Verdigris River Post Flood Channel and Riparian Assessment Report

See-Kan RC&D
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Prepared for

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Table of Contents

List of Figures

List of Tables

Appendixes

Executive Summary

Many streams in Kansas including the Verdigris River are impacted by sediment due to eroding streambanks. Individual producers lose money when top soil is washed away. Communities are affected as sediment accumulates in reservoirs, limiting the usefulness of the body of water for flood control, recreation, and water supply. The Verdigris Watershed Restoration and Protection Strategy (WRAPS) group identified streambank erosion as a high priority concern for their watershed. The Riverworks Rapid Assessment System (RRAS) was used to obtain and analyze data collected from sites volunteered to be assessed by landowners and producers on the main stem of the Verdigris River in spring of 2007. The protocol covered numerous aspects of the stream including physical and biological data. Data were then presented to the stakeholder team so a plan of action could be established.

After the initial assessment, a large flood (500 year magnitude, USGS) occurred in the area causing extensive damage to the local economy and natural resources. A need was recognized to determine the magnitude of the damage caused by the flood. This study was conducted to determine the effectiveness of the riparian zone in protecting and stabilizing the streambanks of the Verdigris River during the 2007 flood. Stream reaches and riparian areas that had been assessed prior to the flood were visited again so physical measurements could be taken. An inventory of aerial photographs was also performed to determine the scale of the damage. Results of the study indicate that flood damage increased below the confluence of the Fall River, a tributary to the Verdigris River; however the increase was not significant in terms of additional volume of soil eroded. It was found that presence of a stable riparian area had a significant affect on minimizing streambank erosion. Areas that lacked a forested canopy prior to the flood lost significantly more soil ($p=0.03$).

Introduction

Many streams in Kansas are impacted by streambank erosion. This loss of soil can be attributed to natural occurrences (such as floods), changes in land use and poor land management; all of which influence the amount of erosion. In some cases, those problems combine to form an even larger erosion event.

During the summer of 2007 heavy rains in the southeastern part of Kansas resulted in a catastrophic flooding event (500 year magnitude, USGS) in local rivers and creeks. This flood caused nearly 40 million dollars of damage to the local communities and agricultural producers in southeast Kansas. (FEMA 2007) No other flood in the recorded history of the local area matched the magnitude of the 2007 flood.

A study of streambank conditions on selected reaches of the Verdigris River had been completed in the spring of 2007, prior to the flood event. Due to the size and effects of the flood and the recently completed streambank assessment, an unprecedented opportunity to evaluate the effects of the flood on the streambanks and riparian area was presented.

Streambank erosion can affect individuals, communities, and entire ecosystems, so efforts are underway to remediate and maintain streambanks in Kansas. However, little information is available for how the land use (especially with regard to riparian zones) in southeast Kansas affects the streambanks of the Verdigris River. The purpose of this study was to determine the effectiveness of the riparian zone in protecting and stabilizing the streambanks of the Verdigris River during the 2007 flood.

Study Area

Portions of the Verdigris River that reach from the spillway of Toronto Reservoir to the Kansas/ Oklahoma state line were assessed. The river passes through two different ecoregions in this area. The first, Chautauqua Hills, is found within the upper reaches of the study area and is near Toronto Reservoir. The remaining area is the Osage Cuestas ecoregion (Figure 1).

The soil type of streambanks is mainly composed of a silt/clay composition which remains consistent throughout the study area. The total length of the Verdigris River from the spillway at Toronto Reservoir to the state line of Kansas and Oklahoma is approximately 180,699 meters or 112 miles long .

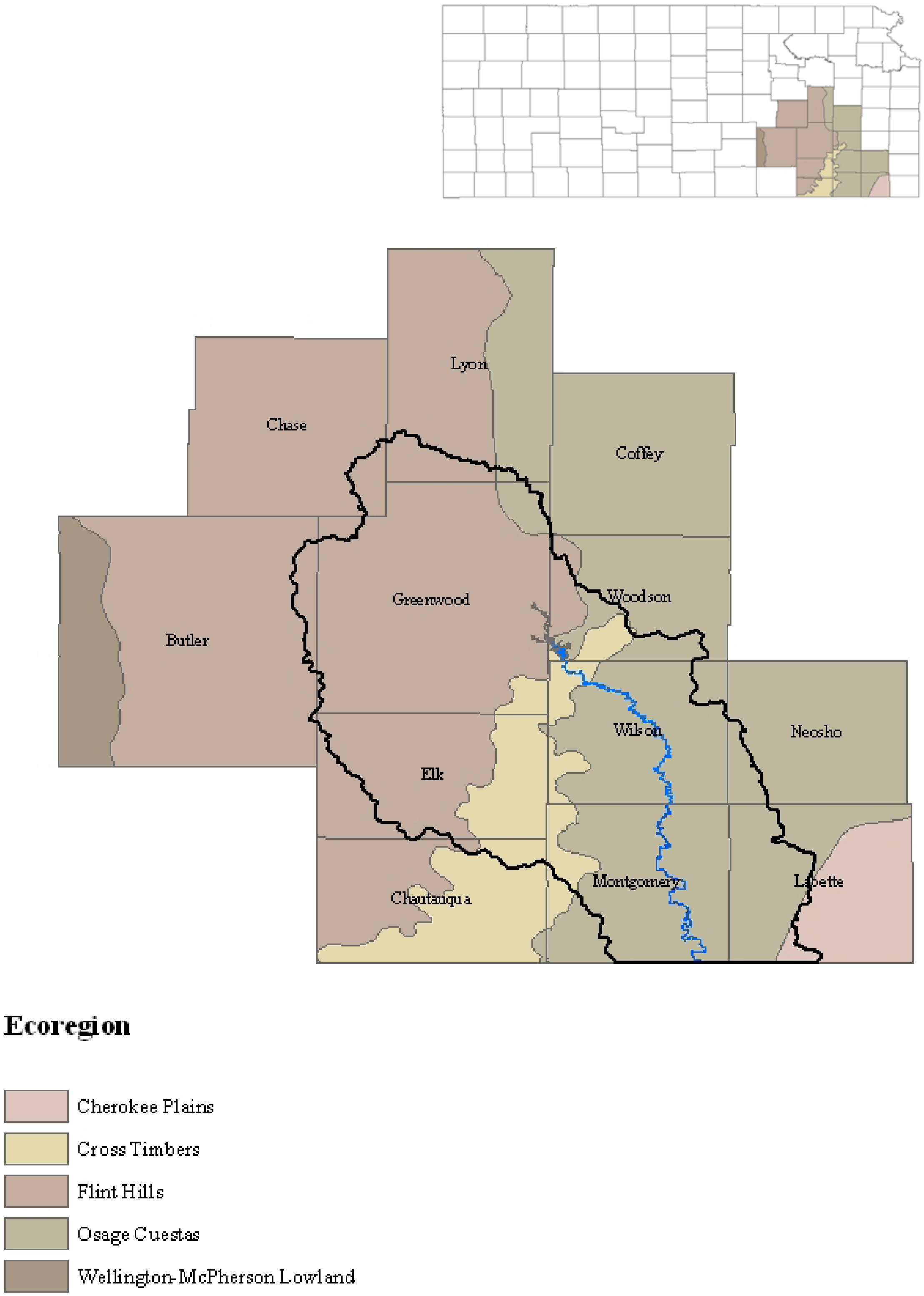

Figure 1. Representative ecoregions of study area

Materials and Methods

A hydrograph for the Altoona and Independence (Figure 2), USGS stream gauging sites was constructed using data from the USGS gauging stations. Data points ranged from May, 1st (Day 122) to August, 29th (Day 242) of 2007. This range was selected because it encompasses the time period before and after the flood event. Another hydrograph was constructed from the same dates (Days 122-242) for the 1951 flood from historic USGS gauging data. This was done to compare the duration and magnitude of the two floods since they have had the greatest impact on the local area in recent history.

