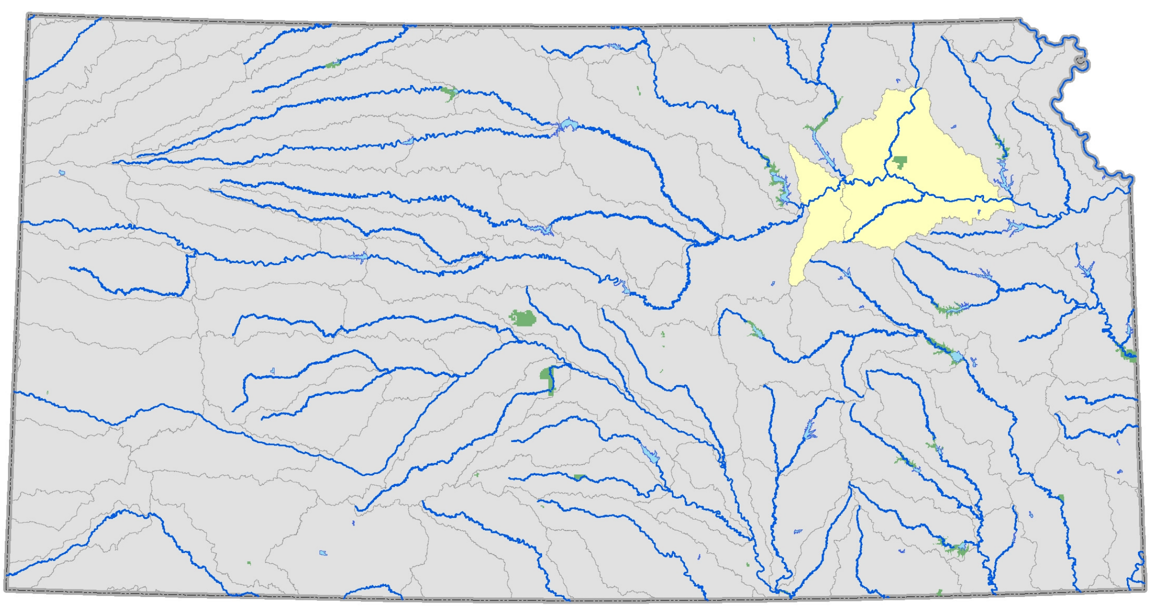
The Watersheds of the Middle and Upper Kansas Sub-Basins

A Report on the Water Quality and Lands



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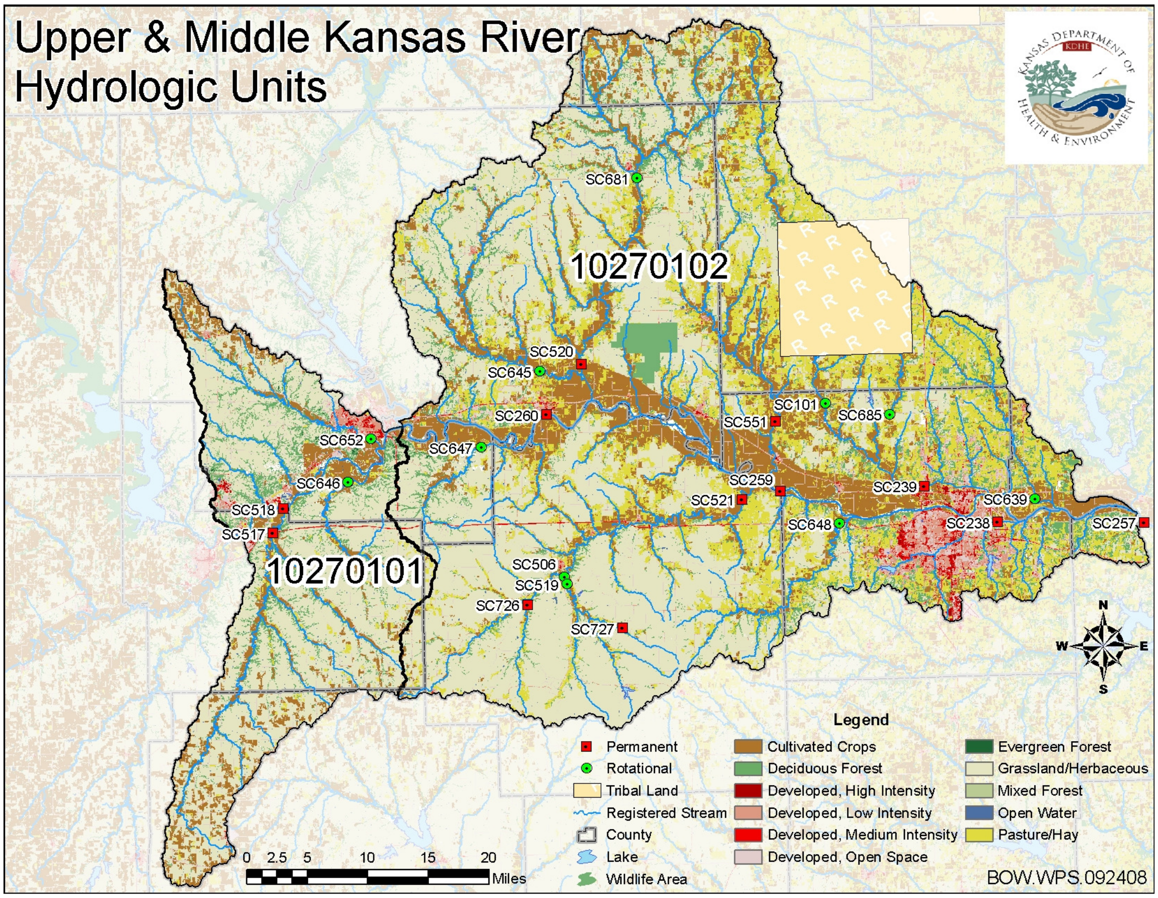
A Sub-Basin Overview:

The Upper and Middle Kansas subbasins (10270101 and 10270102, respectively) (Figure 1) cover approximately 2,700 square miles, largely contained in the Middle Kansas subbasin, which is more than 2,150 square miles. These hydrologic units begin at the junction of the Smoky Hill & Republican Rivers in Geary County near Junction City, and extend downstream to the junction of the Kansas River and the Delaware River on the border between Jefferson and Douglas County northwest of Lawrence.

