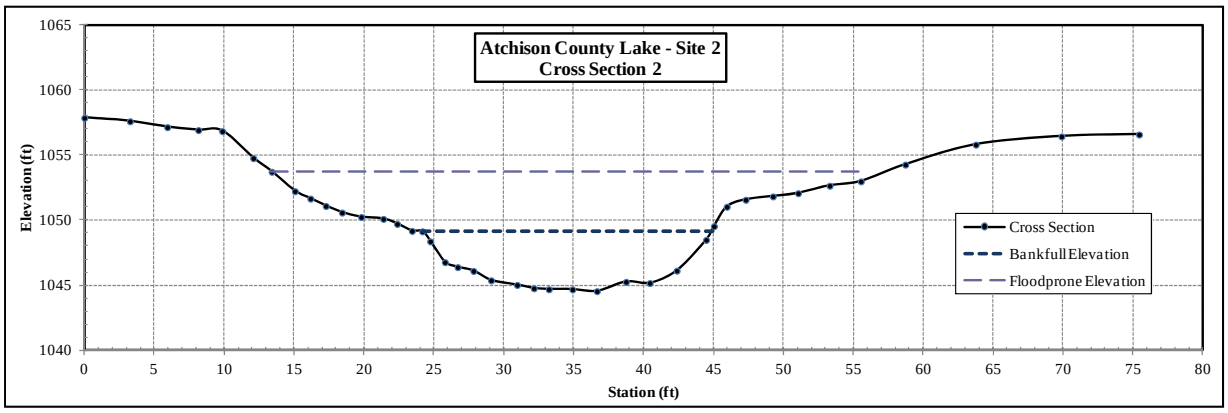


Figure 4: Bankfull indicator at change of streambank angle on left bank.

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.

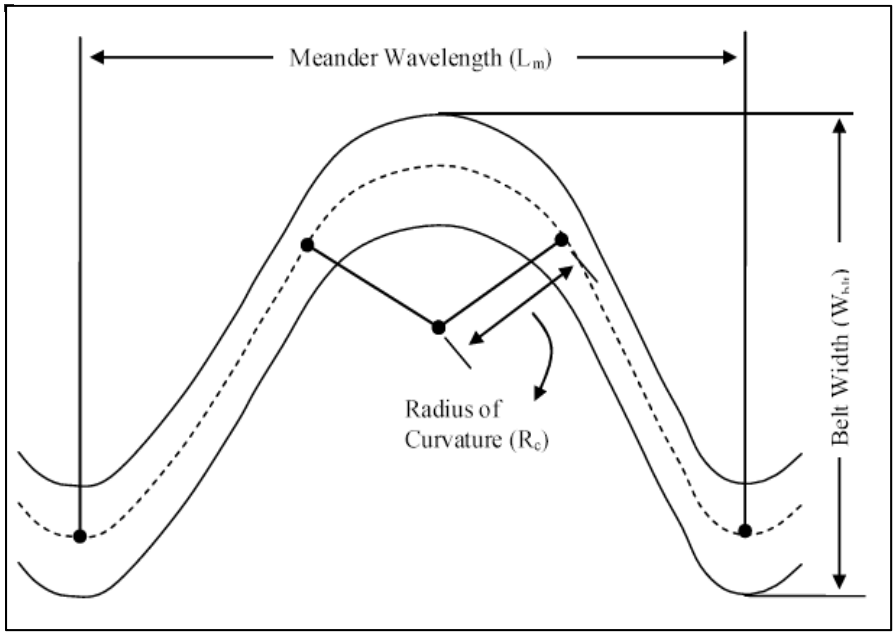


Figure 5: Meander geometry measurements.

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

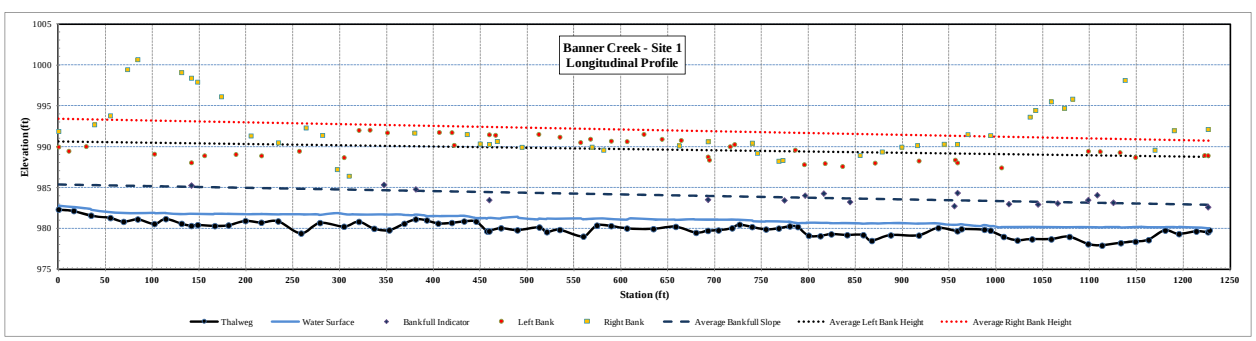


Figure 6: Longitudinal Profile at Banner Creek – Site 1

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).

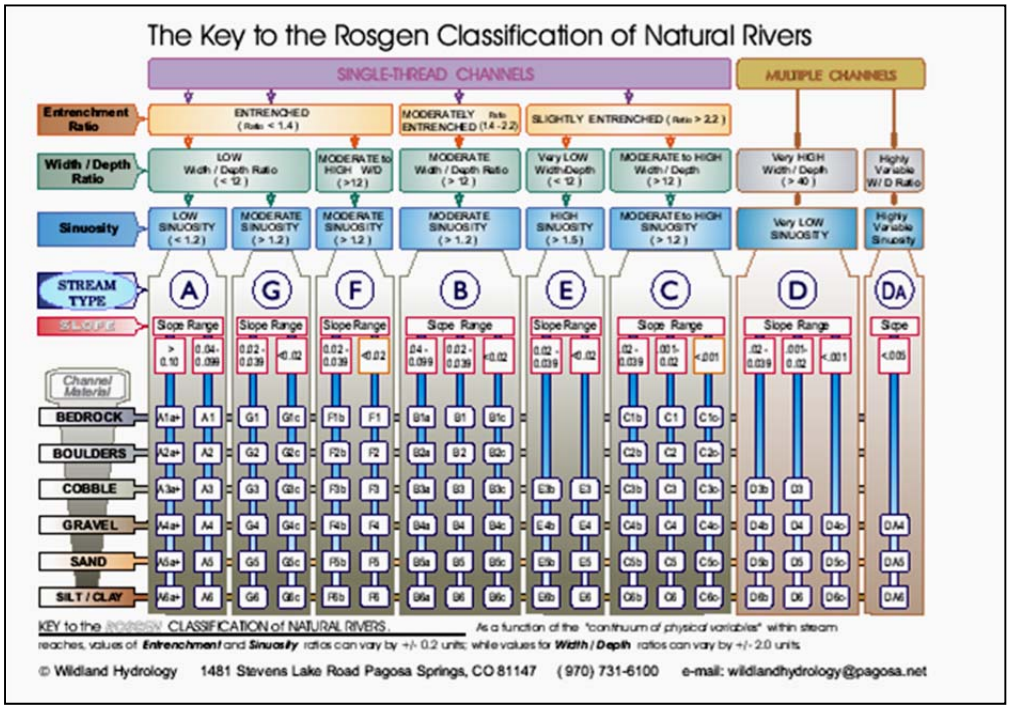


Figure 7: Rosgen Classification of Natural Rivers (from Rosgen 1996)

Discharge Calculation

To estimate discharge, TWI used the Manning relation:

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

in which u is velocity in feet per second, R is hydraulic radius in feet, S is average water slope in feet per feet, and 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:

$$Q_{bkf} = Au$$

in which 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 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.

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

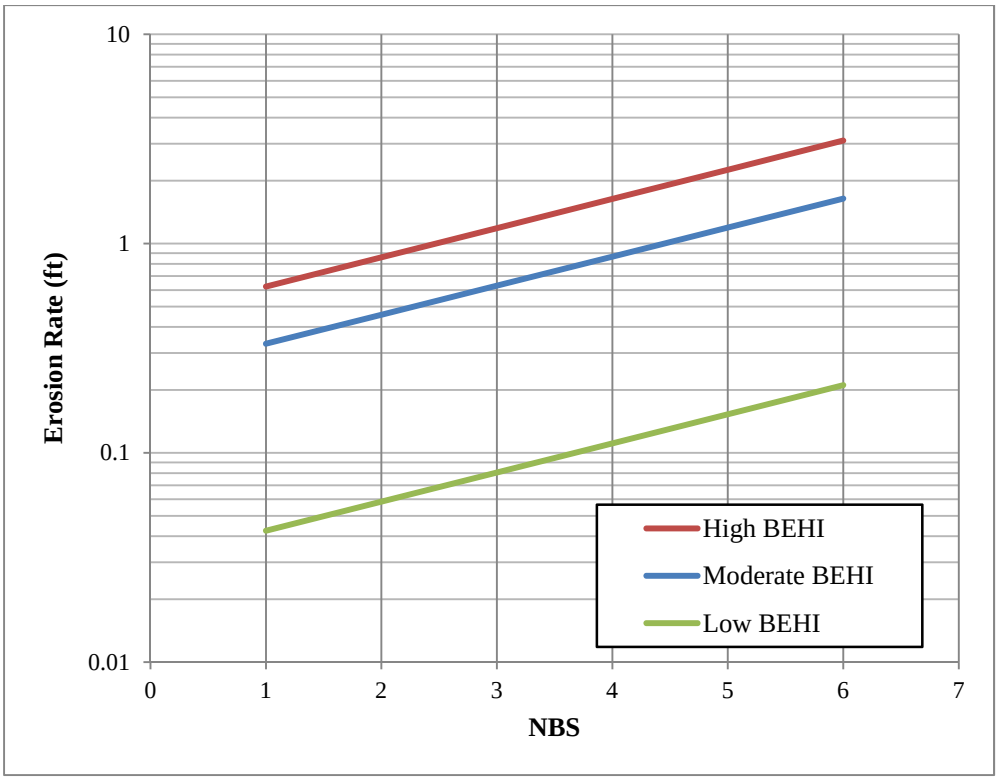


Figure 8: BEHI-NBS erosion prediction curves. Moderate and High BEHI curves are from Sass and Keane (2012).

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.

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.

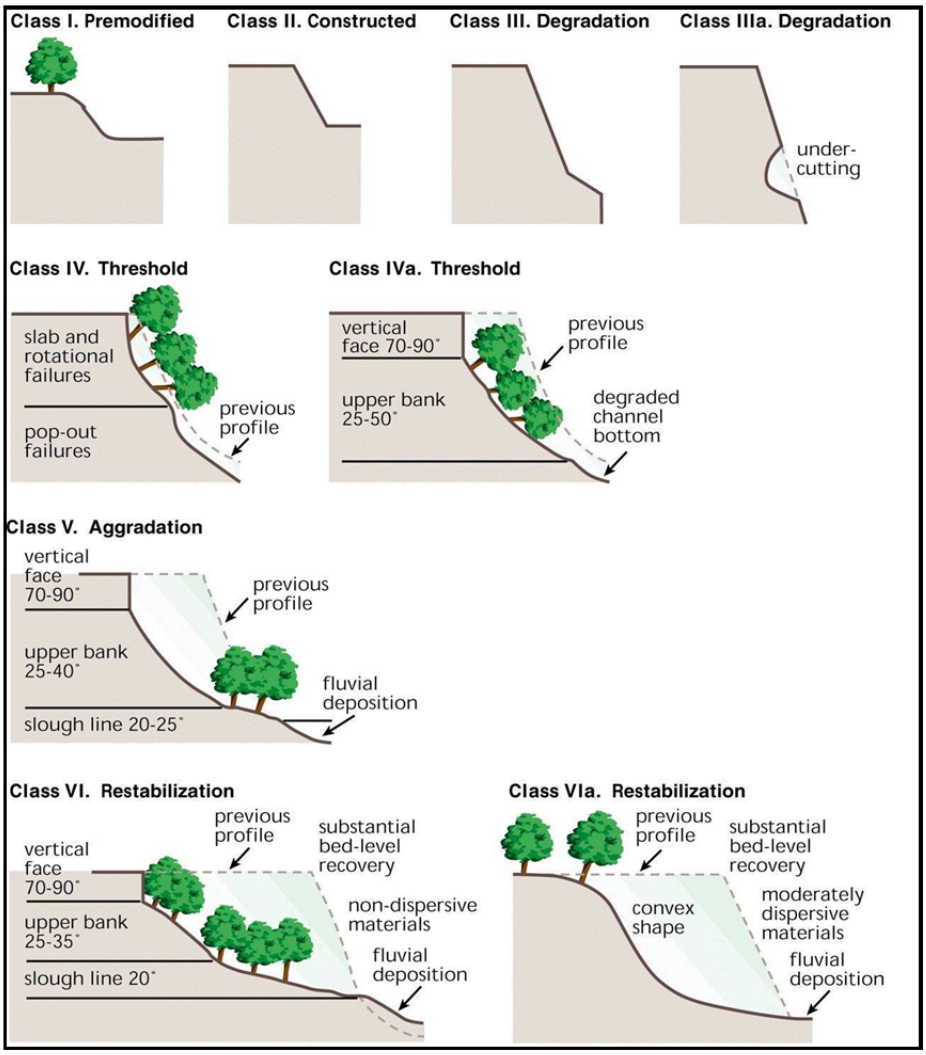


Figure 9: Simon Channel Evolution Sequence (from Simon 1989a).

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.

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

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.

Table 3: Changes is 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

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.

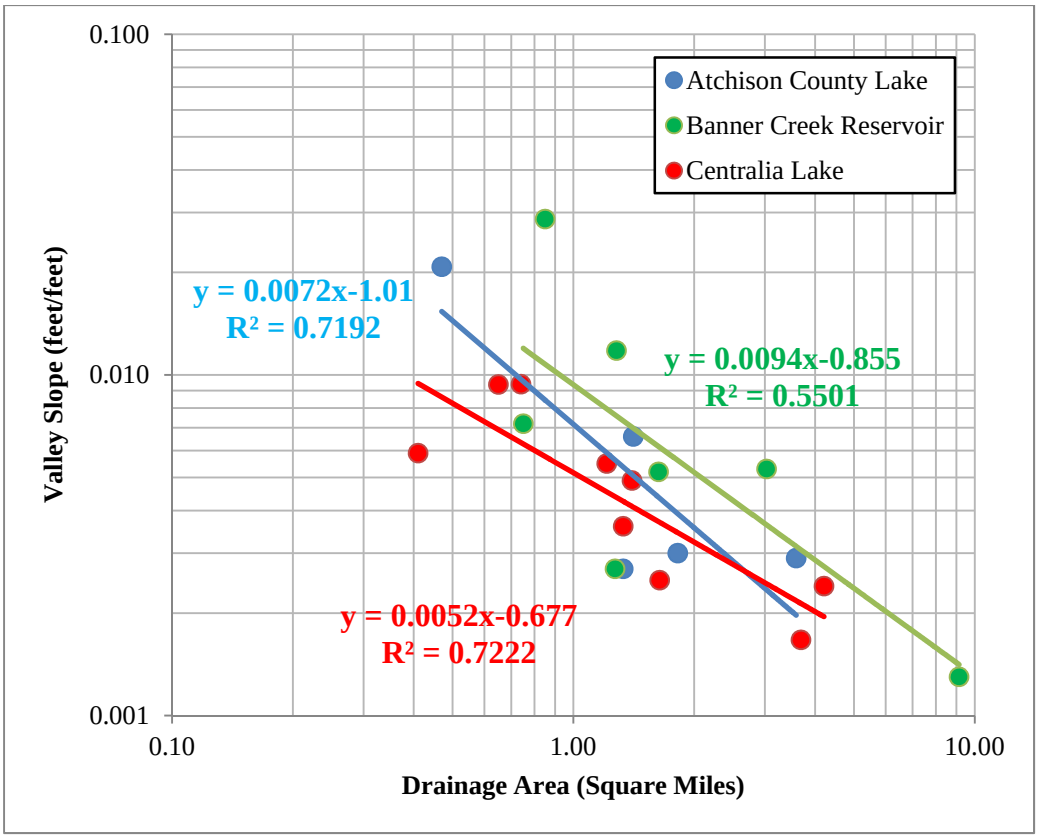


Figure 10: Drainage Area versus valley slope.

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 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.

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

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.

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

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.

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

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

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.

Table 7: Banner Creek channel morphology results

Site	Bankfull Width (ft)	Hyraulic 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

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

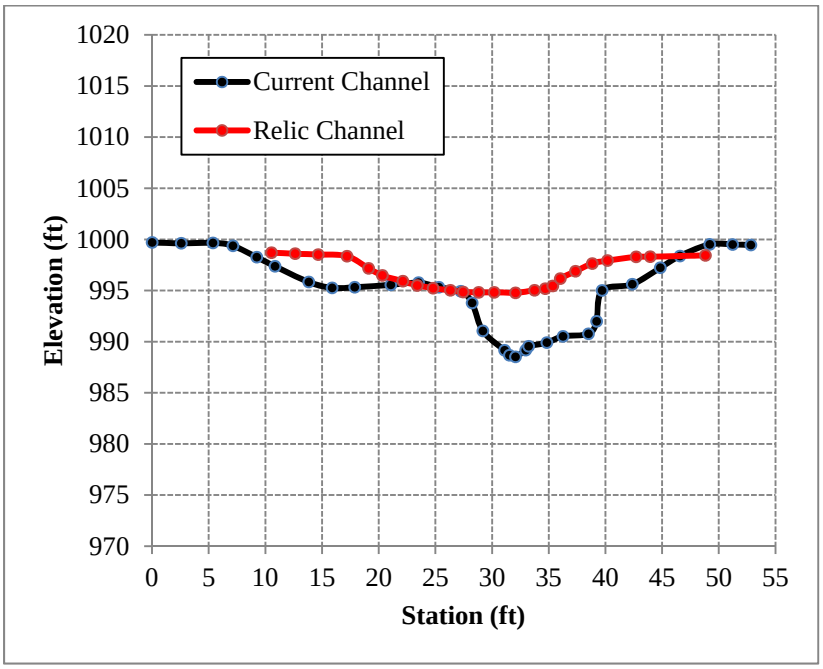


Figure 13: Cross section comparison of Centralia Lake Site 9 current and relic channels.

Table 8: Centralia Lake channel morphology results

Site	Bankfull Width (ft)	Hyraulic 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

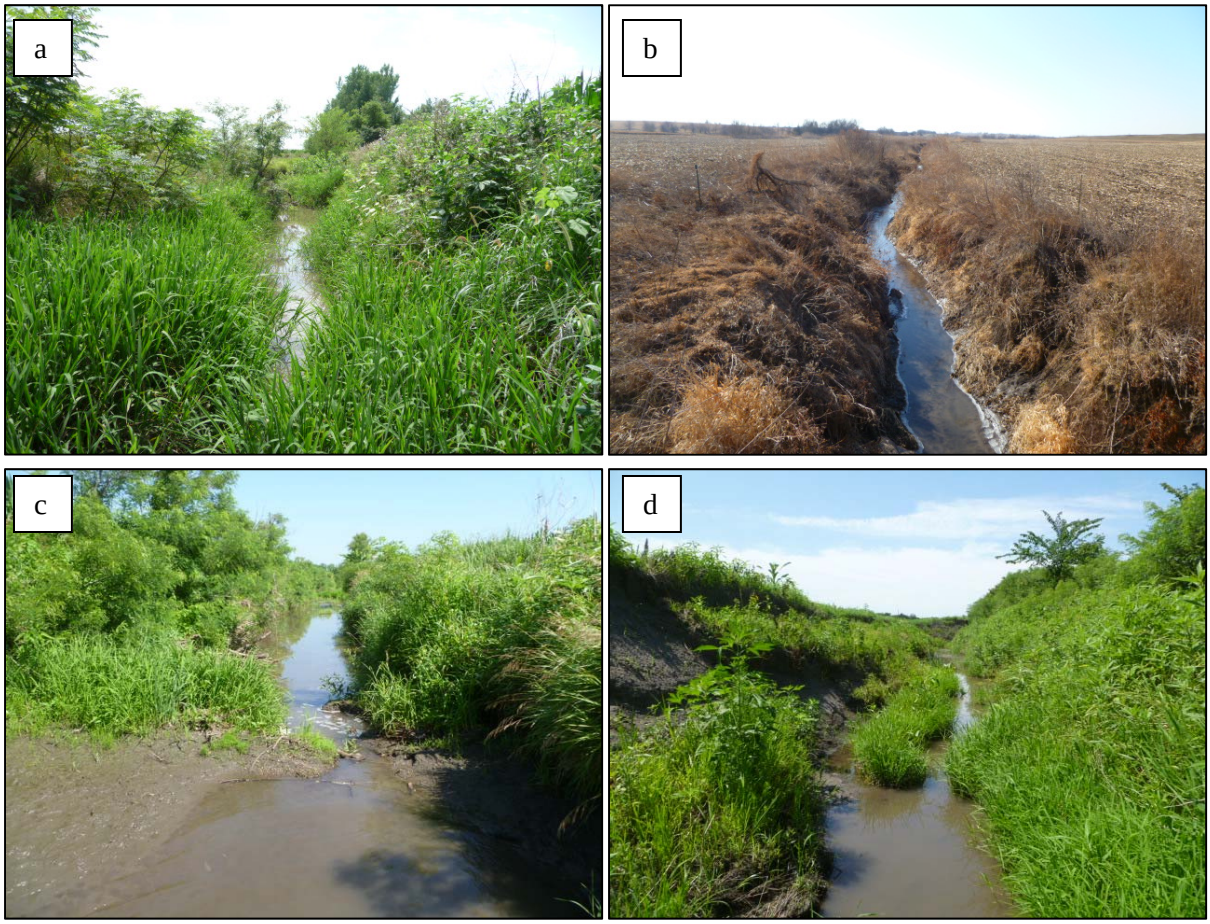


Figure 14: Centralia Lake site photos: (a) Site 2, (b) Site 5, (c) Site 7, and (d) Site 8.

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.

