Effects of Small Impoundments on Total Watershed Sediment Yield in Northeast Kansas, April through August 2011

By

Guy M. Foster

Submitted to the graduate degree program in Civil, Environmental, and Architectural Engineering and the Graduate Faculty of the University of Kansas in partial fulfillment of the requirements for the degree of Master of Science.

____

Chairperson Bryan Young

____

Bruce McEnroe

____

David Parr

Date Defended: December 8, 2011

The Thesis Committee for Guy M. Foster

certifies that this is the approved version of the following thesis:

Effects of Small Impoundments on Total Watershed Sediment Yield in Northeast Kansas, April through August 2011

Chairperson Bryan Young

Date approved: December 8, 2011

Abstract

The effect of very small impoundments (ponds) on total watershed sediment yield is not widely understood. While it is generally assumed that small ponds trap sediment, little empirical data has been collected to quantify this effect. A multi-agency Sediment Baseline Study (SBS) was commissioned by the Kansas Water Office to characterize the baseline sediment loads and yields in three watersheds in northeast Kansas in order to assess the effectiveness of best management practices and potentially reduce sedimentation of downstream reservoirs. The basins selected for the SBS were the watersheds for Atchison County Lake, Banner Creek Lake, and Centralia Lake. Initial results of the SBS indicated that the number of small impoundments in a watershed may play a strong role in affecting sediment yield.

In order to investigate this hypothesis, three small ponds were monitored for flow and sediment data from April to August 2011. Five storm events occurred during this time period. The two impoundments in the Atchison Lake watershed trapped 61 tons of sediment during this study, while a downstream gage recorded a total of 261 tons. The sediment trapped in the impoundments represented 19 percent of the total watershed sediment load recorded at the downstream sediment gage. The Banner Creek Lake watershed impoundment was observed to trap 39 tons of sediment from June 2 to June 23, 2011, but wide variations in water elevation prevented the collection of a complete record over the study period, and calculated loads were subject to large sources of error due to the necessity of estimating elevation-storage below the elevations surveyed.

These results show that small impoundments can trap a significant quantity of sediment, potentially reducing sedimentation in downstream reservoirs. A decrease in trapping efficiency was observed over the period of study, which was likely related to decreasing pond volumes as well as suspended sediments remaining in the water column or being re-suspended by other mechanisms between storm events. Based on these results, watershed managers might consider adding, dredging, or repairing small impoundments as a method to reduce downstream reservoir sedimentation, though environmental and economic factors would have to be considered.

Acknowledgements

I would like to thank Pat Finnegan, Seth Studley, Mandy Stone, Ben Prewitt, Andy Ziegler and Jim Putnam of the USGS Kansas Water Science Center for their support and advice in helping me complete this study. Thanks to Casey Lee, also of the USGS Kansas Water Science Center, who provided equipment and the time to plan and implement this study as well as playing a large part in the formation of its concept and scope. Thanks to Chris Gnau of the Kansas Water Office for supporting the effort. Much appreciation to Brock Emmert of The Watershed Institute, for taking the time to put together a list of land-owner contact information. Thanks to Steve Olson, William Becker, and Lawrence Becker for granting me access to their properties. Special thanks to Eric Looper, now of the USGS Indiana Water Science Center, for assisting me on the many field runs that site maintenance required, which also included dealing with long days, severe heat, and cows with questionable intentions. Thank you to Drs. Parr and McEnroe for serving on my committee. Finally, much appreciation to Dr. Bryan Young, my advisor, whose guidance and support has helped me put this all together.

Funding for this study was provided by the USGS through a cooperative agreement with the Kansas Water Office as part of the Kansas State Water Plan Fund.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

Worldwide, reservoirs play a major role in providing water supply, flood control, hydroelectric power generation, and recreation. A common issue affecting the lifespan, and thus ability for reservoirs to serve their intended functions, is loss of capacity through sedimentation. Reservoir sedimentation has become a global problem, and is compounded by the high cost of reservoir construction and maintenance as well as the high cost of reservoir dredging to maintain capacity (Morris & Fan, 1998). Methods to reduce sedimentation are preferred over dredging, new construction, or loss of reservoir function (Palmieri, Shah, & Dinar, 2001).

Although reservoirs can provide tremendous benefits to society, they can have detrimental effects on a river system. Water entering reservoirs is slowed, reducing its carrying capacity and allowing suspended particles to settle to the bottom. As a result, a reservoir will decrease the sediment naturally available to downstream channels (Lajczak, 1996). The sediment-deprived outflow from reservoirs can in turn cause geomorphological changes in the downstream channel such as straightening, erosion, and bed lowering as the stream tries to regain the normal levels of suspended sediment available pre-impoundment (Williams & Wolman, 1984). The process of sedimentation continues until the reservoir is filled in and the normal up- and downstream sediment balances can be regained (Morris & Fan, 1998)

In Kansas, over 300,000 acres of reservoirs and ponds play a vital role in the state infrastructure, providing municipal, industrial, and agricultural water supply, flood control, and recreation (de Noyelles & Jakubauskas, 2008). Although 80% of the more than 120,000 impoundments in Kansas are smaller than one acre, there are 5,847 ‘major’ reservoirs (de Noyelles & Jakubauskas, 2008). Figure 1 shows the distribution of these lakes across the state.

Recent studies by the U.S. Geological Survey (USGS), Kansas Biological Survey (KBS), and other agencies have shown that large- and medium-size Kansas reservoirs are filling up with sediment at rates greater than anticipated during their planning and construction (Lee, Juracek, & Fuller, 2007; de Noyelles & Jakubauskas, 2008; Lee, Rasmussen, & Ziegler, 2008; Juracek, 2010; Juracek 2011). Kansas reservoirs are relatively wide and shallow compared to lakes in other geographic areas due to somewhat flat topography. These physical characteristics enhance sedimentation due to large volumes relative to inflow volumes, increasing residence times and limiting the ability of lake managers to "flush" sediment-laden storm waters or accumulated bottom sediments (Morris & Fan, 1998). There is currently much interest in Kansas to find ways to reduce reservoir sedimentation to extend the effective lifespan of existing lakes (Kansas Water Office, 2008; Pearce, 2011).

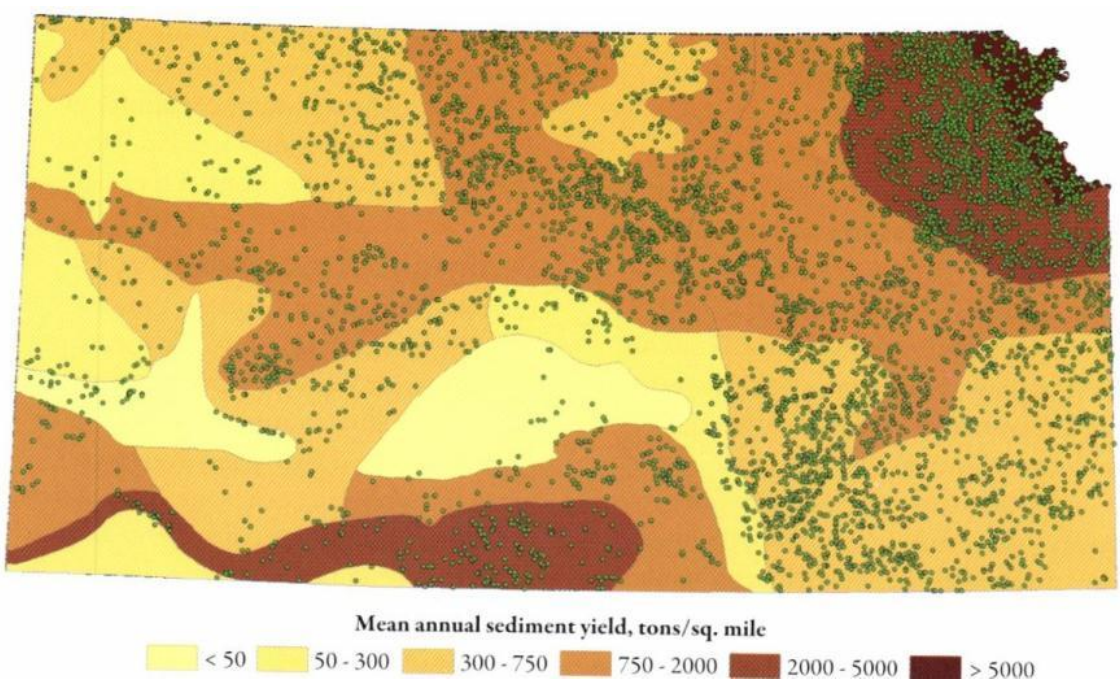

Figure 1: The 5,847 "major" reservoirs in Kansas (represented as green dots) overlying a general map of sediment yield in Kansas (de Noyelles & Jakubauskas, 2008)**.**

The effect of very small impoundments (farm ponds) on total watershed sediment yield is not widely understood. Around twenty percent of the standing water area in the United States is comprised of water bodies smaller than 2.5 acres (Smith, Renwick, Bartly, & Buddemeier, 2002). While it is generally assumed they act as retention ponds by trapping sediment, and therefore reduce total sediment yield in a watershed, little work has been done to quantify this effect. Most research to date has been through hydrologic modeling and bathymetric assessment of past sedimentation (Renwick, Sleezer, Buddemeier, & Smith, 2006). A review of current literature yielded just one other study which collected empirical flow and sediment data in real-time on small impoundments (Tiessen, Elliott, Stainton, & Yarotski, 2011). While hydrologic models provide good estimates of flow and sediment yield, real-time data collection can provide insight into temporal variations that models are not able to assess (Verstraeten & Poesen, 2000).

A multi-agency Sediment Baseline Study (SBS) was commissioned by the Kansas Water Office to characterize the baseline sediment loads and yields in three watersheds in northeast Kansas in order to assess the effectiveness of best management practices and potentially reduce sedimentation of downstream reservoirs (Kansas Water Office, 2009). The three basins selected were the watersheds to Atchison County Lake, Banner Creek Lake, and Centralia Lake. These watersheds all resided in the Western Corn Belt Plains Eco-region (Figure 2). Two of the study watersheds consisted of primarily agricultural land-use (Atchison and Centralia), while the Banner Creek watershed represented the reference condition of grassland and pasture (Figure 3). The U.S. Geological Survey was tasked with measuring continuous streamflow and suspended-sediment concentration (SSC) at stream gages upstream from and downstream from each watershed's reservoir. The gages upstream from the reservoirs collected data on sediment loads entering the reservoirs and were used to compute watershed flow and sediment yields. Data from gages at the reservoir outlets were used to compute reservoir outflow and trapping efficiency (when compared to in-flow totals). The gages began collecting data in March 2009 and were discontinued October 2011 (Table 1).

Table 1: USGS Stream- gages associated with the Baseline Sediment Study

Watershed	USGS Site Number	Site Name	*Parameters Gaged
Atchison	393817095260100	Clear Creek at Decator Rd. near Horton, KS	Stage, Discharge, Turbidity
Atchison	393806095273700	Atchison County Lake near Horton, KS	Elevation, Precipitation, Turbidity
Atchison	393806095274100	Clear Creek Below Atchison County Lake near Horton, KS	Elevation, Discharge
Banner	392652095484100	Banner Creek at M. Rd. near Holton, KS	Stage, Discharge, Turbidity
Banner	392727095454900	Banner Creek Lake near Holton, KS	Elevation, Precipitation, Turbidity
Banner	392727095454500	Banner Creek Below Banner Creek Lake near holton, KS	Elevation, Discharge
Centralia	394126096073500	Black Vermillion River Tributary Above Centralia Lake near Centralia, KS	Stage, Discharge, Turbidity
Centralia	394146096085500	Centralia Lake near Centralia, KS	Elevation, Precipitation
Centralia	394218096095000	Black Vermillion River Tributary Below Centralia Lake near Centralia, KS	Stage, Discharge, Turbidity

* USGS denotes lake stages as "elevation," stream and river stages as "stage." Elevation is typically above a known datum such as mean sea level, stage is height above an arbitrary datum.

In addition to installing stage gages and turbidity meters, the U.S. Geological Survey installed tipping-bucket rain gages at the downstream watershed lake outflow gages. The Atchison County Lake, USGS site number is 393806095273700 and the Banner Creek Lake site number is 392727095454900. Additional flow and turbidity data were obtained from the USGS streamflow and sediment gages at Clear Creek at Decatur Rd., site no. 393817095260100 (Atchison) which drains 5.6 mi^2 and Banner Creek at M. Rd., site no. 392652095484100 (Banner) which drains 9.1 mi^2.

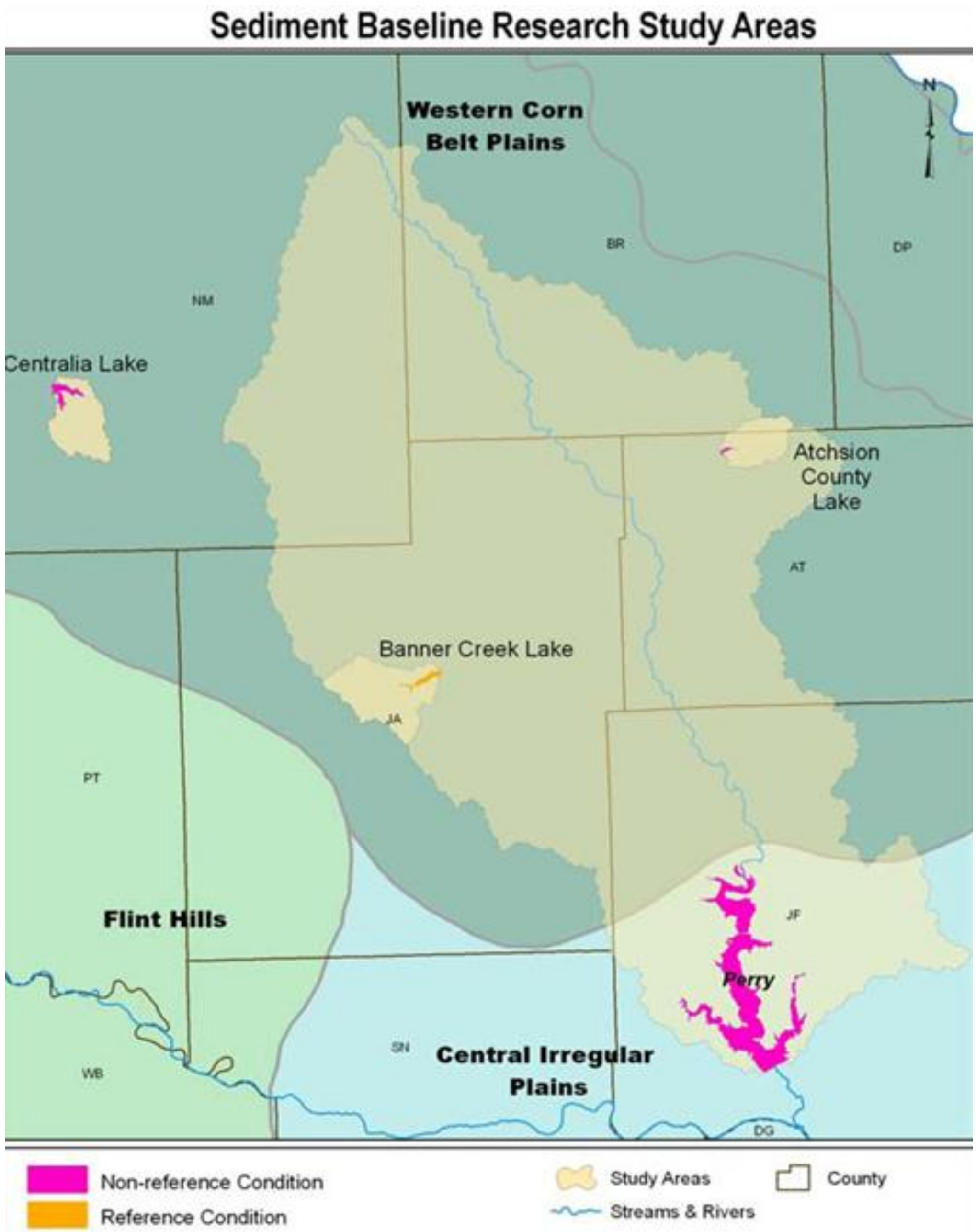

Figure 2: Baseline sediment project regional map showing locations of the research study watersheds (Kansas Water Office, 2009)**.**