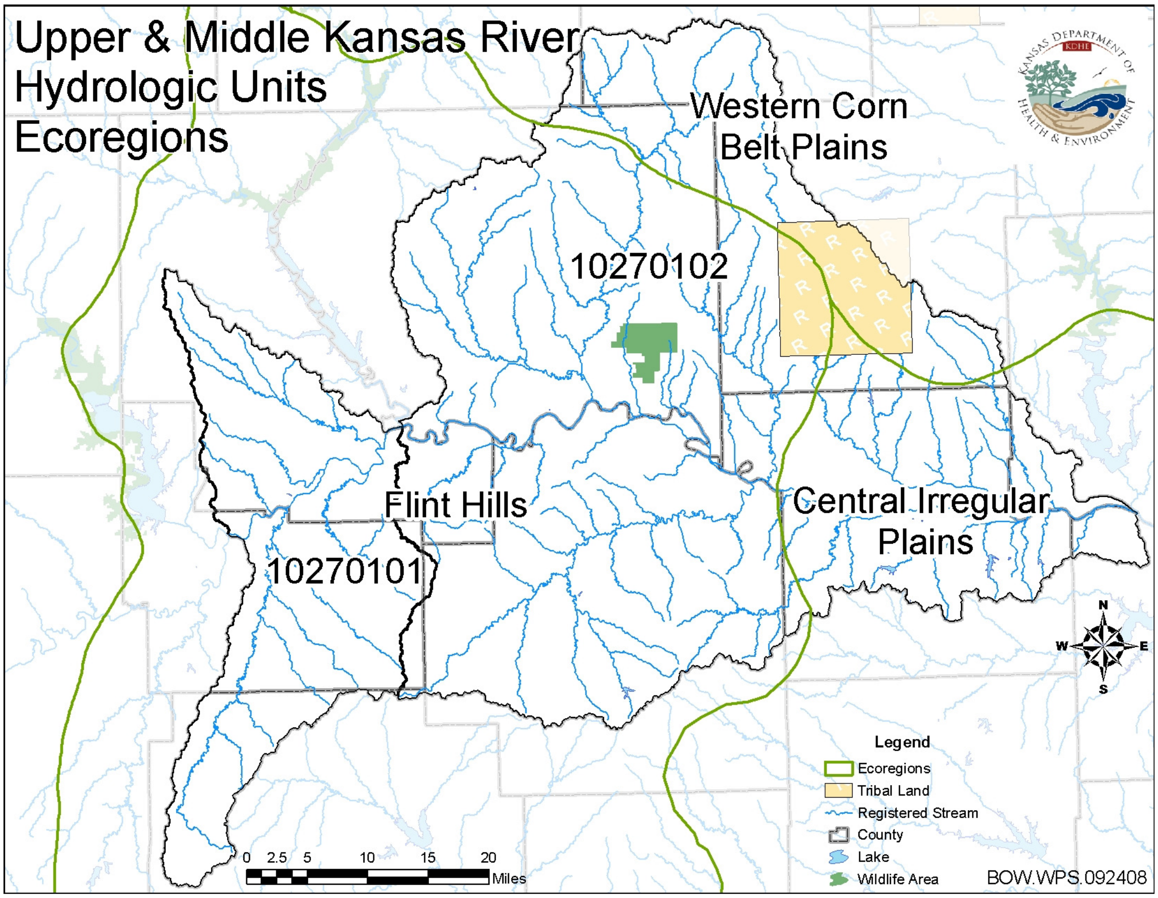


The Upper & Middle Kansas hydrologic units, and associated land uses.

This area contains 22 Kansas Department of Health & Environment (KDHE) stream chemistry monitoring stations, and drains to a 23rd station, SC257, which monitors the Kansas River below the junction with the Delaware River. These stations are evenly divided between permanent stations (11), which are sampled six times per year every year, and rotational stations (11), which are sampled six times per year during every fourth year. Three stations monitor the Kansas River, and the remaining 19 monitor tributary streams.

In addition to the tributary streams included in these two hydrologic units, water quality at Kansas River stations is influenced by the Big Blue River, the Republican River and the Smoky Hill River. The total watershed that drains to this area includes over 50,000 square miles stretching into Nebraska and Colorado.

The area includes parts of three ecoregions (Figure 2), dominated by the Flint Hills (71%), with smaller areas of Western Corn Belt Plains (12%) & Central Irregular Plains (17%) in the east.



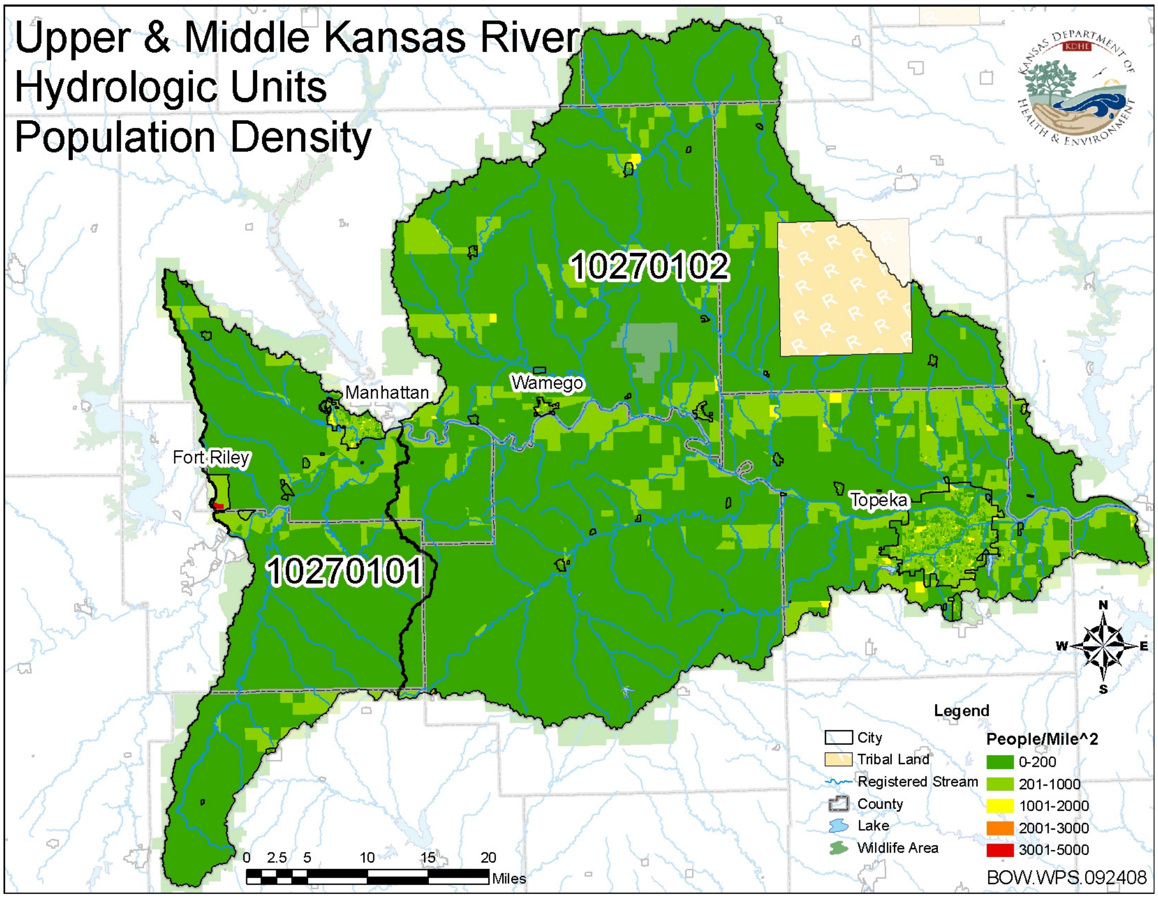
Ecoregions of the Upper & Middle Kansas River hydrologic units.

Land use over the region is dominated by permanent grassland, with significant amounts of row crop production in the alluvial valleys (Table 1, Figure 1). The remainder of the land is largely in woodland areas, typically concentrated around streams and rivers, and developed land concentrated in the cities of the region.

Permanent Grass	65.01%
Cropland	16.08%
Forest	10.29%
Developed Land	7.37%

Land use in the Upper and Middle Kansas hydrologic units. Other minor uses account for the remaining 1% of cover. Land use data drawn from the 2001 National Land Cover Dataset.

As of the 2000 census, the population of the area was slightly more than 250,000 people, largely contained in the cities along the Kansas River (Figure 3). Topeka had nearly half the total population of the area (122,377), Manhattan had nearly 18% (44,831), though some of the Manhattan city limits lie outside these hydrologic units, and the remainder of the population was spread out between smaller cities and the rural areas.