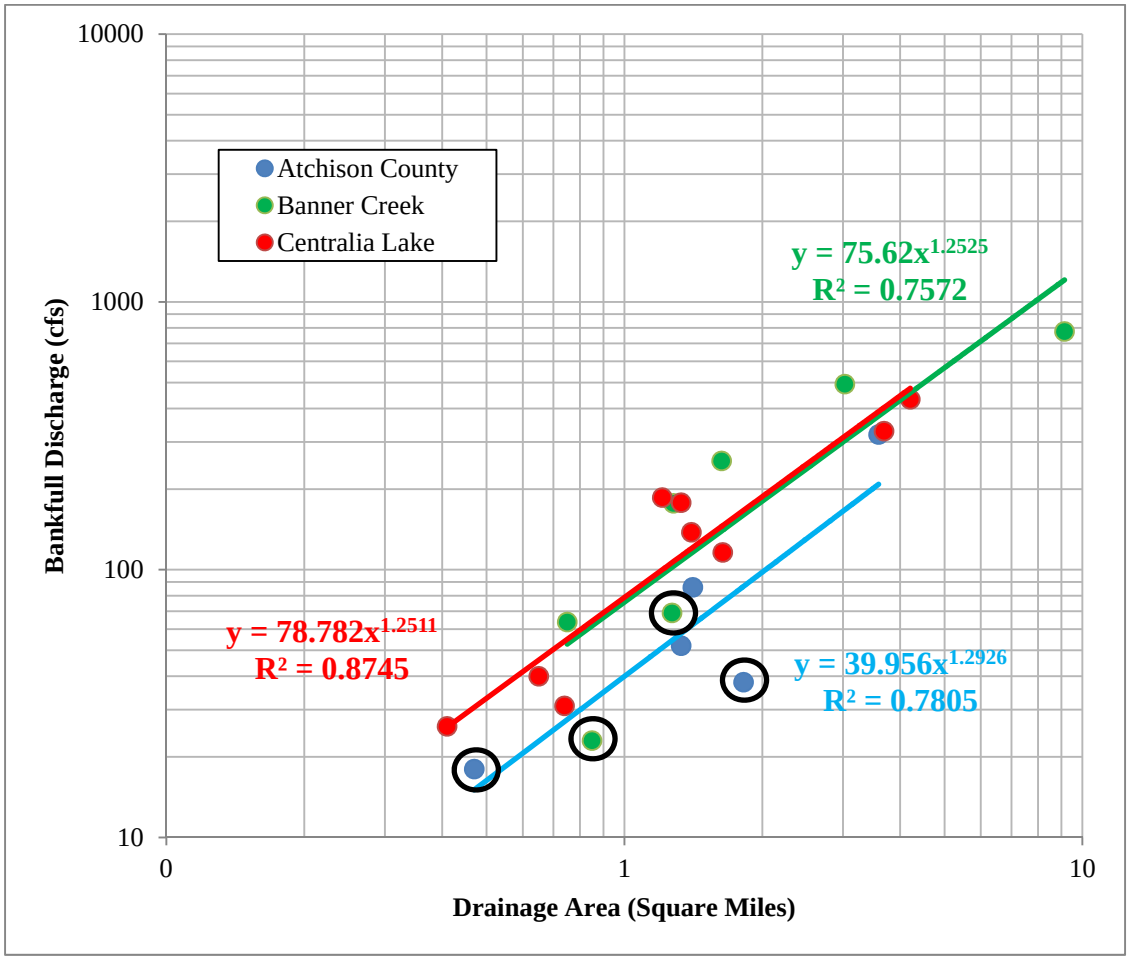


Figure 15: Drainage area versus calculated bankfull discharge.

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 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.

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**

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 above). 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).

Figure 16: Active bank slumping along left banks.

Figure 17: Active knickpoints in tributaries above survey sites.

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 above). 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.

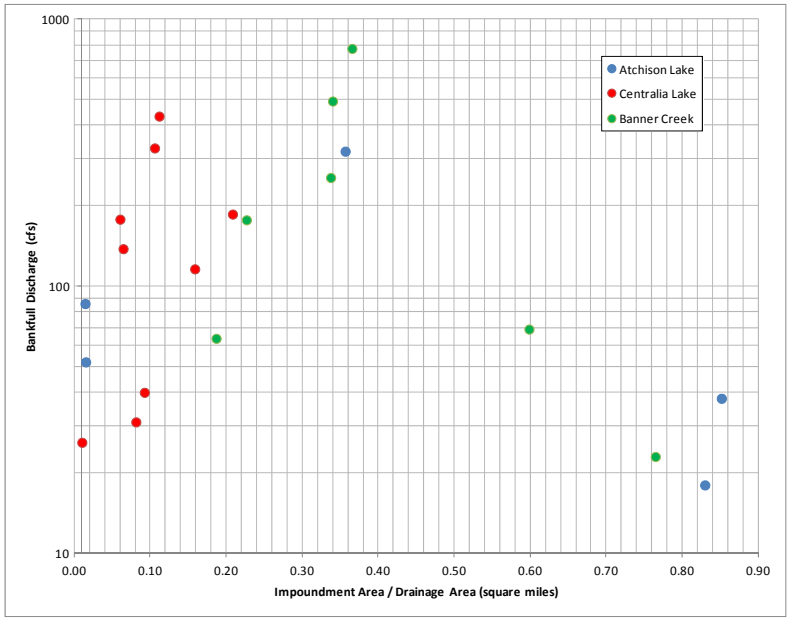


Figure 18: Bankfull discharge versus impoundment area/total drainage area.

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.

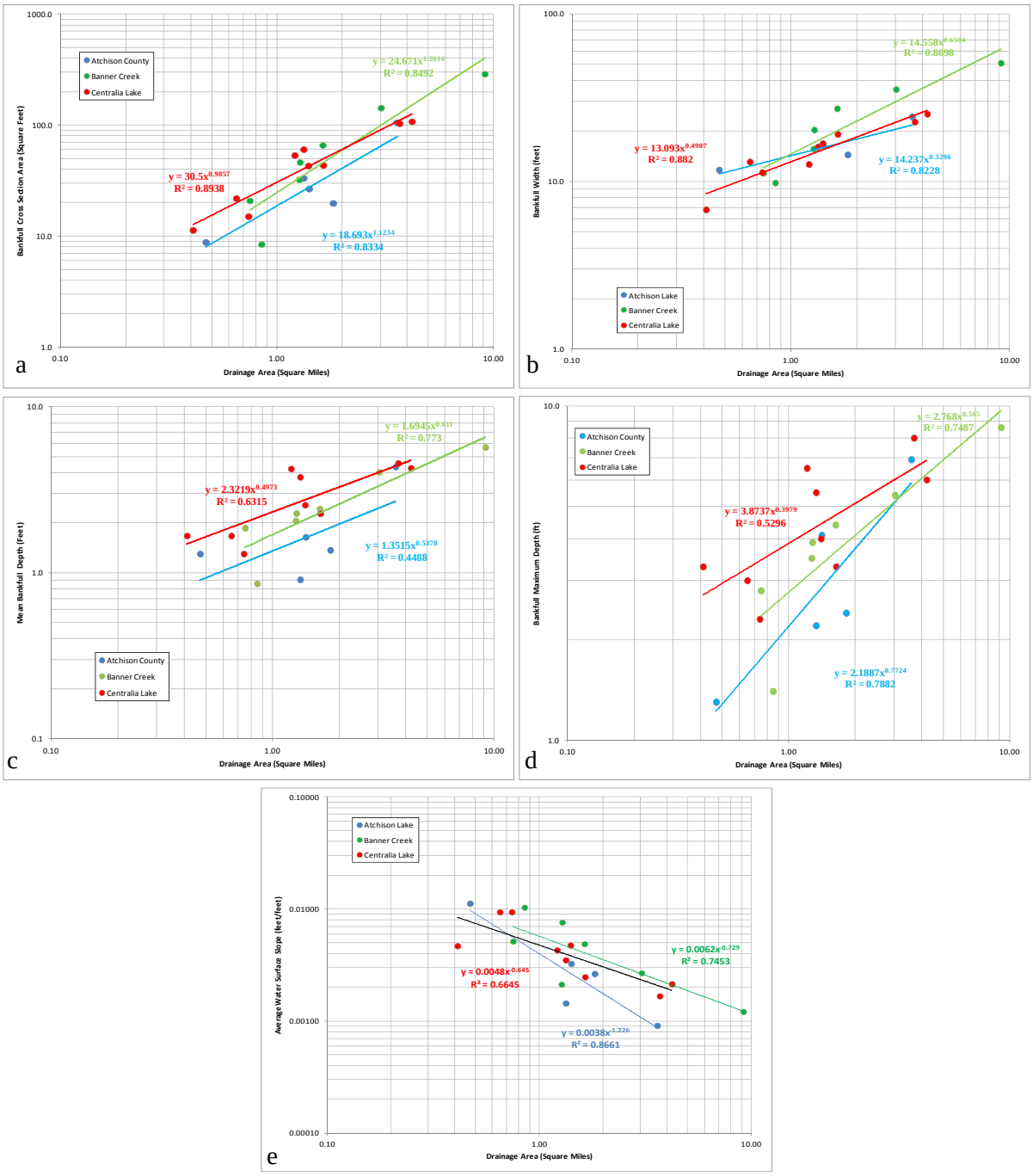


Figure 19: (a) Bankfull cross section area versus drainage area, (b) bankfull width versus drainage area, (c) bankfull mean depth versus drainage area, (d) bankfull maximum depth versus drainage area, and (e) average water surface slope versus drainage area.

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).

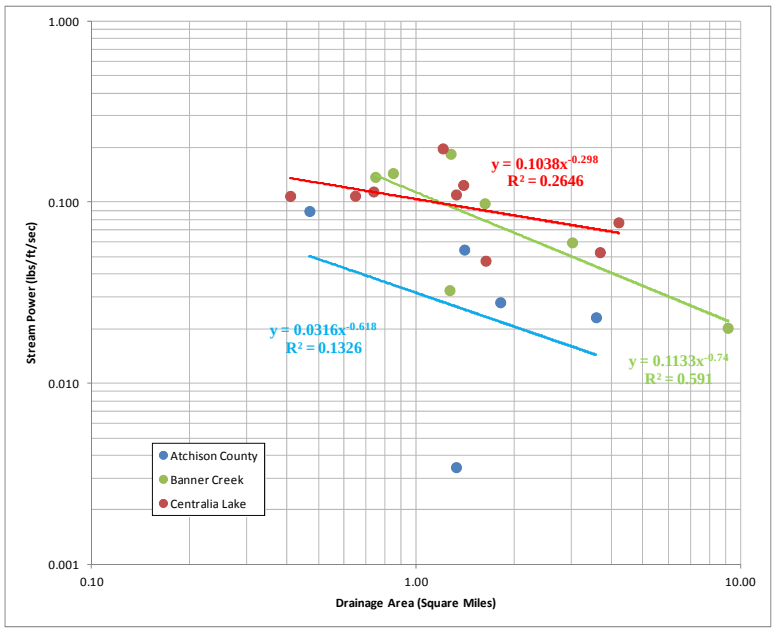


Figure 20: Stream power at bankfull versus drainage area.

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

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 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 and Centralia Lake watersheds. Both watersheds have a similar landuse, drainage density, and topography. TWI did not include Banner Creek since the drainage density, topography and landuse are dissimilar.

TWI used the erosion loss predictions to develop a watershed soil loss rate. 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 and the Site 5 channel morphology has low stream power to transport sediment. 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 (Guy et al. 2012) monitoring time period from March 2009 to September 2011 to calculate an overall sediment yield. The predicted sediment yields from in-channel sources are 2,065 tons per square mile at Centralia Lake and 943 tons per square mile in Atchison County Lake. The USGS monitoring results equaled 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 (Guy et al. 2012) during the monitoring period. TWI suggests that much of the sediment source is from in-channel erosion.

RECOMMENDATIONS FOR FUTURE RESEARCH NEEDS

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.

LITERATURE CITED

Brandt, S.A. 2000. Classification of Geomorphological Effects Downstream of Dams. *Catena*. Vol 40: 375-401.

Dunne, T. and L.B. Leopold. 1978. *Water in Environmental Planning*. W.H. Freeman and Company. New York, New York.

Emmert, B.E. and K. Hase. 2001. *Geomorphic Assessment and Classification of Kansas Riparian Systems*. Prepared for EPA under Contract No. CD 997520-01. December 2001.

Foster, G.M., Lee, C.J., and Ziegler, A.C., 2012, Sediment transport to and from small impoundments in northeast Kansas, March 2009 through September 2011: *U.S. Geological Survey Scientific Investigations Report 2012–5269*, 38 p. (Also available at http://pubs.usgs.gov/sir/2012/5269.)

Grant, G.E., Schmidt, J.C., and S.L. Lewis. 2003. A Geological Framework for Interpreting Downstream Effects of Dams on River. in J.E. O'Connor and G.E. Grant eds. *A Peculiar River. Water Science and Application 7*. American Geophysical Union, p203-219.

Gulf South Research Corporation. 2008. *Kansas River Basin Stream and River Channel Assessment Project Final Report*. Baton Rouge, LA. Available on-line at: http://www.kwo.org/reports_publications/Reports_Publications.htm.

Gulf South Research Corporation. 2010. *Kansas River Basin Regional Sediment Management Section 204 Stream and River Channel Assessment Final Report*. Baton Rouge, LA. Available On-line at: http://www.kwo.org/reports_publications/Reports_Publications.htm.

Harmel, R.D., Haan, C.T., and R.C. Dutnell. 1999. Evaluation of Rosgen's Streambank Erosion Potential Assessment in Northeast Oklahoma. *Journal of the American Water Resources Association.* Vol 35 (1): 113-121.

Harvey, M.D. and C.C Watson. 1986. Fluvial Processes and Morphological Thresholds in Incised Channel Restoration. Water Resources Bulletin. Vol 22 (3): 359-368.

Juracek, K.E. and Ziegler, A.C. 2007. Estimation of Sediment Sources Using Selected Chemical Tracers in the Perry Lake and Lake Wabaunsee Basins, Northeast Kansas. *U.S. Geological Survey Scientific Investigations Report: 2007-5020*. 53p

Keane, T.D. 2004. Learning from nature's stability: building a multi-purpose database applicable to stream assessment, restoration, and education. In *Proceedings of the ASAE Conference: Self-Sustaining Solutions for Streams, Watersheds, and Wetlands Conference.* St. Paul, Minnesota. Pages 99-108.

Mulvihill, C.I. and B.P. Baldigo. 2012. Optimizing Bankfull Discharge and Hydraulic Geometry Relations for Stream in New York State. *Journal of the American Water Resources Association*. Vol 48(3): 449-463.

Petts, G.E. 1980. Morphologic Changes of River Channels Consequent Upon Headwater Impoundment. *Journal of the Institution of Water Engineers and Scientists*. Vol 34: 374-382.

Phillips, J.D. 2003. Toledo Bend Reservoir and Geomorphic Response in the Lower Sabine River. *River Research and Applications*. Vol 19: 137-159.

Rosgen, D.L. 1994. A Classification of Natural Rivers. *Catena*. Vol 22: 169-199.

Rosgen, D.L. 1996. *Applied River Morphology*. Wildland Hydrology Books. Pagosa Springs, Colorado.

Rosgen, D.L.. 2006. *Watershed Assessment of River Stability and Sediment Supply (WARSS)*. Wildland Hydrology Books. Fort Collins, Colorado.

Sass, C.K. and T.D. Keane. 2012. Application of Rosgen's BANCS Model for NE Kansas and the Development of Predictive Streambank Erosion Curves. *Journal of the American Water Resources Association*. Vol 48 (4): 774-787.

Schumm, S.A., Harvey, M.D, and C.C Watson. 1984. *Incised Channels Morphology, Dynamics and Control*. Water Resources Publications, LLC. Littleton, Colorado.

Shankman, D. and S.A. Samson. 1991. Channelization Effects on Obion River Flooding, Western Tennessee. *Water Resources Bulletin*. Vol 27 (2): 247-254.

Shields, F.D., Simon, A., and L.J. Steffen. 2000. Reservoir Effects on Downstream River Channel Migration. *Environmental Conservation*. Vol 27 (1): 54-66.

Shindala, A. and M.S. Priest. 1970. The Meandering of Natural Streams in Alluvial Materials. *Water Resources Bulletin*. Vol 6 (2): 269-276.

Simon, A. 1989a. A Model of Channel Response in Disturbed Alluvial Channels. *Earth Surface Processes and Landforms*. Vol 14: 11-26.

Simon, A. 1989b. The Discharge of Sediment in Channelized Alluvial Stream. *Water Resources Bulletin*. Vol 25 (6): 1177-1188.

Simon, A. 1994. Gradation Processes and Channel Evolution in Modified West Tennessee Streams: Process, Response, and Form. *U.S. Geological Survey Professional Paper 1470*. 84 p.

Simon, A., and C.R. Hupp. 1986. Channel Evolution in Modified Tennessee Channels. In Proceedings *Fourth Federal Interagency Sedimentation Conference*, Las Vegas, March 24-27, Vol. 2, pp 5-71-5-82.

Simon, A., and C.R. Hupp. 1990. The Recovery of Alluvial Systems in Response to Imposed Channel Modifications, West Tennessee: in Thornes, J.B., editor, *Vegetation and Erosion*, proc. 1989 Annual Meeting, British Geomorphic Research Group. John Wiley & Sons Ltd., p. 145-160.

Simon, A. and M. Rinaldi. 2000. Channel Instability in the Loess Area of the Midwestern United States. *Journal of the American Water Resources Association*. Vol 36 (1): 133-150.

Thorne, C.R. 1997. Chapter 7: Channel Types and Morphological Classification. In C.R. Thorne, R.D. Hey, and M.D. Newson (editors). *Applied Fluvial Geomorphology for River Engineering and Management.*

U.S. Department of Agriculture Natural Resource Conservation Service. 2012. Web Soil Survey. Accessed on-line at: http://websoilsurvey.nrcs.usda.gov/app/

U.S. Geological Survey. 2012. Kansas Digital Raster Graphs. Accessed on-line at: http://imageserver.kansasgis.org/arcgis/services.

Watershed Institute, Inc. 2004. *Fall River Watershed Joint District No. 21 Fluvial Geomorphology Report*. Topeka, KS.

Watershed Institute, Inc. 2006. *Kansas Department of Wildlife and Parks 2006 Geomorphology Report*. December 2006.

Wellmeyer, J.L., Slattery, M.C., and J.D. Phillips. 2005. Quantifying Downstream Impacts of Impoundment on Flow Regime and Channel Planform, Lower Trinity River, Texas. *Geomorphology*. Vol 69: 1-13.

Williams, G.P., and Wolman, M.G.,1984, Downstream effects of dams on alluvial rivers: *U.S. Geological Survey Professional Paper 1286*, 83 p.

Wolman, M.G. 1954. A method of sampling coarse river-bed material. *Transactions of American Geophysical Union.* Vol 35: 54-74.

Aquifer Storage and Recovery in Near-Surface Aquifers: Development of a New Recharge Approach Using Small-Diameter, Low-Cost Wells

Basic Information

Title:	Aquifer Storage and Recovery in Near-Surface Aquifers: Development of a New Recharge Approach Using Small-Diameter, Low-Cost Wells
Project Number:	2011KS113G
Start Date:	9/1/2011
End Date:	8/31/2013
Funding Source:	104G
Congressional District:	KS-003
Research Category:	Climate and Hydrologic Processes
Focus Category:	Water Supply, Hydrology, Methods
Descriptors:	None
Principal Investigators:	Gaisheng Liu, Andrea Elizabeth Brookfield, James J. Butler, Marios Sophocleous, Donald Whittemore, Andrew Ziegler

Publications

1. Falk Händel, Gaisheng Liu, Peter Dietrich, Rudolf Liedl, Jim Butler (2013), Numerical investigation of shallow aquifer recharge using small-diameter, low-cost wells and infiltration basins, 2012 NGWA Ground Water Summit, San Antonio, TX, April 29 May 1, 2013.
2. Falk Händel, Gaisheng Liu, Peter Dietrich, Rudolf Liedl, Jim Butler (2013), Numerical investigation of shallow aquifer recharge using small-diameter, low-cost wells and infiltration basins, NovCare (Novel Methods for Subsurface Characterization and Monitoring: From Theory to Practice) 2013 International Conference, Leipzig, Germany, May 13 16, 2013.
3. Falk Händel, Gaisheng Liu, Peter Dietrich, Rudolf Liedl, Jim Butler (2013), Numerical investigations of aquifer recharge using small-diameter wells and surface basin, in preparation for Groundwater.

Aquifer Storage and Recovery in Near-Surface Aquifers: Development of a New Recharge Approach Using Small-Diameter, Low-Cost Wells

Project Number: 2011KS113G
Start Date: 9/1/2011
End Date: 8/31/2013
Funding Source: 104G
Focus Categories: WS, HYDROL, MET
Descriptors: Aquifer Storage and Recovery, Artificial Recharge, Direct-Push Technology, Integrated Hydrological Modeling, Recharge Wells, Infiltration Basin and Trench
Primary PI: Dr. Gaisheng Liu, Kansas Geological Survey, University of Kansas
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Dr. Donald O. Whittemore, Kansas Geological Survey, University of Kansas
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Dr. Andrew C. Ziegler, United States Geological Survey Kansas Water Science Center, Lawrence, Kansas
Dr. James J. Butler, Jr., Kansas Geological Survey, University of Kansas
Project Class: Research

I: Technical Report

Problem Statement

Aquifer storage and recovery (ASR) is the artificial recharge and temporary storage of water in an aquifer during times when water is abundant, and recovery of all or a portion of the water during times when it is needed (Pyne, 2005). In recent years, interest in ASR has increased due to various concerns such as declining groundwater resources, vulnerability of surface water supplies to contamination and reservoir sedimentation, and unfavorable projections of future climate change. Most climate change scenarios indicate that due to a likely increase in future global temperature, there will be more severe and prolonged droughts, with precipitation events becoming more intense but less frequent (IPCC, 2007). By capturing and storing excess water in the underground when precipitation is plentiful, ASR offers one of the most practical approaches for resources managers to combat future water-supply challenges. Compared to a traditional surface-water reservoir, aquifer storage eliminates evaporative losses and the need to convert large land areas into reservoirs, provides a much larger storage capacity (which is critical in the case of multi-year drought), and is much less vulnerable to surface-water contamination activities. Because of these advantages, the number of ASR projects that are either fully operational or in various phases of development is quickly growing across the United States.