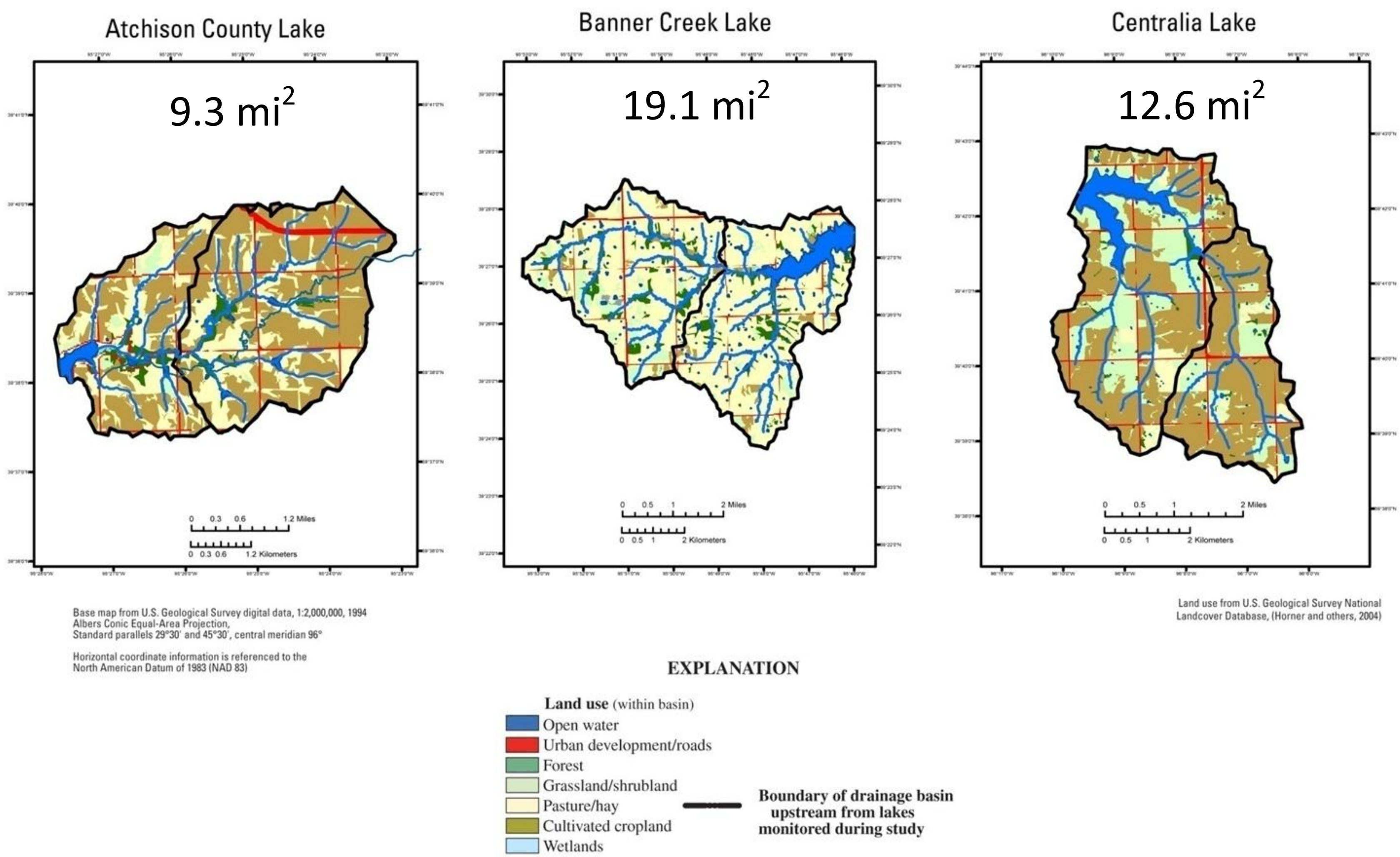

Figure 3: Land-use characteristics for the three Baseline Sediment Study watersheds with drainage area to reservoir outlet (source USGS KSWSC)

Initial results from the SBS indicate a possible correlation between the number of small impoundments in a watershed, as listed by the National Inventory of Dams (NID) (US Army Corps of Engineers, 2010) and watershed sediment yield (Figures 4 & 5). Figure 4 indicates that Centralia's sediment yield was nearly twice as high as Atchison's, even though the two watersheds share similar land-use characteristics. The Atchison watershed was much closer in yield to the Banner watershed, which is considered the reference condition with land-use primarily of pasture and hay (Figure 3). One possible explanation for the drastic difference in sediment yield is the presence of a large number of small impoundments in the Atchison and Banner watersheds (Figure 5).

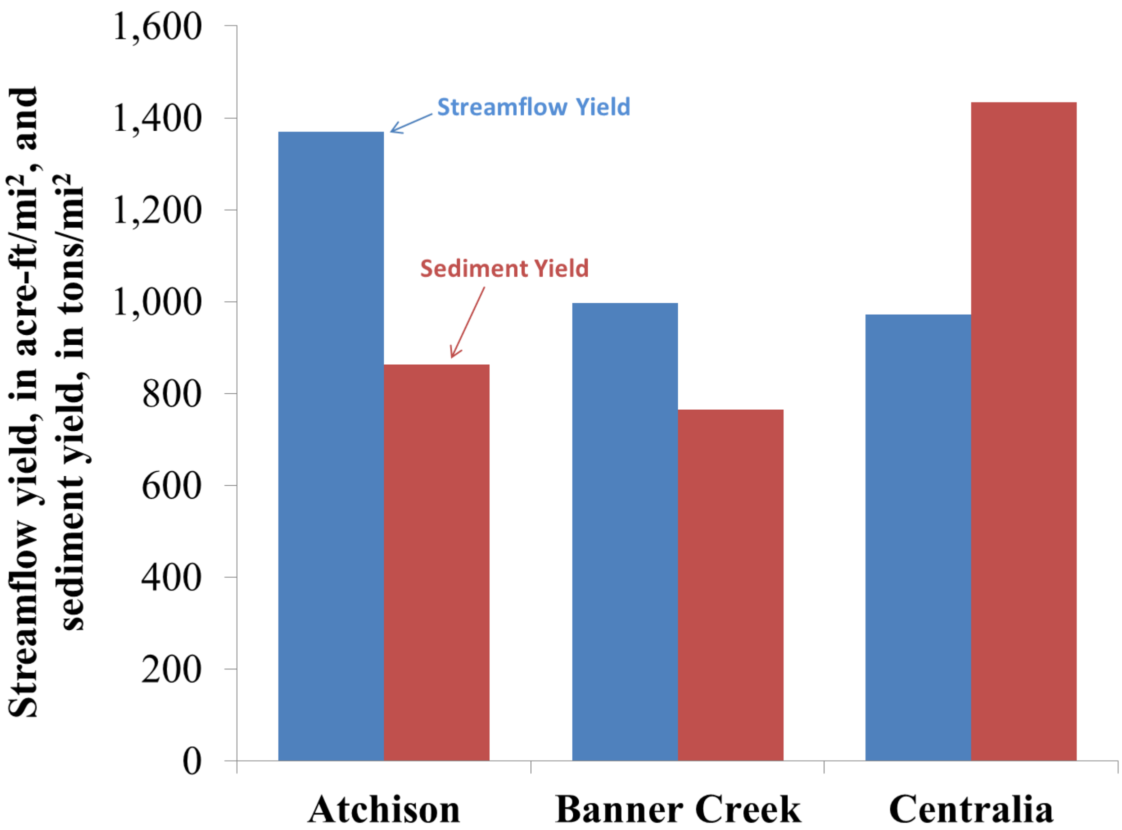

Figure 4: Streamflow and sediment yield in the three Baseline Sediment Study watersheds based on data collected from March 2009 to May 2011 (source USGS KSWSC).

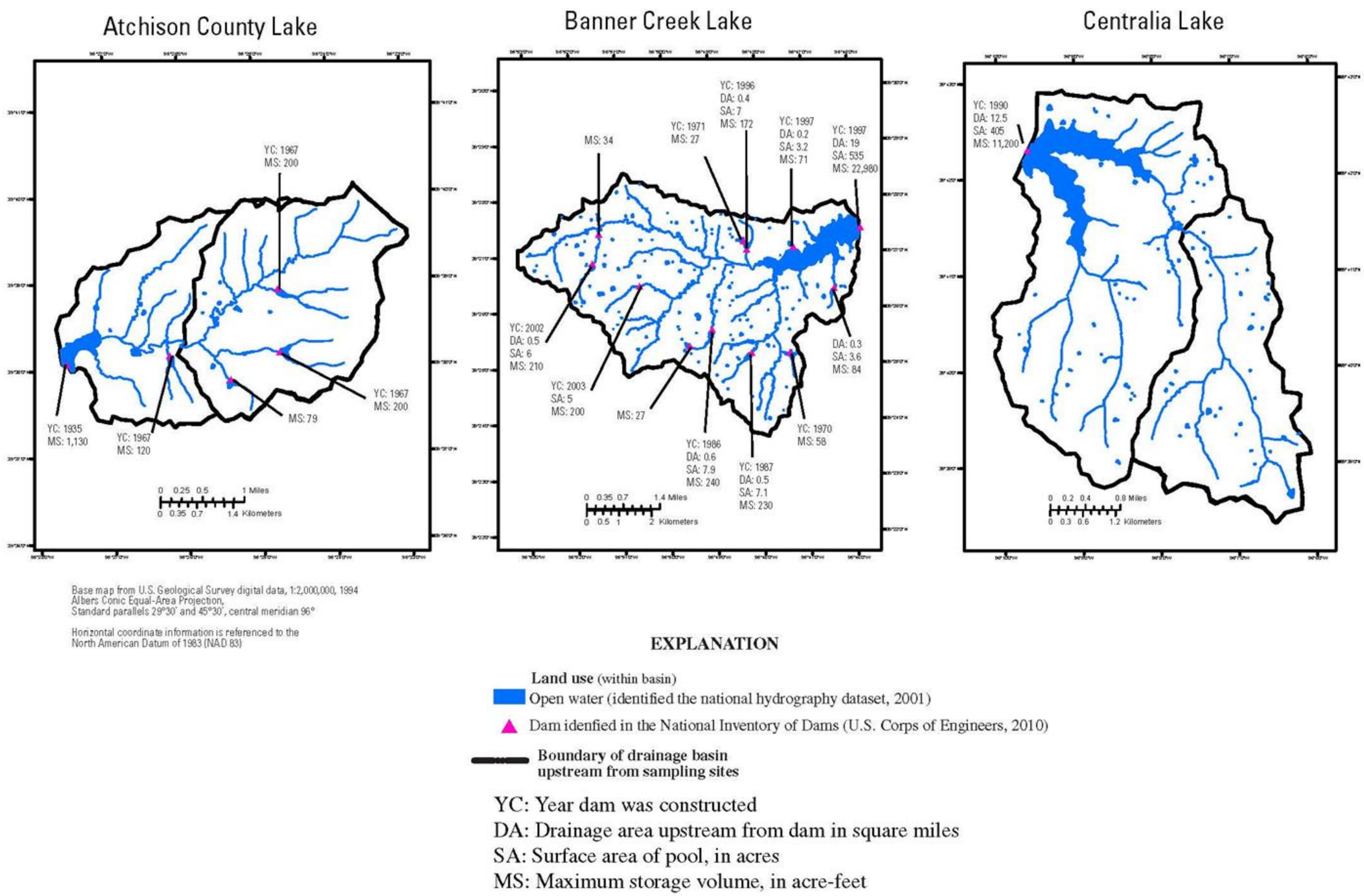

Figure 5: Map showing dams listed by the Corps of Engineers National Inventory of Dams in Baseline Sediment Study watersheds (source USGS KSWSC).

The objective of this study is to assess the importance of small impoundments on watershed sediment yield. Three small impoundments (two in the Atchison Lake watershed and one in the Banner Lake watershed) were gaged for elevation and turbidity in order to estimate the rate of sediment entrapment. The elevation and turbidity data were used to compute streamflow and suspended sediment concentration into and out of the ponds using hydraulic routing equations and a relationship between turbidity and suspended sediment concentration (SSC). This information was then compared to the downstream streamflow and sediment gage which monitors the entire watershed, and the effect of the small impoundments on total watershed sediment yield was determined.

Chapter 2: Experimental Design

Site Locations

Small watershed impoundments were delineated in the Banner and Atchison watersheds to determine drainage area. Land-owner information, where available, was obtained for all potential study sites, and land owners were contacted for permission to access the ponds and install gaging equipment. Limited success was achieved in obtaining access permission, which became a limiting factor in site selection.

Two sites in Atchison and one in Banner were finally selected as gaging sites. The two sites in the Atchison watershed were Little Delaware Mission Dam 5 (LDMD 5) and Little Delaware Mission Dam 17 (LDMD 17). LDMD 5 drains 0.78 mi^2 (8.4% of the Atchison watershed) and LDMD 17 drains 0.77 mi^2 (8.3%) (Figure 6). The two Atchison ponds drain 22% of the drainage area upstream of the USGS Clear Creek at Decator Rd. gage. In the Banner watershed, an impoundment listed as GS DD No. C38 (Dam 38) was selected. Dam 38 drains 0.53 mi^2 (2.8%) of the watershed total (Figure 7). The Banner site's purpose was to provide a point of comparison between small impoundments with differing land-use.

All three ponds selected for this study are listed on the National Inventory of Dams. LDMD 5 and LDMD 17 are located in Atchison County, on Clear Creek, which drains into the Delaware River (Figure 8). Dam 38 is in Jackson County, on Banner Creek, which drains into Elk Creek, and subsequently into the Delaware River (Figure 8).

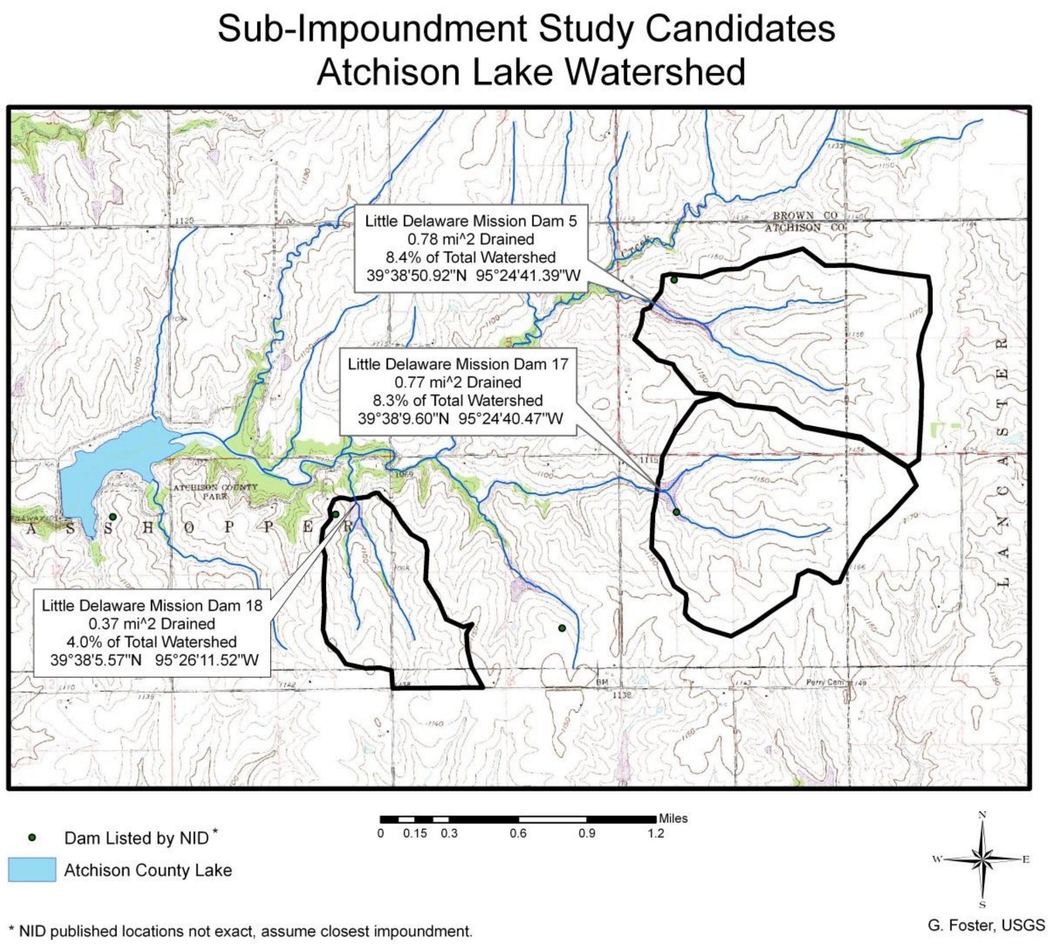

Figure 6: Location of Atchison watershed sub-impoundments in which land-owner access was obtained and respective drainage areas and locations