Population density derived from 2000 federal census block figures, and major cities within the Upper and Middle Kansas hydrologic units.

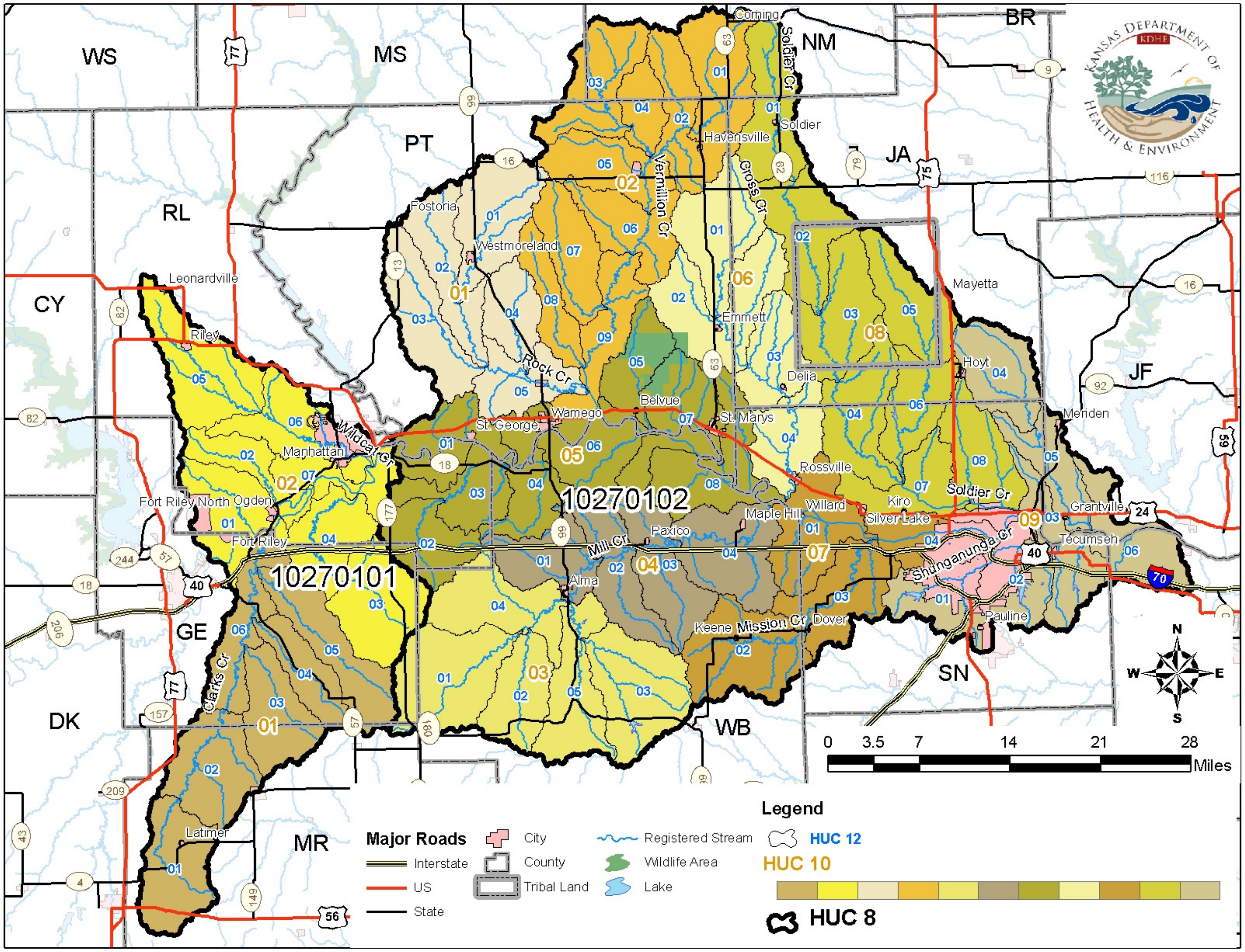
Political jurisdictions in the area include cities, counties, watershed districts, federal lands owned by the Department of Defense, tribal lands within the Prairie Band Pottawatomi reservation, state lands operated by both university and the Kansas Department of Wildlife & Parks, and privately held rural land, which comprises most of the area. The area is completely contained within Kansas' Second Congressional District.

The Mid and Upper-Kansas sub-basins include a large number of subwatershed level boundaries. These hydrologic units, or HUCs, are areas of approximately equal size that share drainage to a common point. They differ from true watersheds in that most have one or more HUC upstream from them, providing water from an area not included in the HUC. In addition a recent change has been made in the identification numbers of the HUCs. A map and explanation of the HUCs of the Mid and Upper-Kansas follows.

In April, 2008, EPA in conjunction with partner agencies released the complete, nationwide GIS coverage data for consistent watershed boundaries in all fifty states. While Kansas has used a HUC8/11/14 system for some years, our neighboring states, and many others have used a HUC8/10/12 system. The disparity has caused some confusion, and required regular explanations to a variety of stakeholders about the reason Kansas system was not consistent with the numbering system used by our neighbors. To avoid future confusion Kansas is officially adopting the HUC8/10/12 system, which will require some re-education of stakeholders and professionals here in Kansas, to ensure that we successfully adopt this new system. In general, the shift is fairly ordinary, as very few of the actual boundaries of Kansas HUC14s were changed when they received their new numbers as HUC12s. Where changes occurred, they typically involved HUCs that were near, or crossing the state boundary, and were adjusted to ensure consistency between neighboring states.

To convert a HUC14 to a HUC12 you remove the trailing zero on each of the sub-codes, so that HUC14 10270102(090)(010) becomes HUC12 10270102(09)(01). This also means that HUC11 10270102(090) becomes HUC10 10270102(09). Below is a map showing the location of the HUC12s in the Mid and Upper-Kansas area. To simplify reading the map, the individual units have been labeled only with their subcodes, and color coded at each level to clarify which part of the HUC12 number is being specified. The HUC10s are color coded, so that any particular group of HUC12s that belong to the same HUC10 are colored the same color as each other. HUC8 codes are marked in black, HUC10 subcodes are marked in orange and HUC12 subcodes are marked in blue.

An example of how to determine the HUC12 within this map-
Westmoreland, located on Highway 99 in Pottawatomie County is on the upper reaches of East Branch Rock Creek. Just north of the town, in small blue numbers is 01, the HUC12 subcode. Just south of the town, in medium sized orange numbers is 01, the HUC10 subcode. In the center of the map in large black letters is **10270102**, the HUC8 code. Westmoreland, then, is located in **10270102**0101, or in ordinary font, 102701020101.