A successful implementation of ASR typically involves four key components, 1) an aquifer that is suitable for temporarily storing a large volume of water, 2) source water that is of good quality and quantity, 3) a means to transfer the source water into the

aquifer, and 4) a means to recover the water from the aquifer. Currently, many limiting factors still hinder the effectiveness of ASR as a new tool for water resources management (Pyne, 2005; Maliva and Missimer, 2010). One of the major technical challenges has been how to design artificial recharge systems that can efficiently transfer source water into the aquifer. Typically aquifer recharge is achieved through various surface infiltration methods (such as basins and trenches) and/or large-diameter injection wells. Surface infiltration methods only work when the storage aquifer is shallow, and no low-permeability layers exist between the ground surface and the aquifer that would constrain downward movement of recharge water. Moreover, surface methods require adequate land area available at reasonable cost. Due to their dependency on natural soil conditions, surface infiltration methods have a limited infiltration capacity. This can greatly undermine the performance of ASR during times when precipitation is intense and a significant amount of water must be stored within a short duration. Surface infiltration methods are often supplemented with injection wells that typically have a diameter of 40 cm or larger. These large-diameter injection wells are equipped with high-power pumps so that water can be forcefully injected into the aquifer at a high rate. When surface infiltration methods are not applicable, e.g., the storage zone is deep or there is a near-surface zone of low permeability, injection wells are the only aquifer recharge option. In general, large-diameter injection wells are more expensive than surface infiltration methods, as they require a much higher amount of logistical and infrastructure support for pump operation and maintenance. Well clogging remains a problem at many ASR projects (Brown et al., 2005), although it can be somewhat alleviated by operating the wells in a dual-purpose mode for both water recharge and recovery (Pyne, 2005).

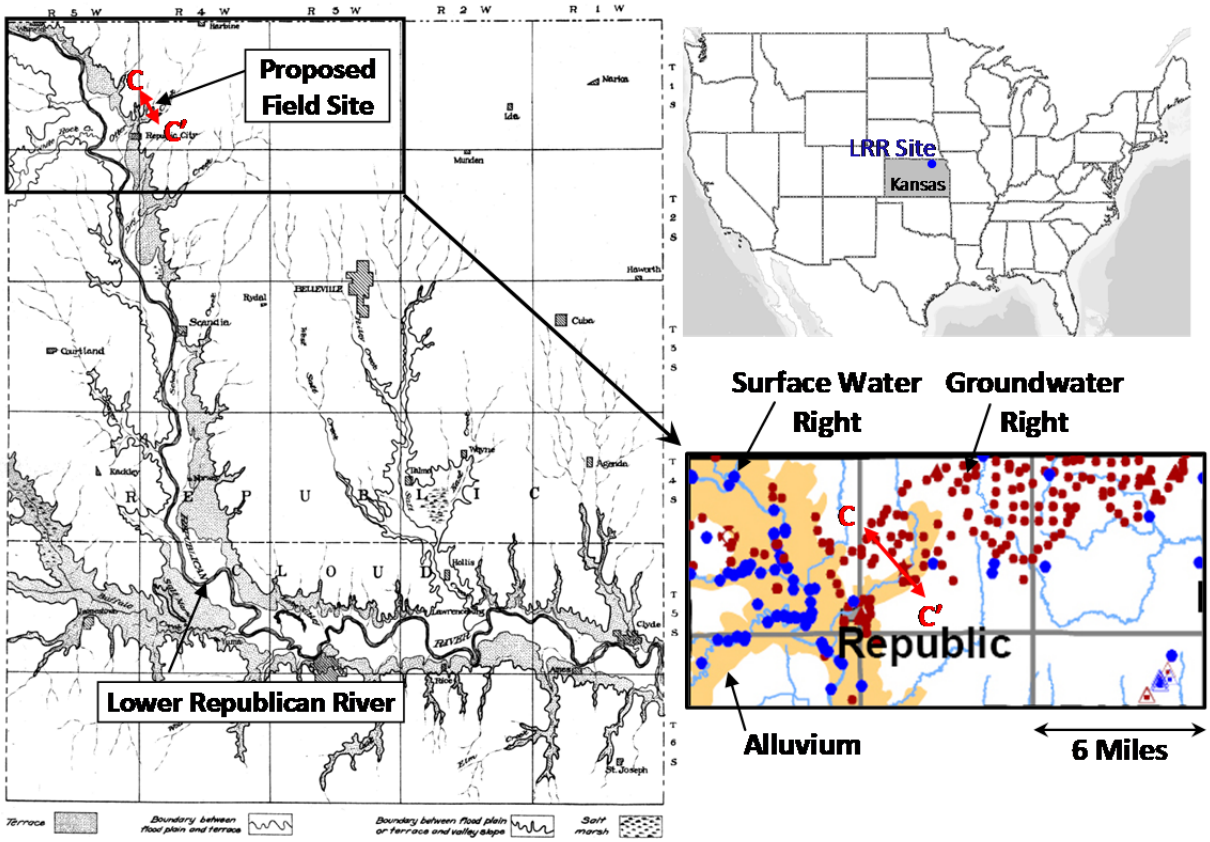
In this research we investigate a new recharge method for near-surface aquifers using small-diameter, low-cost wells installed with direct-push (DP) technology. Unlike the large-diameter injection wells, the DP wells are typically small in diameter (less than 10 cm), low in construction and maintenance costs, and limited to depths less than 30 m. Water is allowed to move through the wells by gravity, so the required logistical and infrastructure support are modest. Given the various constraints of surface infiltration methods, the DP wells, if proven practically useful as a supplemental or alternative recharge option to the surface methods, could greatly increase the effectiveness of ASR in near-surface aquifers.

Objectives and Methods

The main objective of this research is to increase the effectiveness of ASR in near-surface aquifers by developing a new aquifer recharge method through small-diameter, low-cost wells installed with DP technology. Unlike the common large-diameter injection wells that typically have a diameter of 40 cm or larger and require expensive logistical and infrastructure support, the DP wells are small in diameter (less than 10 cm), low in construction and maintenance costs, and limited to depths less than 30 m. Water is allowed to move through the wells by gravity so the required logistical and infrastructure support are modest. DP wells can be employed either as a supplemental or alternative recharge option to surface infiltration methods as long as the aquifer for water storage is relatively shallow.

In this research, we combine numerical model simulations with field tests to systematically investigate the utility of DP wells in artificially recharging near-surface aquifers. We use a site in the Lower Republican River (LRR) basin in Kansas to perform the proposed field investigations (Figure 1a). Figure 1b shows a cross-section of lithology at the site. The sand and gravel portion of the Belleville formation on the south part of the ancestral Republican River valley, which is overlain by a thin layer of silt and clay (also part of the Belleville formation), is used as the intended aquifer for water storage. In addition to the site characteristics suitable for this project, various Kansas state agencies have become increasingly interested in considering ASR implementation in this area as a potential water-resources management method for utilizing high flows of the Republican River in the LRR basin.

(**a**) Location of proposed study area in the Lower Republican River basin



(**b**) Lithologic cross-section of the ancestral Republican River valley in the study area

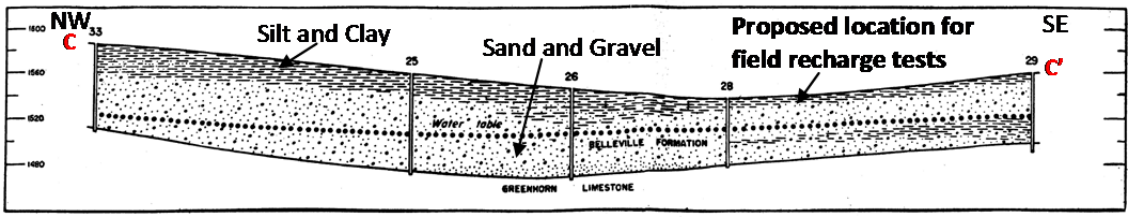


Figure 1. (**a**) Location of proposed study area within a stream valley on the south part of the ancestral Republican River valley. (**b**) Lithologic cross-section of the ancestral Republican River valley in the study area.

This research involves two major activities, 1) a series of numerical simulations to evaluate the recharge process of DP wells as compared to surface infiltration basins, and 2) field water recharge tests under different conditions to directly assess the practical usefulness of DP wells as an artificial recharge option alternative or supplement to the surface methods. The insights developed from the numerical simulations will provide important guidelines for designing and conducting the recharge tests in the field. The DP wells for the field tests at the LRR site will be installed using a Kansas Geological Survey (KGS) DP unit (Geoprobe).

Project Activities and Results

a) During the reporting period (3/1/2012 - 2/28/2013), we have conducted a series of numerical simulations to rigorously evaluate the recharge process of DP wells and surface infiltration basins. The simulation results have been presented at 1) the National Groundwater Association Annual Summit in San Antonio, April 29 – May 1, 2013, and 2) the NovCare (Novel Methods for Subsurface Characterization and Monitoring: From Theory to Practice) 2013 International Conference in Leipzig, Germany, May 13 – 16, 2013. A journal paper is in preparation for publication in Groundwater (see Appendix A for the major findings).
b) We have developed a new approach for measuring water seepage rate underneath the surface basin using active heating and fiber-optic distributed temperature sensing (DTS). Numerical simulations have indicated the validity of this approach (see Appendix B); further field testing is planned for the summer of 2013.
c) A suite of DP characterization and field recharge tests have been planned for the summer and fall of 2013. We have applied for and obtained the drilling and water use permits required for the project from Kansas Department of Agriculture and Kansas Department of Health and Environment. We have performed initial testing of the DP equipment at a site close to the KGS headquarter in order to get ready for the planned field work at the Lower Republican River basin.

II. Presentations and Publications

Falk Händel, Gaisheng Liu, Peter Dietrich, Rudolf Liedl, Jim Butler (2013), Numerical investigation of shallow aquifer recharge using small-diameter, low-cost wells and infiltration basins, *2012 NGWA Ground Water Summit*, San Antonio, TX, April 29 – May 1, 2013.

Falk Händel, Gaisheng Liu, Peter Dietrich, Rudolf Liedl, Jim Butler (2013), Numerical investigation of shallow aquifer recharge using small-diameter, low-cost wells and infiltration basins, *NovCare (Novel Methods for Subsurface Characterization and Monitoring: From Theory to Practice) 2013 International Conference*, Leipzig, Germany, May 13 – 16, 2013.

Falk Händel, Gaisheng Liu, Peter Dietrich, Rudolf Liedl, Jim Butler (2013), Numerical investigations of aquifer recharge using small-diameter wells and surface basin, in preparation for *Groundwater*.

III. Information Transfer Program

Throughout this project, we will dissimilate project results through 1) reports and presentations to regulatory agencies; 2) presentations at local, regional, and national scientific meetings; 3) public information circulars and open-access web publications; 4) short courses and webinars; and 5) articles in peer-reviewed literature. We anticipate the results will be of particular interest to various state agencies and local entities such as Kansas Department of Health and Environment (KDHE), Kansas Water Office (KWO), and Lower Republican River Stakeholder Management Committee (LRRSMC). We will emphasize the transfer of our research findings to KDHE, KWO and LRRSMC and other interested personnel in our outreach activities. Specifically, the project results will be presented at meetings ranging from the American Institute of Hydrology Seminar in Topeka, to the Water and the Future of Kansas Conference, to educational seminars of the KWO and KDHE. Summary of the main findings will be published in public information circulars and open-access web publications (e.g., KSG open-file report) in a timely fashion.

We also anticipate the results of this project will be of significant interest to other states, research institutes and professionals. To effectively transfer the project results to the interested audience beyond Kansas, we will make presentations at national/international meetings of scientific organizations such as the National Groundwater Association, Geological Society of America, and the American Geophysical Union. To allow ready access to the results by the general public, a project page will be created on the KGS web site and project data and reports will be posted there. The results will also be published in scientific journals frequently read by practicing hydrologists. Project results will also be incorporated into short courses and webinars (e.g., Midwest GeoSciences Webinar series) for technology transfer to practicing professionals.

IV. Student Support

Four graduate students have been supported by this project:
Brant Konetchy, M.S., University of Kansas
Angela Thompson, M.S., University of Kansas
Falk Händel, Ph.D., Helmholtz Centre for Environmental Research-UFZ, Leipzig, Germany
Bijendra Bajracharya, M.S., 2012 KGS Applied Geohydrology Summer Research Assistantship program

V. USGS Summer Intern Program

None.

Appendix A (2011KS113G): Numerical investigations of aquifer recharge using small-diameter wells and surface basin

	Infiltration capacity	Construction costs	Ratio of constr. costs to infiltration cap.
DP-well	422 m^3/d	$750	1.8 $/$m^3$/d
Infiltration basin	655 m^3/d	$4800	7.3 $/$m^3$/d

Table A1. The infiltration capacities and construction costs of the simulated basin versus well.

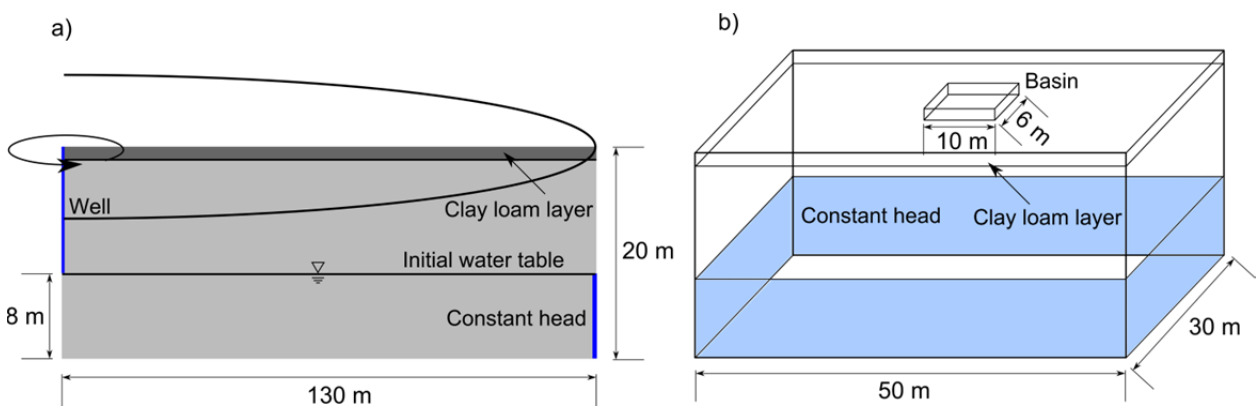


Figure A1. Model setup of a) the DP well, and b) the infiltration basin.

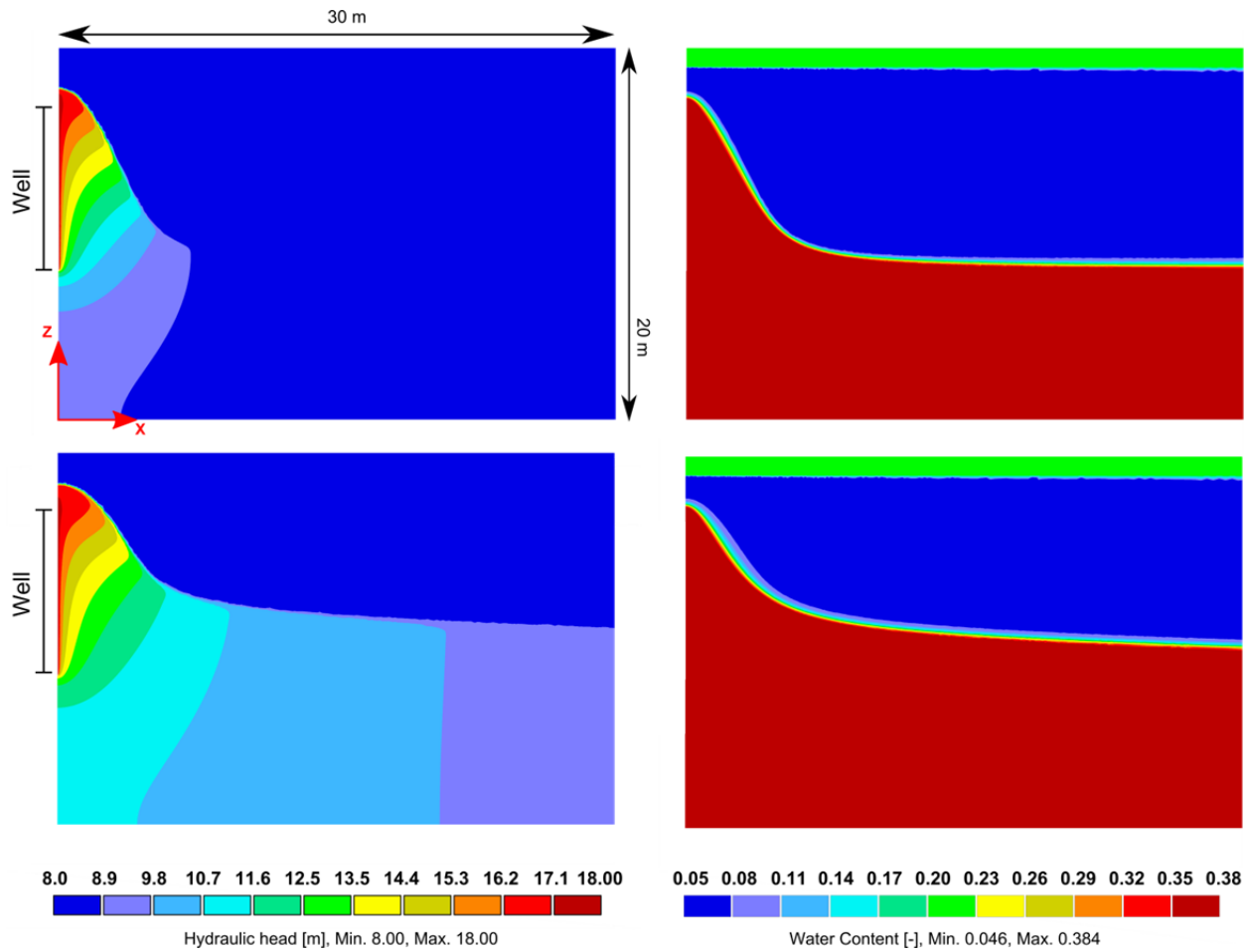


Figure A2. Simulated total hydraulic heads and water contents for small-diameter DP well at 0.5 (top two plots) and 40 days (bottom two plots). Note that results are only shown for a small portion of the simulation domain (30 out of 130 m) in order to facilitate visualization in the near-well region. The aquifer is assumed homogeneous and isotropic.

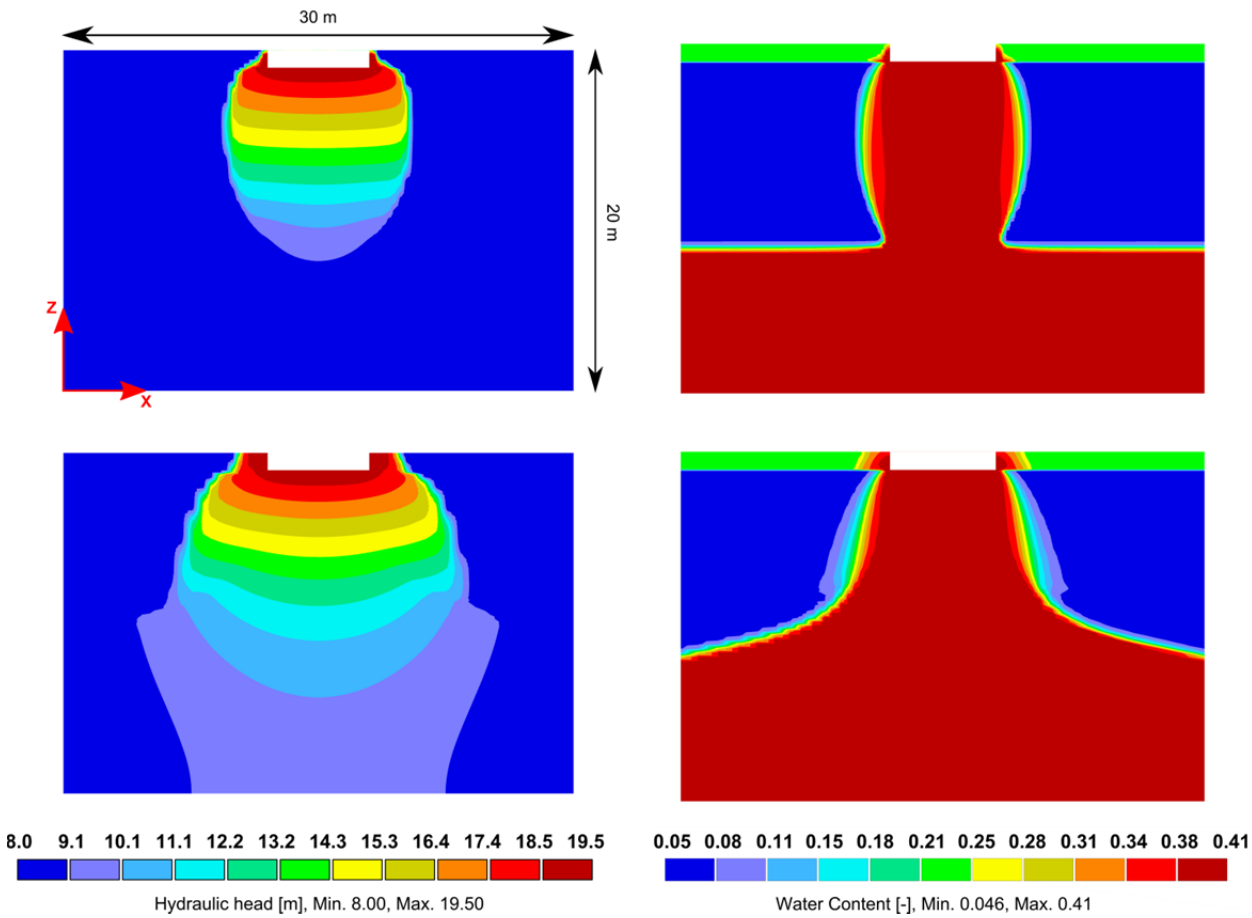


Figure A3. Simulated heads and water contents for the infiltration basin at time 0.5 (top two plots) and 40 days (bottom two plots). The graphs represent a vertical cross-section through the center of the infiltration basin. Discontinuities near the wetting front are the numerical artifacts associated with the sharp head and saturation gradients (a finer mesh will reduce the artifacts, but will cause a significant increase in computational efforts). These numerical artifacts only occur at the wetting front and have a negligible impact on model results.