Figure 2. Locations of USGS gauging stations

Physical assessments were made using the Riverworks Rapid Assessment System (RRAS) a protocol based on the USDA's Stream Visual Assessment Protocol (SVAP). Sites that had been visited the prior year were re-assessed to determine the effects of the flood on the streambanks and riparian area.

The first streambank assessment in the spring of 2007 evaluated all aspects of the stream to help identify the problem areas of the stream. Four indicators were identified as being the most informative in evaluating effects of riparian influences on streambank erosion: channel condition, hydrologic alteration, riparian zone and bank stability. The post flood study evaluated only these indicators. Physical measurements of the stream were also obtained and included bank full height and the width of the adjacent riparian area.

Physical assessment and inventory of available aerial photos was also completed. The inventory compared the 2006 Farm Service Agency (FSA) National Agriculture Imagery Program (NAIP) aerial photographs taken prior to the flood with 2007 United States Geological Survey (USGS) aerial photographs taken after the flood. The aerial inventory was used to identify large scale changes in the riparian area and/or streambanks such as lateral and longitudinal movement. To measure movement of the 2007 streambanks, the streambanks from the 2006 photos were used as a control point.

Geyer et. al (2003) based an assessment of lateral channel movement of the Kansas River after the historic 1993 flood on different types of land use (single tree, forest, grass, or crop), soil type (silt or sand), and channel configuration (straight, outside, or inside). This assessment simplified the types of land use into presence or absence of trees, meaning the presence of trees would indicate single tree or forest, and absence would indicate grass or crop land use. Difference in soil types were not compared because they do not differ dramatically through out the main stem of the Verdigris with the exception of those areas formed from oxbows.

Results and Discussion

Flood Duration and Magnitude

Very few places along the stream had any significant (p= 0.11) alteration of the channel after the 2007 flood. This was likely due to the short duration of the flood (Janicke 2002). Compared to the 1993 flood of the Kansas River, which occurred over a 2 month period (Geyer et al. 2003) and the 1951 flood on the Verdigris River, which lasted 22-23 days; the 2007 flood, which lasted only 4-7 days, (Figure 3), was small. Although the flood duration was shorter, the total flow (magnitude) either matched or exceeded previous flood events. For example, peak flow at the Altoona gauging station nearly matched that of the 1951 flood (Figure 4), while flow recorded at the Independence gauging station exceeded the 1951 record (Figure 5).

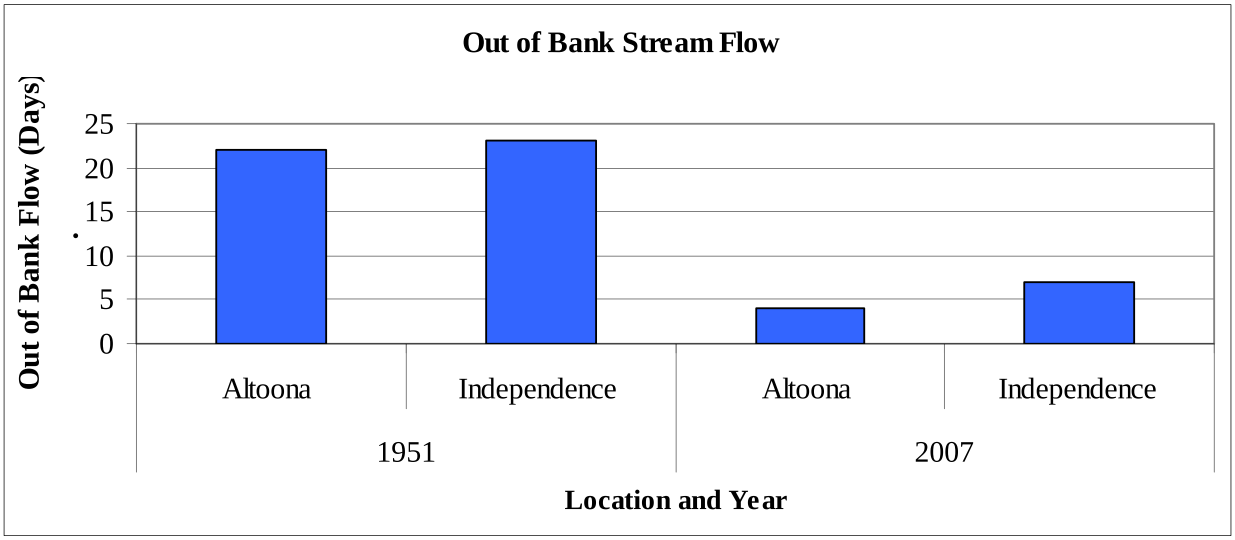

Figure 3. Days of stream flow above bank full for the 1951 flood and 2007 flood.

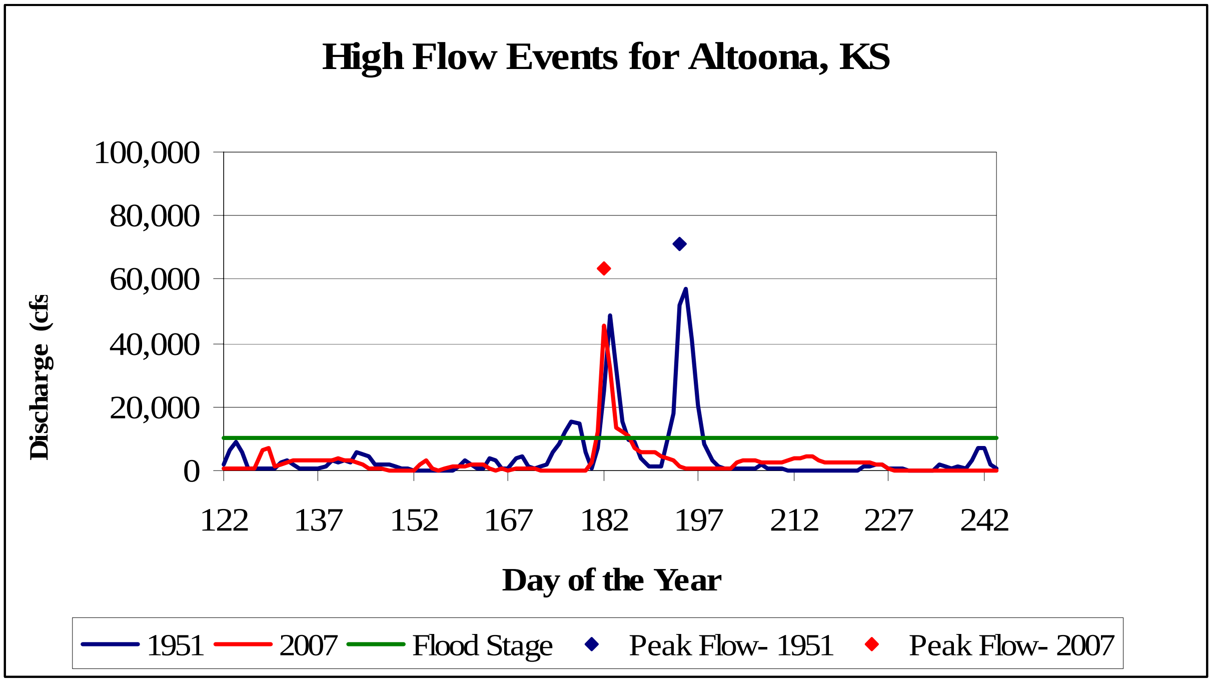

Figure 4. High flow events of 1951 and 2007 at Altoona, KS.