10270101
10270102
WS
MS
PT
RL
CY
GE
DK
MR
WB
SN
JA
JF
NM
BR
Corning
Soldier
Havensville
Fostoria
Westmoreland
Leonardville
Riley
Emmett
Mayetta
Hoyt
Delia
Belvue
Wamego
St. George
St. Marys
Manhattan
Rossville
Fort Riley North
Ogden
Fort Riley
Willard
Maple Hill
Kiro
Silver Lake
Menden
Grantville
Tecumseh
Paxico
Alma
Keene
Dover
Pauline
Latimer
Vermillion Cr
Cross Cr
Soldier Cr
Rock Cr
Wildcat Cr
Mill Cr
Mission Cr
Shunganunga Cr
Clarks Cr
Legend
Major Roads
Interstate
US
State
City
County
Tribal Land
Registered Stream
Wildlife Area
Lake
HUC 12
HUC 10
HUC 8
0
3.5
7
14
21
28
Miles
N
S
E
W

Water Quality-

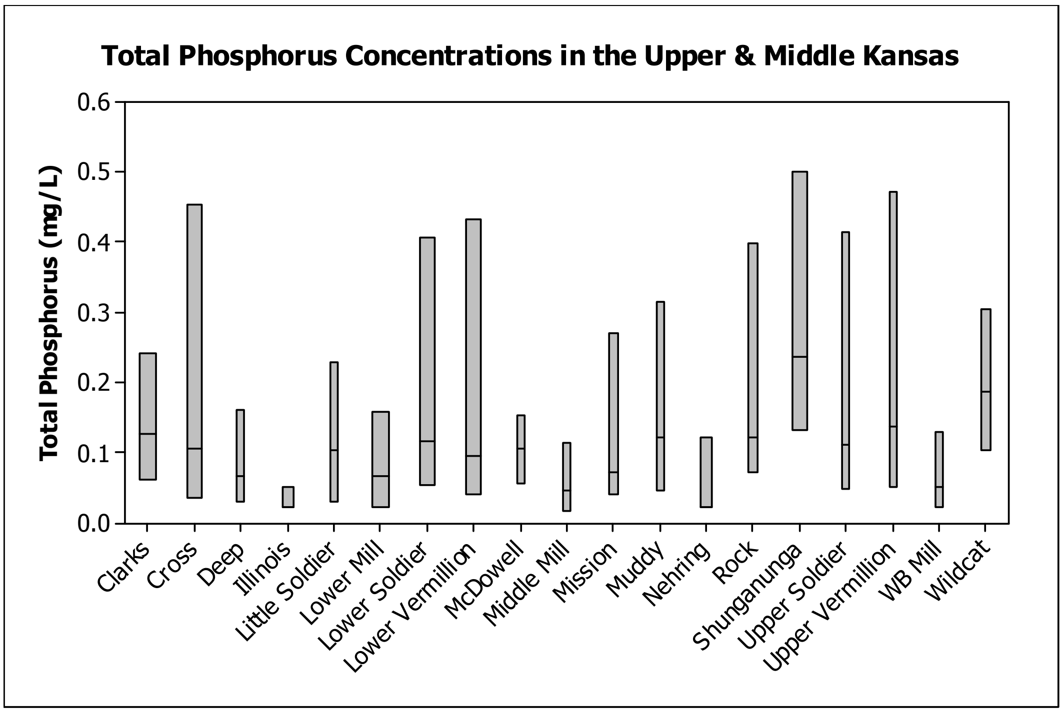
Water quality in the area ranges from exceptional, including a national United States Geological Station benchmark stream to severely degraded. Major influences on the water quality include row crop production, unstable streambanks, cattle grazing, impervious surfaces and urban discharge.

Because this region is largely impacted by nutrients, sediment and bacteria, a ranking approach was used to determine the relative quality at each of the 19 monitoring stations on tributaries. Because these stations have differing record lengths, and because many of these pollutants exhibit a non-normal data distribution, a non-parametric approach similar to the Kruskal-Wallis test was used. The dataset for each included station (1990-2007) was drawn from the KDHE database, and ranked by parameter for total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS) and *E. coli*. The median rank was determined for each site for each parameter. An overall assessment of the condition relative to these four parameters was generated by summing the median rank for each parameter at a site (TN median rank + TP median rank + TSS median rank + *E. coli* median rank). The results of this analysis are presented in Table 2.

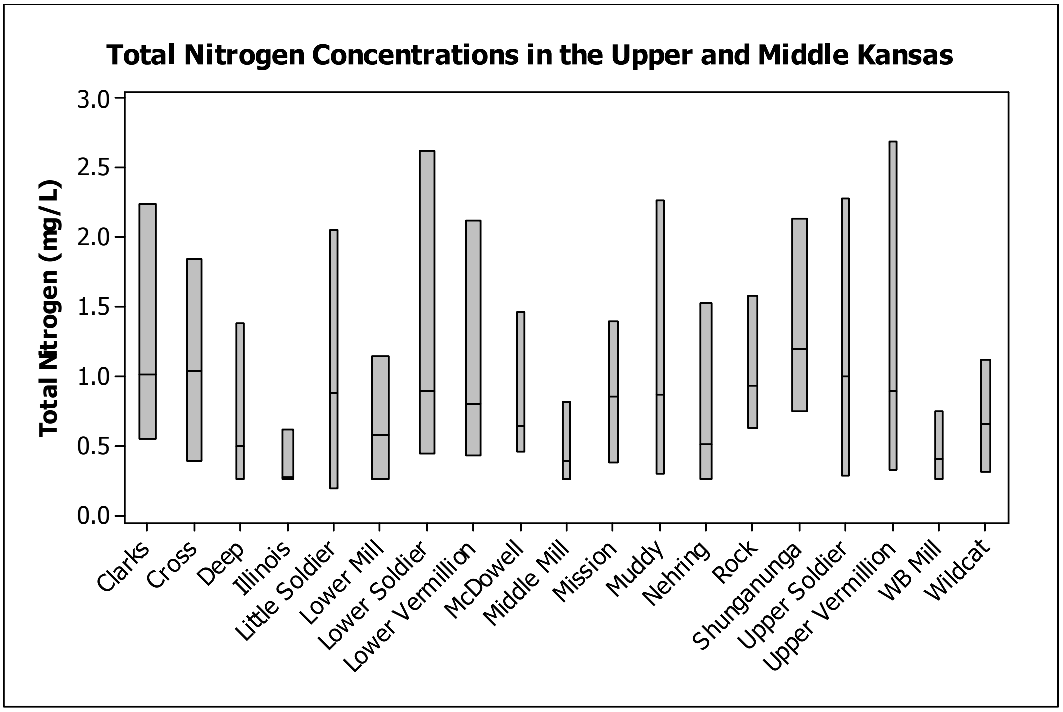
Station	Stream Name	Overall Rank	TP Rank	TN Rank	TSS Rank	*E. coli* Rank
SC726	Illinois Creek	1	2	1	1.5	3
SC519	Middle Mill Creek	2	3	2	3	1.5
SC506	West Branch Mill Creek	3	4	3	4	1.5
SC727	Nehring Creek	4	1	5	1.5	7
SC647	Deep Creek	5	5	4	6	9
SC521	Lower Mill Creek	6	6	6	9	4
SC646	McDowell Creek	7	10	7	7	5
SC648	Mission Creek	8	7	10	8	16
SC520	Lower Vermillion Creek	9	8	9	17	8
SC685	Little Soldier Creek	10	9	12	5	18
SC652	Wildcat Creek	11	18	8	10	14
SC517	Clarks Creek	12	16	17	11.5	6
SC239	Lower Soldier Creek	13	13	14	13	11
SC681	Upper Vermillion Creek	14	17	13	11.5	10
SC639	Muddy Creek	15	15	11	14.5	17
SC551	Cross Creek	16	11	18	18	12
SC101	Upper Soldier Creek	17	12	16	19	13
SC645	Rock Creek	18	14	15	14.5	19
SC238	Shunganunga Creek	19	19	19	16	15

Relative ranks by parameter and overall condition of the 19 tributary monitoring stations located within the Upper and Middle Kansas hydrologic units. Monitoring stations locations are included in figure 1.