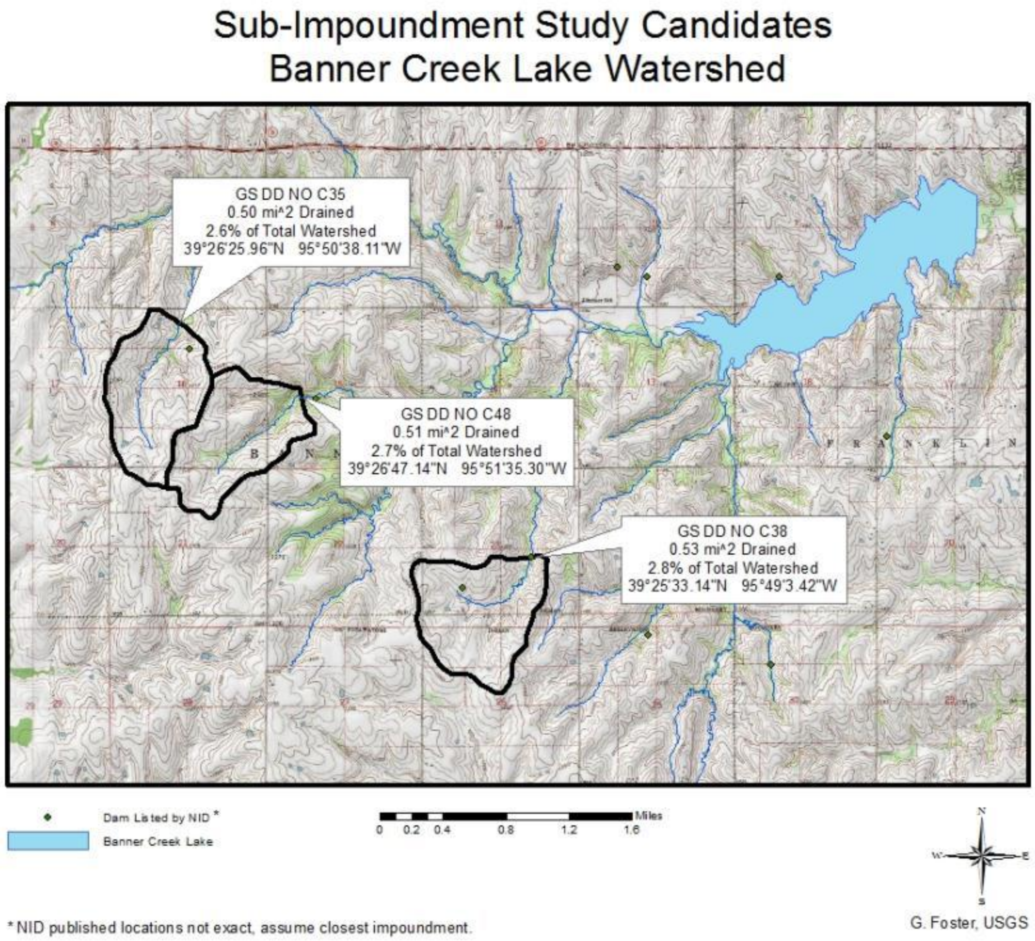

Figure 7: Location of Banner watershed sub-impoundments in which land-owner access was obtained and respective drainage areas and locations

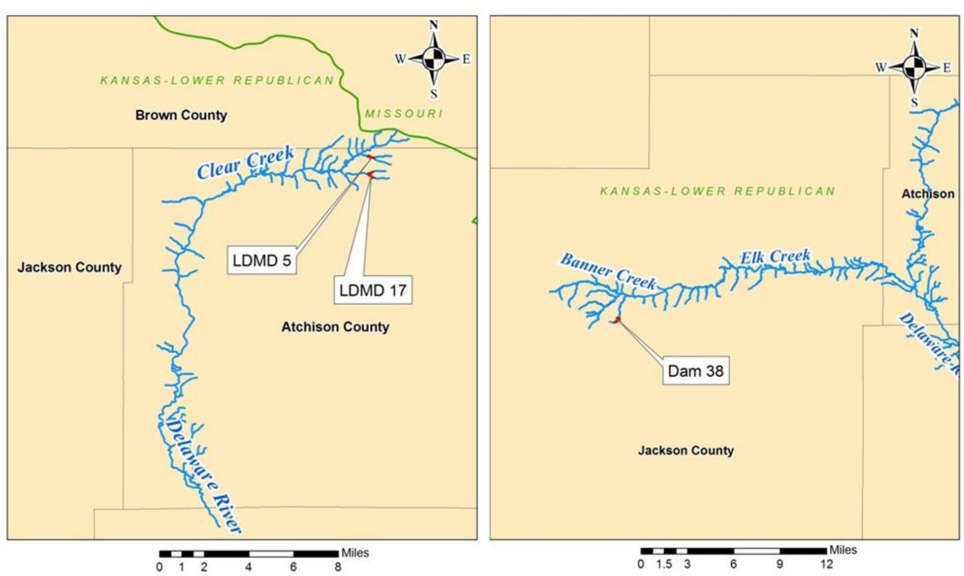

Figure 8: General large scale downstream flowpaths of study impoundments.

LDMD 5 was constructed in 1967 and is on land used for both grazing and row crops. During the period of study, the surrounding fields were planted (soybeans & corn), and livestock were frequently observed grazing and drinking from the pond. A grass buffer of 60 ft (minimum) surrounded the pond. The outflow structure was a vertical corrugated steel pipe of 2.5 ft diameter with a top elevation of 1109.80 ft above NAVD (1988).

LDMD 17 was constructed in 1967 and is on land used for row crops. During the period of study, the surrounding fields were planted (soybeans), and no livestock were observed using the pond. A grass buffer of 50 ft was planted at the beginning of the data collection period; according to the land-owner no buffer existed prior to this. The outflow structure was a vertical corrugated steel pipe of 2.5 ft diameter with a top elevation of 1110.39 ft above NAVD (1988)

Dam 38 was constructed in 1986 and is on land not currently being used for livestock or agriculture, though field contours indicated prior agricultural use. A combination of grassland and wooded areas surrounded Dam 38, with a wooded riparian buffer following the inflow stream. The outflow structure was a horizontal corrugated steel pipe of 1.5 ft diameter and an inlet elevation of 1162.00 ft above NAVD (1988)

Spatial Analysis

The three impoundments were surveyed using a Trimble R8 GNSS survey-grade GPS system. The survey equipment was owned by the USGS Kansas Water Science Center, which also provided technical assistance and support in the operation of the equipment. A total of 370 points were surveyed for the LDMD 5 site, while 294 points were surveyed for LDMD 17. A total of 329 survey points were collected for Dam 38. Each survey took approximately one full day. Collection of denser spatial-resolution data was not practical. Elevations were surveyed above the water level on the survey date; no bathymetric data were collected.

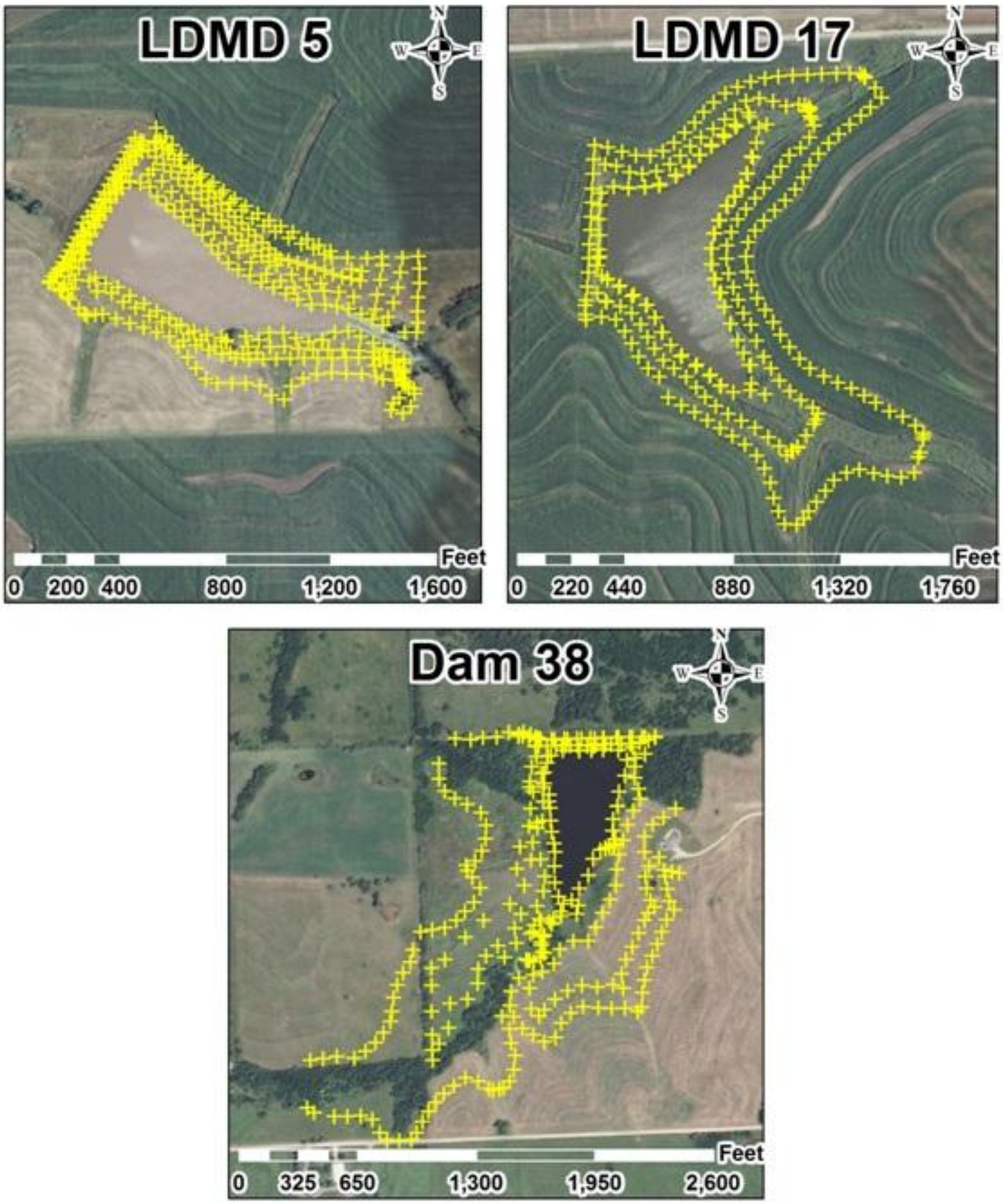

Figure 9: Location of survey points at the three study impoundments.

Survey data consisting of x-y-z tables (in feet) were imported into ArcGIS (Figure 9). These data were then converted to Triangulated Irregular Networks (TINs) which connect all survey points with triangular planes (Figure 10). Grids were then created at multiple specific elevations, and overlaid on the TIN to simulate various water surface elevations (Figure 11). The differences between the ground elevation and water level were then calculated using a "cut/fill" operation, which yielded tables for elevation-area, raw elevation-volume, and elevation-volume above the outflow pipe opening. Raw volumes are defined by how ArcGIS interpolated the lake elevation during TIN creation, and can be inaccurate due to interpolations below the water surface, which was not surveyed. The raw volume data was subtracted from the outflow elevation-volume to produce volume above the outflow pipe.

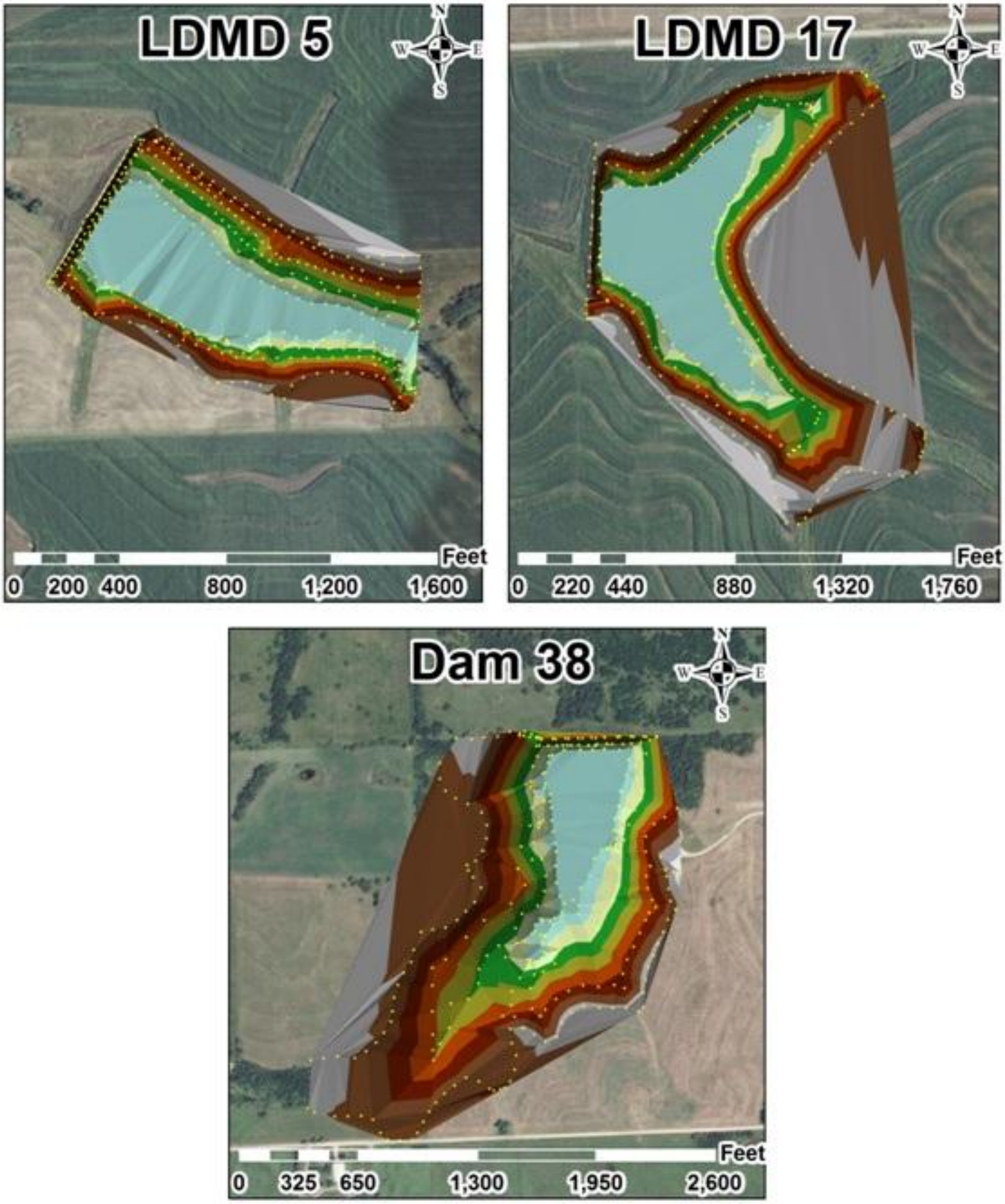

Figure 10: Triangulated Irregular Networks (TINs) at each study impoundment.

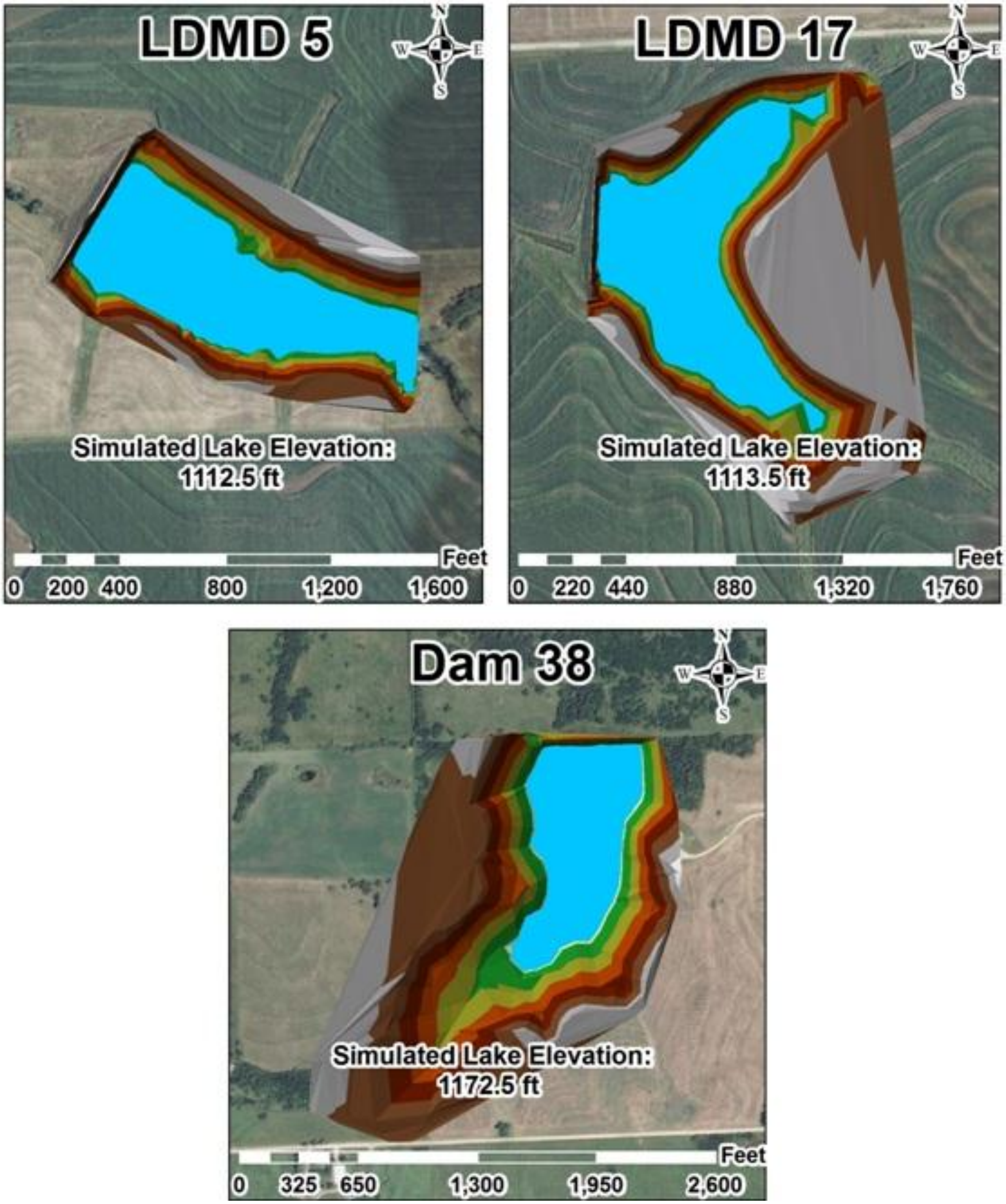

Figure 11: Example "cut-fill" operation to determine elevation-area and elevation-storage tables at each study impoundment.