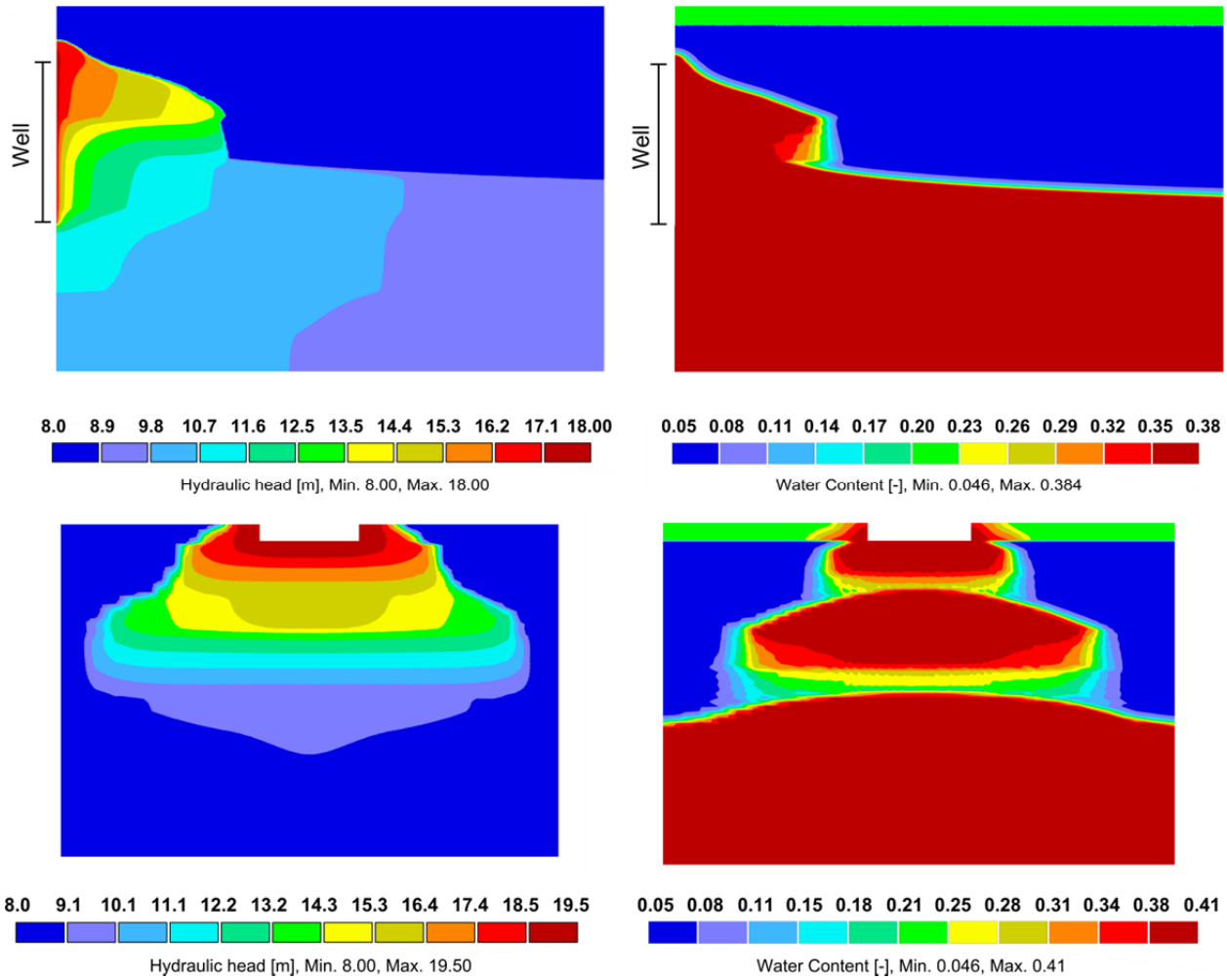


Figure A4. Simulated heads and water contents for the small-diameter well and surface basin using a layered K profile at 0.5 (top two plots) and 40 days (bottom two plots). For the well, water moves laterally above the low-K layers to increase the effective vertical infiltration area so the reduction in infiltration rate by the low-K layers is small. For the basin, due to the restriction of low-K layers, the basin infiltration rate is significantly reduced and the soils below the low-K layers become unsaturated.

Appendix B (2011KS113G): A new approach for measuring the water seepage rate of surface infiltration basin

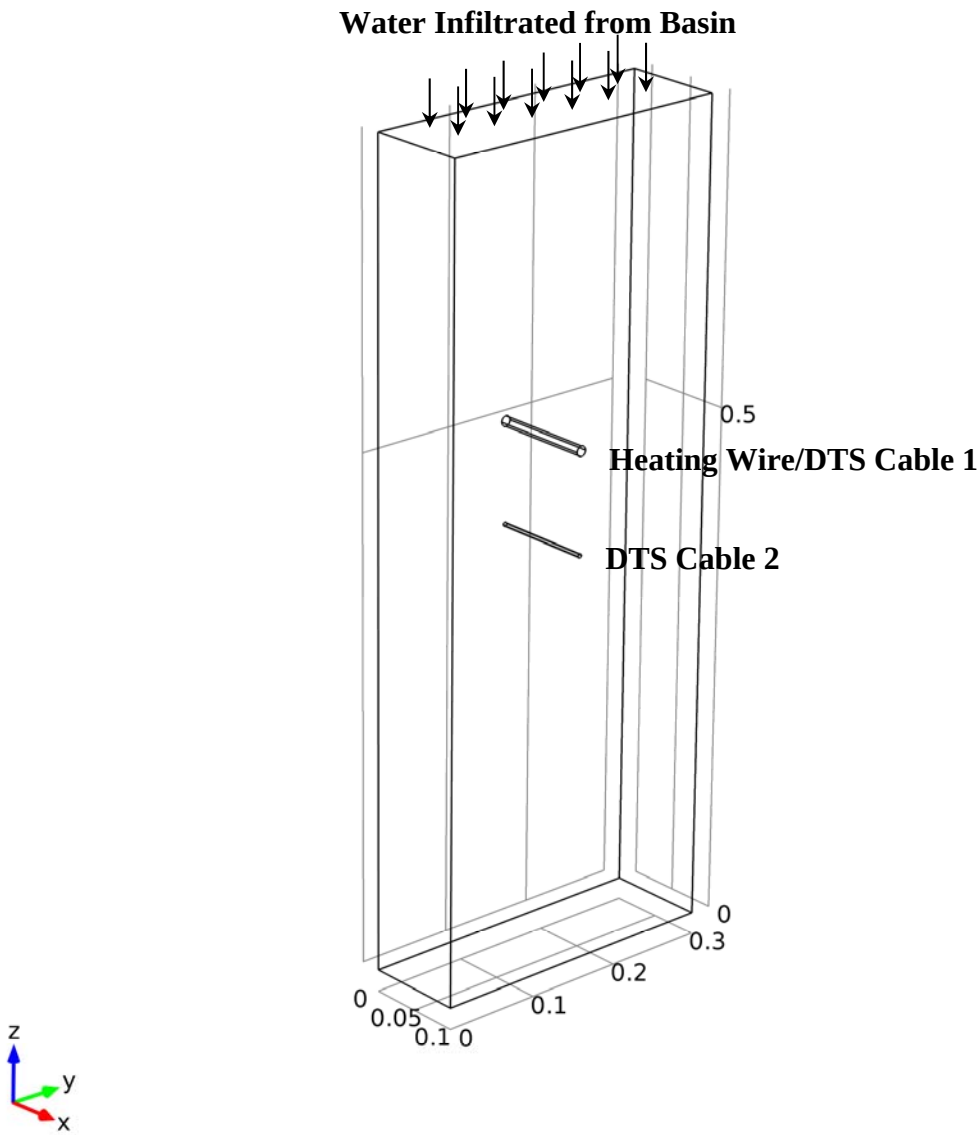


Figure B1. Schematic of the new approach for measuring the water seepage rate of surface infiltration basin. During the seepage measurement, heat is turned on for 5 minutes through the heating wire. Temperature is monitored by the DTS cables 1 and 2 for 1 hour. Seepage rate can be calculated from the temperature increases at the two DTS cables.

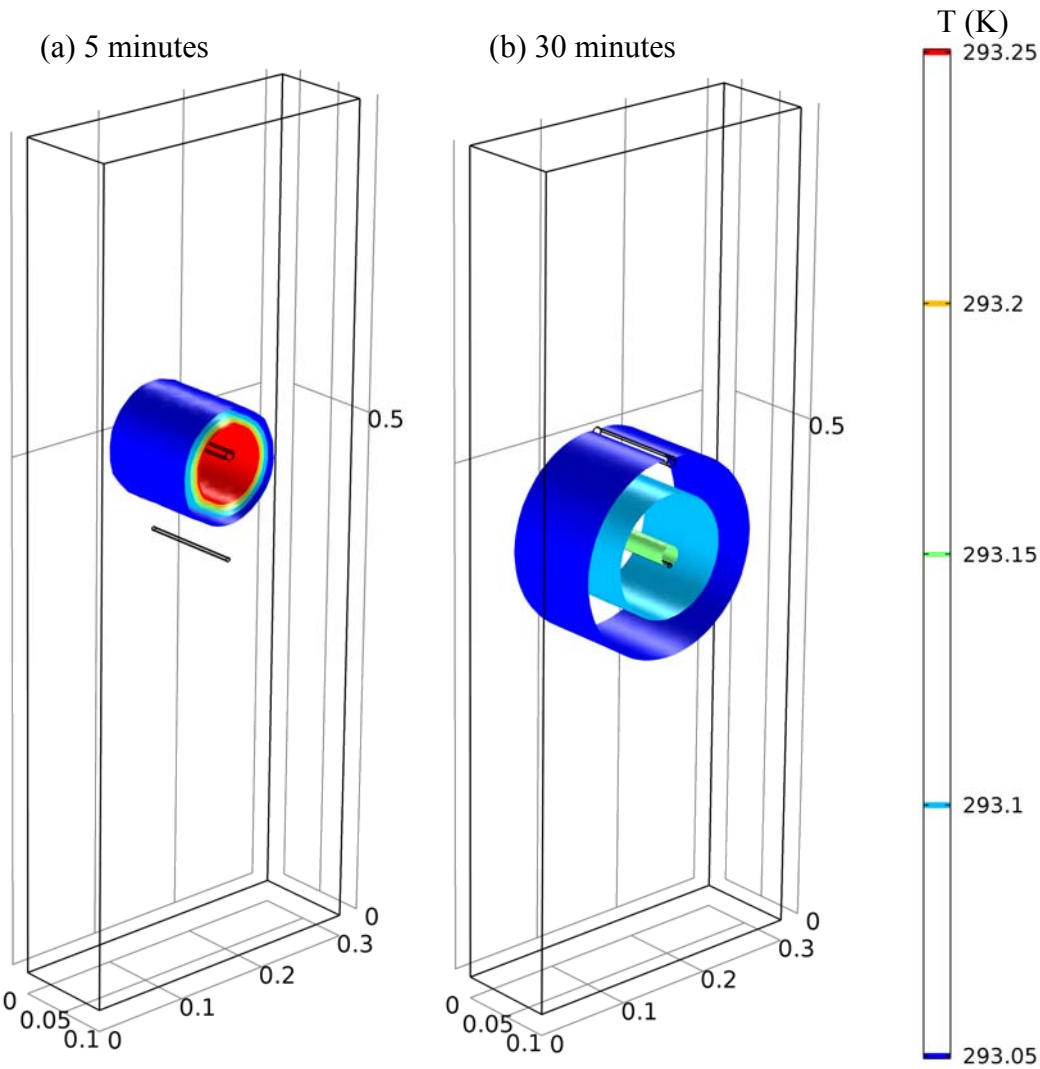


Figure B2. Temperature isosurfaces at (a) 5 minutes, and (b) 30 minutes after heating starts. The heat is only turned on for the first 5 minutes through the heating wire.

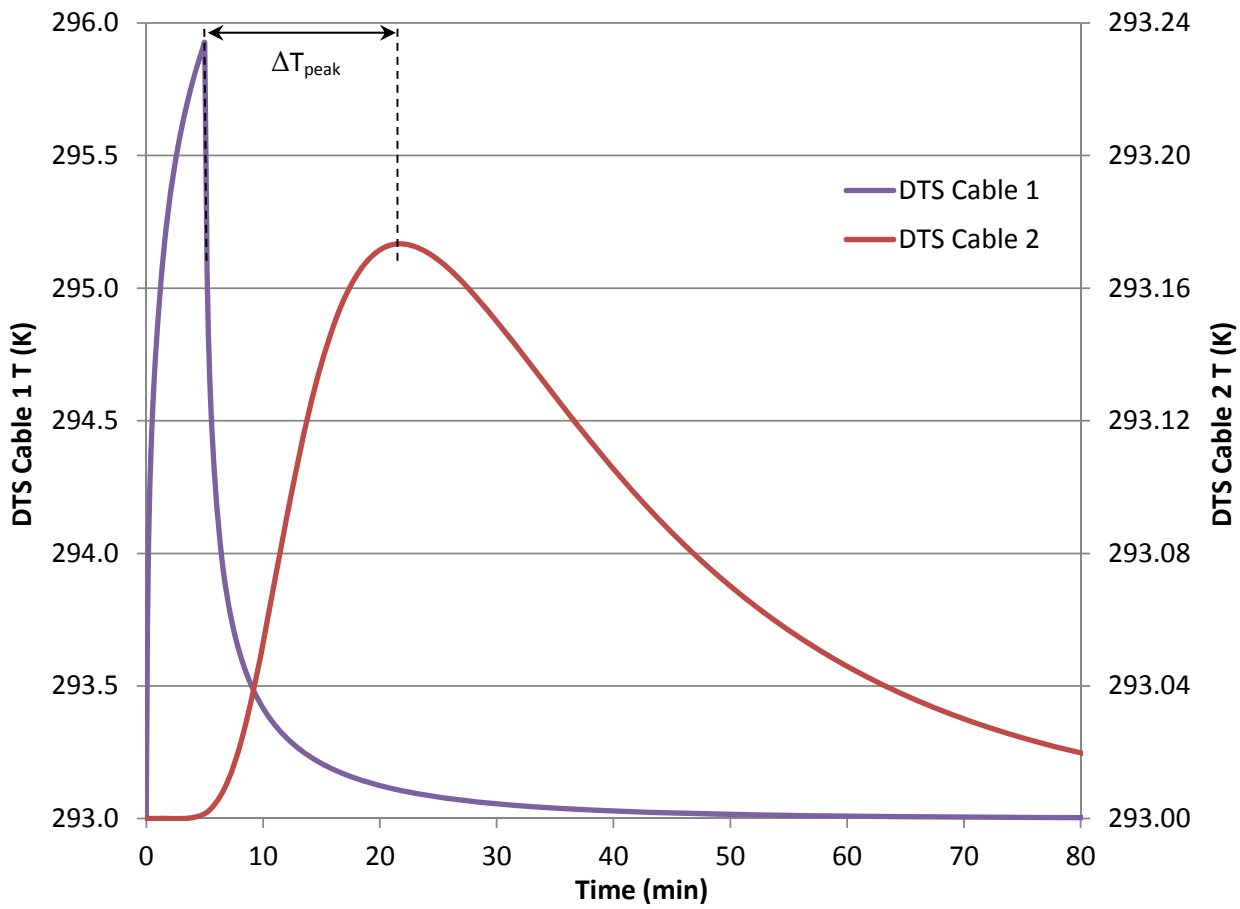


Figure B3. Temperature breakthroughs at the DTS cables. The seepage rate can be determined from the difference between the temperature peak arrival times at the cables (ΔT_{peak}). The velocity of thermal front is $L/\Delta T_{peak}$, where L is the distance between the cables (10 cm). The water seepage rate can then be determined from the thermal velocity (dividing it by the ratio of the heat capacity of water to that of the soil-fluid matrix).

Sediment Core Analysis for Understanding Reservoir History

Basic Information

Title:	Sediment Core Analysis for Understanding Reservoir History
Project Number:	2012KS123B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	KS-002
Research Category:	Water Quality
Focus Category:	Sediments, Hydrology, None
Descriptors:	None
Principal Investigators:	Mark Jakubauskas, Frank deNoyelles, Jr.

Publications

1. Niehues, N. D. and Jakubauskas, M. E. Reservoir sediment charcoal accumulation as indicators of neo-paleo ambient conditions of two time scales. Final preparation, to be submitted to Environmental and Experimental Botany by June 1, 2013.
2. Jakubauskas, M.E., deNoyelles, F., Liechti, P. Martinko, E., Blackwood, A. and Niehues, N. The Curious Case of Atchison Lake Sedimentation. Poster paper, Governors Conference on the Future of Water in Kansas, Manhattan, KS, October 30-31, 2012.
3. Niehues, N. D. and Jakubauskas, M. E. Tracking Historic Prairie Fire Trends within a Lake Sediment Record. Presentation, Governors Conference on the Future of Water in Kansas, Manhattan, KS, October 30-31, 2012.

SEDIMENT CORE ANALYSIS FOR UNDERSTANDING RESERVOIR HISTORY

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Final Report
May 2013

We proposed to examine reservoir sediment cores from Kansas reservoirs for markers or indicators of specific hydrologic, biologic, and environmental events in the history of those reservoirs. We proposed to explore a suite of analysis techniques appropriate for sediment chronosequencing in recent reservoir sediments, support student research, and to establish at KU the capability for analysis of reservoir sediment cores.

Summary of Key Activities Supported by KWRI funding:

- Training in sediment core preparation, scanning, and analysis at National Lacustrine Core Facility at the University of Minnesota;
- Exploration of sediment imaging techniques and apparatus for spectroradiometric scanning of sediment cores;
- Support of Ms. Nicole Niehues, 2012 University of Kansas Environmental Studies student as a research assistant during the 2012-1013 academic year prior to starting graduate work at University of California-Davis in summer 2013;
- Intensive analysis of sediment cores of Lake Kahola, Kansas, to determine effects of climate and land use/management on the sedimentation of the reservoir and link observed sediment core patterns to possible causative events in the reservoirs and watershed.

Specific Activities And Research:

Travel to LacCore for core analysis training:

In 2012, PI Jakubauskas traveled to the National Lacustrine Core Facility at the University of Minnesota for training in sediment core preparation, initial core assessment, and core analysis, including core splitting, core scanning, sample preparation, and preparation and interpretation of smear slides. We also acquired a set of archival D-tubes for sediment core storage.

At the LacCore Facility, a 10-foot long core from Atchison County Lake, Kansas, was split and imaged using the LacCore Geotek Geoscan III system. The system employs a line-scan CCD camera with fluorescent lights fixed in position relative to the camera. This design allows the use of polarizing filters to cover both the light source and the camera lens; the filters are

oriented perpendicular to each other (such that the direction of polarization is 90 degrees relative to the other filter).

The imaging scan and density scan of core Atchison County Lake core AT-6 is provided in Figure 1a and 1b. The use of the high-end Geotek core scanning system reveals details of stratigraphy not apparent to the casual eye; indeed, without the imaging system, the core appears as more or less uniformly brownish-grey in tone. The density scan indicates areas of high or low density; high density often indicates sand layers, while low densities may be associated with layers of organic matter or voids in the core.

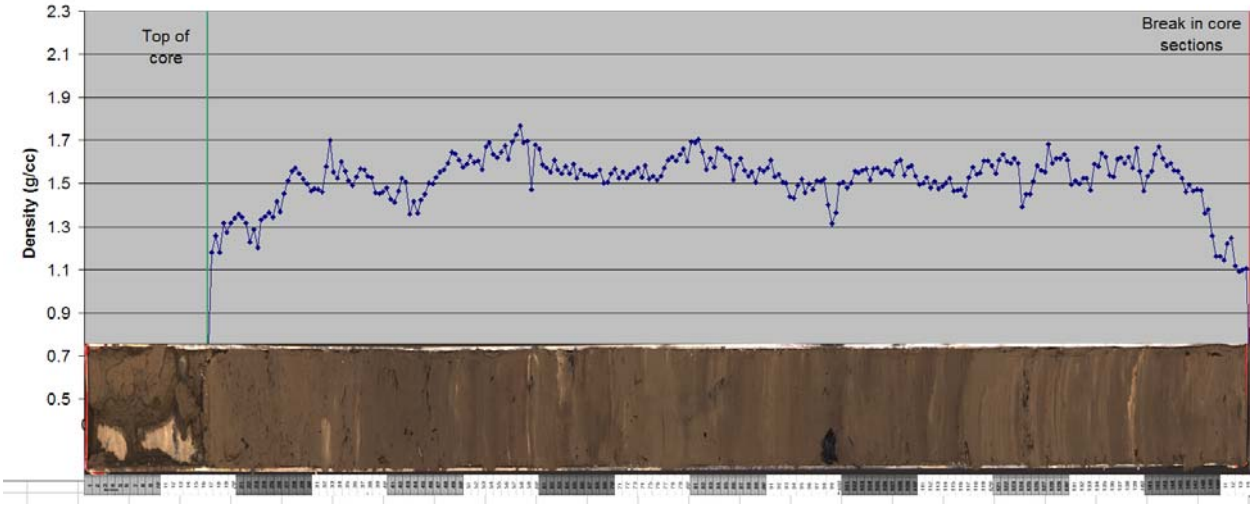

Figure 1a. Upper half of core AT-6 from Atchison County Lake. Top of core is to the left. Density scan (blue line) of upper half of the core indicates relatively uniform and narrow range of sediment density.