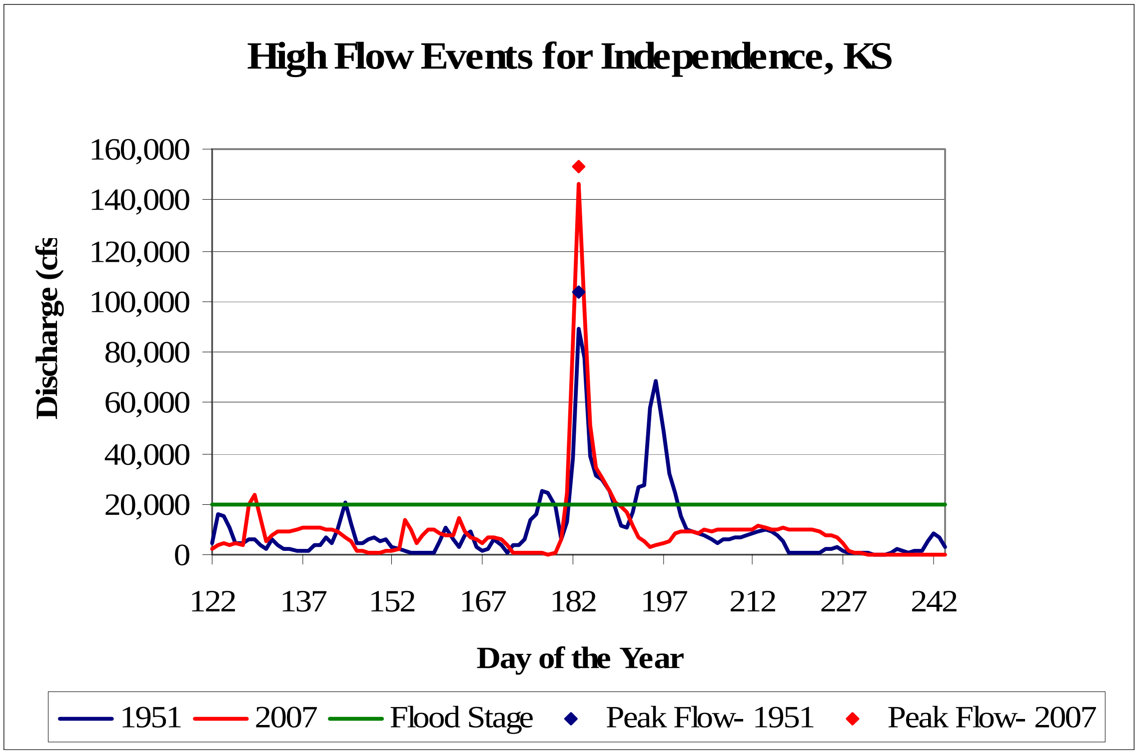

Figure 5. High flow events of 1951 and 2007 at Independence, KS.

Amount of River Damaged

Volume of Streambank Damaged

Data were found to be non-parametric due to a positively skewed distribution. This positive skew is due to a large number of areas lacking change in the eroded width. Because the data are non-parametric the Wilcoxon /Kruskal-Wallis (Rank Sums) test was used to determine significant difference in the loss of streambank soil volume between areas with woody plants and those without. Data were also compared for differences above and below the confluence of Fall River with the Verdigris River for soil volume lost (Table 1). The comparison of areas with woody plants and without woody plants was significantly different ($p= 0.03$) with less soil lost in areas with woody plant presence. No other comparison resulted in a significant difference. This result supports the hypothesis that riparian woody plants help maintain streambank stability.

Table 1. Streambank volume lost based on location and tree presence/ absence

	Previous Canopy (m^3)	No Previous Canopy (m^3)
Above	0	2,913
Below	2,054	1,143

Total volume of soil lost from the streambank is the best indicator of soil that enters the stream; however it is difficult to measure an exact amount of volume from aerial photographs. The detail of the photograph limits the accuracy of the measurement; if the streambank only moves one meter, the difference cannot be measured from the photo. Even with its limitations the volume of streambank lost is still the most valuable measurement of streambank soil erosion.

Length of Streambank Damaged

An aerial inventory was used to identify changes in streambank length. This method was used because it provided the most holistic approach to quantifying the amount of streambank damaged.

Types of streambank damage caused by erosion were broken down into three classes: riparian, streambank, and buffered damage.

- Riparian: This indicates the loss or damage of trees or woody plants.

- Streambank: This indicates loss or damage to the streambank.

- Buffered Damage: This indicates loss or damage to the streambank and/or riparian area but a substantial riparian area lies adjacent to the eroding area making it more resilient to further erosion.

The percent of total river erosion was determined by dividing the length of the damage type by the total length of the river. Previously collected data suggest that 16 % (Table 2) of the Verdigris River had some type of damage prior to the 2007 flood. The 2007 flood event increased the amount of damage by another 6 % (Table 3), resulting in a total of 22 % of the streambank being damaged.

Table 2. Percent of stream length eroded prior to 2007 flood event

Damage Type	m	Percent of Total
Riparian	14,908	8%
Streambank	12,455	7%
Buffered Damage	2,357	1%
Total	29,720	16%

Table 3. Percent of stream length eroded due to 2007 flood event

Damage Type	m	Percent of Total
New Riparian	4,536	3%
New Streambank	1,048	1%
Historic sites with additional damage	3,875	2%
Total	9,459	6%

A Wilcoxon /Kruskal-Wallis (Rank Sums) test was used to measure the differences between the before and after lengths of erosion at historic eroding areas (previously identified). The test resulted in no significant difference (p= 0.11). Data were also compared for differences above and below the confluence for streambank length affected (Table 4) but yielded no significant difference (p= 0.72)

Table 4. Mean streambank length affected based on location and tree presence/ absence

	Previous Canopy (m)	No Previous Canopy (m)
Above	64	111
Below	118	77

Physical Assessment

A post flood physical assessment of the stream was also conducted. A total of sixteen areas were visited.: fourteen of the sixteen areas had been assessed prior to the 2007 flood. Results of the physical assessment show little to no change in most areas assessed (Table 5). Only three of the areas that had been assessed prior to the flood showed any change. Areas 3 and 12 had a greater amount of gully erosion while Area 11 was damaged by a magnitude greater than any other location on the Verdigris River. The increased gully erosion at areas 3 and 12 was likely due to the substantial amount of rainfall that has occurred over the past year. The increased overland flow in combination with high stream flows likely resulted in the degradation of the area. Area 11 was considered an anomaly amongst other areas assessed. The damage that occurred in this area was likely due to the soil properties of the streambank and other confounding factors.

The eroded streambank was thought to be formed from the movement of the channel resulting in a less cohesive substrate than adjacent areas. The lack of cohesiveness would explain why this area received such a great amount of damage as opposed to the surrounding area. It should be noted that Area 11, is not characteristic of the whole stream.

Qualitative notes were made in addition to the scores taken during the physical assessment. A notable observation made during the physical survey indicates the riparian area received damage by not only the 2007 flood but was also aggravated by several smaller floods from the spring and summer of 2008. This is based on personal observation as well as input from local landowners.