In the case of LDMD 5, survey data were not sufficient to cover the full range of expected lake elevations. Recent Light, Detection, and Ranging (LIDAR) data were available via the Kansas GIS website (www.kansasgis.org) and were used to fill in missing areas (Figure 12). The horizontal grid spacing of the LIDAR data was 1.4 meters and vertical bare earth resolution of 1 meter (Kansas Data Access and Support Center, 2011). The LIDAR data were converted to a TIN, then to an appropriately-sized raster containing elevation data. Several ArcGIS tools were then employed to convert these into x-y-z point data. The new spatial-elevation data were appended to the original survey file.

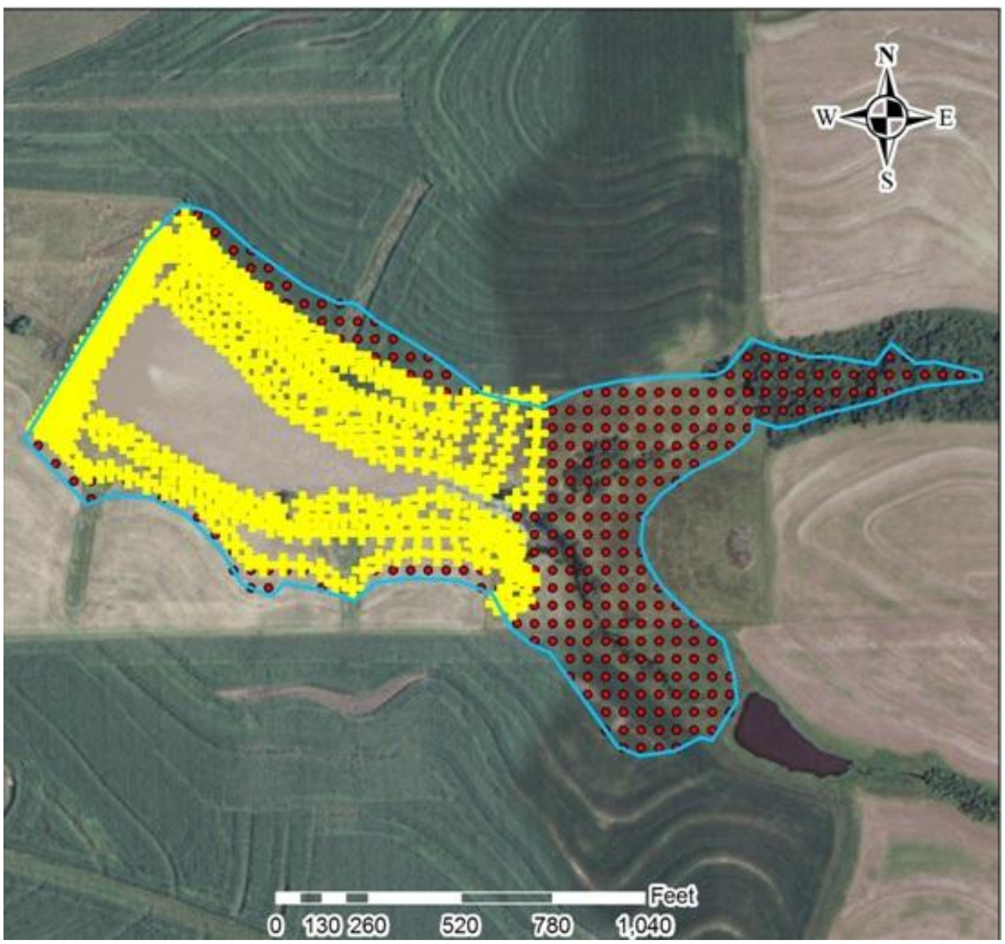

Figure 12: Addition of LIDAR data (red dots) to survey data (yellow crosses) in order to get full coverage of LDMD 5's potential range of lake elevations.

Stage-storage data were generated for LDMD 5 for water-surface elevations ranging from 1109.8 to 1118.0 feet (Table 2). The outflow elevation was measured at 1109.8 feet. The surface area of the pond at the outflow elevation was 8.0 acres. At an elevation of 1118.0 feet, the pond area would be 21.2 acres with total storage above the outlet of 115.7 ac-ft.

Table 2: Elevation-area and elevation-storage table for LDMD 5.

Elevation (ft)	Area (acres)	Raw Volume (acre-ft)	Volume above Storage (acre-ft)
1109.8	8.0	7.8	0.0
1110.0	8.3	9.4	1.6
1110.5	8.9	13.7	5.9
1111.0	9.4	18.3	10.5
1111.5	9.9	23.1	15.3
1112.0	10.4	28.2	20.4
1112.5	11.1	33.5	25.8
1113.0	12.0	39.5	31.7
1113.5	13.0	45.9	38.2
1114.0	13.9	52.7	44.9
1114.5	14.7	59.8	52.0
1115.0	15.6	67.4	59.6
1115.5	16.8	75.9	68.1
1116.0	17.7	84.5	76.7
1116.5	18.6	93.6	85.8
1117.0	19.5	103.1	95.3
1117.5	20.4	113.1	105.3
1118.0	21.2	123.5	115.7

Stage-storage data were generated for LDMD 17 for water-surface elevations ranging from 1110.4 to 1117.0 feet (Table 3). The outflow elevation was measured at 1110.4 feet. The surface area of the pond at the outflow elevation was 8.2 acres. At an elevation of 1117.0 feet, the pond area would be 18.8 acres with total storage above the outlet of 85.0 ac-ft.

Table 3: Elevation-area and elevation-storage table for LDMD 17.

Elevation (ft)	Area (acres)	Raw Volume (acre-ft)	Volume above Storage (acre-ft)
1110.4	8.2	0.3	0.0
1110.5	8.3	1.1	0.9
1111.0	8.6	5.4	5.1
1111.5	9.0	9.8	9.5
1112.0	9.4	14.4	14.1
1112.5	10.1	19.2	19.0
1113.0	10.9	24.5	24.2
1113.5	12.1	30.3	30.1
1114.0	13.3	36.7	36.4
1114.5	14.4	43.6	43.3
1115.0	15.4	51.0	50.8
1115.5	16.3	59.0	58.7
1116.0	17.1	67.3	67.1
1116.5	18.0	76.1	75.8
1117.0	18.8	85.3	85.0

Stage-storage data were generated for Dam 38 for water surface elevations ranging from 1167.0 to 1177.0 feet (Table 4). The outflow elevation was measured at 1170.4 feet. The surface area of the pond at the outflow elevation was 6.4 acres. At an elevation of 1177.0 feet, the pond area would be 18.2 acres with total storage above the outlet of 91.9 ac-ft.

Table 4: Elevation-area and elevation-storage table for Dam 38.

Elevation (ft)	Area (acres)	Raw Volume (acre-ft)	Volume above Storage (acre-ft)
1167.0	6.4	2.0	0.0
1167.5	7.0	5.4	0.0
1168.0	7.5	9.0	0.0
1168.5	8.2	13.0	0.0
1169.0	8.8	17.3	0.0
1169.5	9.4	21.8	0.0
1170.0	10.0	26.7	0.0
1170.5	10.6	31.9	0.0
1171.0	11.2	37.3	5.5
1171.5	11.8	43.1	11.2
1172.0	12.3	49.1	17.2
1172.5	12.8	55.3	23.5
1173.0	13.3	61.9	30.0
1173.5	13.8	68.6	36.7
1174.0	14.3	75.6	43.8
1174.5	14.8	82.9	51.0
1175.0	15.4	90.5	58.6
1175.5	16.0	98.3	66.5
1176.0	16.6	106.5	74.6
1176.5	17.3	114.9	83.1
1177.0	18.2	123.8	91.9

Gaging Plan & Data Collection

In order to determine sediment loads, both flow and suspended sediment concentration (SSC) data were required. The data required to compute these parameters were lake elevation and turbidity. Inflow was determined indirectly due to the complexities involved in creating a stage-discharge relationship at the inflow. Each lake was gaged for elevation near the outflow structure using Solinst “Level-Logger Gold” submersible pressure transducers. Fluctuations in elevation data caused by changes in atmospheric pressure were compensated for by using a recording barometer Solinst “Baro-logger Gold” installed near the lakes. The correction for atmospheric pressure was applied using Solinst software. Elevation data were verified during each site visit using standard USGS stage measurement techniques (Sauer & Turnipseed, 2010). Turbidity data were collected using YSI 6136 turbidity sensors deployed both near the outflow structure and near the lake inflow (in the case of LDMD 17, both inflows). Generalized maps of the gage locations and in-field equipment can be found in Appendix B.

To ensure the best resolution of data relative to the small watershed size, five-minute recording intervals were used on all sensors. Site visits to clean sensors, verify lake elevations, and download data were made approximately every two weeks. It was not possible to verify measurements of flow or SSC due to the flashiness of the storm flow and distance to the sites.

Data Analysis Techniques

Since each impoundment had a static outflow structure, only lake elevation and a corresponding stage-storage relationship were needed to determine flow in-to and out-of each pond. Outflow was computed based on the hydraulic characteristics of the outflow structure, and inflow was computed using a continuity routing equation:

$$Inflow_2\ (cfs) = \left(\frac{2Storage_2(af)}{\Delta time(s)} + Outflow_2(cfs)\right) - \left(\frac{2Storage_1(af)}{\Delta time(s)} + Outflow_1(cfs)\right) - Inflow_1 + 2Outflow_1(cfs)$$

(Eq. 1)

Where vertical pipes acted as outflow structures, flow equations based on weir flow and orifice flow were applied, depending on water elevation above the riser, to compute outflow discharge (Equations 2, 3; Figures 13, 14; U.S. Bureau of Reclamation, 1987). Rating tables for LDMD 5 and 17 can be found in Appendix C.

$$Q_{weir} = C_w \pi d h^{\frac{3}{2}}$$ (Eq. 2)

$$Q_{orifice} = C_c \frac{\pi d^2}{4} \sqrt{2gh}$$ (Eq. 3)

Where C_w is the graphically determined circular crest coefficient, C_c is the coefficient of contraction (0.5 for a sharp crest), d is the pipe diameter, and h is the water elevation above the inlet.

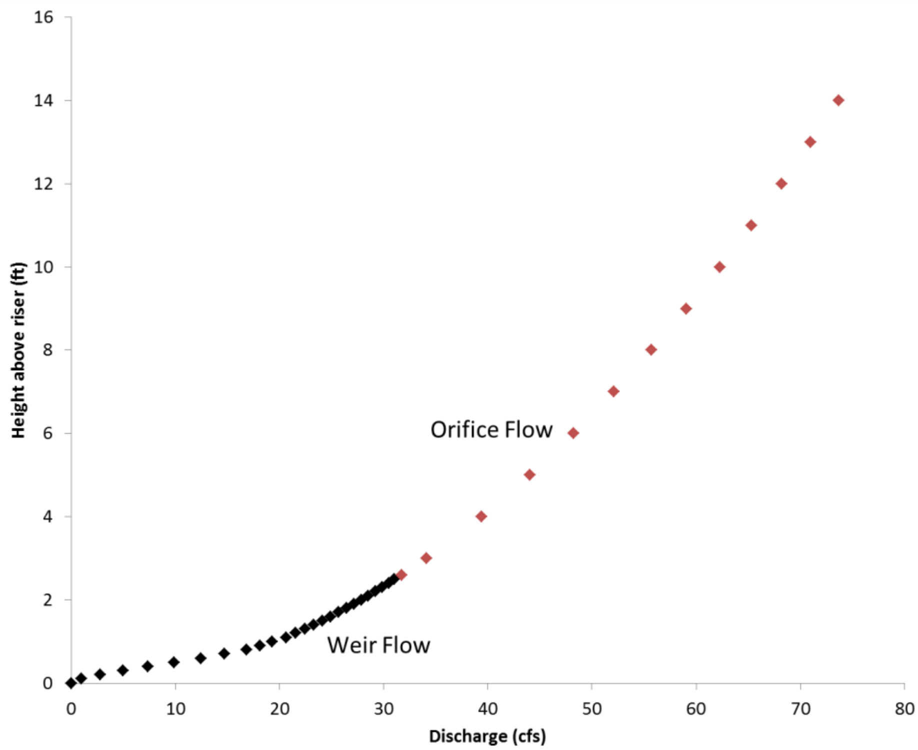

Figure 13: Rating curve for LDMD 5.

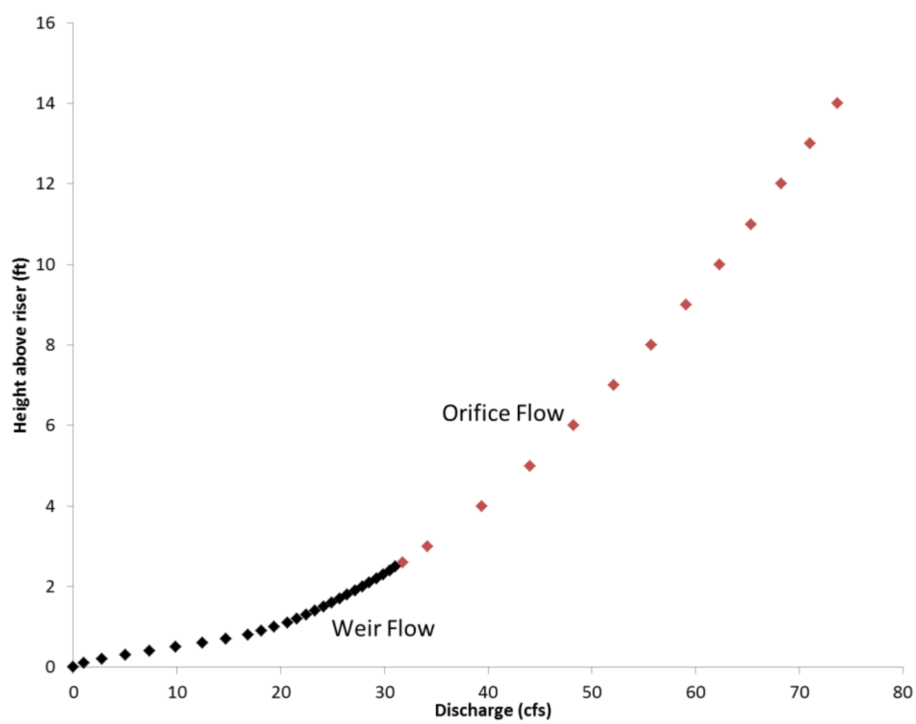

Figure 14: Rating Curve for LDMD 17.

Anomalies in the stage data were generally deleted, and the missing data estimated by simple linear interpolation between known good data points. These erratic data are usually caused by wave action and are visible in the elevation record as large oscillations in stage that are not following the general trend of the hydrograph. Pressure transducers are prone to a slight drift over time. To compensate for this, the elevation data were corrected based on field visit verification of elevation by applying an increasing or decreasing correction between known, field-verified elevations.

Initial results for the computed inflows exhibited dramatic oscillations. The oscillations were a result of resolution differences between elevation, which was recorded 0.01-foot intervals, and storage, which was estimated based on elevation-storage tables which indicated a range of 0.08 to 0.21 acre-ft difference for every 0.01 ft change in elevation. This was especially a factor during days of moderate to gusty winds, which also can be associated with storms that caused wave action making lake elevation erratic. A moving-average smoothing function was applied to the elevation record to address these oscillations (Figure 15).

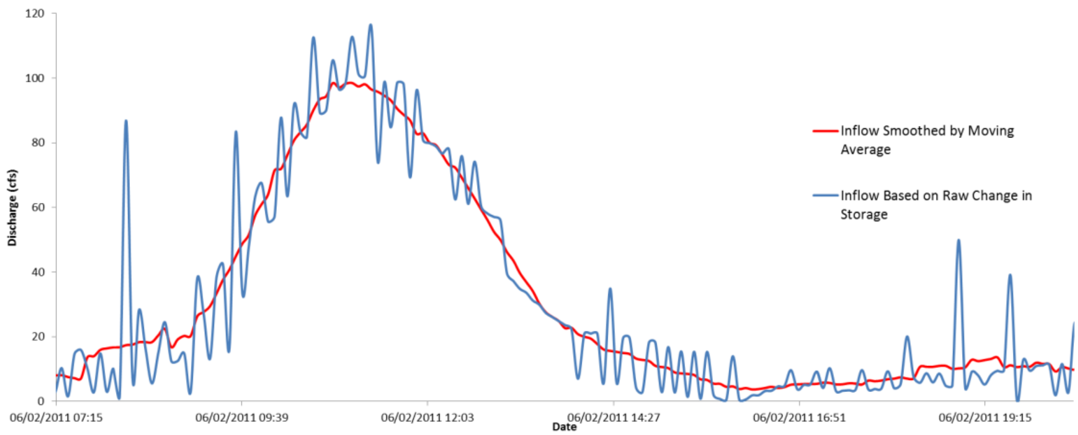

Figure 15: Example of inflow data before and after applying a moving average smoothing function at LDMD 5 to reduce erratic oscillations which occurred as a result of resolution differences between elevation data and changes in storage.