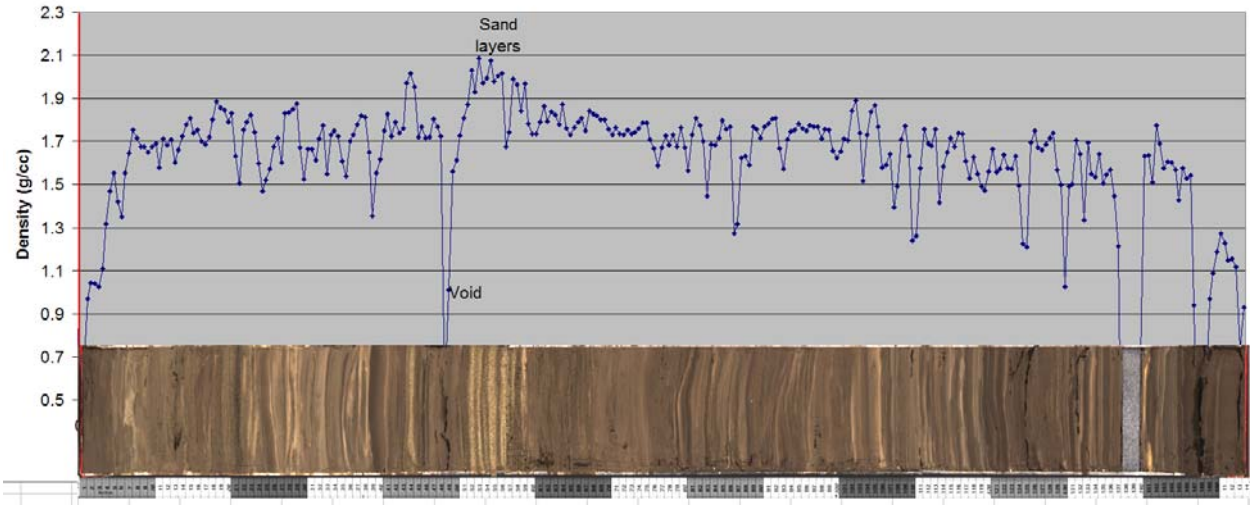

Figure 1b. Lower half of core AT-6 from Atchison County Lake. Top of core is to the left. Density scan of the lower half of core AT-6 showed a wide range in sediment densities.

Results suggest a change in sedimentation regimes about midway along the core, from an episodic depositional pattern characterized by distinct layers of sand in the lower half of the core, to a more continuous sedimentation rate without the presence of sand and dominated by clay without the strong banding apparent in the lower part of the core. This may be to several factors, most likely changes in land management practices (e.g., emplacement of watershed dams, grassed waterways, terraces, and other control features, but also possibly due to including changes in precipitation regime, and changes in hydrogeomorphologic regimes as the lake silted in over time. We plan additional investigations in 2013-2014, including coring of sediment in watershed dams, to address these questions.

Development of photographic and spectroradiometric core imaging at KU:

Core photography: Motivated by the excellent core images obtained by the University of Minnesota GeoTek scanning system, we endeavored to develop at KU some means of photographically documenting split cores of reservoir sediment. Initially, we attempted to modify a Hewlett-Packard ScanJet 5200 SCSI-interface CCD (charge-coupled device, as opposed to the cheaper CIS – contact image sensor) type scanner, inverting the scanner over the exposed scraped split core section in an roller-tray apparatus designed to allow the core to be rolled as a unit under the scanner bed. This approach would have produced high-resolution distortion-free photographic images of the core surface. While this approach was reasonably successful for several early test cores that were strongly sandy in composition (Figure 2), ultimately, reflections and glare from more clayey cores rendered the system useless. Attempts to fit the scanner head with polarizing filters were unsuccessful. We then abandoned the scanner approach to photographic core imaging in favor of a high-end Canon ___ digital camera with illumination provided by photographic halogen lights fitted with polarizing filters. The Canon camera, while providing glare- and reflection-free photos of the core, obviously did/does not provide as much detail as the high-end dedicated Geotek core scanning system.

Figure 2. HP scanner image of core KAN-12. Top of core is to the right.

Spectroradiometric scanning of cores: Under KWRI funding, we explored the feasibility of using a 512-band spectroradiometer to collect narrow-band reflectance data over a range of 350nm – 2500nm. We used an Analytical Spectral Devices (Boulder, Colorado) system with an ASD halogen illumination system. In order to increment the scanning head along the core in a consistent manner, we designed and fabricated a scanning bed apparatus to hold the ASD

Fieldspec fiber-optic sensor head and the illumination unit on an aluminum base that moved along a commercial ball-bearing linear motion slide (Figure 3). The base was moved along the slide by means of a threaded rod attached to a 12-rpm motor; thus, by knowing the threads-per-inch of the threaded rod, and the number of turns/minute of the motor, we could calculate a distance of linear travel per second (e.g., for a standard ¼-20 thread turning at 12 RPM, our linear travel was 0.05 inches (1.27 mm) per turn. We further calculated the field-of-view (FOV) of the ASD sensor head, based on a 25° FOV angle, to obtain the area imaged at a given distance from the core.

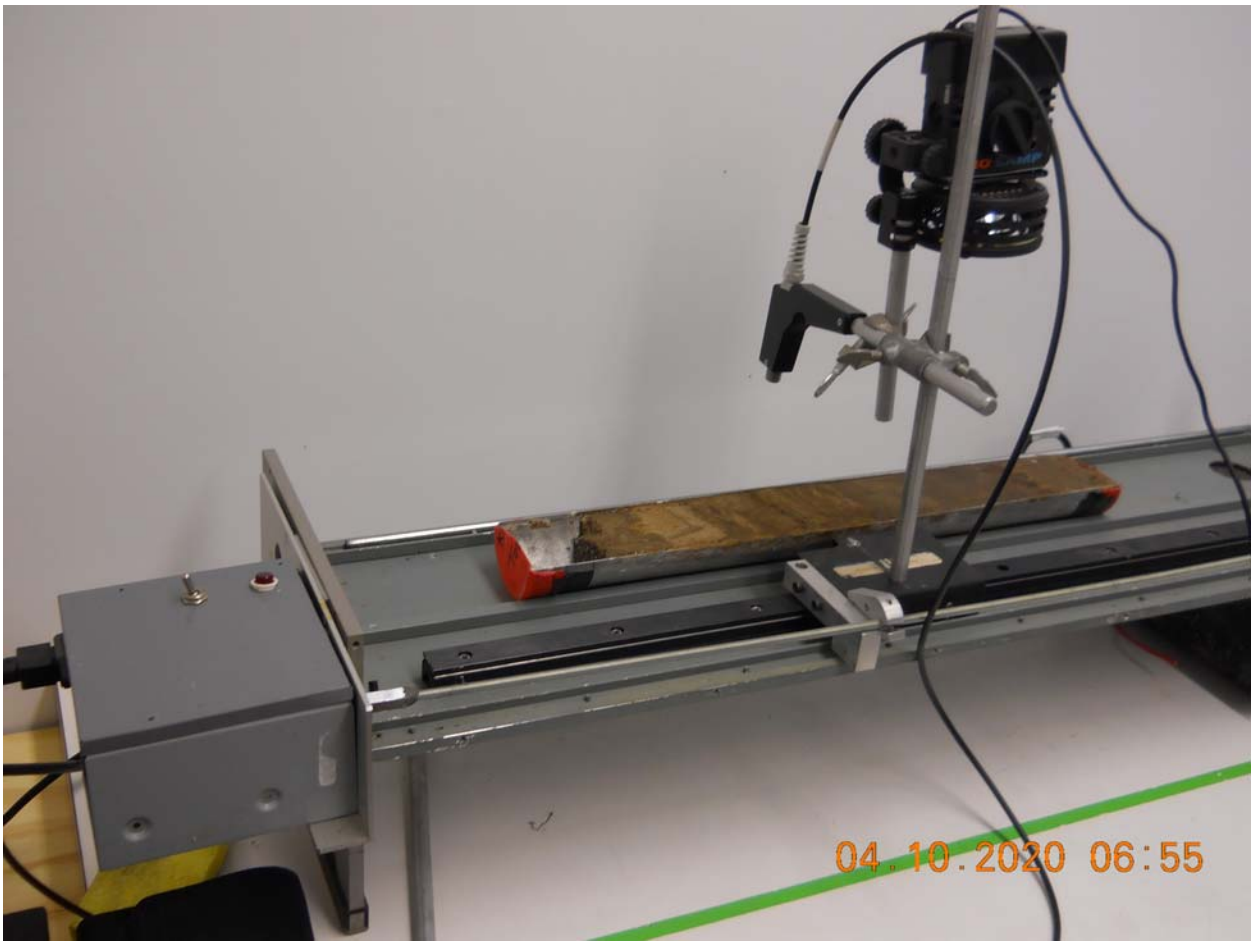

Figure 3. Spectroradiometric scanning system.

We imaged core KAN-12 (Figure 2) as our test subject. Reflectance data from the core was collected in 10-nm ranges over the spectral range 250-2500 nm. Spectra were collected every 0.050" along the core for a total of 249 samples along the core. Data were calibrated to reflectance using a standard white reference prior to imaging the core. Data were output from the ASD system as comma-delimited ASCII files; these were imported to Excel for graphing (Figure 4), and also imported to ERDAS *.img format to create a pseudo-image of the core spectra (Figure 5).

Figure 4. Spectroradiometric reflectance scan of core KAN-12, Scan line 125 (mid-core). Strong absorption bands are present at ~1400 nm and 1900 nm.

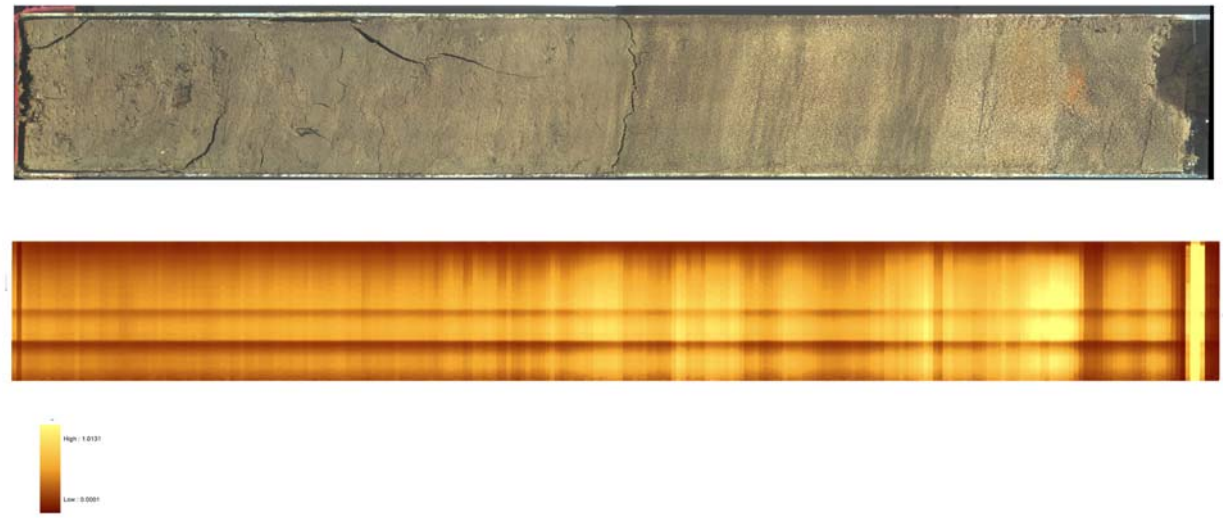

Figure 5. Flatbed scanner image (top) and spectroradiometric reflectance pseudoimage (bottom) of core KAN-12. Top of core is to the right.

Lake Kahola Sediment Core Research:

A study of charcoal in the sediment cores of Lake Kahola encapsulated many of the analysis approaches that we wished to develop as part of a core analysis capability at KBS. This study sought to test whether deposition trends of macroscopic grass charcoal derived from annual prescribed tall grass prairie fires within a small reservoir's sediments are indicative of changes in local rainfall and temperature throughout the reservoir's history. Kahola Lake is a private lake located northwest of Emporia, Kansas, in the Flint Hill region. The 354-acre lake was constructed in 1936 as a water supply for the City of Emporia, and has a watershed dominated by tallgrass prairie, which is burned annually in the spring. The lake has never been dredged, but has undergone at least one major period of near-complete drydown during the 1950s drought.

We extracted a series of sediment cores from Kahola Lake on May 22, 2012 using a vibracorer from Specialty Devices, Inc.. The corer was fitted with a 3" diameter thinwall aluminum pipe which could be exchanged by the operator for desired lengths. Cores for charcoal analysis (samples KAH-2 and KAH-5), were pulled from the southern coves. An additional core for radionuclide dating (sample KAH-1), was taken from near the center of the lake. Each core was capped and labeled for transport back to the lab. At the lab, the core tubes were sawed lengthwise and the sediment was likewise sliced using a thin piano wire pulled lengthwise along the core. One of each resulting half was used for charcoal or radionuclide analysis and the other retained for archives.

We dated sediments using radionuclide activity of plutonium$^{239+240}$ while charcoal deposition was quantified as total particles per gram of dry sediment. We observed relationships between charcoal to climatic parameters over growing season and two-week timescales to infer the influence of aboveground net primary productivity and immediate ambient conditions surrounding individual burns. Charcoal residue in sediment cores was found to be best correlated with precipitation patterns over both timescales and the probable primary driver of charcoal production while we considered temperature to be secondary on these counts. Ultimately, we feel that our study offers methods in which reservoirs could be employed as tools historical reconstructions of local environmental histories.

The Kahola Lake work has resulted in one manuscript ready for submission to either *The Holocene* or to *Environmental and Experimental Botany* by June 1, 2013.

Refereed Articles:

Niehues, N. D. and Jakubauskas, M. E. Reservoir sediment charcoal accumulation as indicators of neo-paleo ambient conditions of two time scales. Final preparation, to be submitted to Environmental and Experimental Botany by June 1, 2013.

Posters and Presentations:

Jakubauskas, M.E., deNoyelles, F., Liechti, P. Martinko, E., Blackwood, A. and Niehues, N. The Curious Case of Atchison Lake Sedimentation. Poster paper, Governors Conference on the Future of Water in Kansas, Manhattan, KS, October 30-31, 2012.

Niehues, N. D. and Jakubauskas, M. E. Tracking Historic Prairie Fire Trends within a Lake Sediment Record. Presentation, Governors Conference on the Future of Water in Kansas, Manhattan, KS, October 30-31, 2012.

Impacts of In-channel Dredging on the Morphology of the Kansas River

Basic Information

Title:	Impacts of In-channel Dredging on the Morphology of the Kansas River
Project Number:	2012KS125B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	KS-002
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Sediments, None
Descriptors:	None
Principal Investigators:	Melinda Dawn Daniels

Publication

1. Mehl*, H.E., M. Daniels, B. Swenson*, and L. Calwell. 2012. Commercial sand dredging in the Kansas River. Presented at the Governor s Conference on Water and the Future of Kansas; Manhattan, KS, 31 Oct.

Impacts of In-Channel Dredging on the Morphology of the Kansas River

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May 2013

In year one of the project we have surveyed two active dredge holes in the Kansas River, one in Topeka and one in Lawrence. A third (also near Lawrence and the Mudd Creek confluence) has been targeted for survey, but low water has prevented access to the site even with small boats (kayaks). The Topeka and Lawrence dredge holes were surveyed using an ADCP (Acoustic Doppler Current Profiler) on two occasions, once in Fall of 2012 and once in Spring of 2013. During this time period, no significant transport active flow occurred on the Kansas River. Our repeat surveys show substantial deepening and enlargement of each dredge hole due to continued excavation and no/insufficient transport-related replacement or infilling by the river. We remain ready to re-sample with the ADCP when flow rises on the Kansas.

While we wait for flow to rise on the Kansas, the GRA has been assembling a HEC-RAS model of the Kansas river main stem and major tributary network architecture.

Publications

Mehl, H.E., **M. Daniels**, B. Swenson*, and L. Calwell. 2012. Commercial sand dredging in the Kansas River. Presented at the Governor's Conference on Water and the Future of Kansas; Manhattan, KS, 31 Oct.*

Student Support

During the first year of our project, the majority of our budget has been used to support one full time Masters level GRA in the Department of Geography (Mr. Barrett Swenson).

Evaluation of the Kansas P Index using APEX

Basic Information

Title:	Evaluation of the Kansas P Index using APEX
Project Number:	2012KS126B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	KS-002
Research Category:	Not Applicable
Focus Category:	Agriculture, None, None
Descriptors:	None
Principal Investigators:	Nathan O. Nelson

Publications

1. Nelson, N.O. and J. Lory. 2012. Using Models to Evaluate P Indices. SERA-17 Annual Meeting. Oct. 24-25, 2012. Cincinnati, OH.
2. Nelson, N.O. 2013. Nutrient Management Planning for Agronomic Production and Water Quality Protection. 2013 Kansas WRAPS Non-point Source Pollution Conference. April 16-17, 2013. Junction City, KS.

Evaluation of the Kansas P Index using APEX

2012/2013 Report of Progress

Activities

During the first year of our study we have collaborated with research scientists in Missouri and Nebraska to establish standardized guidelines for predicting phosphorus loss using the Agricultural Policy Environmental Extender (APEX) model. This consisted of a detailed review of over 230 parameters defining the operating options and equation parameters for the model. We also developed standardized soil and management templates for data collection and organization. We further developed and defined methodology to represent best management practices specific to our region within the APEX model including grassed water ways, terraces, buffers, and conservation tillage.

We have initiated collaborations with the APEX development team to integrate new non-linear adsorption isotherm equations into the APEX model. These improvements will be tested with our model calibration. Additional soil information was collected at both the Crawford and Franklin County sites. This included a detailed soil survey of both locations based on 6 to 12 soil horizon descriptions. Soil analysis included Total P, Mehlich 3 extractable P, organic C, total N, and soil texture.

We assembled all the weather, soils, cropping, and water quality data required for the APEX model exercises. We parameterized the APEX for base-line model predictions at the Crawford county location. We are in the process of finalizing the model setup for Crawford county and developing the model for the and Franklin County location. Preliminary results are not available at this time because we are still in the process of model evaluation and calibration.

We recruited and trained a Ammar Bhandari as a Ph.D. student. He has developed his Ph.D. proposal and completed two semesters of course work related to water resource management. We have trained him on how to appropriately develop a model that will be representative of the soil and hydrologic conditions observed in the field. His training included collaborative work with research faculty at the University of Nebraska, University of Missouri, USDA-ARS, USDA-NRCS, as well as faculty at Kansas State University. This included travel to Nebraska and Missouri.

Publications

Shao, H., C. Baffaut, J.E. Gao, N.O. Nelson, K.A. Janssen, G.M. Pierzynski, P.L. Barnes. 2013. Development and application of algorithms for simulating terraces within SWAT. Trans. ASABE (submitted 11/27/12; in review).

Presentations

Nelson, N.O. and J. Lory. 2012. Using Models to Evaluate P Indices. SERA-17 Annual Meeting. Oct. 24-25, 2012. Cincinnati, OH.

Nelson, N.O. 2013. Nutrient Management Planning for Agronomic Production and Water Quality Protection. 2013 Kansas WRAPS Non-point Source Pollution Conference. April 16-17, 2013. Junction City, KS.

Submitted Abstracts

Claire Baffaut, Carl Bolster, Nathan Nelson, Mike van Liew, Jeff Arnold, Jimmy Williams. 2013. How to SWAT your APEX model. 2013 International SWAT Conference & Workshops. July 15-19, 2013. Toulouse, France.

Bhandari, A.B., R. Gelderman, D.P. Todey, D.R. German. 2013. Manure Application Timing and Tillage Influence On Nutrient Loss From Snowmelt Runoff. ASA-CSSA-SSSA International Annual Meeting. Nov. 4-6, 2013. Tampa Bay, FL. In ASA-CSSA-SSSA-CSSS Abstracts 2013 [CD-ROM]. ASA, CSSA, and SSSA, Madison, WI.

Bhandari, A.B., N.O. Nelson, D.W. Sweeney, C. Baffaut, J.A. Lory, M. Van Liew. 2013. Phosphorus Timing and Rate Effects in P Loss Predictions Using the Apex Model. ASA-CSSA-SSSA International Annual Meeting. Nov. 4-6, 2013. Tampa Bay, FL. In ASA-CSSA-SSSA-CSSS Abstracts 2013 [CD-ROM]. ASA, CSSA, and SSSA, Madison, WI.

Investigation of Recharge to the High Plains Aquifer, Northwestern Kansas

Basic Information

Title:	Investigation of Recharge to the High Plains Aquifer, Northwestern Kansas
Project Number:	2012KS129B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	KS-002
Research Category:	Ground-water Flow and Transport
Focus Category:	Conservation, None, None
Descriptors:	None
Principal Investigators:	Randy Stotler, James J. Butler

Publications

There are no publications.

Investigation of Recharge to the High Plains Aquifer, Northwestern Kansas, Year 1 Report

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Jim Butler, Kansas Geological Survey, Univ. of Kansas, jbutler@kgs.ku.edu, 785-864-2116
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Introduction

The High Plains region of the United States hosts some of the most productive irrigated agricultural land in the world owing to the vast HPA that it overlies. This extensively utilized aquifer provides irrigation and, to a much lesser extent, drinking and industrial water supplies that account for about 23% of all groundwater withdrawals in the United States (Maupin and Barber 2005). The HPA, which is a critically important resource for Kansas agriculture, extends over much of the western half of the state (Figure 1). A large area of the Kansas HPA is on a fundamentally unsustainable path; large pumping-induced declines in groundwater levels have called into question the viability of the aquifer as a continuing source of water for irrigated agriculture (Dennehy et al. 2002, Waksom et al. 2006, Sophocleous 2010). The future is further clouded by the prospect of climate change; sizable portions of the High Plains region are characterized by relatively steep lateral gradients in climatic variables, indicating the potential vulnerability of the region to the impacts of a changing climate (Rosenberg et al. 1999, 2003; Brunsell et al. 2010; Logan et al. 2010).