Table 5. Summary of scores from sites reassessed

Area	1		2		3		4	
	Past	Present	Past	Present	Past	Present	Past	Present
Channel Condition	7	7	5	5	4	4	3	3
Hydrologic Alteration	6	6	2	2	5	5	5	5
Riparian Zone	7	7	6	6	4	4	2	2
Bank Stability	7	7	5	5	3	3	3	3
Score	7	7	5	5	4	4	3	3
Bed Full Width (m)	25	25	25	25	25	25	31.6	31.6
Bed Full Height (m)	3.6	3.6	7	7.6	4.5	4.5	6	6
Average Width of RMZ (m)	5.1	5.1	50	50.0	24.4	24.4	24.4	24.4

Area	5		6		7		8	
	Past	Present	Past	Present	Past	Present	Past	Present
Channel Condition	7	4	3	3	8	8	8	8
Hydrologic Alteration	5	3	7	7	8	8	8	8
Riparian Zone	8	3	8	8	7	7	3	3
Bank Stability	7	3	4	4	7	7	3	3
Score	7	3	6	6	6	8	6	6
Bed Full Width (m)	34.5	40	70	70	45	45	40	40
Bed Full Height (m)	5.5	5.5	3.7	3.7	5.8	5.8	5.8	5.8
Average Width of RMZ (m)	20	0	100	100	25	25	25	25

Area	9		10		11		12	
	Past	Present	Past	Present	Past	Present	Past	Present
Channel Condition	5	5	x	5	4	3	3	3
Hydrologic Alteration	5	5	x	5	8	6	5	5
Riparian Zone	5	5	x	5	3	0	3	2
Bank Stability	5	5	x	4	3	1	2	2
Score	5	5	x	5	5	3	3	3
Bed Full Width (m)	55.0	55.0	x	50.0	40	47.4	45.5	45.5
Bed Full Height (m)	4.6	4.6	x	3.5	3.6	4	3.2	3.2
Average Width of RMZ (m)	20	20	x	5	2	0	0	0

Table 5. Summary of scores from sites reassessed. (continued)

Area	13		14		15		16	
	Past	Present	Past	Present	Past	Present	Past	Present
Channel Condition	6	6	x	4	7	7	3	3
Hydrologic Alteration	4	4	x	5	8	8	3	3
Riparian Zone	5	5	x	4	7	7	3	3
Bank Stability	6	6	x	4	7	7	3	3
Score	5.25	5.25	x	4.25	7	7	3	3
Bed Full Width (m)	71	71	x	71	30	30	30	30
Bed Full Height (m)	2.74	2.74	x	3	3.35	3.35	6.1	6.1
Average Width of RMZ (m)	30	30	x	5	25	25	10	10

RMZ= Riparian Management Zone

x - Not Assessed Prior To 2007 Flood

Trees vs. crops/grass

In addition to sites that had been previously assessed a new site near Neodesha, KS was assessed during the post flood survey. This area had many of the post flood characteristics as other areas in the Verdigris River. Riparian trees had fallen into the stream creating new point bars and creating flow diversions that were eroding banks opposite of the fallen trees. The trees seemed to have been more affected by smaller flood events from the spring of 2008 than the large flood event of 2007 based on information received from landowners. The amount of large woody debris that is now present in the stream is substantial, making some areas of the stream un-navigable by boat at low flows. The presence of the additional large woody debris could have further implications, such as log jams and streambank erosion.

It is important to understand the integral role trees have in maintaining streambank stability. It may seem that they have a negative impact due to the increased surcharge or weight and pressure that they put on the streambank. It is true that trees do have a greater surcharge than grasses or forbs, but their advantages far outweigh their disadvantages (Abernathy & Rutherfurd 2000). The root systems of trees extend both laterally and vertically through the soil allowing for greater contact with the soil particles. In contrast grass roots penetrate only vertically. Tree roots have a greater tensile strength than grass roots (Simon & Collison 2002). These two attributes combine to make trees more effective when trying to stabilize a streambank. Trees play a major role in keeping the streambank soil intact on a large scale, but grasses and forbs should also be incorporated because they can also maintain the soil, trap sediment from overland flow, and provide habitat.

A streambank lacking a riparian area, with crops as the only adjacent vegetation, presents a different problem than grasses. Crop fields are more susceptible to erosion during the early spring when some crops such corn are immature; these young plants lack the mature roots systems necessary to reinforce the soil (Simon &Collison 2002).

Another important feature of perennial vegetation (trees/shrubs/grasses) is that they provide a better connection with the water table (Simon & Collison 2002). Perennial vegetation is able to both draw moisture from the water table as well as return water back to it. If the water table becomes disconnected from the stream, such as in an incised streambank and channel, it will be more likely to erode.

Soil Properties

Soil type in the streambank plays a large role in the integrity of the streambank. Streambanks with a higher composition of silt and clay are more stable than those with an equal amount of sand (Geyer et. al 2003). Fortunately for the Verdigris River only one soil type found in the streambanks has a major component of sand (Tables 6, 7, 8, & 9). The major soil type (8302) of streambanks of the Verdigris River has a silt/clay texture (Tables 6, 7, 8, & 9). Other areas with a seemingly stable soil type are not stable because of their stratification. The stratification leads to a more unstable soil because the layers are less cohesive. An area south of Liberty KS demonstrated the importance of cohesive soils. The area indicated in Figures 6, 7, 8, and 9 shows the lack of cohesiveness in the streambank soil. This problem was likely caused by the mode of formation of the soil. The eroding area is unique because it is found in an area of the stream that has been historically actively meandering. This is indicated by the presence of oxbow lakes and meander scars (Figure 10). It appears that the stream channel has changed course several times, eroding and depositing soil, forming new streambanks.

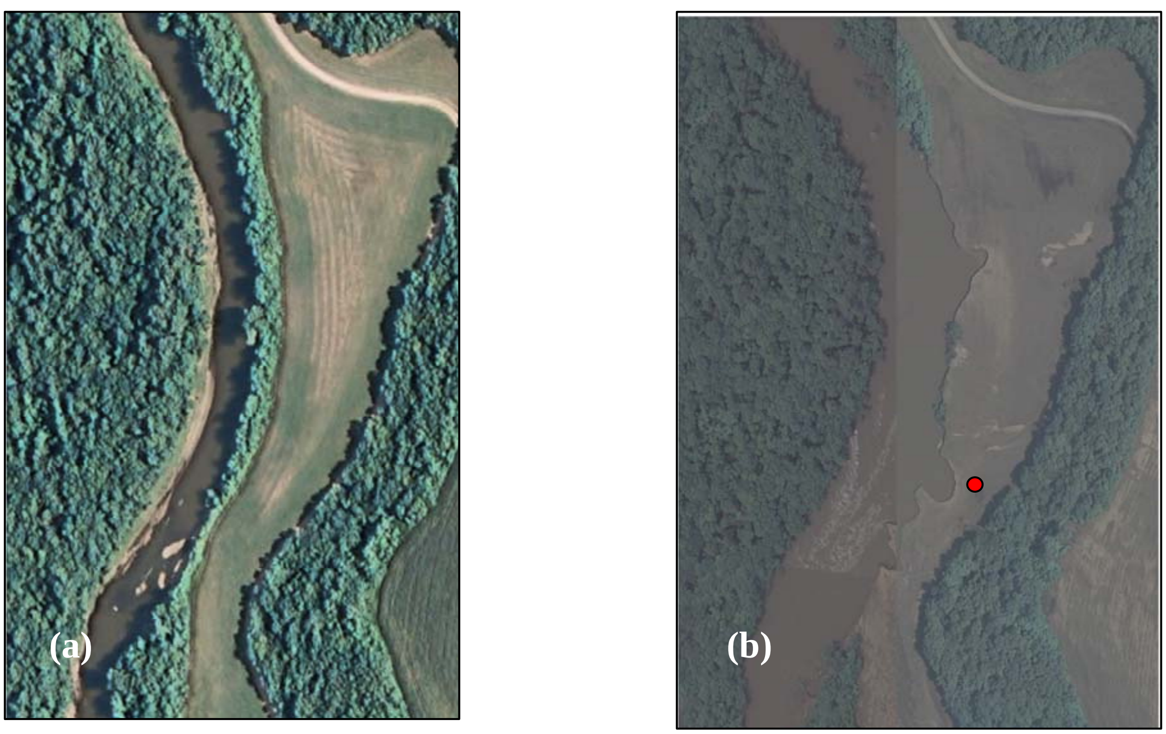

Figure 6. Eroded area (Area 11) south of Liberty, KS representing damage from flood.(a) 2006. (b) 2007.