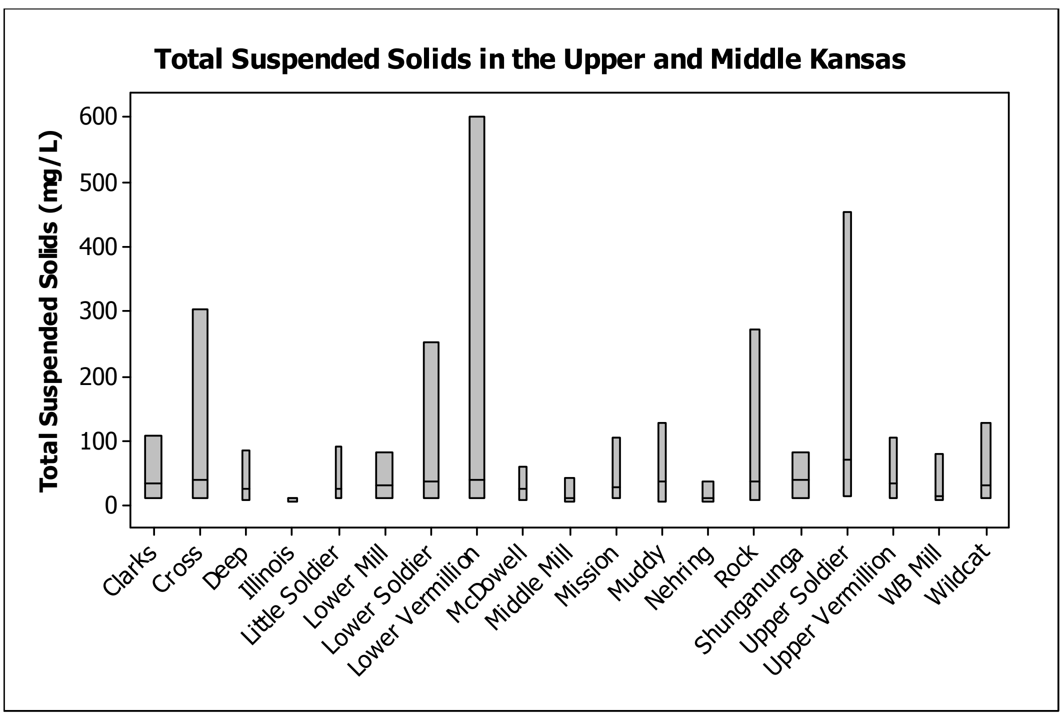
The top 8 overall ranks were assigned to streams draining the south central portion of the area, and represent areas with relatively low cropland uses. The poorest overall rank is assigned to Shunganunga Creek, which captures a large portion of the city of Topeka upstream of the monitoring station. Shunganunga Creek is the receiving stream for wastewater discharge from the Sherwood Improvement District, which is authorized for a design flow 2.4 million gallons per day, and currently receives about a million gallons per day of discharge. During estimated median flow this discharge may account for as much as half of the flow in Shunganunga Creek. Other poorly ranking streams tend to be located in the north-central and northeastern portions of the area, areas dominated by cropland.



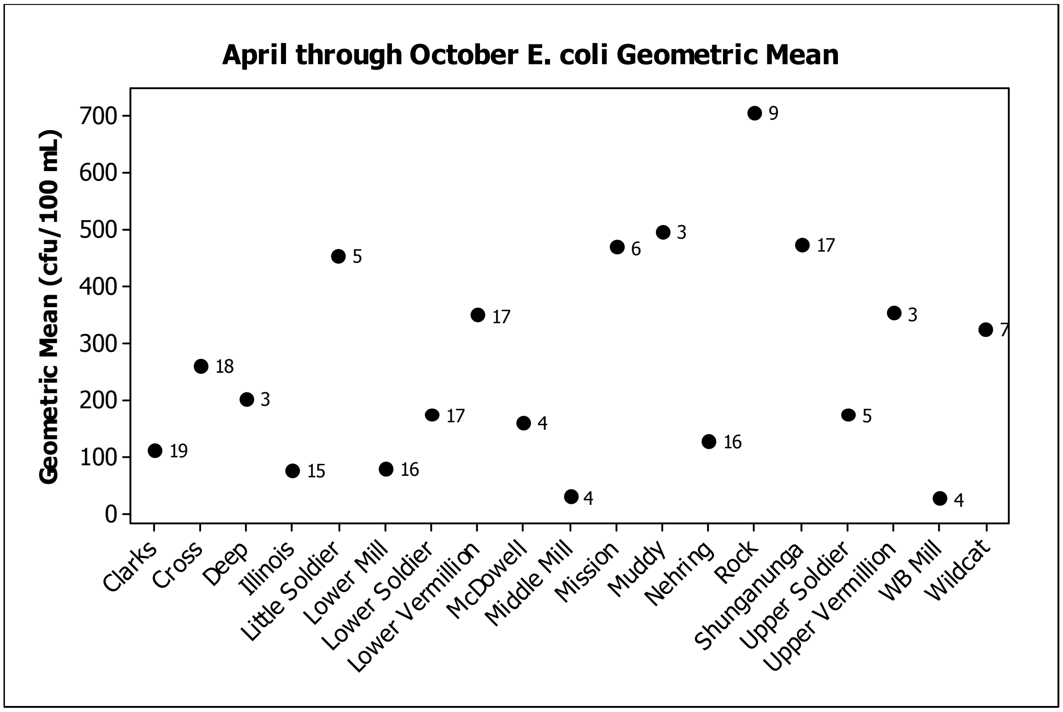
Total phosphorus concentrations in tributary streams in the Upper and Middle Kansas hydrologic units. Box indicates the 10th, 50th and 90th percentiles of the data. Box width is proportional to sample size.



Total nitrogen concentrations in tributary streams in the Upper and Middle Kansas hydrologic units. Box indicates the 10th, 50th and 90th percentiles of the data. Box width is proportional to sample size.



Total suspended solids concentrations in tributary streams in the Upper and Middle Kansas hydrologic units. Box indicates the 10th, 50th and 90th percentiles of the data. Box width is proportional to sample size.



Geometric mean of *E. coli* concentrations in tributary streams in the Upper and Middle Kansas hydrologic units during the months of the primary recreation season. Data labels indicate sample size.)

A detailed description of selected watersheds, their monitoring stations and their contributing areas follows.