SSC was computed using YSI 6136 turbidity sensors and procedures outlined in Rasmussen et al. (2009). The regression developed for Clear Creek at Decatur Rd (Equation 4; Figure 14) was used for SSC calculations in the Atchison watershed, and the regression developed for Banner Creek at M Rd. (Equation 5; Figure 16) was used for SSC calculations in the Banner watershed. Red diamonds represent outliers which were not used in the final regression equation. Currently not all collected samples have been built into this equation for QA/QC reasons. These regressions were built with data up to May 15, 2011. The USGS classifies these regressions currently as “provisional” and subject to change, though changes to the equations from additional samples are likely to have minor or negligible consequences to computed SSC. Lee and Ziegler (2010) showed that turbidity-SSC regressions collected within the same watershed were typically the same, likely due to similar geology and other site-specific characteristics. SSC samples taken at Clear Creek at Decatur Rd. averaged 94% silts and clays (n=22) and Banner Creek at M. Rd averaged 84% silts and clays (n=26).

$$\log SSC = 1.15 \log(turbidity) - 0.15 \quad \text{(Eq. 4)}$$

$$logSSC = 1.03 \log(turbidity) + 0.21 \quad \text{(Eq. 5)}$$

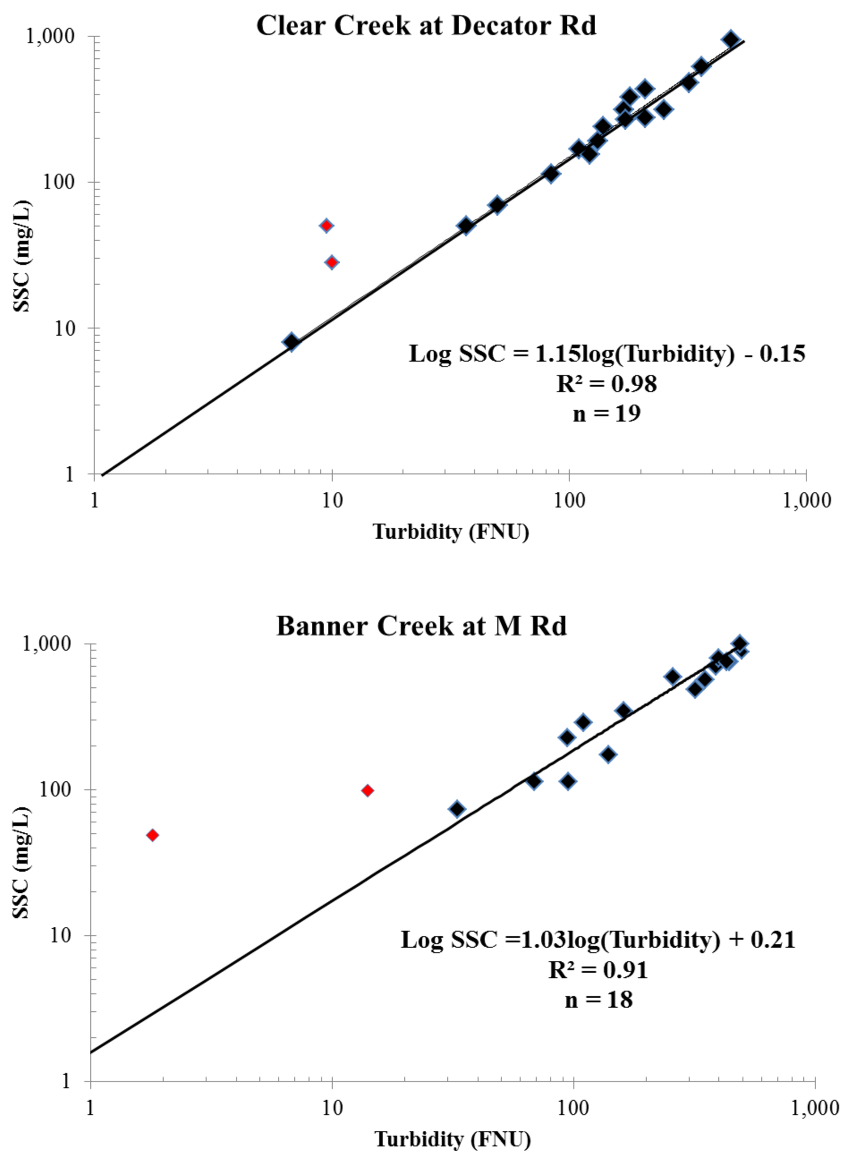

Figure 16: Turbidity-SSC regressions developed for USGS stream gages at Clear Creek at Decator Rd. and Banner Creek at M. Rd.

Turbidity sensors deployed in natural environments with low flows are subject to periodic "spikes" caused by a number of factors including wind-stirred bottom sediments, aquatic animals entering the sensor cage, and biological fouling. The YSI 6136 turbidity sensor has a built-in wiper to minimize these occurrences; however it is not capable of removing all erroneous data. Where erroneous data were present, they were deleted and estimated based on simple linear interpolation between points of good data.

A possible source of error in this study is turbidity truncation. Turbidity truncation occurs when the SSC exceeds the maximum recording limit of a turbidity sensor, typically at SSC values greater than 2,000 mg/L. Truncation is displayed as a "plateau" in turbidity data (Rasmussen, Gray, Glysson, & Ziegler, 2009). Turbidity truncation was observed at the LDMD 17 south fork inflow during storms 3-5. The actual peak sediment concentration was not estimated, as truncation only occurred over a small period.

LDMD 17 had two inflow streams, designated north fork (NF) and south fork (SF). Delineation of each inlet in GIS showed NF drained 46.5% of LDMD 17's drainage area, and the SF the other 53.5%. For inflow calculations, total inflow was split according to each inlet's percentage of the total drainage area. In cases where one inlet had long periods of bad turbidity data, the SSC was set to be equal for the two forks.

In order to better evaluate data at sites with differing flows, loads, and rainfall, sediment yield and flow yield were calculated for each impoundment. These yields normalize values with respect to area by providing terms of tons per mi^2 for sediment yield and acre-feet per mi^2 for flow yield. This normalization is useful in allowing comparisons of relative streamflow with the sediment loads they produce and vice-versa.

Chapter 3: Results

Storms

Five storms were observed during the study period which generated flow through the Atchison ponds. Rainfall depths for each storm were recorded at the Atchison County Lake tipping-bucket rain gage, maintained and operated by the USGS (Table 5). Storms two and three each had two peaks, a small initial peak and a later larger peak. These two peaks were considered a single storm because lake elevation did not fall below the inlet elevation.

Table 5: Precipitation totals recorded at the USGS Atchison Lake rain gage during the period of study.

Storm	Dates	Precipitation (inches)
1	May 25 to May 26	1.9
2	May 31 to June 6	2.4
3	June 25 to June 29	2.3
4	July 3 to July 5	0.2
5	July 7 to July 9	2.1

Little Delaware Mission Dam 5

Storm flow, loads, yields, and trapping efficiency for LDMD 5 can be found in Table 6. Graphs of discharge and SSC can be found in Figure 17. Lake elevation data for the entire period can be found in Appendix D.

Table 6: Storm flow, loads, trapping efficiency, and yields for LDMD 5.

	Peak Inflow (cfs)	Load IN (tons)	Load OUT (tons)	Trapped in Pond (tons)	Trapping Efficiency (%)	Sediment Yield (tons IN/mi^2)	Flow OUT (AF)	StreamFlow Yield (AF/mi^2)	StreamFlow Yield (inches)
Storm 1	38	4.2	0.3	3.9	93%	5.3	7.8	10.0	0.19
Storm 2	59	10.1	6.5	3.6	35%	12.9	27.1	34.7	0.65
Storm 3	84	8.5	8.6	-0.1	-2%	10.8	31.5	40.4	0.76
Storm 4	18	0.4	0.4	0.1	15%	0.5	2.6	3.3	0.06
Storm 5	99	5.5	7.1	-1.6	-29%	7.0	31.9	40.9	0.77
Totals (unless noted as average)		28.6	22.8	5.8	20% Average Trapping Efficiency	36.6 Average Sediment Yield (tons IN/mi^2)	100.9	129.4	2.43

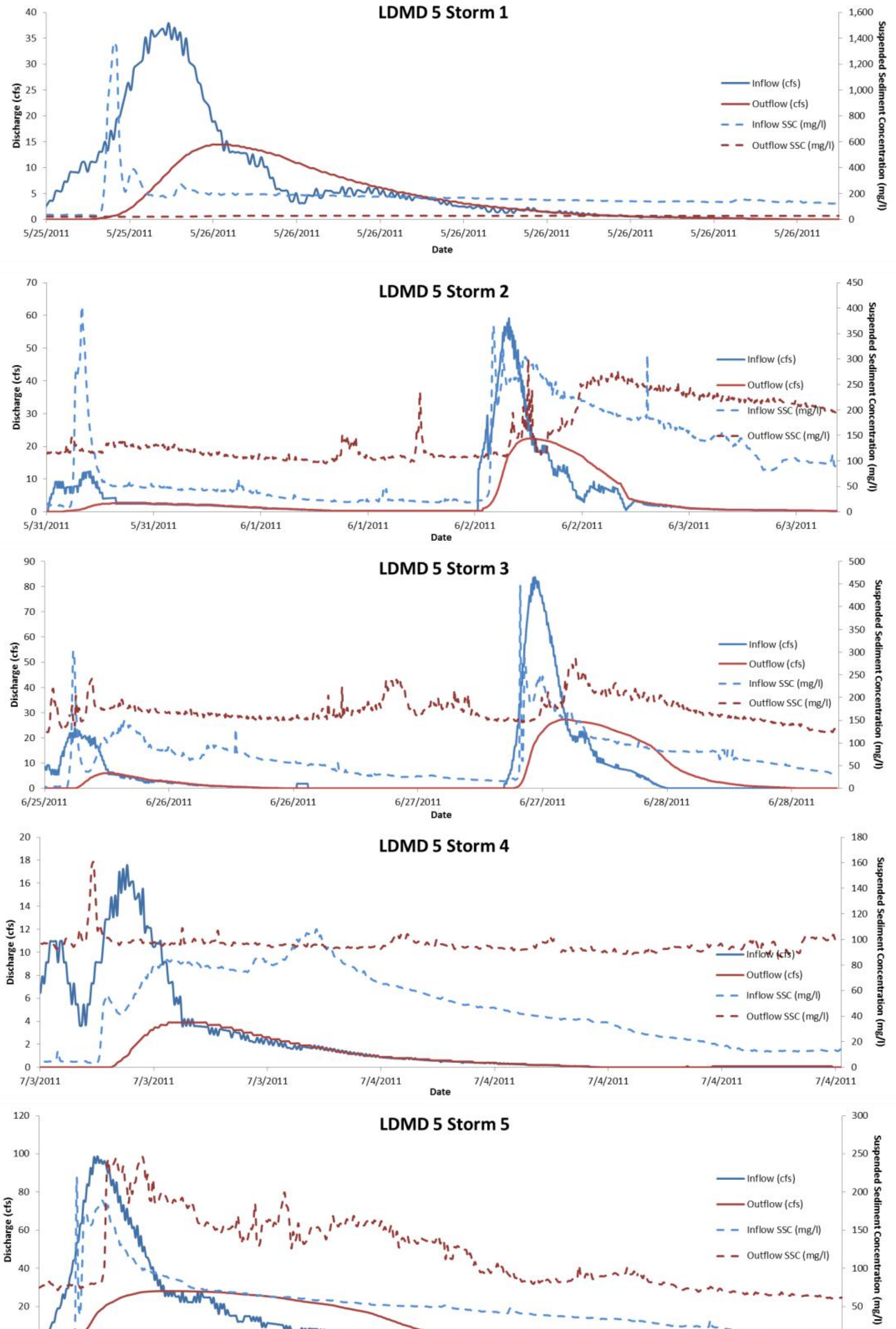

Figure 17: Flow and suspended sediment concentrations hydrographs for LDMD 5 for five storms during the study period.

Little Delaware Mission Dam 17

Storm flow, loads, yields, and trapping efficiency for LDMD 17 can be found in Table 7. Graphs of discharge and SSC can be found in Figure 18. Lake elevation data for the entire period can be found in Appendix D.

Table 7: Storm flow, loads, trapping efficiency, and yields for LDMD 17.

	Peak Inflow (cfs)	Load IN (tons)	Load OUT (tons)	Trapped in Pond (tons)	Trapping Efficiency (%)	Sediment Yield (tons IN/mi^2)	Flow OUT (AF)	StreamFlow Yield (AF/mi^2)	StreamFlow Yield (inches)
Storm 1	39	15.3	3.9	11.4	74%	19.9	16.1	20.9	0.39
Storm 2	53	25.0	10.3	14.7	59%	32.4	33.7	43.8	0.82
Storm 3	85	63.6	31.5	32.0	50%	82.5	47.1	61.2	1.15
Storm 4	33	9.7	5.2	4.5	46%	12.5	9.0	11.7	0.22
Storm 5	148	30.0	37.1	-7.1	-24%	39.0	55.5	72.1	1.35
Totals (unless noted as average)		143.5	88.1	55.5	39% Average Trapping Efficiency	186.4 Average Sediment Yield (tons IN/mi^2)	161.4	209.6	3.93

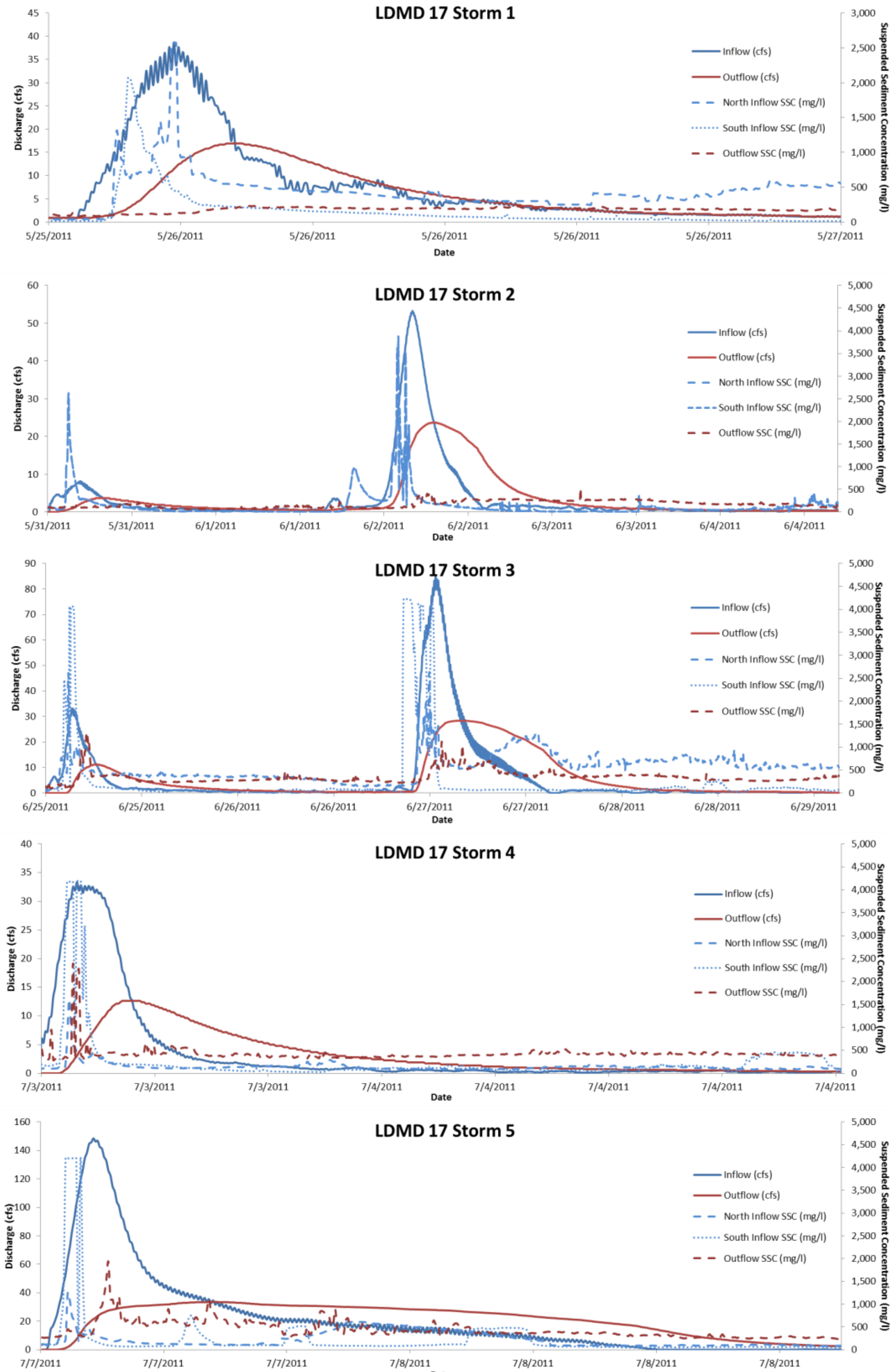

Figure 18: Flow and suspended sediment concentrations hydrographs for LDMD 17 for five storms during the study period.