Figure 7. A large scour pool caused by the 2007 flood, it is located at the red dot in Figure 4 (b).

Figure 8. Area above scour pool looking downstream.

Figure 9. Sediment accumulation in riparian area of adjacent stream.

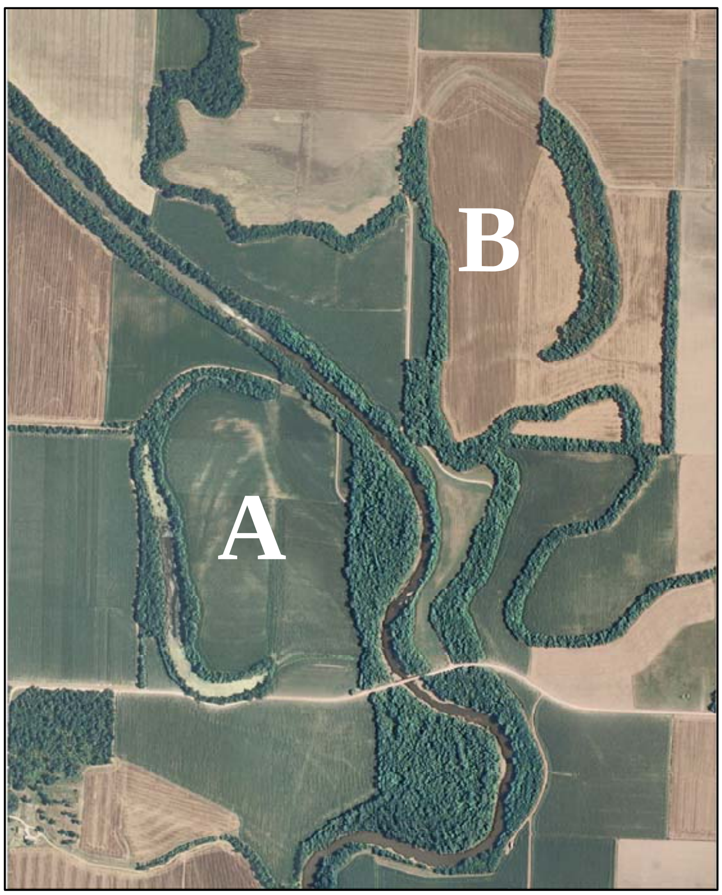

Figure 10. Representative oxbow lake (A), and meander scar (B).

Table 6. Soil types of the Verdigris River in Wilson County, KS.

Typical Soil Profile — Map Unit Symbol vs. Depth (in)

Map Unit Symbol	
6951	Cobbly Fine Sandy Loam (0–5); Cobbly Fine Sandy Loam (5–9); Silty Clay (9–23); Silty Clay (23–35); Bedrock (35–40)
6961	Loam (0–10); Clay Loam (10–16); Clay Loam (16–37); Silty Clay (37–60)
6982	Fine Sandy L (0–6); Fine Sandy Loam (6–16); Sandy Clay Loam (16–26); Weathered Bedrock (26–31)
8150	Silt Loam (0–6); Silty Clay Loam (6–36); Silty Clay (36–60)
8201	Silty Loam (0–10); Silty Clay (10–60)
8203	Silty Clay (0–6); Clay (6–15); Silty Clay (15–44); Silty Clay (44–60)
8300	Silt Loam (0–9); Silt Loam (9–29); Silt Loam (29–47); Silt Loam (47–60)
8302	Silt Loam (0–7); Silty Clay Loam (7–21); Silty Clay Loam (21–60)
8623	Loam (0–7); Loam (7–10); Clay Loam (10–18); Paragravelly Clay Loam (18–26); Weathered Bedrock (26–30)
8626	Loam (0–9); Loam (9–11); Clay Loam (11–18); Paragravelly Clay Loam (18–26); Weathered Bedrock (26–30)
8628	Loam (0–6); Loam (6–12); Clay Loam (12–19); Paragravelly Clay Loam (19–24); Weathered Bedrock (24–29)
8679	Silt Loam (0–9); Silt Clay Loam (9–15); Silty clay (15–60)
8775	Silt Loam (0–8); Silty Clay (8–24); Silty Clay (24–40); Silty Clay (40–60)
8872	Silt Clay Loam (0–10); Silt Clay Loam (10–20); Silty Clay (20–25); Weathered Bedrock (25–30)
8876	Silty Clay Loam (0–10); Silty Clay Loam (10–20); Silty Clay (20–25); Weathered Bedrock (25–30)
8961	Silt Loam (0–7); Silty Clay (7–27); Silty Clay (27–49); Silty Clay (49–60)

Table 7. Soil types of the Verdigris River in Montgomery County, KS.

Typical Soil Profile

Map Unit Symbol	Depth (in)	Soil type
6951	1–6	Fine Sandy Loam
6951	7–15	Paragravelly Fine Sandy Loam
6951	16–20	Weathered Bedrock
8150	1–8	Silty Loam
8150	9–21	Silty Loam
8150	22–39	Silty Clay Loam
8150	40–60	Silty Clay
8151	1–11	Silty Clay Loam
8151	12–31	Silty Clay Loam
8151	32–60	Silty Clay Loam
8300	1–10	Silt Loam
8300	11–29	Silt Loam
8300	30–47	Silt Loam
8300	48–60	Silty Clay Loam
8203	1–6	Silty Clay
8203	7–17	Silty Clay
8203	18–60	Clay
8302	1–7	Silt Loam
8302	8–28	Silt Loam
8302	29–46	Silt Loam
8302	47–60	Silt Clay Loam
8501	1–7	Silt Loam
8501	8–17	Silt Loam
8501	18–60	Silty Clay Loam
8627	1–15	Loam
8627	16–27	Loam
8627	28–31	Paragravelly Loam
8627	32–35	Weathered Bedrock
8629	1–14	Loam
8629	15–26	Clay Loam
8629	27–30	Gravelly Clay Loam
8629	31–35	Weatherd Bedrock
8643	1–9	Silty Clay Loam
8643	10–15	Silty Clay Loam
8643	16–19	Silty Clay
8643	20–29	Clay
8643	30–34	Unweathered Bedrock
8679	1–9	Silt Loam
8679	10–15	Silty Clay Loam
8679	16–60	Silty Clay
8683	1–7	Silt Loam
8683	8–13	Silty Clay Loam
8683	14–60	Silty Clay
8733	1–10	Silty Clay
8733	11–31	Clay
8733	32–36	Weathered Bedrock
8735	1–10	Silty Clay Loam
8735	11–31	Silty Clay
8735	32–35	Weathered Bedrock
8765	1–10	Silty Clay Loam
8765	11–31	Silty Clay
8765	32–35	Weathered Bedrock
8853	1–15	Gravelly Silt Loam
8853	16–20	Very Gravelly Silty Clay
8853	21–60	Very Gravelly Silty Clay
8885	1–9	Silty Loam
8885	10–30	Silty Clay Loam
8885	31–34	Unweatherd Bedrock
8923	1–6	Silty Clay Loam
8923	7–13	Silty Clay
8923	14–16	Silty Clay
8923	17–20	Weathered Bedrock
8991	1–5	Silty Clay
8991	6–13	Silty Clay
8991	14–50	Silty Clay
8991	51–60	Silty Clay
9983	1–60	Gravel Pits
9989	1–7	Silty Clay Loam
9989	8–60	Silty Clay

Table 8. Soil Composition of streambanks found in Wilson County, KS.