Clarks Creek-

Monitoring Station- SC517
USGS Gaging Station- 06879200, 10/1/1957-9/30/1965
Included area-
HUC 8: 10270101
HUC 10: 01
HUC 12: 01, 02, 03, 04, 05, 06
Streams Flowing to Monitoring Station-

Name	Segment #
Clarks Creek-	8
Clarks Creek-	9
Humbolt Creek-	10
Davis Creek-	18
Dry Creek-	19
Mulberry Creek-	20
Ralls Creek-	21

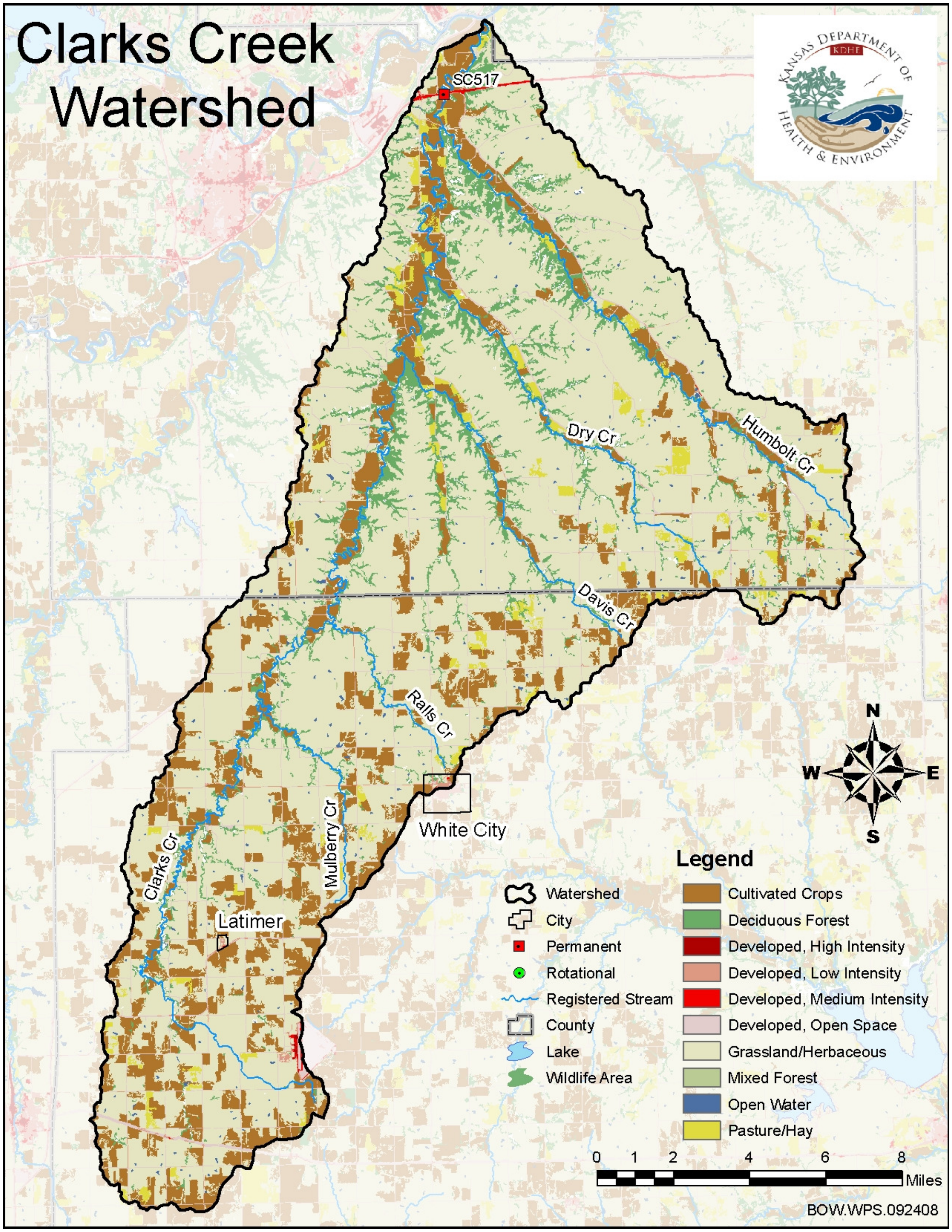
Land use-

Permanent Grass	68.76%
Cropland	17.51%
Forest	9.60%
Developed Land	3.68%

Counties- Geary, Morris
Cities- Latimer, White City
Humboldt Creek Watershed District- Includes only the portion of the watershed draining directly to Humboldt Creek (HUC12-102701010105)
2000 Population- 1,439
Kansas House Districts-65 & 68
Kansas Senate Districts- 17 & 22
Monitored Watershed Size- 247 square miles

2008 303(d) impaired waters- None
TMDLs- Bacteria, approved 1/26/2000
NPDES Permitted Facilities- None
Permitted Confined Animal Feeding Operations-16

Animal Type	Total Animals
Beef	17,775
Dairy	240
Swine	36,772



Overview map of the Clarks Creek watershed. Land use from the 2001 National Land Cover Dataset.