Flow and Loads at Clear Creek at Decatur Rd.

Streamflow and sediment loads for the entire Atchison watershed were calculated for the gage at Clear Creek at Decatur Rd. (USGS Gage 393817095260100). It must be noted that the discharge rating curve and computed streamflow were computed by methods and procedures delineated by Turnipseed (2010), which are more accurate and refined than the estimations used at the study ponds. The difference in total runoff for all storms, 264 acre-ft passing through the dams total and 664 acre-ft passing the Clear Creek gage, was greater than expected considering the dams drain 22% of the upstream drainage area of the gage, and the flow observed was 28% of the total flow. This might be explained by uneven distribution of rainfall, agricultural diversions, or stream losses to groundwater considering the other tributaries and impoundments in the watershed. Storm flow, loads and yields for the Clear Creek at Decatur Rd. gage can be found in Table 8 with comparative data from the ponds.

Table 8: Storm flow, loads, and yields for the USGS streamgage at Clear Creek at Decatur Rd. for each of the five observed storms. Comparative pond data is also included.

	Peak Inflow (cfs)	Load Passed (tons)	Flow (AF)	Sediment Yield (tons IN/mi^2)	StreamFlow Yield (AF/mi^2)	StreamFlow Yield (inches)	Load Observed Entering Ponds (tons)	Load Trapped in Study Ponds (tons)	Percent of Total Load Trapped (Trapped/(Passed+Trapped))(tons)
Storm 1	160	46.0	119.2	8.2	21.3	0.40	19.5	15.3	25%
Storm 2	200	61.9	184.6	11.1	33.0	0.62	35.0	18.3	23%
Storm 3	190	81.3	178.3	14.5	31.8	0.60	72.0	31.9	28%
Storm 4	17	6.9	13.8	1.2	2.5	0.05	10.1	4.5	39%
Storm 5	160	64.7	168.1	11.6	30.0	0.56	35.5	-8.7	-16%
Totals (unless noted as average)		260.9	664.0	46.6 Average Sediment Yield (tons IN/mi^2)	118.6	2.22	172.1	61.3	19% Percent of Total Load (Trapped/(Passed+Trapped))

For these five storm events, a total of 261 tons of sediment passed by the Clear Creek gage at Decatur Rd. It is estimated that 61.3 tons of sediment were trapped in the two study ponds during this time, amounting to 19% of total watershed sediment yield. Sediment inflow during periods where the lake elevation was below the outflow structure was not estimated, and would increase the amount of sediment trapped. There are two more NID- listed impoundments in the Atchison watershed, and numerous non-listed smaller impoundments likely trap sediment in the same manner.

Banner Dam 38

During the period of the study, Dam 38's water-surface elevation varied greatly, making consistent data collection difficult. At no time was water observed to reach the level of the outflow pipe. A second, smaller, outflow pipe was observed in the lake at extreme low elevations consisting of a small, horizontal, perforated PVC pipe. Due to safety concerns, this smaller outflow was not measured for calculations of outflow, and its capacity was small. Further surveying for storage and area was not possible due to safety concerns and budget constraints. Data collected for Dam 38 are presented in Appendix A, but were not included in data analysis.

Chapter 4: Discussion

Inflow calculations for the ponds were initially subject to wide variations in discharge due to the sensitivity of the reservoir routing equation to fluctuations in the recorded water surface elevation. Observed fluctuations in stage were caused by waves generated by wind, livestock in the ponds, or other disturbances which the 0.01-ft recording precision of the elevation sensor. To smooth out the inflow data, a moving average was applied to elevation data. It is unknown how much error this moving average introduced to the lake elevation.

Another source of error in the flow computations was debris collecting on the outlet structure. The weir equation used for calculating outflow (Equation 2) assumes a constant outlet elevation, and that the elevation around the entire pipe was level. After storm events, grass and other agricultural debris was observed to have built up on the inlet during several site visits. The grass would raise the elevation of zero flow, decreasing the actual amount flowing out of the structure from what was computed. Since no calibration measurements were obtained, no correction was applied to the data.

As a whole, LDMD 17 showed a higher inflow SSC than LDMD 5 during storm peaks. This can be attributed to the grass buffer which was already established at LDMD 5, while the grass buffer was only recently planted, and is much thinner at LDMD 17.

Trapping efficiency decreased to a net loss of sediment in both Atchison ponds over the period of the study. Though loss of trapping efficiency is expected as pond volume decreases, causes for this decrease were not readily apparent in the data; higher ambient turbidity between storms could be driven by suspended sediment or algae growth, data errors, or some combination of these factors. One possible cause is that sediment flushed into the ponds from earlier storms stayed suspended, allowing it to be flushed with the initial inflow of the next storms flow. SSC levels between storms which occurred at relatively short intervals remained steady, as seen in Figures 17 and 18.

Since the majority of the suspended load was comprised of silts and clays, long suspension times can be expected. Days of moderate to high winds would assist in maintaining suspension, and possibly cause re-suspension of sediments, especially since the two Atchison Lakes are fairly shallow. The relatively short interval between the final three storms was likely a factor in the flushing of previously suspended sediments.

The single negative trapping efficiency observed at LDMD 17 during storm 5 could be partially explained by turbidity truncation of the peak inflow. Additionally, peak inflow discharges occurred during storm 5 at both ponds, which could have produced some scour of the existing pond bottom, especially sediments which were laid down in the previous storm. The observed 2% trapping efficiency during storm 3 at LDMD 5 was likely due to a similar combination of factors as described above, considering the second highest peak inflow discharge occurred during that storm.

Bathymetric data were not available below the elevation of the outlet structures. Qualitative field observations of lake depth were not possible due to murky water, and very soft bottom sediments prevented wading past shore safely. It would be useful to collect bathymetric survey data on similar small impoundments over time to assess the effect of lake volume and mean hydraulic retention time on trapping efficiency.

Due to the age of the impoundments (44 years at the time of this writing) and sedimentation rates typically seen in this region of Kansas, it is likely these ponds are nearly filled with sediment. This would suggest that the ponds are only acting as shallow holding basins, where suspended sediments are flushed depending on the magnitude of the outflow during periods when sediment becomes suspended, which can be caused by storm flow, wind, livestock and agricultural activities. Therefore, the amount of sediment trapped in each impoundment is a function of time between flushing events where particles can settle.

This study also yielded valuable lessons in data collection techniques which can and should be applied to future, similar studies. Several of the above mentioned sources of error (samples and measurement checks, unknowns related to disparity in precipitation coverage and flow, sensitivity of models, etc.) could be addressed and reduced depending on the study length, available manpower, and equipment available. Moreover, the additional collection of bathymetric data would also be beneficial in determining changes in impoundment volume.

Chapter 5: Conclusion

This study estimated that two small impoundments in the Atchison watershed detained a quantity of sediment equal to nineteen percent of the total watershed sediment load during five storms in the summer of 2011. These results show that small impoundments can trap a significant amount of sediment, potentially reducing sedimentation in downstream reservoirs. This study estimated total sediment entrapment for the two impoundments. Determining how the trapping efficiency changes with seasonal or annual variations in precipitation, watershed land-use, geology, mean hydraulic retention time, and changes in volume would require a long-term study of multiple small watersheds. This study was able to acquire data from seeding to full growth in agricultural watersheds, during the northeast Kansas spring wet season, during which the maximum annual loads could be expected. The temporal variations in trapping efficiency could only have been observed by the empirical data collection techniques employed during this study.

Small impoundments in this watershed may be playing an important role in controlling downstream sedimentation. Therefore, from the sole perspective of reducing downstream reservoir sedimentation, these results suggest that watershed managers may want to consider adding, dredging, or repairing small impoundments, though other factors such as environmental impact and economic issues would have to be considered.

References

de Noyelles, F., & Jakubauskas, M. (2008, June). Current State, Trend, and Spatial Variability of Sediment in Kansas Reservoirs. *Sedimentation in Our Reservoirs: Causes and Solutions*, 500. (D. O. University, Ed.) Kansas State University Agricultural Experiment Station and Cooperative Extension Service.

Juracek, K. E. (2010). *Sedimentation, Sediment Quality, and Upstream Channel Stability, John Redmond Reservoir, east-central Kansas, 1964-2009.* U.S. Geological Survey Scientific Investigations Report, U.S. Geological Survey.

Juracek, K. E. (2011). *Sedimentation and accurance and trends of selected nutrients, other chemical constituents, and cyanobacteria in bottom sediment, Clinton Lake, northeast Kansas, 1977-2009.* U.S. Geological Survey Scientific Investigations Report, U.S. Geological Survey.

Kansas Data Access and Support Center. (2011). *State of Kansas GIS Data Access & Support Center*. Retrieved March 2011, from Kansas Geological Survey: http://www.kansasgis.org/

Kansas Water Office. (2008). *Sedimentation in our reservoirs: causes and solutions.* Topeka.

Kansas Water Office. (2009, February 2). *Sediment Baseline Assessment Work Plan.* Retrieved October 20, 2011, from Kansas Water Office Website: http://www.kwo.org/reservoirs/SedimentGroup/Rpt_Sediment_Baseline_Assessment_Work_Plan_022009_cbg.pdf

Lajczak, A. (1996). Modelling the long-term course of non-flushed reservoir sedimentation and estimating the life of dams. *Earth Surface Processes and Landforms, 21*, 17.

Lee, C. J., & Ziegler, A. C. (2010). *Effects of urbanization, construction activity, management practices, and impoundments on suspended-sediment transport in Johnson County, northeast Kansas, February 2006 through November 2008.* Scientific Investigations Report 2010-5128, U.S. Geological Survey.

Lee, C. J., Juracek, K. E., & Fuller, C. C. (2007). *Bottom-sediment accumulation and quality in Shawnee Mission Lake, Johnson County, Kansas, 2006.* U.S. Geological Survey Scientific Investigations Report, U.S. Geological Survey.

Lee, C. J., Rasmussen, P. P., & Ziegler, A. C. (2008). *Characterization of suspended-sediment loading to and from John Redmond Reservoir, east-central Kansas, 2007-2008.* U.S. Geological Survey Scientific Investigations Report, U.S. Geological Survey.

Morris, G. L., & Fan, J. (1998). *Reservoir Sedimentation Handbook: Design and Management of Dams, Reservoirs, and Watersheds for Sustainable Use.* New York, New York: Mc-Graw Hill.

Palmieri, A., Shah, F., & Dinar, A. (2001, September 29). Economic of reservoir sedimentation and sustainable management of dams. *Journal of Environmental Management, 61*, 14.

Pearce, M. (2011, October 23). Sediment's a growing problem in Kansas lake and reservoirs. *The Wichita Eagle*. Wichita, KS: Kansas.com.

Rasmussen, P. P., Gray, J. R., Glysson, G. D., & Ziegler, A. C. (2009). *Guidelines and procedures for computing time-series suspended-sediment concentrations and loads from in-stream turbidity-sensor and streamflow data.* U.S. Geological Survey Techniques and Methods book 3, chap. C4, U.S. Geological Survey.

Renwick, W. H., Sleezer, R. O., Buddemeier, R. W., & Smith, S. V. (2006). Small artificial ponds in the United States: impacts on sedimentation and carbon budget. *Proceedings of the Eighth Federal Interagency Sediment Conference*, (p. 7). Reno.

Sauer, V. B., & Turnipseed, D. P. (2010). *Stage measurement at gaging stations.* U.S. Geological Survey Techniques and Methods book 3, chap. A7, U.S. Geological Survey.

Smith, S. V., Renwick, W. H., Bartly, J. D., & Buddemeier, R. W. (2002). Distribution and significance of small, artificial water bodies across the united States landscape. *The Science of the Total Environment, 299*, 15.

Tiessen, K. H., Elliott, J. A., Stainton, M., & Yarotski, J. (2011, June). The Effectiveness of Small-Scale Headwater Storage Dams and Reservoirs on Stream Water Quality and Quantity in the Canadian Praries. *Journal of Soil and Water Conservation, 66*(3).

Turnipseed, D. P., & Sauer, V. B. (2010). *Discharge Measurements at Gaging Stations: U.S. Geological Survey Techniques and Methods book 3, chap. A8.* U.S. Geological Survey.

U.S. Bureau of Reclamation. (1987). *Design of Small Dams* (Third ed.).

US Army Corps of Engineers. (2010). *National Inventory of Dams*. Retrieved 02 01, 2011, from http://geo.usace.army.mil/pgis/f?p=397:12:903104061182741

Verstraeten, G., & Poesen, J. (2000). Estimating Trap Efficiency of Small Reservoirs and Ponds: Methods and Implications for the Assessment of Sediment Yield. *Progress in Physical Geography, 24*(2), 33.

Williams, G. P., & Wolman, M. G. (1984). *Downstream Effects of Dams on Alluvial Rivers.* U.S. Geological Survey. Washington DC: U.S. Government Printing Office.

Appendix A: Analysis of Dam 38

Wide variations in elevation (+/- ~7 feet) observed at Dam 38 made continuous data collection throughout the study period tenuous at best. Bank and lakebed material was extremely soft at low elevations, so no wading out to deeper waters to move sensors was possible due to safety concerns. Additionally, a second, small, perforated outflow riser was noted at extremely low elevations, which could not be measured to determine its hydraulic properties.

Elevation data were only recorded from May 17 until June 30, and during this period the inflow turbidity sensor was only submerged from June 2 until June 23. The majority of this time lake elevations were well below the lowest surveyed elevations. Therefore, computed flows and loads for Dam 38 were subject to large errors, and should be considered estimates.

To analyze the available data, elevation-storage was estimated below the lowest surveyed elevation by simple curve fit (Figure 19, Table 9). The lake elevation never reached the level of the main outflow pipe, and the small riser was not measured (and likely negligible), so outflow was not calculated. Decreasing lake elevation was likely a combination of evaporation, seepage, and water lost through the small outflow riser. To calculate inflow discharge, change in storage with respect to time was converted to inflow discharge. All other computations were performed as discussed in “Data Analysis Techniques.”

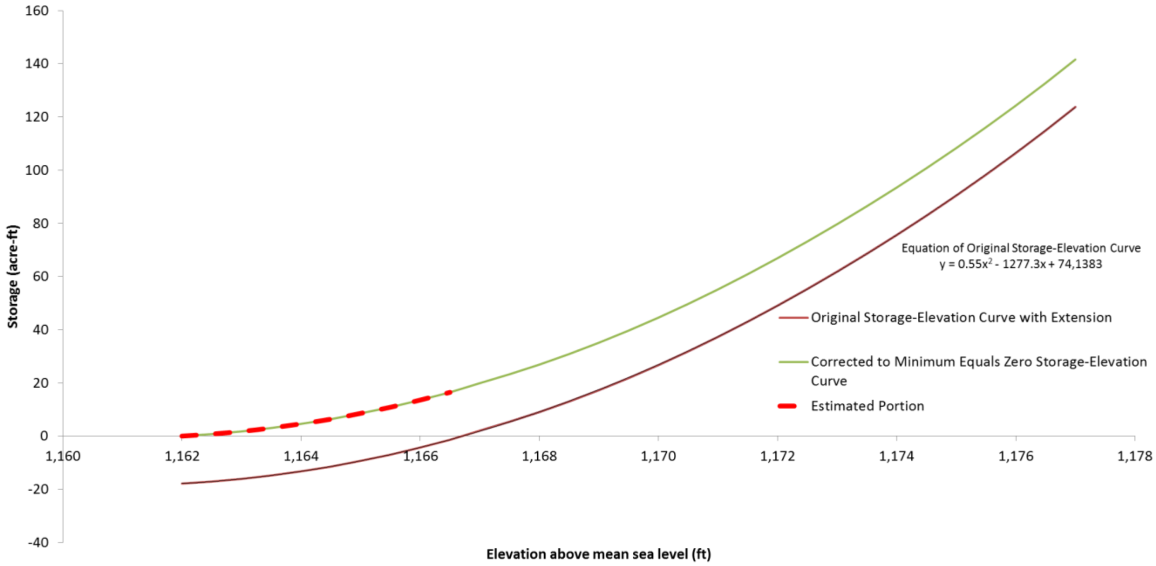

Figure 19: Elevation-storage curves showing extension below surveyed area and corrections applied to set minimum elevation to zero storage.

Table 9: Extended elevation-area and elevation-storage table for Dam 38.