				Pre Flood		Post Flood	
Map Symbol Unit	Streambank (m)	Streambank Composition	Erosion (m)	% of Streambank	% of Eroded Streambank	% of Streambank	% of Eroded Streambank
6951	1,942	1.0%	0	0.0%	0.0%	0.0%	0.0%
6961	126	0.1%	0	0.0%	0.0%	0.0%	0.0%
6982	889	0.5%	0	0.0%	0.0%	0.0%	0.0%
8150	289	0.2%	0	0.0%	0.0%	0.0%	0.0%
8201	3,533	1.9%	853	0.5%	5.5%	0.0%	0.0%
8203	3,085	1.6%	761	0.4%	4.9%	0.0%	0.0%
8300	290	0.2%	72	0.0%	0.5%	0.0%	0.0%
8302	171,610	91.7%	13,109	7.0%	84.1%	0.7%	100.0%
8623	138	0.1%	140	0.1%	0.9%	0.0%	0.0%
8626	865	0.5%	0	0.0%	0.0%	0.0%	0.0%
8628	438	0.2%	0	0.0%	0.0%	0.0%	0.0%
8679	2,636	1.4%	386	0.2%	2.5%	0.0%	0.0%
8775	111	0.1%	0	0.0%	0.0%	0.0%	0.0%
8872	257	0.1%	0	0.0%	0.0%	0.0%	0.0%
8876	555	0.3%	0	0.0%	0.0%	0.0%	0.0%
8961	336	0.2%	274	0.1%	1.8%	0.0%	0.0%
Total	187,100	-	15,595	8.3%	-	0.7%	-

Table 9. Soil Composition of streambanks found in Montgomery County, KS.

				Pre-Flood		Post Flood	
Map Symbol Unit	Streambank (m)	Streambank Composition	Erosion (m)	% of Streambank	% of Eroded Streambank	% of Streambank	% of Eroded Streambank
6951	1,773	1.0%	0	0.0%	0.0%	0.1%	2.6%
8150	1,819	1.0%	0	0.0%	0.0%	0.0%	0.0%
8151	7,524	4.3%	339	0.2%	2.4%	0.3%	7.1%
8300	142	0.1%	111	0.1%	0.8%	0.0%	0.0%
8203	20,663	11.9%	2,046	1.2%	14.5%	0.3%	8.1%
8302	126,727	72.7%	11,391	6.5%	80.6%	3.4%	82.2%
8501	1,138	0.7%	0	0.0%	0.0%	0.0%	0.0%
8627	858	0.5%	0	0.0%	0.0%	0.0%	0.0%
8629	596	0.3%	0	0.0%	0.0%	0.0%	0.0%
8643	651	0.4%	0	0.0%	0.0%	0.0%	0.0%
8679	734	0.4%	0	0.0%	0.0%	0.0%	0.0%
8683	364	0.2%	0	0.0%	0.0%	0.0%	0.0%
8733	716	0.4%	0	0.0%	0.0%	0.0%	0.0%
8735	895	0.5%	0	0.0%	0.0%	0.0%	0.0%
8765	1,475	0.8%	0	0.0%	0.0%	0.0%	0.0%
8853	770	0.4%	0	0.0%	0.0%	0.0%	0.0%
8885	1,638	0.9%	0	0.0%	0.0%	0.0%	0.0%
8923	2,994	1.7%	86	0.0%	0.6%	0.0%	0.0%
8991	314	0.2%	0	0.0%	0.0%	0.0%	0.0%
9983	1,346	0.8%	152	0.1%	1.1%	0.0%	0.0%
9989	1,161	0.7%	0	0.0%	0.0%	0.0%	0.0%
Total	174,298	-	14,125	8.1%	-	4.2%	-

Types of Erosion

Fluvial Entrainment

Fluvial entrainment is the erosion of the streambank by the water in the stream (Thorne 1982). Most of the eroded areas were due to fluvial entrainment. Figures 7 and 8 provide good examples of fluvial entrainment occurring in the Verdigris River. Figure 7 shows a clay point bar extending from the toe (bottom) of the bank. This layer of soil was observed to be a common occurrence in the lower reaches of the Verdigris River. This occurrence is notable because the presence of the clay bar can influence the fluvial entrainment of the streambank. The clay bar acts as a protective layer to the fluvial entrainment since it is more cohesive and resistant to erosion. The toe of the bank is the most important area to protect since it is the foundation of the streambank as well as being in contact with water. The area above the clay bar is less stable as is indicated by the massive soil loss in Figures 7 and 8.

Mass Wasting

Mass wasting is the massive movement of soil due to a geotechnical failure (weak soil structure) beneath the affected area (Thorne 1982). Mass wasting appears to be a common problem in the upper reaches of the Verdigris River, probably due to the incised banks found in this area. Occurrences range from individual trees slumping into the river to larger areas with failed banks. Observations were made of individual trees slumping into the river while the movement of larger areas was accounted for by local landowners. Areas in the lower reaches of the Verdigris River were also affected by mass wasting. The trees toppling into the stream in these areas were likely affected not only by mass wasting but also by fluvial entrainment of bank full and out of bank flows.

Overland Erosion

Overland erosion is caused by run off of water during rain events. Because they create a link between the land and the river, gullies pose the greatest overland erosion threat to streambanks. . This allows them to carry large amounts of overland sediment into the stream as well as weakening the streambanks. Though most areas did not show a dramatic change in streambank erosion a couple of areas (Areas 3 & 12) did show problems with overland erosion, specifically gullies. Gullies that were previously present had become increasingly worse since before the flood. This was likely due to the large amounts of rain that fell prior to the flood as well as the rainfall received earlier in 2008. The presence of roads had a substantial impact on overland erosion. Most areas with a road close to the stream were impacted by erosion. Figure 13 shows the effects of a road near a streambank that lacks trees. Figure 14 shows the common problem of a head cut. These photos help demonstrate the role of riparian areas in helping control soil loss.

Figure 11. Mass wasting in upper reaches of the study area.

Figure 12. Mass wasting in lower reaches of study area.

Figure 13. A streambank lacking a riparian area and suffering from overland erosion.

Figure 14. Gully erosion caused by road presence.

Conclusions

Several problems appear to be influencing the Verdigris River in its post 2007 flood condition. Many of these were problems prior to the flood. Roads, bridges, and dams continue to degrade the integrity of the streambanks. In some areas these structures magnified the impact of the flood due to backwater affects. In areas influenced by roads and bridges, the affects of the flood were greater.