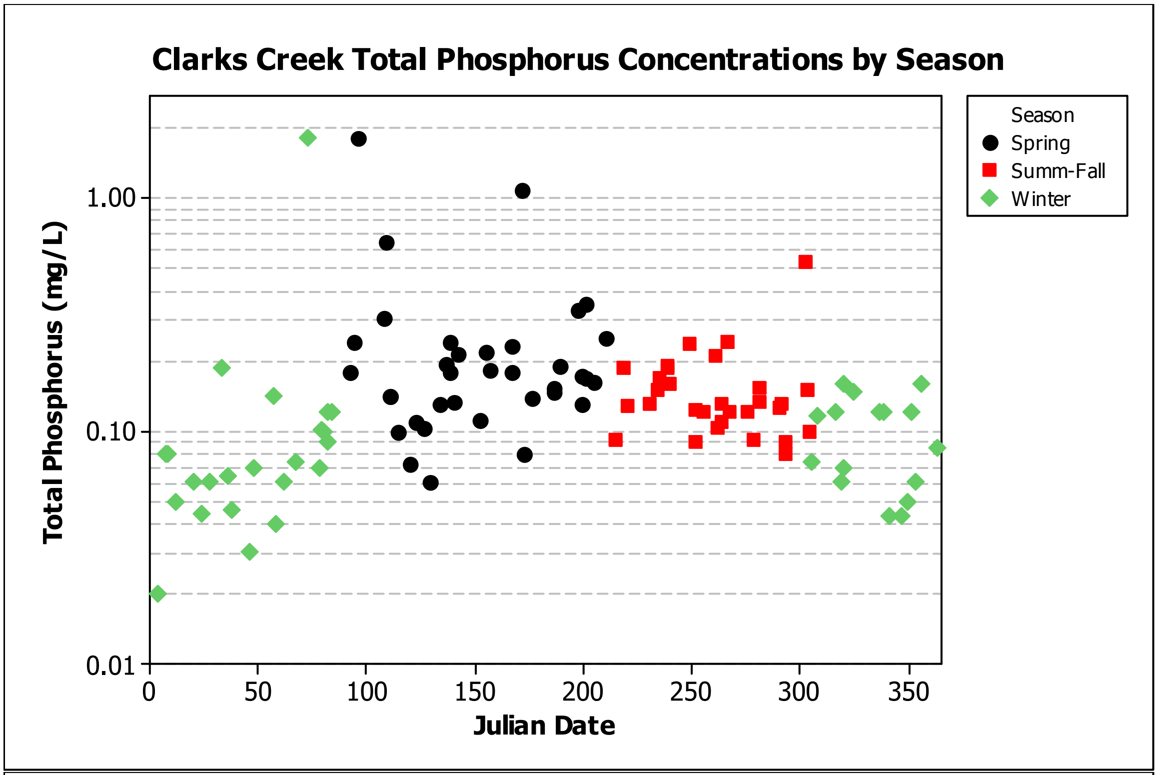
Stream Chemistry-

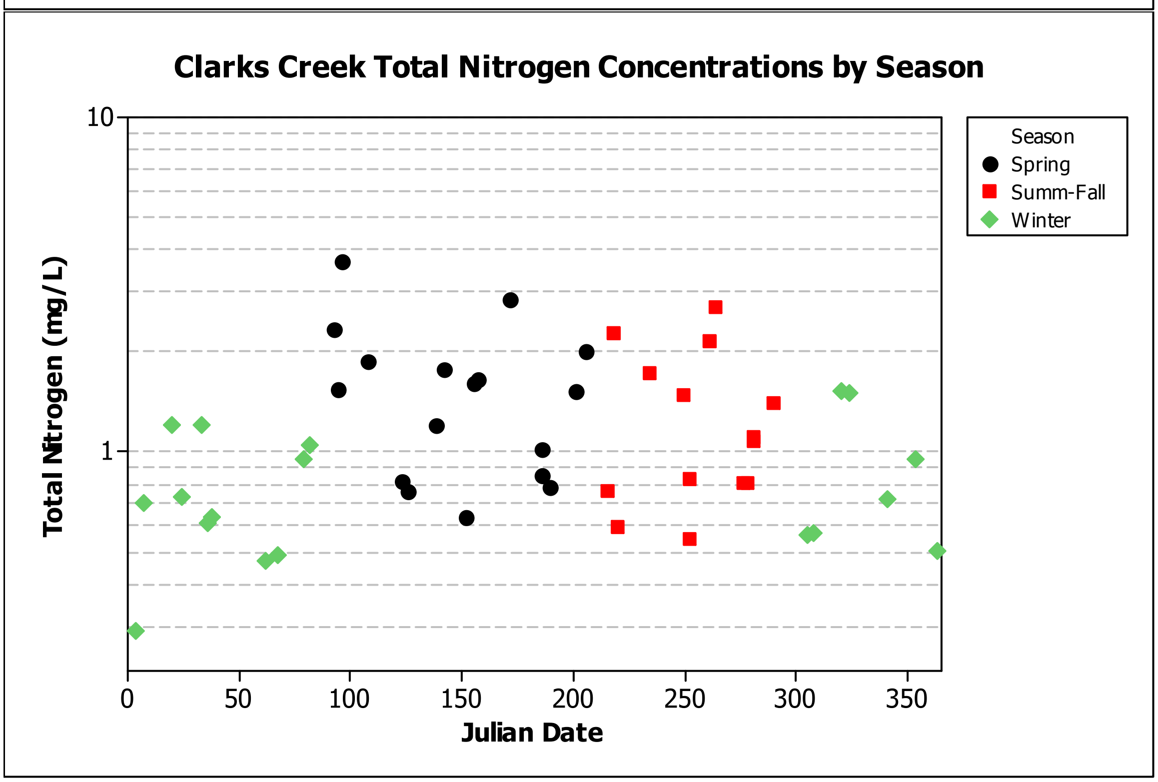
Clarks Creek has a moderate ranking for TSS when compared to other stations in these hydrologic units, a moderately good ranking for *E. coli*, and very poor ranking for total phosphorus and total nitrogen. Clarks Creek experiences its highest pollutant concentrations during the spring season (April-July) some reductions during the summer/fall (August- October), and the lowest concentrations during the winter (November-March). While Clarks Creek does not have an active gaging station, these results are consistent with similar results in other gaged watersheds for areas experiencing runoff and high flow event contamination for sediment, phosphorus and organic nitrogen. Inorganic nitrogen shows no seasonal behavior, with high concentrations occurring throughout the year, suggesting a groundwater input that consistently leaches nitrogen into these streams.

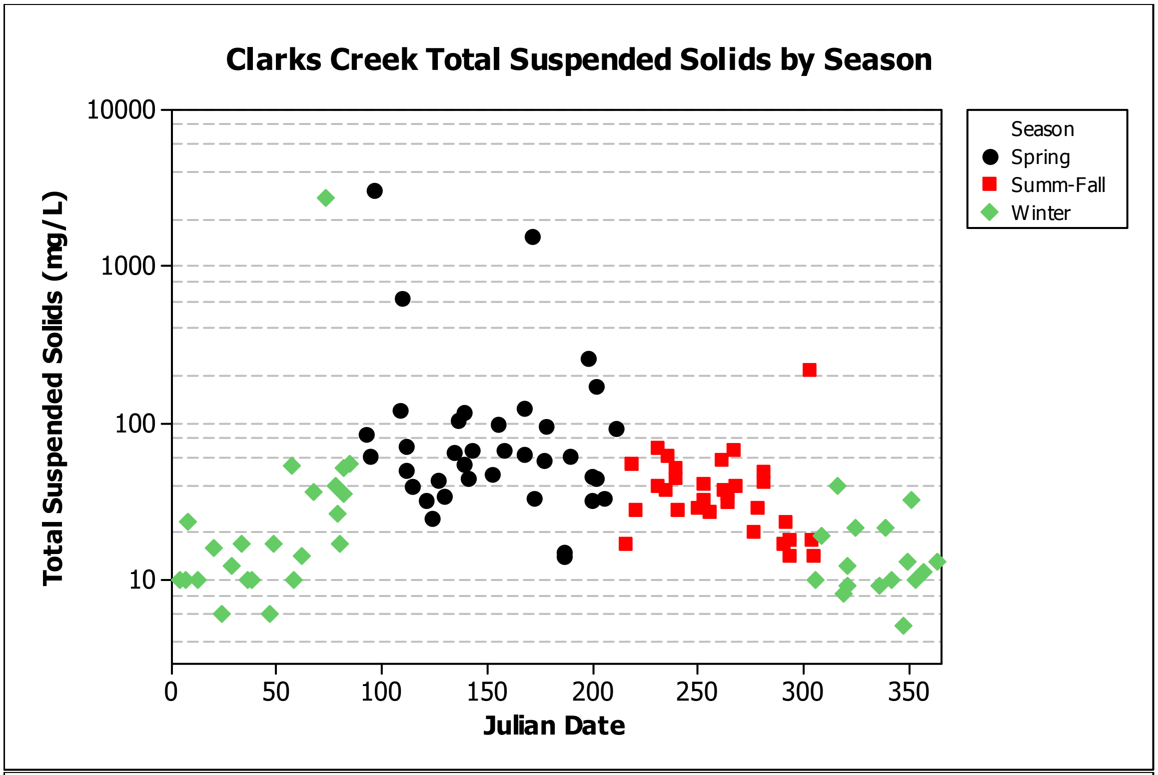
The strong seasonal nature of most of the contaminants suggests that measures targeting soil erosion, including stream bank stabilization, and buffering of streams from cropland will have significant beneficial impacts. Strategies for reducing livestock interaction with streams will likely have positive impacts on the observed bacteria levels. Long-term reductions in dissolved inorganic nitrogen levels may be produced by increased riparian buffering with forest. Once trees develop deep root systems that intercept groundwater flows reductions in inorganic nitrogen loads can be expected. Long-term reductions may occur with increased use of soil testing to ensure that fertilizer application rates do not exceed crop needs.