Dam 38 with Extension

Elevation (ft)	Area (acres)	Raw Volume (acre-ft)	Volume above Storage (acre-ft)	Raw Volume with Curve Fit Extension (acre-ft)	Corrected to 0 Volume with Curve Fit Extension (acre-ft)
1162.00				*-17.86*	*0.00*
1162.50				*-17.10*	*0.75*
1163.00				*-16.10*	*1.76*
1163.50				*-14.80*	*3.06*
1164.00				*-13.25*	*4.61*
1164.50				*-11.50*	*6.36*
1165.00				*-9.30*	*8.56*
1165.50				*-7.00*	*10.86*
1166.00				*-4.30*	*13.56*
1166.50				*-1.40*	*16.46*
1167.00	6.39	2.05	0.00	2.05	19.90
1167.50	6.98	5.40	0.00	5.40	23.26
1168.00	7.51	9.03	0.00	9.03	26.88
1168.50	8.23	13.00	0.00	13.00	30.86
1169.00	8.83	17.27	0.00	17.27	35.12
1169.50	9.44	21.83	0.00	21.83	39.69
1170.00	10.03	26.70	0.00	26.70	44.56
1170.50	10.61	31.86	0.00	31.86	49.72
1171.00	11.19	37.32	5.45	37.32	55.17
1171.50	11.76	43.05	11.19	43.05	60.91
1172.00	12.29	49.07	17.20	49.07	66.92
1172.50	12.79	55.34	23.47	55.34	73.19
1173.00	13.27	61.85	29.99	61.85	79.71
1173.50	13.77	68.61	36.75	68.61	86.47
1174.00	14.29	75.63	43.76	75.63	93.48
1174.50	14.84	82.91	51.04	82.91	100.76
1175.00	15.40	90.47	58.60	90.47	108.32
1175.50	15.99	98.32	66.45	98.32	116.17
1176.00	16.59	106.46	74.60	106.46	124.31
1176.50	17.29	114.93	83.06	114.93	132.78
1177.00	18.16	123.78	91.92	123.78	141.64

From June 2 to June 23, Dam 38 water-surface elevations ranged from 1162.2 to 1169.2 feet, which resulted in computed volumes ranging from 0.4 to 37 acre-ft above the lowest point of the elevation-storage curve extension. A storm on June 2 (2.16" recorded at the Banner Lake rain gage) generated a peak inflow of 124 cfs, and an estimated 39 tons of sediment entered the pond. Sediment yield was 73.6 tons/mi^2 and streamflow yield was 426 ac-ft/mi^2. The downstream USGS stream gage (392652095484100 Banner Creek at M Rd) recorded 16.4 tons of sediment and 430 acre-ft of flow was recorded passing downstream. This equates to 70% of available sediment upstream of Dam 38 was trapped, however this does not consider the trapping of other impoundments in the watershed. Hydrographs of flow and SSC can be found in Figure 20.

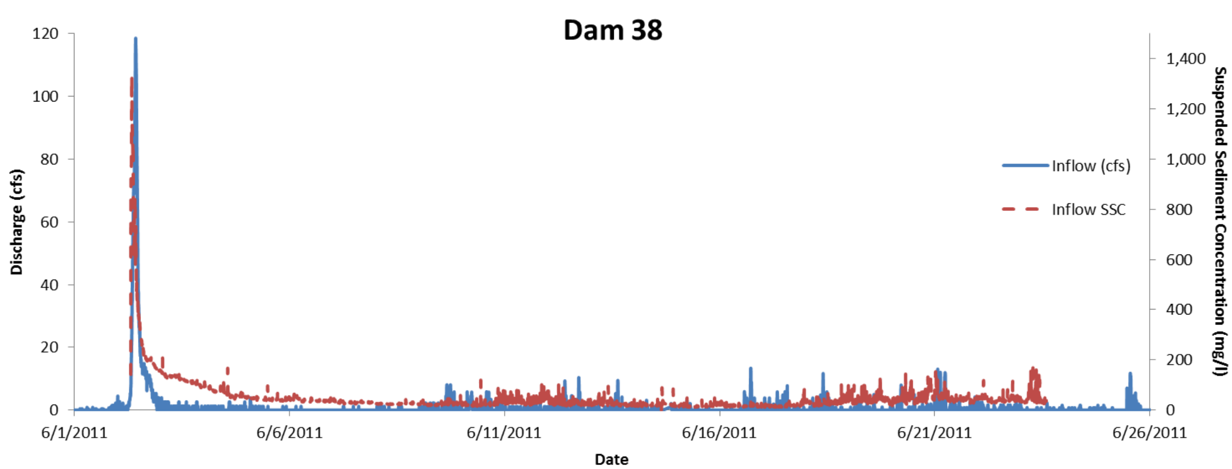

Figure 20: Flow and suspended sediment concentration hydrograph at Dam 38.

Appendix B: Gage Placement and Photos of Sites

LDMD 5

Figure 21: Aerial view of LDMD 5 showing general locations of elevation and turbidity sensors (photo source: Google Earth).

Figure 22: View looking upstream LDMD 5 from the top of the dam. The outflow structure is visible in the foreground. Photo taken April 2011.

Figure 23: View of inflow turbidity sensor at LDMD 5 looking north. Photo taken April 2011.

Figure 24: View of outflow elevation sensor (right) and turbidity sensor (left attached to outflow structure) at LDMD 5. Photo taken April 2011.

LDMD 17

Figure 25: Aerial view of LDMD 17 showing general locations of elevation and turbidity sensors (photo source: Google Earth).

Figure 26: View looking upstream towards the south fork of LDMD 17 from the top of the dam. The outflow structure is visible in the foreground. Photo taken April 2011.

Figure 27: View of the north fork inflow turbidity sensor at LDMD 17 looking northwest. Photo taken April 2011.

Figure 28: View of the south fork inflow turbidity sensor at LDMD 17 looking southwest. Photo taken April 2011.

Figure 29: View of outflow elevation sensor (right) and turbidity sensor (left attached to outflow structure) at LDMD 17. Photo taken April 2011.

Dam 38

Figure 30: Aerial view of Dam 38 showing general locations of elevation and turbidity sensors (photo source: Google Earth).

Figure 31: View looking downstream Dam 38 near the inflow turbidity sensor. Photo taken April 2011.

Figure 32: View of inflow turbidity sensor at Dam 38 looking west. Photo taken April 2011.

Figure 33: View of outflow turbidity sensor at Dam 38. Photo taken April 2011.

Figure 34: View of outflow elevation sensor at Dam 38. Photo taken April 2011.

Appendix C: Rating Tables for LDMD 5 and 17

Table 10: Rating table for LDMD 5 applying weir, orifice, and full pipe flow discharges depending on elevation above riser.

Diameter of Pipe (ft):	**2.5**	
Height of Riser (ft)	**9.3**	
Horizontal Pipe Length (ft):	**147.96**	
Pipe Length (ft):	**157.26**	**(includes riser length)**
Pipe Slope (ft/ft):	**0.0683**	
Pipe Specific Roughness, ε (ft)	**0.0002**	**(suitable for corrugated steel pipe)**

H/r (ft/ft)	**H, Height above Riser (ft)**	**C_w (graphically determined)**	**Q_{weir} (cfs)**	**$Q_{orifice}$ (cfs)**	**Q (cfs)**
0.00	0.00		0.00	0.00	0.0
0.08	0.10	4.02	1.00	6.23	1.0
0.16	0.20	3.95	2.77	8.81	2.8
0.24	0.30	3.87	4.99	10.79	5.0
0.32	0.40	3.70	7.35	12.46	7.4
0.40	0.50	3.56	9.89	13.93	9.9
0.48	0.60	3.41	12.45	15.26	12.4
0.56	0.70	3.20	14.72	16.48	14.7
0.64	0.80	3.00	16.86	17.62	16.9
0.72	0.90	2.70	18.11	18.69	18.1
0.80	1.00	2.46	19.32	19.70	19.3
0.88	1.10	2.30	20.84	20.66	20.7
0.96	1.20	2.10	21.68	21.58	21.6
1.04	1.30	1.94	22.58	22.46	22.5
1.12	1.40	1.83	23.81	23.30	23.3
1.20	1.50	1.73	24.96	24.12	24.1
1.28	1.60	1.62	25.75	24.91	24.9
1.36	1.70	1.52	26.46	25.68	25.7
1.44	1.80	1.45	27.50	26.43	26.4
1.52	1.90	1.36	27.97	27.15	27.1
1.60	2.00	1.28	28.43	27.85	27.9
1.68	2.10	1.22	29.16	28.54	28.5
1.76	2.20	1.16	29.73	29.21	29.2
1.84	2.30	1.10	30.14	29.87	29.9
1.92	2.40	1.05	30.66	30.51	30.5
2.00	2.50	1.00	31.05	31.14	31.0
	2.60			31.76	31.8
	3.00			34.11	34.1
	4.00			39.39	39.4
	5.00			44.04	44.0
	6.00			48.25	48.2
	7.00			52.11	52.1
	8.00			55.71	55.7
	9.00			59.09	59.1
	10.00			62.28	62.3
	11.00			65.32	65.3
	12.00			68.23	68.2
	13.00			71.02	71.0
	14.00			73.70	73.7

Table 11: Rating table for LDMD 17 applying weir, orifice, and full pipe flow discharges depending on elevation above riser.

Diameter of Pipe (ft):	**2.5**	
Height of Riser (ft)	**9**	
Horizontal Pipe Length (ft):	**131.73**	
Pipe Length (ft):	**140.73**	**(includes riser length)**
Pipe Slope (ft/ft):	**0.0577**	
Pipe Specific Roughness, ε (ft)	**0.0002**	**(suitable for corrugated steel pipe)**

H/r (ft/ft)	H, Height above Riser (ft)	C_w (graphically determined)	Q_{weir} (cfs)	$Q_{orifice}$ (cfs)	Q (cfs)
0.00	0.00		0.00	0.00	0.0
0.08	0.10	4.02	1.00	6.23	1.0
0.16	0.20	3.95	2.77	8.81	2.8
0.24	0.30	3.87	4.99	10.79	5.0
0.32	0.40	3.70	7.35	12.46	7.4
0.40	0.50	3.56	9.89	13.93	9.9
0.48	0.60	3.41	12.45	15.26	12.4
0.56	0.70	3.20	14.72	16.48	14.7
0.64	0.80	3.00	16.86	17.62	16.9
0.72	0.90	2.70	18.11	18.69	18.1
0.80	1.00	2.46	19.32	19.70	19.3
0.88	1.10	2.30	20.84	20.66	20.7
0.96	1.20	2.10	21.68	21.58	21.6
1.04	1.30	1.94	22.58	22.46	22.5
1.12	1.40	1.83	23.81	23.30	23.3
1.20	1.50	1.73	24.96	24.12	24.1
1.28	1.60	1.62	25.75	24.91	24.9
1.36	1.70	1.52	26.46	25.68	25.7
1.44	1.80	1.45	27.50	26.43	26.4
1.52	1.90	1.36	27.97	27.15	27.1
1.60	2.00	1.28	28.43	27.85	27.9
1.68	2.10	1.22	29.16	28.54	28.5
1.76	2.20	1.16	29.73	29.21	29.2
1.84	2.30	1.10	30.14	29.87	29.9
1.92	2.40	1.05	30.66	30.51	30.5
2.00	2.50	1.00	31.05	31.14	31.0
	2.60			31.76	31.8
	3.00			34.11	34.1
	4.00			39.39	39.4
	5.00			44.04	44.0
	6.00			48.25	48.2
	7.00			52.11	52.1
	8.00			55.71	55.7
	9.00			59.09	59.1
	10.00			62.28	62.3
	11.00			65.32	65.3
	12.00			68.23	68.2
	13.00			71.02	71.0
	14.00			73.70	73.7

Appendix D: Hydrographs

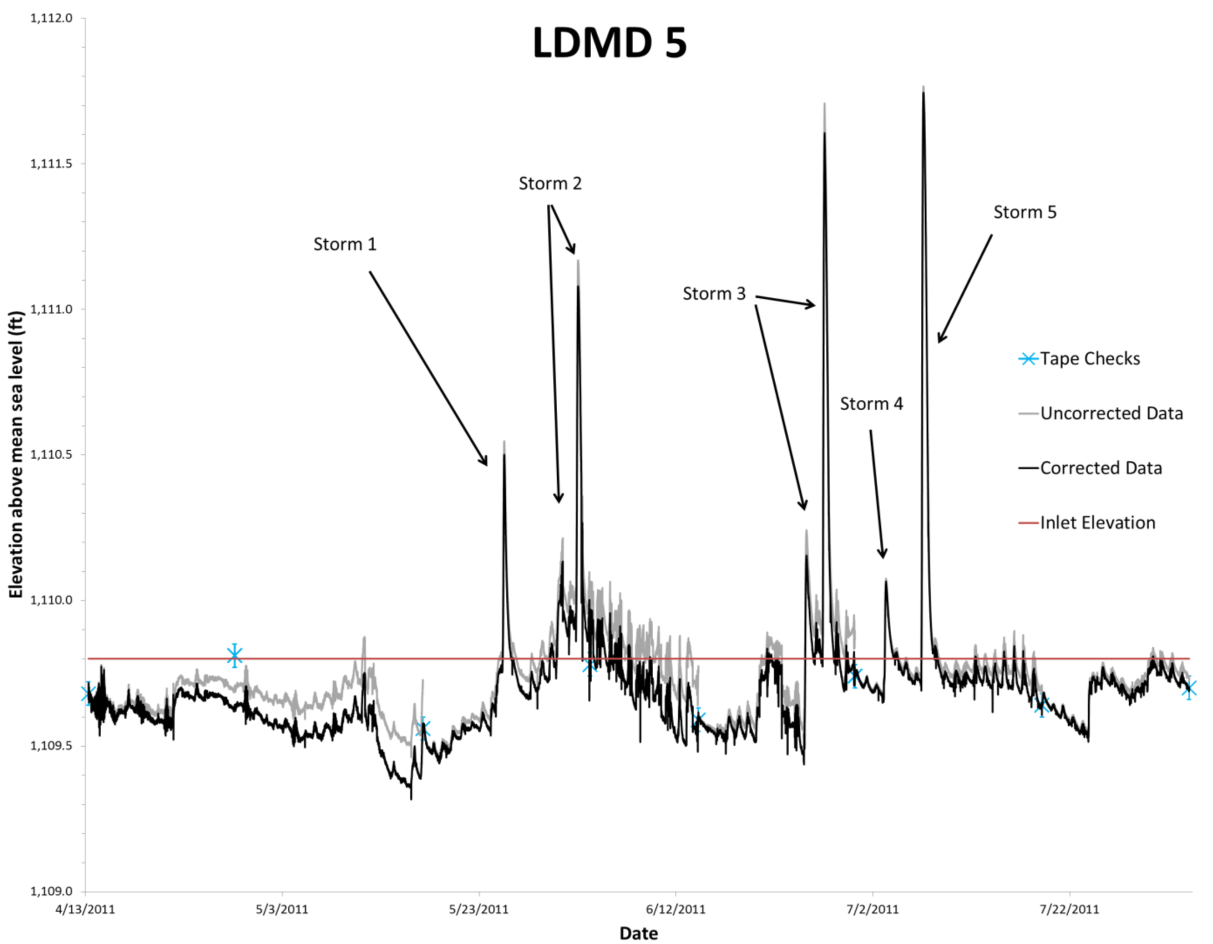

Figure 35: Elevation hydrograph over entire period of study for LDMD 5.

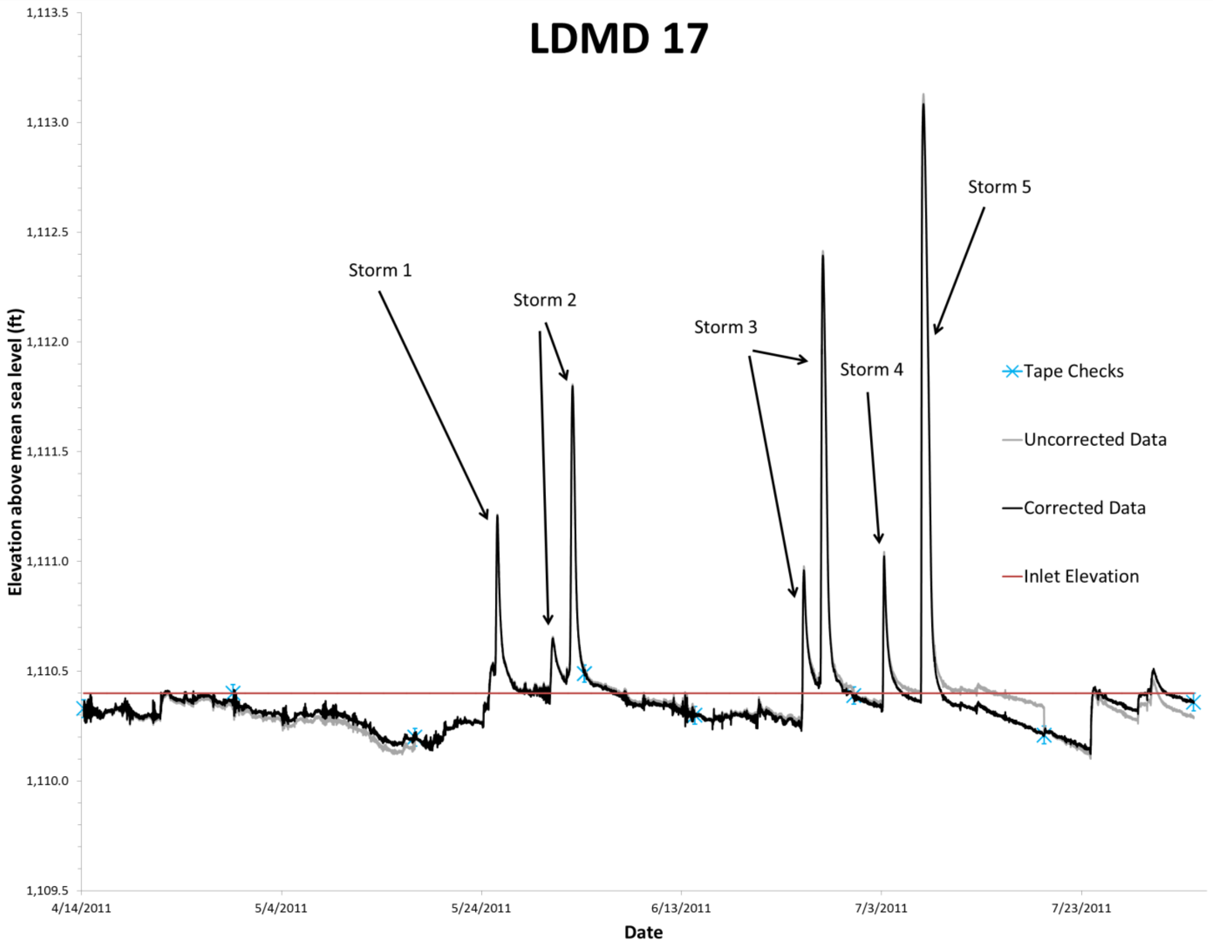

Figure 36: Elevation hydrograph over entire period of study for LDMD 17.