The presence of woody plants made a significant difference ($p = 0.03$) in the amount of soil lost from the streambanks of the Verdigris River during the 2007 flood. Areas that lack trees were more likely to lose soil than those which had trees. Areas that had stratified soil layers appeared to be less stable, resulting in greater damage from the flood. In these areas of stratified soil, the benefit of trees is lessened due to the inherently unstable soil. Trees play an important role in protecting the streambank but soil type/texture plays a larger role in the integrity of the streambank. Fortunately for the Verdigris River most of the soil found in the streambanks is composed of a soil type that is more resilient to erosion than others. The soil type and structure should be considered when stabilization projects are designed. This would allow for a targeted approach to identifying weak areas of the stream that are more susceptible to erosion than others. These characteristics should take top priority over other problems since the soil structure of the streambank can not be changed.

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Appendix A. Stream Length

Location	m	miles
WL	95,242	59
MG	85,457	53
Total	180,699	112

Appendix B. Flood Erosion Data

Previous Canopy

NFID	ID	ER_FEATURE	ER_LENGTH	ER_WIDTH	ER Volume	Canopy_N	Canopy_O	HUC_ID	OFID
0	0	Riparian Loss	30	0	0	115	124	2	0
3	0	Riparian Loss	147	0	0	39	39	2	0
4	1	Streambank Loss	103	0	0	26	34	2	0
7	2	Historic Loss	80	0	0	1	13	2	3
14	0	Riparian Loss	65	0	0	26	30	4	0
15	2	Historic Loss	9	0	0	0	6	4	22
17	1	Streambank Loss	35	0	0	0	9	4	0
18	2	Historic Loss	19	0	0	0	10	4	0
21	2	Historic Loss	157	0	0	0	11	4	27
25	0	Riparian Loss	27	0	0	0	9	4	0
26	2	Historic Loss	96	0	0	0	10	4	33
49	0	Riparian Loss	14	0	0	0	22	5	0
51	2	Historic Loss	48	0	0	0	15	5	47

No Previous Canopy

NFID	ID	ER_FEATURE	ER_LENGTH	ER_WIDTH	ER Volume	Canopy_N	Canopy_O	HUC_ID	OFID
22	1	Streambank Loss	85	0	0	0	0	4	0
23	1	Streambank Loss	135	4	2700	0	0	4	30
24	2	Historic Loss	58	0	0	0	0	4	32
27	2	Historic Loss	151	0	0	0	0	4	39
45	0	Riparian Loss	5	0	0	0	0	5	0
56	2	Historic Loss	127	9	5715	0	0	6	52
57	2	Historic Loss	251	9	11295	0	0	6	53
58	1	Streambank Loss	72	10	3600	0	0	6	0

Previous Canopy

NFID	ID	ER_FEATURE	ER_LENGTH	ER_WIDTH	ER Volume	Canopy_N	Canopy_O	HUC_ID	OFID
4	0	Riparian Loss	12	0	0	0	7	9	0
6	0	Riparian Loss	26	0	0	23	29	9	0
7	1	Streambank Loss	20	0	0	0	9	9	78
8	0	Riparian Loss	15	0	0	56	60	9	0
9	1	Streambank Loss	20	0	0	5	20	9	0
10	2	Historic Loss	17	0	0	0	7	9	79
11	0	Riparian Loss	165	0	0	0	33	9	81
13	2	Historic Loss	20	0	0	0	8	9	82
14	2	Historic Loss	122	0	0	10	10	9	84
15	3	Historically Present	30	0	0	0	0	9	0
17	2	Historic Loss	200	0	0	72	72	9	87
20	1	Streambank Loss	25	0	0	5	7	9	0
22	0	Riparian Loss	446	0	0	17	17	9	0
23	2	Historic Loss	27	0	0	0	9	10	97
24	1	Streambank Loss	90	0	0	0	7	10	100
25	2	Historic Loss	17	0	0	0	8	10	100
26	2	Historic Loss	69	0	0	0	6	10	101
27	0	Riparian Loss	300	0	0	50	50	10	0
31	0	Riparian Loss	50	0	0	0	18	6	0
32	0	Riparian Loss	465	0	0	10	21	6	0
33	1	Streambank Loss	132	10	6600	0	15	6	0
35	0	Riparian Loss	183	10	9150	0	20	6	0
37	0	Riparian Loss	20	0	0	8	23	6	0
38	1	Streambank Loss	100	0	0	7	51	6	0
38	1	Streambank Loss	100	0	0	7	51	6	0
40	0	Riparian Loss	16	0	0	50	50	6	0
41	0	Riparian Loss	120	0	0	40	49	6	0
43	3	Historically Present	81	0	0	8	9	7	0
45	2	Historic Loss	17	5	425	10	12	7	62
46	0	Riparian Loss	250	0	0	11	16	7	0
47	0	Riparian Loss	20	0	0	19	34	7	0
48	0	Riparian Loss	42	0	0	10	24	7	0
49	0	Riparian Loss	145	7	5075	44	55	7	0
50	2	Historic Loss	120	9	5400	0	10	7	65
51	2	Historic Loss	65	0	0	0	12	7	65
55	0	Riparian Loss	275	0	0	0	27	7	0
56	0	Riparian Loss	110	0	0	15	27	7	0
57	0	Riparian Loss	20	0	0	10	12	7	69
61	2	Historic Loss	100	0	0	0	10	7	72
62	2	Historic Loss	100	4	2000	5	16	7	72
63	2	Riparian Loss	430	30	64500	11	22	7	72
64	2	Historic Loss	145	5	3625	0	10	7	73
65	0	Riparian Loss	155	5	3875	36	43	7	0
67	0	Riparian Loss	300	0	0	33	42	8	0
68	0	Riparian Loss	59	0	0	35	44	8	0
69	3	Historically Present	75	0	0	22	48	8	0
70	0	Riparian Loss	42	0	0	100	110	8	0
71	0	Riparian Loss	86	0	0	24	47	8	0
72	0	Riparian Loss	29	0	0	25	41	8	0
73	0	Riparian Loss	74	0	0	26	36	8	0
74	0	Riparian Loss	318	0	0	29	36	8	0
75	0	Riparian Loss	82	0	0	0	37	8	0

No Previous Canopy

NFID	ID	ER_FEATURE	ER_LENGTH	ER_WIDTH	ER_Volume	Canopy_N	Canopy_O	HUC_ID	OFID
5	2	Historic Loss	150	6	4500	0	0	9	76
18	2	Historic Loss	20	0	0	0	0	9	95
19	1	Streambank Loss	30	0	0	0	0	9	0
34	1	Streambank Loss	48	5	1200	0	0	6	0
36	2	Historic Loss	12	5	300	0	0	6	56
39	2	Historic Loss	60	0	0	0	0	6	57
42	2	Historic Loss	130	0	0	0	0	6	58
44	2	Historic Loss	150	0	0	0	0	7	61
52	2	Historic Loss	35	0	0	0	0	7	67
53	1	Streambank Loss	40	0	0	0	0	7	0
54	2	Historic Loss	230	5	5750	0	0	7	68
58	2	Historic Loss	20	0	0	0	0	7	70
59	1	Streambank Loss	25	0	0	0	0	7	70
60	2	Historic Loss	120	9	5400	0	0	7	71
66	1	Streambank Loss	80	0	0	0	0	8	74