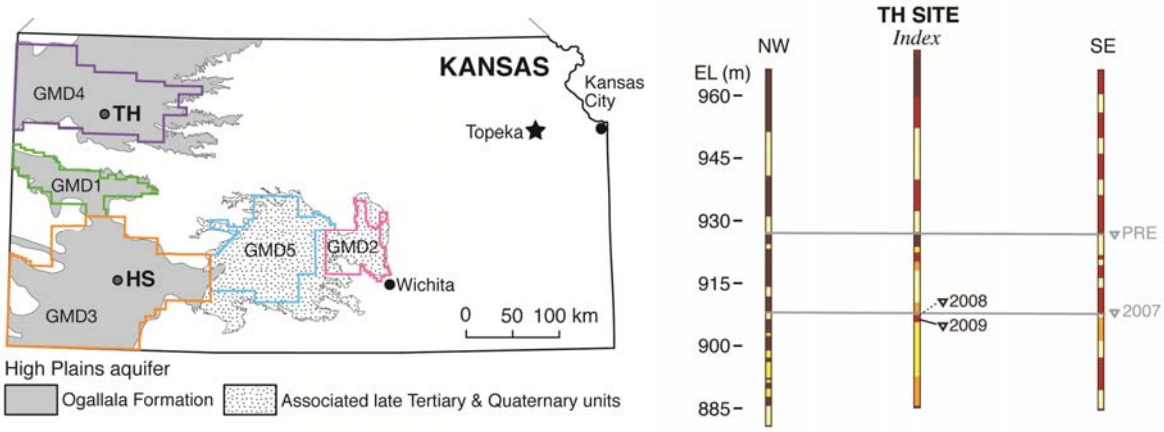

Figure 1: The HPA in Kansas with the overlying groundwater management districts (GMDs), TH indicates the location of the field site discussed here. Sediment characteristics from drillers' logs at the field sites (elevation above mean sea level abbreviated by EL). These logs terminate at or near the bottom of the HPA. Yellows and orange colors denote aquifer units, red is silt to sandy clay, and dark brown is clay. "PRE" denotes the water level prior to onset of large-scale irrigation pumping; individual years denote the water levels manually measured in January of that year as part of the annual cooperative water-level measurement program in Kansas (Miller et al. 1998, Bohling and Wilson 2011).

In areas of groundwater mining, year-over-year increases in water levels are not expected to occur because water extracted from the aquifer is not replaced by recharge (e.g., Butler et al.

2013a). In one area of the Kansas High Plains Aquifer (HPA) with assumed groundwater mining conditions (water level declines exceed 20 m, saturated thicknesses reduced in excess of 35% of pre-development values), unexpected year-over-year increases in water-levels were recently recorded by enhanced monitoring as part of the Kansas Geological Survey (KGS) Index Well Program (Stotler et al. 2011). Hydrograph analysis indicates post-irrigation season recovery is not tied to precipitation, amount of water pumped, length of pumping, or pumping rate. Rather, recovery is constant from year to year – indicating an unknown source of inflow (recharge) to the system (Butler et al. 2013a). This study directly addresses the issue of water availability in a high priority area of the HPA by identifying recharge sources, quantifying recharge amounts, and providing important information on the behavior of low permeability units that have become perched as a result of declining water levels.

Study Site Background

As part of the Kansas Water Plan, eight aquifer subunits were delineated by Northwest Kansas Groundwater Management District #4 (GMD4) for potential enhanced management. To obtain water-level information on spatial and temporal scales reasonable for enhanced groundwater management in aquifer subunits, a monitoring well was installed by the KGS at the base of the HPA in Thomas County as part of the Index Well Program. Average annual water use for 2007-10 over the 32.5 km^2 area centered on the monitoring well was 3.01×10^6 m^3. The HPA hydrostratigraphy in the vicinity of the site consists of an interbedded mix of coarse gravels through clays on top of primarily shale (Pierre Formation) bedrock. Well responses to pumping and changes in barometric pressure indicate that the saturated unconsolidated interval at the site acts as an unconfined aquifer (Buddemeier et al. 2010, Stotler et al. 2011).

Hourly water level and barometric pressure data have been collected at this monitoring well since 2007 (Figure 2). Over six years of monitoring, water levels were more or less stable, until the drought in the last two years, with maximum recorded water levels registering a 1 ft decline from 2008 to 2009, a 1.5 ft increase from 2009 to 2010, 1.5 ft decrease from 2010 to 2011, and a 1.5 ft decrease from 2011 to 2012. However, in all years, water levels were still increasing at the onset of pumping for the next irrigation season. By applying pumping-test interpretation methods to these long-term water-level records, boundaries limiting regional flow were identified (Butler et al. 2013a). The strikingly consistent hydrograph response during the recovery period (Figure 3) indicated a previously unidentified inflow to the area, rather than amount, duration, or length of pumping, is the primary control on recovery. The response was observed in all five of the monitored recovery seasons (2007-08, 08-09, 09-10, 10-11, 11-12) at both the Thomas well and another monitoring well in Scott County, indicating a process that likely affects large portions of the HPA in Kansas (Stotler et al. 2011). A recent, more-detailed, evaluation of these water-level data indicated that this inflow appears to be a relatively steady, vertical inflow throughout the year to the unconfined aquifer (Butler et al., 2013). Hourly water-level data have also been collected from five nearby active and retired irrigation wells since 2010, indicating similar water-level responses occur across the aquifer subunit (Stotler et al. 2011). Analysis of annual water-

level program data indicates the inflow trend could extend across Thomas County and much of northwest Kansas (Butler et al., 2013). Identification of the source of that inflow is critical for determining the long-term prospects of the High Plains aquifer in this portion of northwest Kansas.

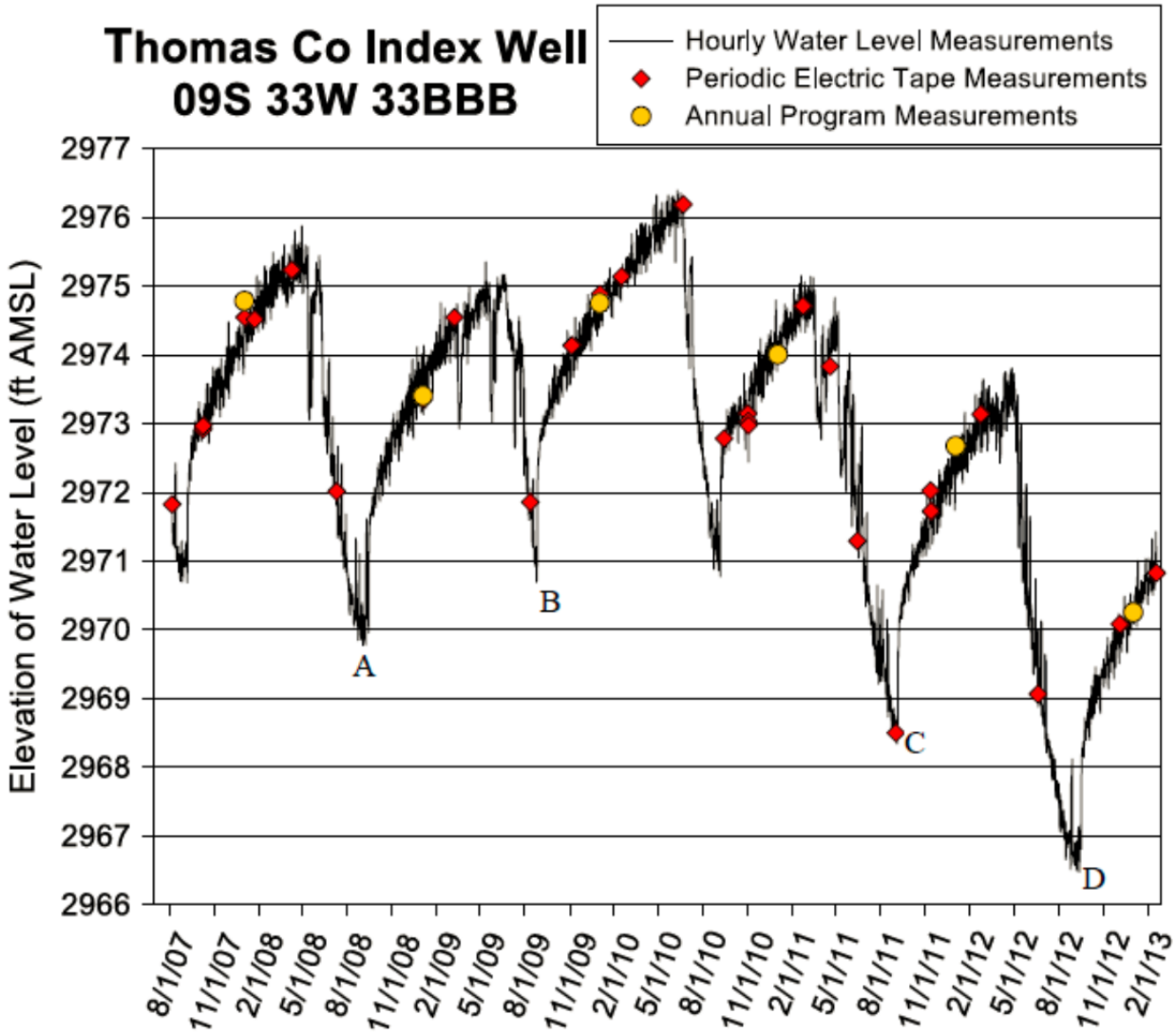

Figure 2: Water-level elevation in Thomas Co. index well from August 2007 to February 2013. A water-level elevation of 2975.75 ft above sea level corresponds to a depth to water of 211.6 ft. The hydrograph "band" is produced by water-level fluctuations in response to variations in barometric pressure. Diamonds represent periodic manual measurements to check transducer calibration, circles denote measurements of annual water-level measurement program. Increased water levels were recorded during the 2009-10 recovery (start at point "B") compared with the 2008-09 recovery (start at point "A") From Butler et al. (2013b).

Several possible mechanisms could explain the inflow. The first is downward flow originating as irrigation return flow or irrigation enhanced recharge. Although not consistent with previous recharge studies (e.g. Sophocleous 2005), it is possible recharge associated with irrigation is just starting to complete its traverse of the thick (60+ m) vadose zone. Drainage of overlying low-

permeability units induced by a falling water table is a second possible mechanism contributing to the inflow.

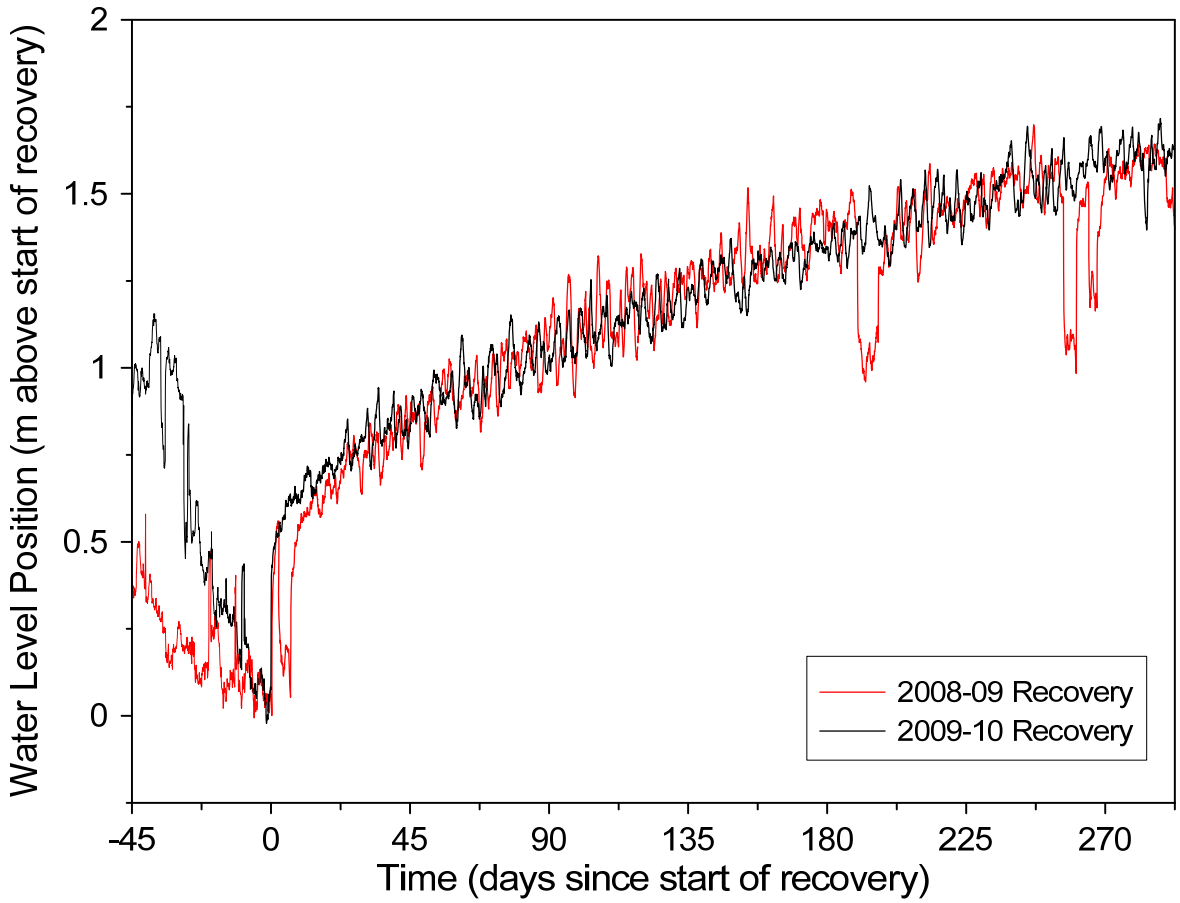

Figure 3: Water-level change since start of recovery versus time of recovery for the 2008-09 and 2009-10 recovery periods (recovery for 2008-09 starts at point A, for 2009-10 at point B on Figure 2; the time and water-level elevation at the start of recovery were set to zero for each period).

Methods

The two possible recharge sources are being evaluated by obtaining high resolution stratigraphic and physical information, and chemical and isotopic profiles in core sampled through the 64m thick unsaturated zone. The site chosen for coring was located approximately one mile south-southeast of the Thomas county index well. Core was obtained using a wire-line split-spoon sampler advanced ahead of a hollow-stem auger. Drilling was conducted approximately 15 m within the irrigated circle. This location makes it possible to investigate the effects of return flow on groundwater recharge. The samples are currently undergoing magnetic sensibility logging for stratigraphic correlation.

Over the summer of 2013, fluid will be extracted from core subsamples using a centrifuge, which will be analyzed on an ion chromatograph for Cl^- and NO_3^- concentrations, and for δ^2H and $\delta^{18}O$ simultaneously on a *Picarro Water Isotope Analyzer*. Intact samples will be run on a hanging

column and pressure-plate extractor to determine depth functions of soil hydraulic parameters (e.g., water retention curve parameters and hydraulic conductivity), and sieved to determine grain size. Water flux simulations will then be run with Hydrus (Šimůnek et al., 2005) using assumed and historical irrigation information.

Figure 4: Core retrieval operations at the drill site by the Kansas Geological Survey. A total depth of 65 m was sampled.

2012-13 Results, Information Transfer, and Student Support

In objectives for the first year of the project were achieved when a total depth of 65 m was cored by April 2013. Due to complications during drilling, a few sections were sampled more than once as three total holes were drilled, with different sampling intervals within 2 m of the original drill location. One undergraduate student was trained on laboratory methods through this project in the first year. One Master's student was trained on core sampling for this project through other funding, assisted with core collection, and will be funded through this project over the next year. At this early stage of the project, publications have not yet been submitted.

	Section 104 Awards		NIWR-USGS Internship	Supplemental Awards	Total
	Base Grants	Competitive Awards			
Undergrad.	1				1
Masters	1				1

PhD.					0
Post-Doc.					0
Total					1

References

Bohling, G.C., and B.B. Wilson. 2011. Statistical and geostatistical analysis of the Kansas High Plains water table elevations, 2011 measurement campaign. *Kansas Geological Survey Open-File Rept. 2011-16*.

Brunsell, N.A., A.R. Jones, T.L. Jackson, and J.J. Feddema. 2010. Seasonal trends in air temperature and precipitation in IPCC AR4 GCM output for Kansas, USA: Evaluation and implications. *International Journal of Climatology* **30**, no. 8: 1178-1193, doi: 10.1002/joc.1958.

Buddemeier, R.W., Stotler, R., Butler, J.J., Jr., Jin, W., Beeler, K., Reboulet, E., Macfarlane, P.A., Kreitzer, S., Whittemore, D.O., Bohling, G., and Wilson, B.B. 2010. High Plains Aquifer Calibration Monitoring Well Program: Third Year Progress Report*. Kansas Geological Survey, Open File Rept. 2010-3*.

Butler, J.J., Jr., R.L. Stotler, D. Whittemore, and E.C. Reboulet. 2013a. Interpretation of water-level changes in the High Plains aquifer in western Kansas. *Ground Water* **51**(2): 180-190.

Butler, J.J., Jr., D. Whittemore, G.C. Bohling, E. Reboulet, R.L. Stotler, and B.B. Wilson. 2013b. High Plains Aquifer Index Well Program: 2012 Annual Report. *Kansas Geological Survey Open File Report No. 2013-1*.

Dennehy, K.F., D.W. Litke, and P.B. McMahon. 2002. The High Plains aquifer, USA: Groundwater development and sustainability. In: K.M. Hiscock, M.O. Rivett, R.M Davison (eds) Sustainable groundwater development. *Geological Society of London Special Publication 193*: 99-119.

Maupin, M.A. and N.L. Barber. 2005. Estimated withdrawals from principal aquifers in the United States. *U.S. Geological Survey Circular 1279*.

Miller, R.D., R.C. Buchanan, and L. Brosius. 1998. Measuring water levels in Kansas. *Kansas Geological Survey Public Information Circular 12* http://www.kgs.ku.edu/Publications/pic12/ pic12_1.htm (accessed Sept. 6, 2011).

Rosenberg, N.J., D.J. Epstein, D. Wang, L. Vail, R. Srinivasan, and J.G. Arnold. 1999. Possible impacts of global warming on the hydrology of the Ogallala aquifer region. *Climatic Change* **42**: 677-692.

Rosenberg, N.J., R.A. Brown, R.C. Izaurralde, and A.M. Thomson. 2003. Integrated assessment of Hadley Centre (HadCM2) climate change projections on agricultural productivity and irrigation water supply in the conterminous United States I. Climate change scenarios and impacts on irrigation water supply simulated with the HUMUS model. *Agricultural and Forest Meteorology* **117**: 73-96.

Šimůnek, J., M.Th. van Genuchten, and M. Šejna. 2005. The HYDRUS-1D software package for simulating the one-dimensional movement of water, heat, and multiple solutes in variably-saturated media, Ver. 3.0, HYDRUS Software Series 1. Dept. of Environmental Sciences, University of California – Riverside, Riverside, CA.

Sophocleous, M. 2005. Groundwater recharge and sustainability in the High Plains aquifer in Kansas, USA. *Hydrogeology Journal* **13**, no. 2: 351-365.

Sophocleous, M. 2010. Review: groundwater management practices, challenges and innovations in the High Plains aquifer USA – lessons and recommended actions. *Hydrogeology Journal* **18**: 559-575.

Stotler, R., J.J. Butler, Jr., R.W. Buddemeier, G.C. Bohling, S. Comba, W. Jin, E. Reboulet, D.O. Whittemore, and B.B, Wilson. 2011. High Plains aquifer calibration monitoring well program: Fourth year progress report. *Kansas Geological Survey Open-File Rept. 2011-4*.

Waksom, R., J. Pritchett, and J. Schneekloth. 2006. Outlook on the High Plains aquifer: What's in store for irrigated agriculture? *Great Plains Soil Fertility Conference, Proceedings*, Denver, CO, March 2006, pp 122-128.

Getting the information modelers need: Extracting hydrostatigraphic information from drillers' logs

Basic Information

Title:	Getting the information modelers need: Extracting hydrostatigraphic information from drillers' logs
Project Number:	2012KS130B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	KS-002
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Geoffrey Bohling, James J. Butler, Blake Wilson

Publication

1. C. Helm, G. Bohling, D. Adkins-Heljeson, and B. Wilson, 2012, Extracting hydrostratigraphic information from drillers logs in the vicinity of the Thomas County index well, Governor s Conference on the Future of Water in Kansas, Oct. 30-31, 2012, Manhattan, KS.

May 13, 2013

Report of First Year Activities for WRRA 104(b) Project
Getting the information modelers need: Extracting hydrostratigraphic information from drillers' logs (HyDRA: Hydrostratigraphic Drilling Record Assessment)

Reporting Period: March 1, 2012 – February 28, 2013

Principal Investigator: Geoffrey C. Bohling, Associate Scientist, Geohydrology Section, Kansas Geological Survey, University of Kansas, 1930 Constant Avenue, Lawrence, KS 66047, (785) 864-2093, geoff@kgs.ku.edu

Other participants (all KGS Geohydrology Section): James J. Butler, Jr., Senior Scientist; Dustin Fross, High Plains Data Manager; Ed Reboulet, Field Hydrogeologist; Don Whittemore, Senior Scientific Fellow; Brownie Wilson, GIS/Support Services Manager

Student participant funded by this grant: Carolyn Helm, a graduate student in The Department of Geology at The University of Kansas, is working as a Graduate Research Assistant on this project, which will serve as the basis for her master's thesis.

Publication (Poster Presentation): C. Helm, G. Bohling, D. Adkins-Heljeson, and B. Wilson, 2012, Extracting hydrostratigraphic information from drillers' logs in the vicinity of the Thomas County index well, Governor's Conference on the Future of Water in Kansas, Oct. 30-31, 2012, Manhattan, KS.

Introduction

Understanding aquifer characteristics is important for effective ground-water management practices. A largely overlooked source of geologic information is drillers' logs, which contain vast amounts of qualitative information regarding subsurface structure. The purpose of this project, which has recently been dubbed HyDRA (Hydrostratigraphic Drilling Record Asssessment), is to develop and test procedures for employing this lithologic information in the development of quantitative three-dimensional depictions of subsurface properties for estimation of aquifer yield and use in flow and transport models. As stated in the project proposal, the objectives of this project are to:

1) Develop software and protocols to increase efficiency and accuracy of transcription of drillers' log forms into a standardized and accessible database.

2) Develop protocol for three-dimensional (3D) interpolation of lithological data from drillers' logs, properly accounting for the categorical nature of these data, and related crossvalidation procedure for assessing quality of logs.
3) Apply procedures developed under objectives 1 and 2 to develop 3D depictions of subsurface for use in simulations of water-level variations in vicinity of continuously-monitored wells in Thomas County, Kansas.
4) Provide educational opportunities through student participation in data processing, database and software design and development, and model development and interpretation.
5) Disseminate developed procedures and project outcomes in peer-reviewed publications, professional meetings, technical reports, and communication with state and local agencies.

During the first year of this project we have made progress on all of these objectives, as documented in the following sections.

Data Transcription and Database Development

Since 1975, water well drillers in the State of Kansas have been required to submit forms recording various information for each well they drill to the Kansas Department of Health and Environment. These forms include a lithologic log, a list of the driller's descriptions of the sediment or rock types encountered during the course of drilling. The Kansas Geological Survey is responsible for serving this information to the public and does so through the web-accessible WWC5 database. The WWC5 database currently contains records for around 236,000 wells. Approximately 198,000 of those records include a scanned image of the form submitted by the driller, an example of which is shown in Figure 1.