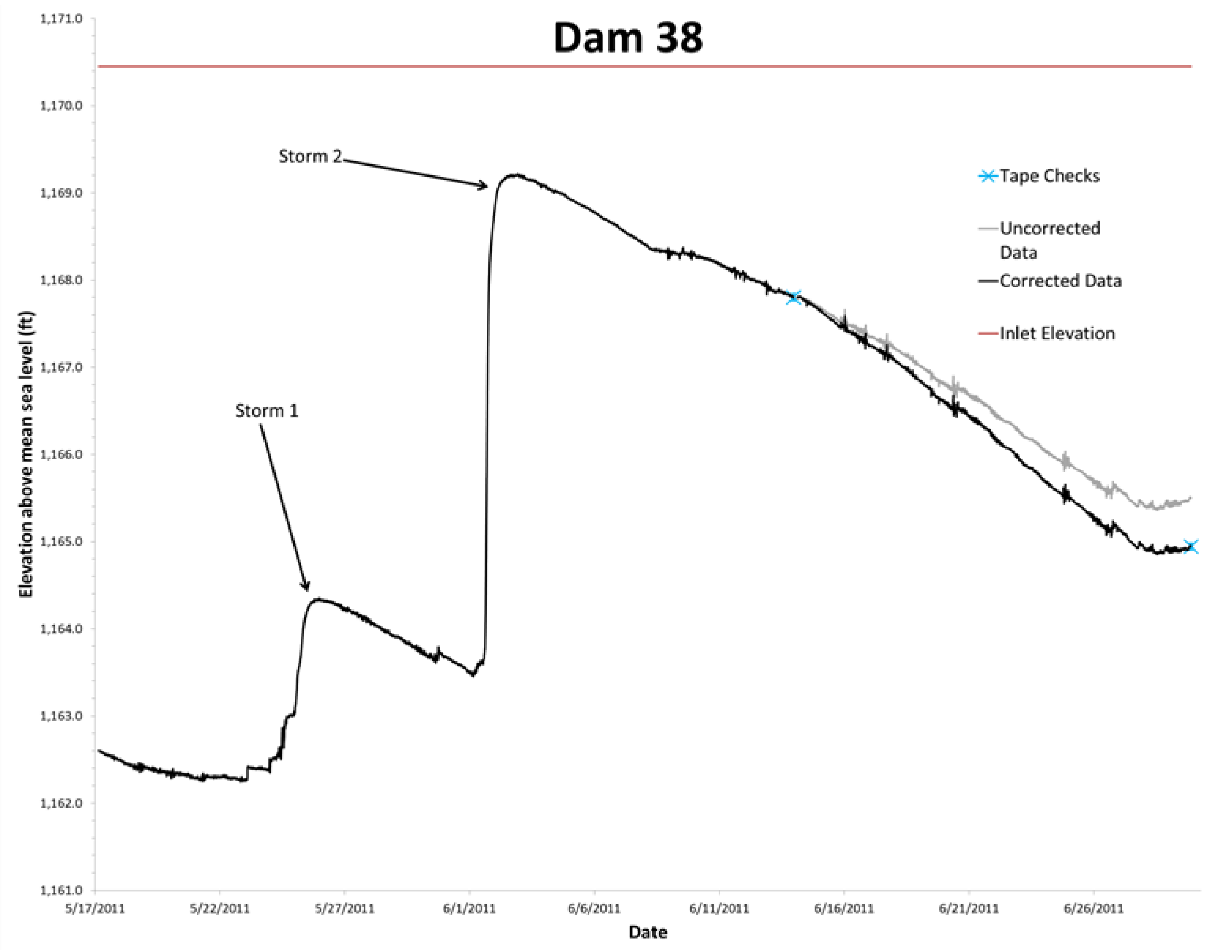

Figure 37: Elevation hydrograph over period of study where data was available for Dam38.

Appendix E: High Resolution Contour Maps of Study Impoundments

The survey data set also allowed for the creation of high-resolution contour maps at each impoundment. The TIN layer for each lake was used to create index contours of one foot, and normal contours of 0.2 feet. All surveys were taken to a low elevation defined by the water surface on the day of the survey, so any interpolated contours below this elevation were deleted. High elevations surveyed were generally, but not limited to, the dam crest elevation.

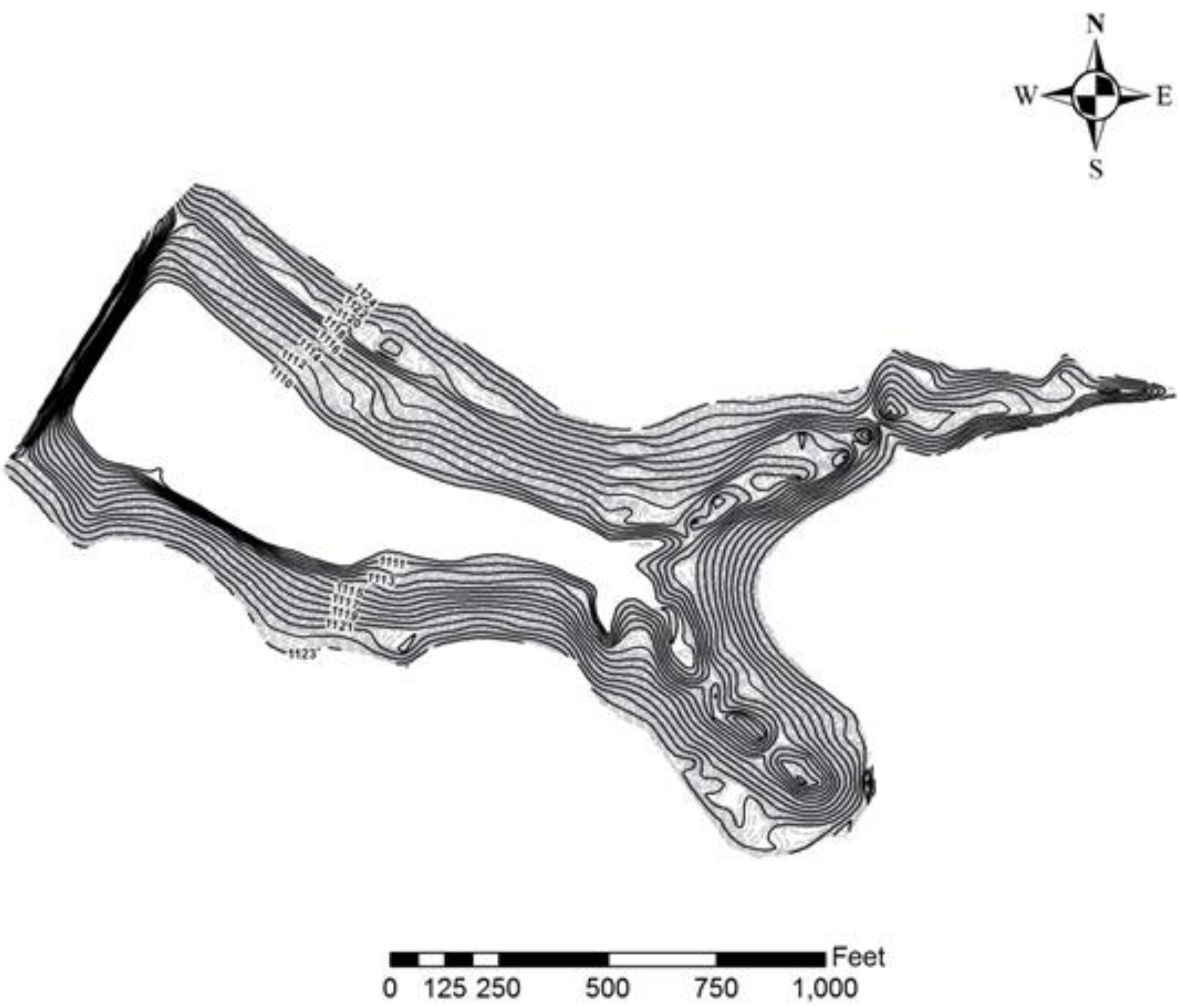

Figure 38: Contour map created from survey and LIDAR data at LDMD 5. Index contours are at 1 foot intervals, normal contours at 0.2 intervals.

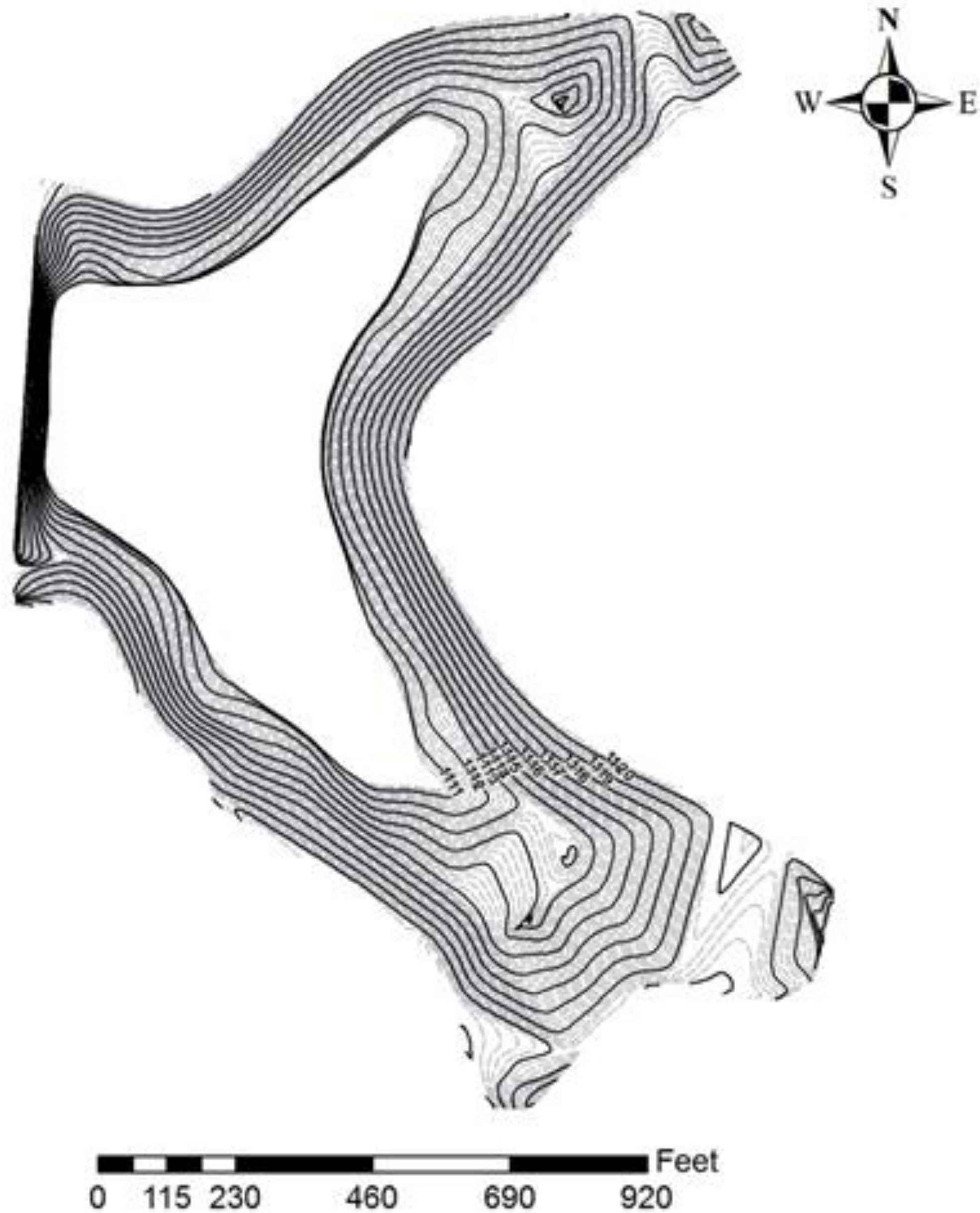

Figure 39: Contour map created from survey data at LDMD 17. Index contours are at 1 foot intervals, normal contours at 0.2 intervals.

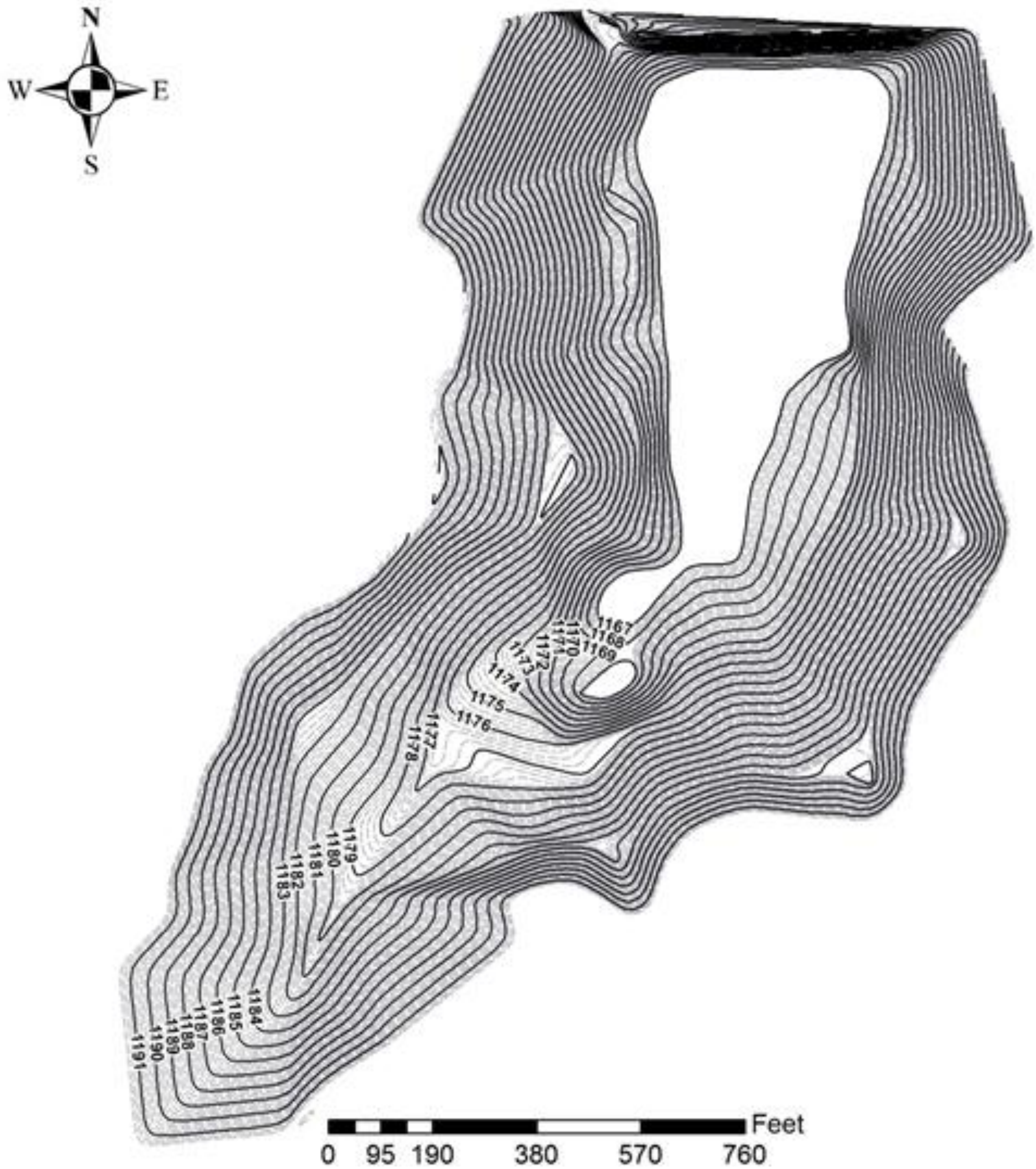

Figure 40: Contour map created from survey data at Dam 38. Index contours are at 1 foot intervals, normal contours at 0.2 intervals.