Appendix C1. Altoona Flow Data

Month	Day	Day of year	1951	2007	Month	Day	Day of year	1951	2007
April	1	122	1,930	333	May	1	152	320	221
April	2	123	6,160	425	May	2	153	285	1850
April	3	124	9,180	463	May	3	154	246	3180
April	4	125	5,750	485	May	4	155	211	630
April	5	126	797	625	May	5	156	201	258
April	6	127	550	686	May	6	157	188	735
April	7	128	468	6,640	May	7	158	175	1,200
April	8	129	400	6,960	May	8	159	1230	1,180
April	9	130	383	1,100	May	9	160	3420	1,180
April	10	131	2,390	1,920	May	10	161	2,200	1,820
April	11	132	3,510	2,380	May	11	162	900	1,930
April	12	133	1,690	3,030	May	12	163	800	2,070
April	13	134	700	3,040	May	13	164	3720	693
April	14	135	420	2,980	May	14	165	3460	155
April	15	136	370	3,000	May	15	166	750	579
April	16	137	350	3,090	May	16	167	417	274
April	17	138	1,350	2,930	May	17	168	3,590	496
April	18	139	3,020	3,350	May	18	169	4,740	703
April	19	140	2,310	3,560	May	19	170	1,040	710
April	20	141	3,300	3,480	May	20	171	431	395
April	21	142	2,700	3,360	May	21	172	1,390	142
April	22	143	6,060	2,700	May	22	173	1,690	124
April	23	144	5,230	1,670	May	23	174	5,830	118
April	24	145	4,660	868	May	24	175	8,180	120
April	25	146	1,690	650	May	25	176	12,300	115
April	26	147	1,650	648	May	26	177	15,600	116
April	27	148	1,960	220	May	27	178	14,700	113
April	28	149	1,010	214	May	28	179	5,580	111
April	29	150	471	259	May	29	180	930	2760
April	30	151	373	233	May	30	181	6780	11900
					May	31	182	24900	45700

Month	Day	Day of year	1951	2007	Month	Day	Day of year	1951	2007
July	1	214	181	4260	July	1	214	181	4260
July	2	215	166	4180	July	2	215	166	4180
July	3	216	150	3310	July	3	216	150	3310
July	4	217	134	2630	July	4	217	134	2630
July	5	218	125	2610	July	5	218	125	2610
July	6	219	112	2590	July	6	219	112	2590
July	7	220	101	2,550	July	7	220	101	2,550
July	8	221	99	2,510	July	8	221	99	2,510
July	9	222	228	2,470	July	9	222	228	2,470
July	10	223	1,390	2,420	July	10	223	1,390	2,420
July	11	224	1,580	2,290	July	11	224	1,580	2,290
July	12	225	1,880	2,220	July	12	225	1,880	2,220
July	13	226	1880	2,150	July	13	226	1880	2,150
July	14	227	475	739	July	14	227	475	739
July	15	228	588	130	July	15	228	588	130
July	16	229	360	100	July	16	229	360	100
July	17	230	213	69	July	17	230	213	69
July	18	231	177	63	July	18	231	177	63
July	19	232	152	64	July	19	232	152	64
July	20	233	134	64	July	20	233	134	64
July	21	234	189	63	July	21	234	189	63
July	22	235	1,610	44	July	22	235	1,610	44
July	23	236	1,160	25	July	23	236	1,160	25
July	24	237	471	18	July	24	237	471	18
July	25	238	1,120	26	July	25	238	1,120	26
July	26	239	873	27	July	26	239	873	27
July	27	240	3,380	18	July	27	240	3,380	18
July	28	241	7,060	15	July	28	241	7,060	15
July	29	242	6800	100	July	29	242	6800	100
July	30	243	2080	108	July	30	243	2080	108
July	31	244	645	166	July	31	244	645	166

Appendix C2. Independence Flow Data.

Month	Day	Day of Year	1951	2007	Month	Day	Day of Year	1951	2007
April	1	122	4,210	1,990	May	1	152	3,300	1,570
April	2	123	16,200	3,950	May	2	153	2,240	2,010
April	3	124	15,500	4,830	May	3	154	1,180	13,700
April	4	125	10,300	3,980	May	4	155	673	10,200
April	5	126	4,320	4,240	May	5	156	606	4,310
April	6	127	4,940	3,940	May	6	157	502	7,350
April	7	128	6,030	20,000	May	7	158	466	9,860
April	8	129	5,790	23,600	May	8	159	1,020	9,800
April	9	130	3,450	14,100	May	9	160	5,150	8,450
April	10	131	2,460	5,670	May	10	161	10,300	7,380
April	11	132	6,190	7,880	May	11	162	6,240	7,570
April	12	133	4,060	8,980	May	12	163	3,060	14,200
April	13	134	2,540	9,400	May	13	164	7,920	9,320
April	14	135	2,010	9,360	May	14	165	9,170	6,790
April	15	136	1,840	10,100	May	15	166	2,810	6,230
April	16	137	1,580	10,500	May	16	167	1,240	4,920
April	17	138	1,730	10,400	May	17	168	2,340	6,600
April	18	139	3,690	10,800	May	18	169	5,790	6,490
April	19	140	3,530	10,400	May	19	170	3,510	5,730
April	20	141	6,920	9,810	May	20	171	1,130	3,450
April	21	142	4,530	9,580	May	21	172	4,150	749
April	22	143	10,100	8,860	May	22	173	4,090	709
April	23	144	20,800	6,930	May	23	174	6,210	573
April	24	145	12,000	5,300	May	24	175	13,500	460
April	25	146	4,670	1,820	May	25	176	15,800	450
April	26	147	4,320	1,280	May	26	177	25,100	409
April	27	148	6,330	893	May	27	178	24,500	377
April	28	149	7,000	544	May	28	179	18,800	499
April	29	150	5,700	658	May	29	180	6,020	6,380
April	30	151	6,120	1,340	May	30	181	13,300	24,700
					May	31	182	38,200	83,700

Month	Day	Day of Year	1951	2007	Month	Day	Day of Year	1951	2007
June	1	183	89,200	146,000	July	1	214	10,100	10,500
June	2	184	77,600	96,900	July	2	215	9,150	10,100
June	3	185	39,000	51,100	July	3	216	7,540	10,200
June	4	186	31,400	34,600	July	4	217	5,230	10,800
June	5	187	29,800	30,100	July	5	218	995	9,980
June	6	188	25,400	25,500	July	6	219	575	9,800
June	7	189	18,000	20,900	July	7	220	463	10,000
June	8	190	11,200	18,800	July	8	221	393	9,960
June	9	191	10,300	17,100	July	9	222	420	9,870
June	10	192	17,100	11,500	July	10	223	960	9,270
June	11	193	26,600	6,540	July	11	224	2,200	7,920
June	12	194	27,300	5,460	July	12	225	2,350	7,430
June	13	195	57,900	3,400	July	13	226	2,920	6,870
June	14	196	68,400	3,550	July	14	227	1,640	4,870
June	15	197	49,100	4,210	July	15	228	1,100	1,420
June	16	198	32,100	5,220	July	16	229	870	549
June	17	199	24,500	8,320	July	17	230	640	405
June	18	200	15,200	9,200	July	18	231	442	269
June	19	201	9,630	9,350	July	19	232	320	251
June	20	202	9,040	9,250	July	20	233	230	240
June	21	203	8,610	8,760	July	21	234	170	186
June	22	204	7,960	10,200	July	22	235	862	170
June	23	205	6,120	9,070	July	23	236	1,910	128
June	24	206	4,720	9,880	July	24	237	1,680	100
June	25	207	5,770	10,100	July	25	238	960	97
June	26	208	5,960	10,000	July	26	239	1,380	87
June	27	209	6,490	9,940	July	27	240	1,720	86
June	28	210	6,660	9,870	July	28	241	5,480	82
June	29	211	7,460	10,000	July	29	242	8,220	72
June	30	212	8,200	10,200	July	30	243	6,780	65
June	31	213	9,300	11,500	July	31	244	3,040	127

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