The first step in extracting information from the drillers' lithologic logs is to transcribe the material descriptions for each depth interval more or less verbatim into a database table (the WWC5 "logs" table). To date, there have been essentially three different log transcription efforts at the Kansas Geological Survey, one associated with the PST+ project (the predecessor of this project) focused on Groundwater Management District (GMD) 3 in southwestern Kansas and GMD 1 in west central Kansas, one performed primarily by the survey's webmaster, Dana Adkins-Heljeson, and, most recently, one associated specifically with this project, performed by Carolyn Helm, the Graduate Research Assistant employed on this project, and Dustin Fross, a staff member in the survey's Geohydrology Section. In this latter effort, we are taking advantage of the web-based log transcription interface developed by Adkins-Heljeson. A related effort is import of records from the PST+ database (a "local" database developed in Microsoft Access) into the publicly accessible WWC5 logs table, part of the survey's Oracle database, also using a web-based interface developed by Adkins-Heljeson. Figure 2 shows a map of the transcription and import progress to date.

WATER WELL RECORD Form WWC-5 KSA 82a-1212

1 LOCATION OF WATER WELL: County: Thomas | Fraction: NE ¼ SW ¼ SE ¼ | Section Number: 31 | Township Number: T 7 S | Range Number: R 33 E/W

Distance and direction from nearest town or city street address of well if located within city?
410 E. 4th

2 WATER WELL OWNER: Colby Locker
RR#, St. Address, Box # : 410 E. 4th
City, State, ZIP Code : Colby, Ks. 67701

DPRA #B4 -Easement of City of Colby
Board of Agriculture, Division of Water Resources
Application Number:

3 LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX:
N, NW, NE, W, E, SW, SE, X, S, 1 Mile

4 DEPTH OF COMPLETED WELL 125 ft. ELEVATION:
Depth(s) Groundwater Encountered 1. ft. 2. ft. 3. ft.
WELL'S STATIC WATER LEVEL 103.6 ft. below land surface measured on mo/day/yr
Pump test data: Well water was ft. after hours pumping gpm
Est. Yield gpm: Well water was ft. after hours pumping gpm
Bore Hole Diameter 8 in. to 125 ft., and in. to ft.
WELL WATER TO BE USED AS: 5 Public water supply 8 Air conditioning 11 Injection well
1 Domestic 3 Feedlot 6 Oil field water supply 9 Dewatering 12 Other (Specify below)
2 Irrigation 4 Industrial 7 Lawn and garden only 10 Monitoring well
Was a chemical/bacteriological sample submitted to Department? Yes No X; If yes, mo/day/yr sample was submitted
Water Well Disinfected? Yes No X

5 TYPE OF BLANK CASING USED: 5 Wrought iron 8 Concrete tile CASING JOINTS: Glued Clamped
1 Steel 3 RMP (SR) 6 Asbestos-Cement 9 Other (specify below) Welded
2 PVC 4 ABS 7 Fiberglass Threaded X
Blank casing diameter 4 in. to 95 ft., Dia in. to ft., Dia in. to ft.
Casing height above land surface 0 in., weight 2.071 lbs./ft. Wall thickness or gauge No. .237
TYPE OF SCREEN OR PERFORATION MATERIAL: 7 PVC 10 Asbestos-cement
1 Steel 3 Stainless steel 5 Fiberglass 8 RMP (SR) 11 Other (specify)
2 Brass 4 Galvanized steel 6 Concrete tile 9 ABS 12 None used (open hole)
SCREEN OR PERFORATION OPENINGS ARE: 5 Gauzed wrapped 8 Saw cut 11 None (open hole)
1 Continuous slot 3 Mill slot 6 Wire wrapped 9 Drilled holes
2 Louvered shutter 4 Key punched 7 Torch cut 10 Other (specify)
SCREEN-PERFORATED INTERVALS: From 95 ft. to 125 ft., From ft. to ft.
From ft. to ft., From ft. to ft.
GRAVEL PACK INTERVALS: From 93 ft. to 125 ft., From ft. to ft.
From ft. to ft., From ft. to ft.

6 GROUT MATERIAL: 1 Neat cement 2 Cement grout 3 Bentonite 4 Other
Grout Intervals: From 0 ft. to 81 ft., From 81 ft. to 93 ft., From ft. to ft.
What is the nearest source of possible contamination: 10 Livestock pens 14 Abandoned water well
1 Septic tank 4 Lateral lines 7 Pit privy 11 Fuel storage 15 Oil well/Gas well
2 Sewer lines 5 Cess pool 8 Sewage lagoon 12 Fertilizer storage 16 Other (specify below)
3 Watertight sewer lines 6 Seepage pit 9 Feedyard 13 Insecticide storage
Direction from well? North How many feet? 80'

FROM	TO	LITHOLOGIC LOG	FROM	TO	PLUGGING INTERVALS
0	5	Surface	120	125	Med. Sand
5	20	Lt. Brown Clay			
20	40	Lt. Brown Clay w/sand strks.			
40	45	Lt. Brown Sandy Clay			
45	55	Lt. Brown Clay & Sand			
55	65	Red Sandy Clay			
65	76	Med. Sand			
76	89	Caliche & Clay			
89	91	Med Sand			
91	93	Caliche			
93	94	Sand			
94	100	Clay & Cemented Strks/Caliche			
100	105	Cemented Sand			
105	112	Clay & Sand Strks.			
112	120	Sand			

7 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was (1) constructed, (2) reconstructed, or (3) plugged under my jurisdiction and was completed on (mo/day/year) 11-8-92 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. 554 This Water Well Record was completed on (mo/day/yr) 11-19-92 under the business name of WOOFTER PUMP & WELL, INC. by (signature)

INSTRUCTIONS: Use typewriter or ball point pen. PLEASE PRESS FIRMLY and PRINT clearly. Please fill in blanks, underline or circle the correct answers. Send top three copies to Kansas Department of Health and Environment, Bureau of Water, Topeka, Kansas 66620-0001. Telephone: 913-296-5545. Send one to WATER WELL OWNER and retain one for your records.

OFFICE USE ONLY T R E/W SEC ¼ ¼ ¼

Figure 1. Example water well drilling record, including, in this case, a very high quality lithologic log. Style and quality of lithologic logs varies considerably.

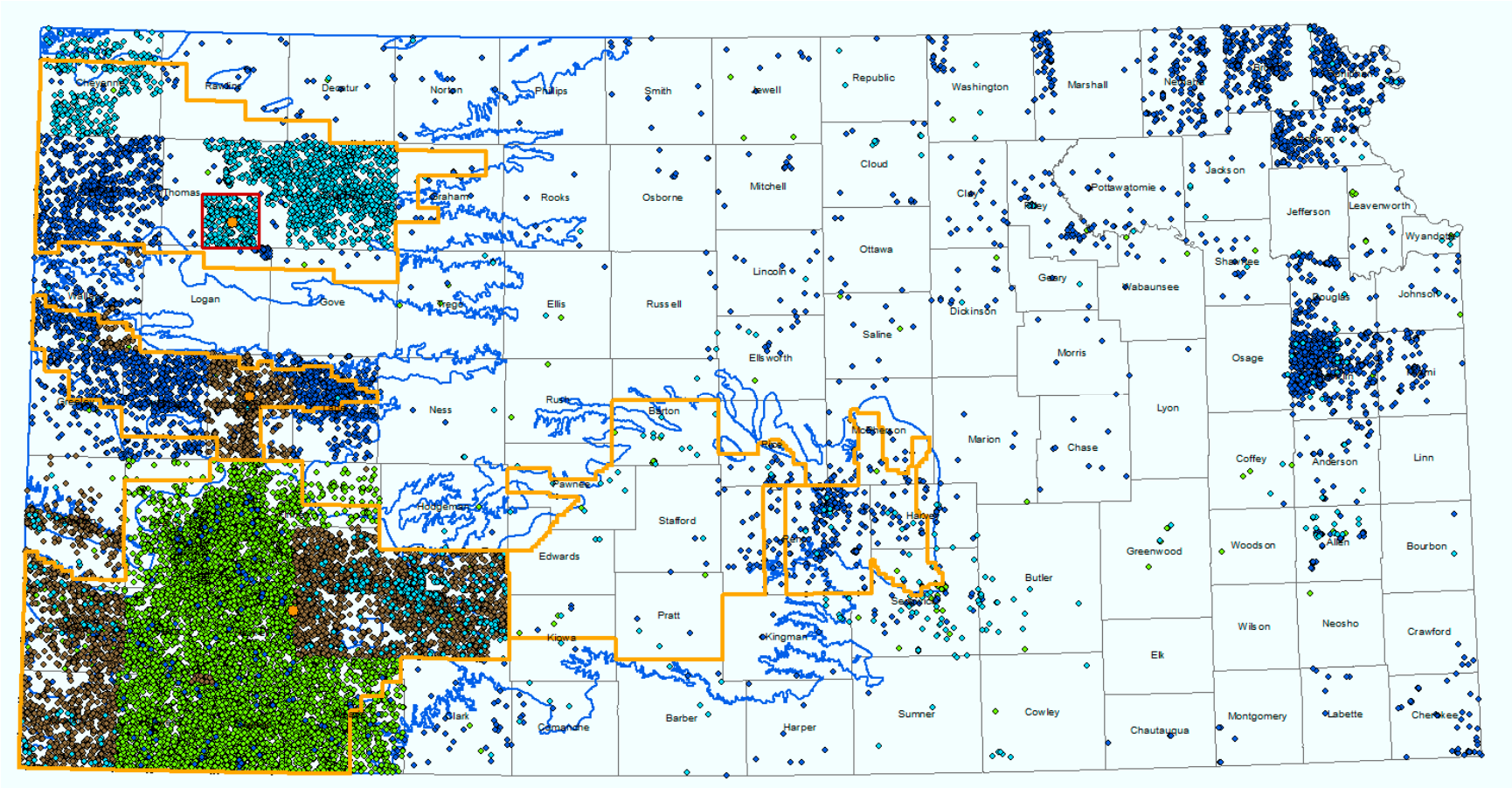

Figure 2: Log transcription progress as of May 13, 2013. Light blue: WWC5 logs transcribed by HyDRA project team members (Fross and Helm, 2824 wells); dark blue: WWC5 logs transcribed by other KGS staff members (7239 wells); brown: logs imported to WWC5 from PST+ database (5445 wells); green: logs remaining to be imported from PST+ (10,643 wells). Larger orange circles are three KGS index wells, blue outline is extent of High Plains aquifer, gold outlines are Groundwater Management District boundaries, and red outline highlights 250 wells in vicinity of Thomas County index well.

So far, members of the HyDRA project (Fross and Helm) have transcribed logs for 2824 wells, primarily in Groundwater Management District (GMD) 4 in northwestern Kansas. In addition, as part of this project, Fross is currently working on importing logs in GMD3 (southwestern Kansas) from PST+ into WWC5 and is responsible for the majority logs imported so far in GMD3 (4426 wells).

Helm's master's thesis work involves development of a 3D groundwater flow model based on drillers' logs in the vicinity of the Thomas County index well. Assessing the ability of this model to accurately simulate the highly detailed water level record from the index well will provide a means to test both the utility of the information contained in drillers' logs as well as the effectiveness of the proposed interpolation procedures for developing a 3D property model from the logs. Helm's first task, upon beginning work in August, 2012, was to transcribe the logs for 250 wells in the vicinity of the Thomas County index well. This area, approximately 15 miles on a side, is represented by the red square in Figure 2.

Helm has also assessed the quality of these 250 logs, scoring each log as excellent, good, fair, or poor, based on both the amount of vertical detail in the log (average thickness of described intervals) and the amount of detail or care evident in the individual descriptions. Figure 1 is an example of a log that would be considered excellent. An example of a poor log is one that contains only two intervals, 0 to 60 feet of "clay" followed by 60 to 245 of "sand and gravel with clay streaks". Not surprisingly, individual drillers are fairly consistent in their style. Figure 3 summarizes the log quality for the five predominant drilling contractors in the Thomas County index well area (who collectively drilled 216 of the 250 wells). Of all 250 logs, 99 (40%) are considered excellent, 80 (32%) good, 50 (20%) fair, and 21 (8%) poor.

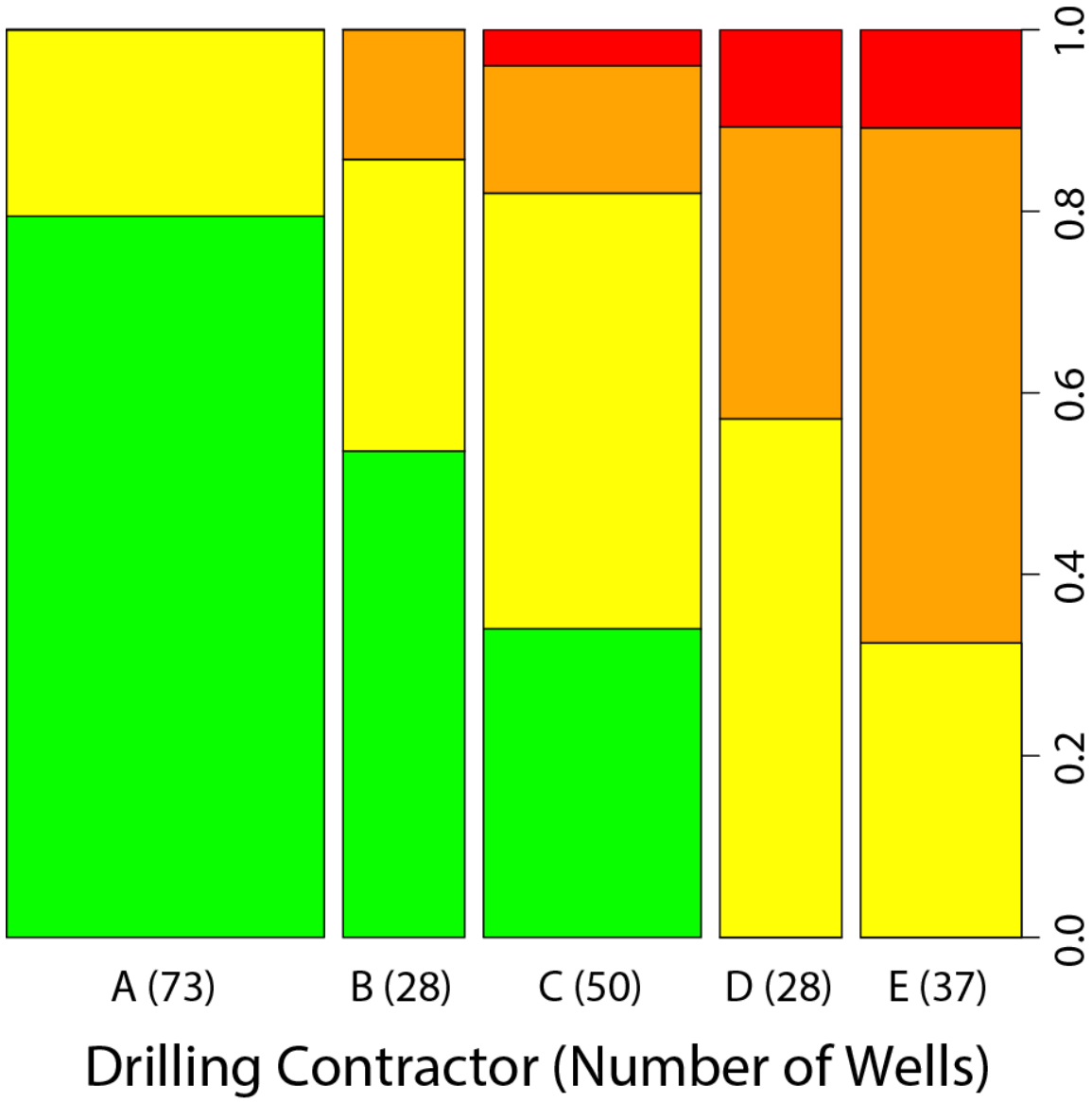

Figure 3: Proportion of logs scored as excellent (green), good (yellow), fair (orange), and poor (red) for the five contractors who drilled most of the wells (216 of 250) in the Thomas County index well area. Bar widths are proportional to number of wells drilled by each driller (shown in parentheses), so that overall area of each color reflects overall proportion of each quality.

The next step in the process of converting the logs into quantifiable information is to standardize the sediment descriptions in some fashion. Thus far, we are employing the standardization approach developed as part of the PST+ project and implemented in the Access database associated with that project. This involves identifying every unique description encountered in the collection of transcribed logs and manually assigning each description to a set of one or more codes representing standardized lithologies. For example, the description "fine sand and clay" would be assigned two codes, "fsnd" for fine sand and "c" for clay. The codes are from a list of 71 standardized lithology codes. The PST+ project developed a table of over 60,000 unique descriptions found in ~225,000 individual interval descriptions from ~17,400 logs, mostly in GMD3. When new logs are entered into the PST+ database, any descriptions that do not match existing entries in the table of unique descriptions are placed at the top of that table, awaiting manual mapping to standardized codes. Thus, as the table is built up over time, more and more of the newly imported descriptions will match existing descriptions and will not need to be mapped (again) into standardized lithologies. This table (referred to as the "filters" table) is applied to the logs in order to cast them into standardized form.

Helm has applied this process to the 250 logs in the Thomas County index well area in order to standardize these logs. The 250 logs contained only about 20 descriptions that did not match previously mapped descriptions. Fross is currently working on re-implementing this mapping process in the KGS Oracle database, to make it more accessible to a variety of investigators, and is also looking into means of introducing more automation into the mapping process in order to reduce the amount of manual editing involved and, perhaps more importantly, the subjective nature of this manual mapping process.

Development of 3D Interpolation Procedures

Bohling has worked on development of the geostatistical procedures used to develop a 3D hydrogeologic property model from the drillers' lithologic logs. These procedures are currently implemented in a sequence of programs and scripts that will eventually be tied together in a single data processing package. The first step in this procedure is to map the set of 71 standardized lithologies into a smaller number of categories associated with expected hydrogeologic property ranges. The example shown here uses five categories associated with different ranges of permeability or hydraulic conductivity (K), with category 1 representing the lowest-permeability materials (such as shale and clay) and category 5 representing the highest permeability materials (such as sand and gravel). These will be referred to as K categories in the following. The categorization could be different for different modeling projects or for different properties considered within the same project.

To build a 3D property model from the categorized logs, the categorical information must be represented in terms of quantitative values that can be interpolated. The approach adopted here is to segment each well (log) into a sequence of regularly

spaced depth intervals (specifically, 10-foot intervals) and compute the proportion of each K category within each interval. It is these proportions that are then interpolated to the 3D grid. This is similar to the approach described in Faunt et al. (2010), although they divided the lithologic descriptions into only two classes (coarse-grained and fine-grained). In addition, we are not interpolating the proportions directly. Instead, because the proportions represent a composition (parts of a whole), we are following the advice of Pawlowsky-Glahn and Olea (2004) regarding geostatistical analysis of compositional data and interpolating log-ratio transforms of the proportions instead, backtransforming the interpolated values to proportions in each cell of the model grid. Nevertheless, the process can be thought of as interpolation of the category proportions, resulting in a grid of spatially varying proportion values for each category. An important outcome of this process is that the set of interpolated proportion grids preserve more of the information contained in the logs than one would obtain by some obvious alternative processes, such as computing average K values within each depth interval in each well and then interpolating those values. Based on the interpolated proportions, a number of summary measures could be computed within each model grid cell, such as the dominant K category (associated with the highest proportion), a proportion-weighted average K, and an entropy measure reflecting the degree of mixing of categories within each cell. Figure 4 shows slices through a 3D model for the Thomas County index well area, showing, in this case, the proportion-weighted average K category in each grid cell.

A related cross-validation procedure for helping with the identification of anomalous logs has also been developed. This procedure involves removing each well in turn from the data set, interpolating the category proportions from the surrounding wells to the location of that well, and computing the degree of agreement (or disagreement) between the actual and interpolated proportions at the well using a cross-entropy measure. Presumably, high values of cross-entropy should indicate logs that differ significantly from expectations based on other logs in their neighborhood. Assessment of the effectiveness of this procedure is underway.

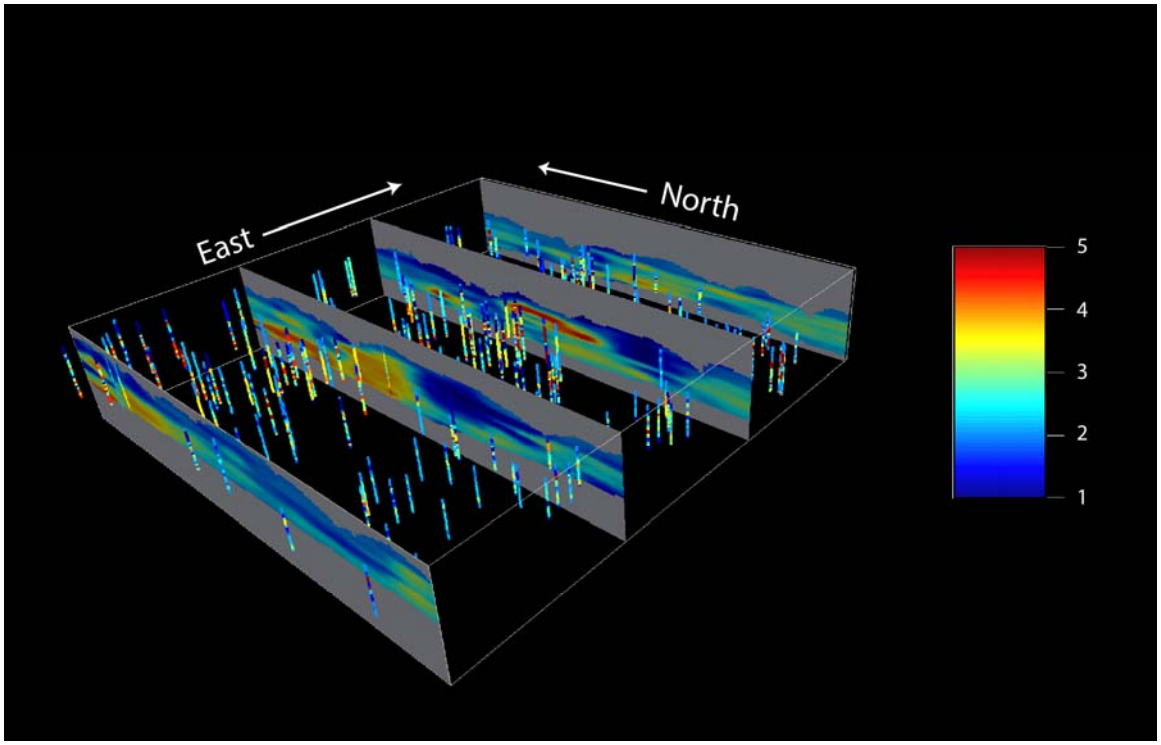

Figure 4. Slices through a 3D model of the Thomas County index well area developed using the 179 "excellent" and "good" drillers' logs in the vicinity of the index well. The property displayed is proportion-weighted average permeability (K) category in each model cell, with 1 representing lowest-K category and 5 representing highest-K category. The model domain is 15 miles on a side (east-west and north-south), centered on the index well, and 490 feet thick. Gray regions are above ground surface and below bedrock. The property displayed at the wells (between slices) is proportion-weighted average K category within each 10-foot interval of the well.

Flow Model Development

Helm, who has just completed her first year of graduate study at the University of Kansas, has started the process of developing the 3D flow model of the Thomas County index well area, beginning with development of a simple 2D model to familiarize herself with the modeling software (MODFLOW) and with the input data requirements. Two significant challenges associated with development of this model will be the representation of the spatial and temporal distribution of irrigation pumping (the primary driver of water level variations in the index well) in a form appropriate for model input and the specification of reasonable boundary conditions. Brownie Wilson has provided water use data associated with "points of diversion" (primarily irrigation wells) in the area and Helm has started looking into how this information can be combined with information on well screen depths (contained in the WWC5 records) to properly locate the pumping in the 3D model

space. Development of the flow model will be the primary focus of Helm's work this summer (2013).

Educational and Training Opportunities

As mentioned above, this project is supporting a Graduate Research Assistant, Carolyn Helm, and providing a basis for her master's thesis in the Department of Geology at the University of Kansas. It is providing her with training in the interpretation of drillers' logs and in groundwater modeling procedures as well as providing familiarity with the geostatistical procedures used in the development of the 3D property model. In addition, although he is not currently a student, Dustin Fross, a young staff member at the KGS, is gaining significant experience in basic geological and hydrogeological concepts, drillers' log interpretation, and database development in his work on this project.

Dissemination of Results

Carolyn Helm presented a poster on this project at the Governor's Conference on the Future of Water in Kansas in October 2012 (details on first page of report). This was her first public presentation and thus provided a significant learning experience. She has just received the Kansas Geological Survey's Frank C. Foley travel award, intended to support a student's travel to a professional meeting to present results of their work. Most likely, Carolyn will use this to travel to Geological Society of America Annual Meeting in Denver in October 2013. This meeting should provide a good venue for presenting her results to a broad scientific audience. Bohling gave a presentation on this project at the KGS's Advisory Committee meeting in April 2013. Although this is outside the reporting period for this report, the presentation largely covered work within the reporting period.

References

Faunt, C.C., K. Belitz, and R.T. Hanson, 2010, Development of a three-dimensional model of sedimentary texture in valley-fill deposits of Central Valley, California, USA, *Hydrogeology Journal* 18: 625-649.

Pawlowsky-Glahn, V., and R.A. Olea, 2004, Geostatistical Analysis of Compositional Data, Oxford University Press, 181 pp.

Information Transfer Program Introduction

The KWRI is committed to transferring knowledge generated by its researchers to clientele. The KWRI uses a variety of methods. These include:

1. The first statewide Kansas "Governor's Conference on the Future of Water in Kansas Conference" was held on October 30-31, 2012 in Manhattan, Kansas. The conference was highly successful with 573 people attending both days of the conference. Forty-eight volunteer scientific and 10 invited presentations were presented in plenary and concurrent sessions. Thirty scientific posters were presented in the poster session. An undergraduate/graduate student poster award program was conducted to encourage student participation. Twenty-two students participated. The program agenda is included with this report. The conference website is located at: http://www.kwo.org/Ogallala/Governors_Conference_2012/Governors_Conference_2012.htm The conference will be held again on October 24-25, 2013.

2. A new publication, "Summary of Water-Related Research in Kansas," was published by the Kansas Water Resources Institute. This publication includes short summaries of 72 water-related Kansas research projects by research organizations that are part of the Institute. Over 1000 copies were distributed to the public.

3. The KWRI website, http://www.kcare.ksu.edu/p.aspx?tabid=921, is used to transfer project results and inform the public on issues and scientists on grant opportunities.

Governor's Water Conference

Basic Information

Title:	Governor's Water Conference
Project Number:	2011KS98B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	KS-002
Research Category:	Not Applicable
Focus Category:	Water Use, Sediments, Economics
Descriptors:	None
Principal Investigators:	Dan Devlin

Publications

1. Selfa, T. and T. Becerra. 2011. Conservation decision-making factors. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF3035. 2 pg.
2. Barnes, P. and N. Nelson. 2011. Water quality monitoring. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF3037. 2 pg.
3. Nelson, N., K. Douglas-Mankin, D. Devlin, A. Bontrager, P. Barnes and L. Frees. 2011. Prioritization of conservation practice implementation. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF3031. 2 pg.
4. Nelson, N., D. Devlin, K. Douglas-Mankin and P. Barnes. 2011. Modeling the effect of no-till. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF3036. 2 pg.
5. Devlin, D. and L. French. 2011. Local leadership: goals and actions. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF3032. 2 pg.
6. Douglas-Mankin, K., P. Daggupai, A. Sheshukov, P. Barnes, D. Devlin, and N. Nelson. 2011. Erosion from ephemeral gullies. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF3030. 2 pg.
7. Devlin, D., K. Douglas-Mankin, T. Selfa, N. Nelson, P. Barnes, H. Miller, L. French, L. Frees and M. Langemeier. 2011. Assessing the effect of conservation practices. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF3033. 2 pg.
8. Rogers, D., G. M. Powell, and K. Ebert. 3021. Water primer: part 2. The hydrologic cycle. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF3031. 4 pg.
9. Rogers, D., G. M. Powell, and K. Ebert. 3020. Water primer: part 1. Overview. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF3031. 4 pg.
10. Presley, D., D. Shoup, J. Holman and A. Schlegel. 2012. Efficient crop water use in Kansas. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF3066. 40 pg.
11. Rogers, D., G. Powell and K. Ebert. 2013. Water Law. Water Primer: Part 5. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF3037. 8 pg.
12. Rogers, D., G. Powell and K. Ebert. 2012. The Hydrologic Cycle. Water Primer: Part 2. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF3037. 4 pg.
13. Van der Merwe, D., C. Blocksome and L. Hollis. 2012. Identification and management of blue-green algae in farm ponds. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF3065. 4 pg.

14. Rogers, D., G. Powell and K. Ebert. 2012. Overview. Water Primer: Part 1. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF3020. 4 pg.
15. Rogers, D., G. Powell and K. Ebert. 2012. Groundwter. Water Primer: Part 3. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF3022. 4 pg.
16. Rogers, D., G. Powell and K. Ebert. 2012. Surface Water. Water Primer: Part 4. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF3023. 4 pg.

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Kansas

Governor's Conference on the Future of Water in Kansas

October 30-31, 2012

Hilton Garden Inn & Conference Center
Manhattan, Kansas

AGENDA – Day 1

Tuesday, October 30, 2012

7:00 - Registration *(Foyer)*

7:30 - Overview on the State of Water in Kansas *(Kaw Nation & Big Basin Rooms)*
Tracy Streeter, Kansas Water Office - (Continental Breakfast)

9:00 - Introduction *(Kaw Nation & Big Basin Rooms)*
Gary Harshberger, Chairman, Kansas Water Authority

9:05 - Welcome *(Kaw Nation & Big Basin Rooms)*
Dr. April Mason, Kansas State University Provost

9:10 - Kansas Water Future *(Kaw Nation & Big Basin Rooms)*
Governor Sam Brownback

9:35 - Managing a Shared Pool Resource *(Kaw Nation/Big Basin)*
Dr. Bill Blomquist, Indiana University Purdue University Indianapolis

10:05 - Water Infrastructure *(Kaw Nation & Big Basin Rooms)*
Lieutenant General Thomas P. Bostick, Commanding General USACE

10:35 - Questions & Discussion *(Kaw Nation & Big Basin Rooms)*

10:45 - *Break & Tour Exhibits*

11:00 - Water & Energy *(Kaw Nation & Big Basin Rooms)*
Mike Hightower, Sandia National Labs

11:30 - *Break & Tour Exhibits*

12:00 - Lunch *(Kaw Nation & Big Basin Rooms)*
Remarks from Senator Pat Roberts

1:00 - Ogallala Initiative Panel *(Kaw Nation & Big Basin Rooms)*

1:45 - *Break & Tour Exhibits*

2:10 - Panel Sessions

A. Nutrient Water Quality *(Flint Hills, Kings & Konza Rooms)*
B. Water in Agriculture *(Kaw Nation & Big Basin Rooms)*
C. Water & Energy *(McDowell, Tuttle & Alcove Rooms)*
D. Federal & State Water Infrastructure *(Big Blue River & Fort Riley Rooms)*

3:40 - *Break & Tour Exhibits*

4:05 - Questions & Discussion for all Speakers *(Kaw Nation & Big Basin Rooms)*

4:25 - Wrap Up *(Kaw Nation & Big Basin Rooms)*

4:45 - Adjourn

5:30 - Social - Flint Hills Discovery Center (5:30 pm - 7:00 pm)

PANELS – Day 1

Tuesday, October 30, 2012

1:00 - Ogallala Initiative, LEMAs & what would help make them more successful?

Moderator: *Tracy Streeter, Director KWO*

(Kaw Nation & Big Basin Rooms)

Panel: *Scott Foote, Hoxie Feedyard*

Bill Murphy, USDA-RMA

Steve Irsik, Ingalls, KS

2:10 - Session A: Nutrient Water Quality - Cindy Wallis-Lage, Black & Veatch

Moderator: *Mike Tate, Kansas Department of Health & Environment*

(Flint Hills, Kings & Konza Rooms)

Panel: *Steve Swaffar, Kansas Farm Bureau*

John O'Neill, Johnson County Wastewater

Mark Dugan, Dugan, Scholzman LLC

Wayne Gieselman, Deputy Division Director for Water, Wetlands and Pesticides, EPA

2:10 - Session B: Water in Agriculture - Secretary Dale Rodman, KDA

Moderator: *Chad Bontrager, Kansas Department of Agriculture*

(Kaw Nation & Big Basin Rooms)

Panel: *Greg Graff, KS Grain Sorghum Commission, KS Representative on U.S. Grain Sorghum Council*

Gary Harshberger, KWA/OAAC, Serves on Bonanza BioEnergy and Arkalon Energy Boards

Tim Lust, Sorghum Checkoff

Steve McNinch, Western Plains Energy, LLC CEO

2:10 - Session C: Water and Energy - Mike Hightower, Sandia National Labs

Moderator: *Susan Metzger, Kansas Water Office*

(McDowell, Tuttle & Alcove Rooms)

Panel: *Rorik Peterson, EDP Renewables*

Brad Loveless, Westar

Sarah Hill-Nelson, Bowersock

Robert Stanbery, Shell Oil

2:10 - Session D: Federal/State Water Infrastructure - Steve Iverson, Kansas City District & Col. Michael J. Teague, Tulsa District

Moderator: *Earl Lewis, Kansas Water Office*

(Big Blue River & Fort Riley Rooms)

Panel: *Robin Jennison, Kansas Department of Wildlife, Parks & Tourism*

Dennis Schwartz, Vice President, Kansas Rural Water Association

John Mitchell, Burns and McDonnell

AGENDA – Day 2

Wednesday, October 31, 2012

7:30 - Registration, View Posters, *(Foyer)*
(Continental Breakfast)

8:30 - Welcome
Dr. Dan Devlin, Kansas State University (Kaw Nation & Big Basin Rooms)

8:45 - Economics of Water
Dr. Frank Ward, New Mexico State Univ. (Kaw Nation & Big Basin Rooms)

9:30 - Value of Ogallala Water *(Kaw Nation & Big Basin Rooms)*
Dr. Bill Golden, Kansas State University

10:15 - Horizontal Drilling & Hydraulic Fracturing *(Kaw Nation & Big Basin Rooms)*
Rex Buchanan, Kansas Geological Survey

11:00 - *Break & View Posters (McDowell & Tuttle Rooms)*

11:30 - Lunch *(Kaw Nation & Big Basin Rooms)*
Student Poster Awards
Recognition of KELP Graduates

12:15 - *Break & Move to Sessions*

12:30 - Topical Session 1
A. Algal Blooms & Reservoirs *(Flint Hills, Kings & Konza Rooms)*
B. Irrigation, Crops & Water Resources *(Kaw Nation & Big Basin Rooms)*
C. Impact of Extreme Events & Climate Change on Kansas Water *(Alcove Room)*
D. WRAPS Projects & Effectiveness *(Big Blue River & Fort Riley Rooms)*

1:30 - *Break*

1:40 - Topical Sessions 2
A. Sediment Transport & Control *(Flint Hills, Kings & Konza Rooms)*
B. Ogallala Aquifer: Conditions, Trends & Policies *(Kaw Nation & Big Basin Rooms)*
C. Water Infrastructure Development & Sustainability *(Alcove Room)*
D. WRAPS Projects *(Big Blue River & Fort Riley Rooms)*

2:40 - *Break*

3:00 - Topical Session 3
A. Reservoir Sedimentation *(Flint Hills, Kings & Konza Rooms)*
B. New Approaches with GIS & Other Technology *(Kaw Nation & Big Basin Rooms)*
C. Municipal Water Management *(Alcove Room)*
D. Hydraulic Fracturing & Emerging Issues *(Big Blue River & Fort Riley Rooms)*

4:00 - Adjourn

Topical Sessions – Day 2

Wednesday, October 31, 2012

12:30 - Topical Session 1

A. Algal Blooms & Reservoirs *(Flint Hills, Kings & Konza Rooms)*

Moderator: *Andy Ziegler*, U.S. Geological Survey*

- Potential Short-Term Management Strategy to Reduce Toxic Cyanobacterial Blooms by Manipulation of the Nitrogen to Phosphorus Ratio
  Theodore Harris, U.S. Geological Survey
- Algal Toxin and Taste-and-Odor Transport in the Kansas River
  Jennifer Graham, U.S. Geological Survey
- Harmful Algae Blooms in Kansas City District U.S. Army Corps Lakes
  Marvin Boyer, U.S. Army Corps of Engineers
- The Ecology of Problem Growths of Cyanobacteria in Reservoirs as Related to Sedimentation
  Jerry deNoyelles, Kansas Biological Survey, KU

B. Irrigation, Crops & Water Resources *(Kaw Nation & Big Basin Rooms)*

Moderator: *Joe Harner*, Kansas State University*

- The Potential for Conserving Water with SDI for Corn Production
  Freddie Lamm, Northwest Research-Extension Center, KSU
- Cropping Systems Under Limited Irrigation
  Alan Schlegel, Southwest Research-Extension Center, KSU
- The Use of KanSched, an ET-based Scheduling Program for Various Irrigation & Climatic Regimes
  Danny Rogers, Biological & Agricultural Engineering, KSU
- Limited/Deficit Irrigation Management from Production Functions to Decision Aids
  Norm Klocke, Retired Irrigation Engineer, KSU

C. Impact of Extreme Events & Climate Change on Kansas Water *(Alcove Room)*

Moderator: *Susan Stover*, Kansas Water Office*

- Hydrologic Impacts of Climate Change in NE Kansas Using SWAT & an Ensemble of Global Climate Models
  Aleksey Sheshukov, Biologcial & Agricultural Engineers, KSU
- Trends and Implications of Extreme Weather Events
  Nathaniel Brunsell, Department of Geography, KU
- Changing Kansas Climate
  Mary Knapp, Agronomy, Weather Data Library, KSU
- Republican River Basin Study: The Start of a Multi-State Research Effort
  Andrea Brookfield, Kansas Geological Survey, KU

D. WRAPS Projects & Effectiveness *(Big Blue River & Fort Riley Rooms)*

Moderator: *Jaime Gaggero, Kansas Department of Health & Environment*

- Are We Making a Difference? A Framework for Evaluating WRAPS Projects
  Robert Wilson, K-State Research & Extension
- Research Meets the Real World: The Intersect Between Science & Watershed Mngt.
  Lisa French, Cheney Lake Water Quality Project
- Assessing the Health of Streams in Agricultural Landscapes: How & When will Land Management Effect Change
  Don Huggins, Kansas Biological Survey, KU
- Water Quality Results from BMP Implementation in the Little Arkansas Watershed
  Ron Graber, KCARE, KSU

1:40 - Topical Session 2

A. Sediment Transport & Control *(Flint Hills, Kings & Konza Rooms)*
Moderator: *Jeff Gross*, NRCS*

- Beyond Targeting: Paying for Sediment
  Kyle Douglas-Mankin, Biological & Agricultural Engineering, KSU
- Sediment Loads & Yields, Small Pond Trapping Efficiency, & Downstream Reservoir Trapping Efficiency of Three Headwater Watersheds in NE Kansas
  Guy Foster, U.S. Geological Survey
- Missouri River Degradation in the Kansas City Reach
  John Shelley, Corps of Engineers
- Impacts of Sand Dredging on the Kansas River
  Heidi Mehl, Geography, KSU

B. Ogallala Aquifer: Conditions, Trends & Policies *(Kaw Nation & Big Basin)*
Moderator: *Lane Letourneau*, Kansas Department of Ag, DWR*

- Conserving & Extending the Useful Life of the High Plains/Ogallala Aquifer in KS
  Marios Sophocleous, Kansas Geological Survey, KU
- Potential Economic Impact of Water Use Changes in Southwest Kansas
  Bill Golden, Agricultural Economics, KSU
- Water Resources of the Dakota Aquifer in Kansas
  Donald Whittemore, Kansas Geological Survey
- Hot & Dry: Western Kansas Farmers' Views of the Future
  B.J. Gray, Department of Anthropology, KU

C. Water Infrastructure Development & Sustainability *(Alcove Room)*
Moderator: *Marcia Schulmeister*, Emporia State University*

- Asset Management-A Common Sense Approach to Prioritizing Infrastructure Needs
  Katie Miller & Angela Buzard, Environmental Finance Center, WSU
- The Restoration & Rehabilitation of the City of Osage Water Supply System
  Randall Root, Burns & McDonnell
- Kansas State University Stormwater Management Design - Build Project
  Lee Skabelund, Landscape Architecture/Regional & Community Planning, KSU
- KSU: Urban Water Institute
  Stacy Hutchinson, Department of Biological & Agriculture Engineering, KSU

D. WRAPS Projects *(Big Blue River & Fort Riley Rooms)*
Moderator: *Josh Roe, Kansas State University*

- Utilizing Water Samples, Windshields, Working with Landowners, & Wisdom to Target BMPs in HUC 12 Watersheds
  Stacie Minson, Watershed Specialist, KSU/KCARE
- Kansas WRAPS Program: The Landscape of the Future
  Jaime Gaggero, Kansas Department of Health & Environment
- Delaware River Streambank Restoration Program-Reducing Sedimentation Economically, Locally & Effectively
  Marlene Bosworth, Glacial Hills Resource Conservation & Development Region
- Locating Ephemeral Gullies Using GIS-Based Methods
  Kyle Douglas-Mankin, Biological & Agricultural Engineering, KSU

Topical Sessions – Day 2
Wednesday, October 31, 2012

3:00 - Topical Session 3

A. Reservoir Sedimentation *(Flint Hills, Kings & Konza Rooms)*
Moderator: *Ed Martinko*, Kansas Biological Survey*

- Reservoir Sediment Accounting & Management
  Steve Spaulding, Corps of Engineers
- Tracking Historic Prairie Fire Trends Within a Lake Sediment Record
  Nicole Niehues, Kansas Biological Survey
- Wetland Retention as an Effective BMP to Reduce Nutrient & Sediment Loads to Clinton Lake
  Tom Huntzinger, WRAPs
- Corps of Engineers Water Resources Partnering in Kansas
  John Grothaus, Corps of Engineers

B. New Approaches with GIS & Other Technology *(Kaw Nation & Big Basin)*
Moderator: *Brownie Wilson, Kansas Geological Survey*

- Making Kansas Aquatic Resource Data Available Through Online Mapping Services
  Michael Houts, Kansas Biological Survey
- Development & Application of the Kansas Topographic Wetland I.D. Process
  Michael Houts, Kansas Biological Survey
- Mapping Irrigated Cropland in Kansas
  Jude Kastens, Kansas Biological Survey
- High Resolution Algal Density Characterization by Remote Sensing
  Deon van der Merwe, Kansas State Veterinary Diagnostic Laboratory, KSU

C. Municipal Water Management *(Alcove Room)*
Moderator: *Stacy Hutchinson, Kansas State University*

- In-Ground Irrigation Systems Affect Lawn-Watering Behaviors of Residential Home-owners
  Dale Bremer, Horticulture, Forestry & Recreation Resources, KSU
- Fort Riley - A Net Zero Water Installation
  Chris Otto, Fort Riley Directorate of Public Works
- Kansas Public Water Systems Face Increasing Costs
  Pat McCool, Consultant, Kansas Rural Water Association
- Mukti Water Technology from Household to Community Scale for Reducing Arsenic Risks in Drinking Water
  Meer Husain, Academy of Healthy Water, Ecosystem & Environment

D. Hydraulic Fracturing & Emerging Issues *(Big Blue River & Fort Riley Rooms)*
Moderator: *Dave Newell, Kansas Geological Survey*

- Shell: Focused on Water Use & Protection
  Erik Bartsch, Shell Energy
- Regulating Water for Oil & Gas Operations
  David Barfield, Kansas Department of Agriculture, DWR
- The Power of Public & Private Partnerships: Harper County's Experience
  Al Roder, Administrator, Harper County
- Partnering on Lake Anthony to Meet Oil Development & Community Needs
  Mike Moore, Select Energy

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USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	0	0	2
Masters	4	0	0	0	4
Ph.D.	2	0	0	0	2
Post-Doc.	0	0	0	0	0
Total	8	0	0	0	8

Notable Awards and Achievements