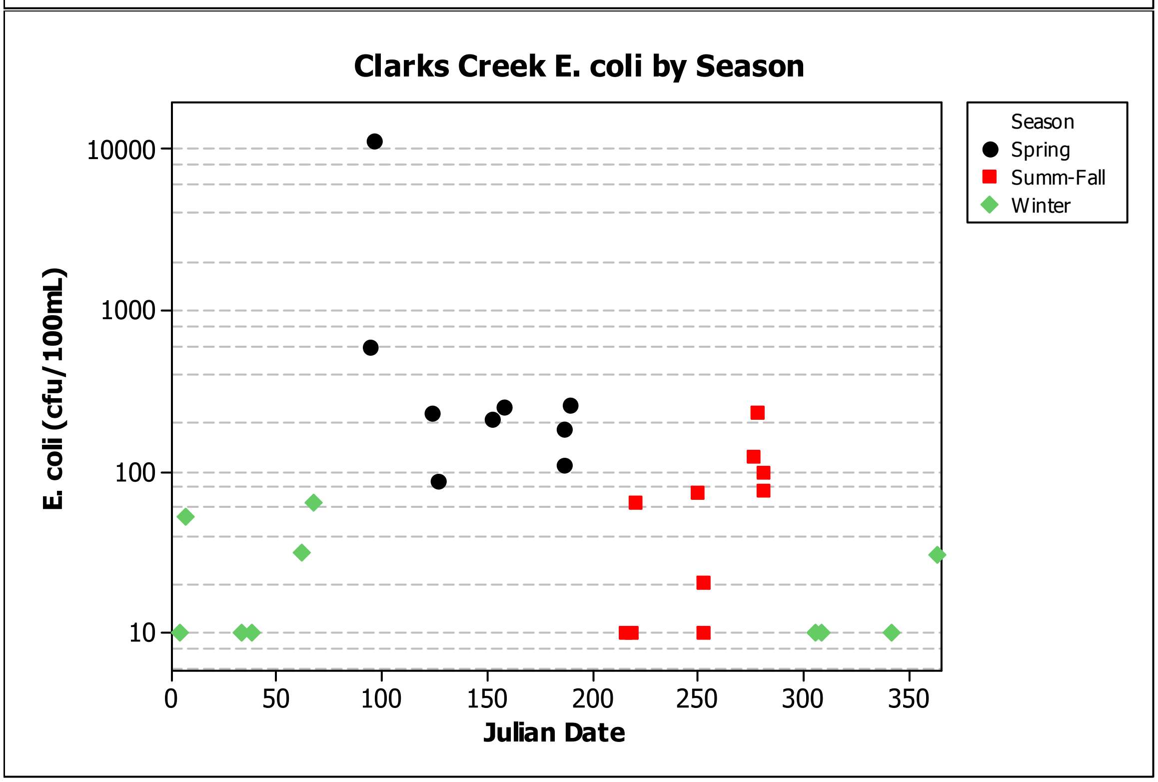
	TP Median	TSS Median	Turbidity Median	TOC Median	Kjeldahl Median	*E.coli* Median	TN Median
Overall	0.1265 (106)	34 (107)	13 (107)	3.776 (42)	0.53 (49)	63 (29)	1.01 (49)
Spring	0.176 (36)	62 (37)	27 (37)	5.688 (15)	0.825 (17)	231 (9)	1.529 (17)
Summer Fall	0.13 (31)	35 (31)	13 (31)	3.105 (13)	0.569 (14)	68 (10)	1.091 (14)
Winter	0.074 (39)	13 (39)	5.85 (39)	3.3565 (14)	0.3715 (18)	≤10 (10)	0.7105 (18)

Numbers in parenthesis indicate sample size.


Clarks Creek Total Phosphorus Concentrations by Season
Total Phosphorus (mg/L)
1.00
0.10
0.01
0
50
100
150
200
250
300
350
Julian Date
Season
Spring
Summ-Fall
Winter

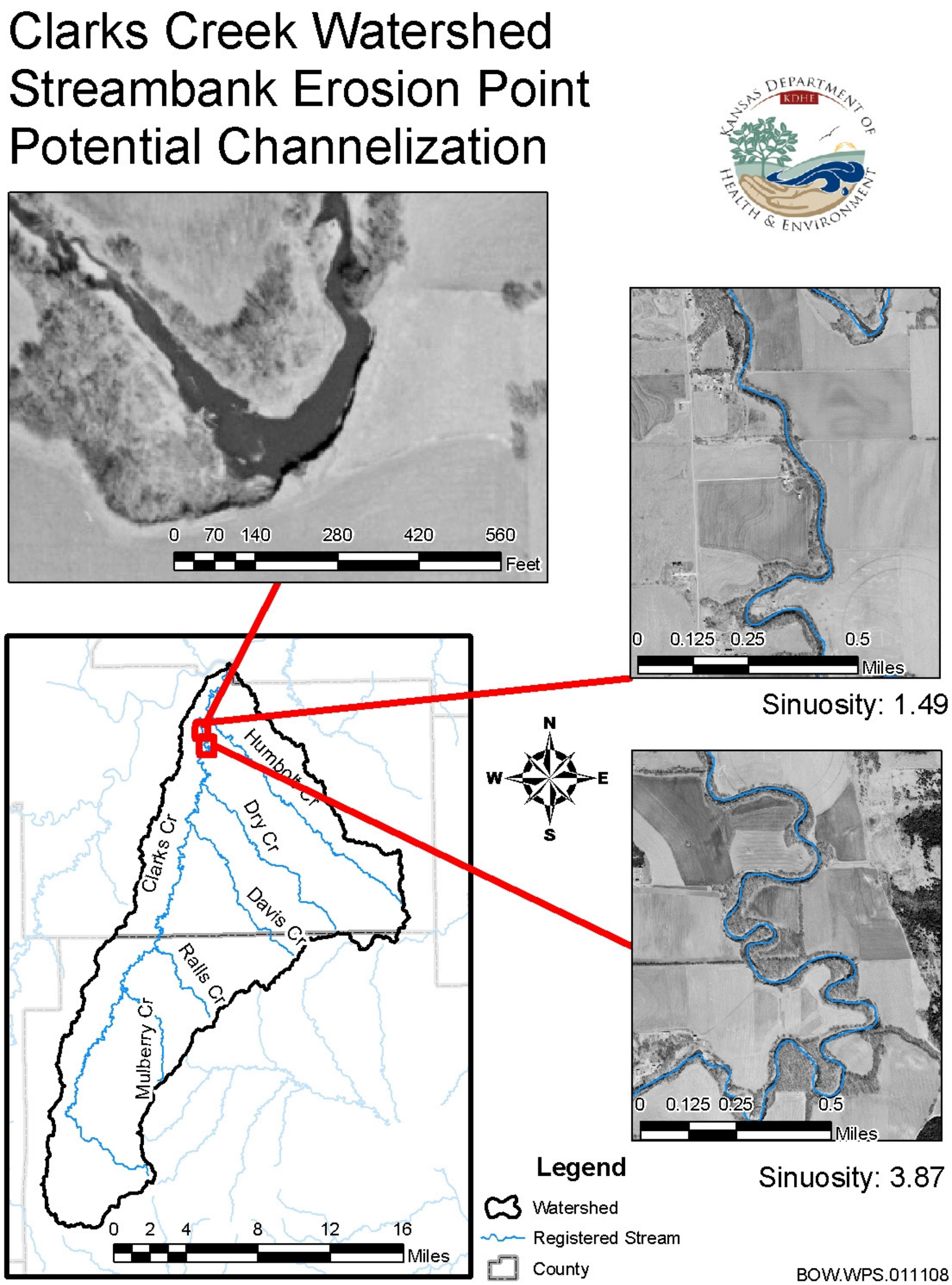

Clarks Creek Total Nitrogen Concentrations by Season
Total Ntrogen (mg/L)
10
1
0
50
100
150
200
250
300
350
Julian Date
Season
Spring
Summ-Fall
Winter





Streambank stabilization may play an important role in improving water quality in the Clarks Creek watershed. One meter resolution aerial photographs were used to identify a number of potential unstable streambanks in the lower reaches of the watershed.

Inspection of stream channel sinuosity also suggests that channelization has occurred, and may be contributing to the observed water quality.



Uncertainty-

Because no gage data are available concurrently with the stream chemistry data, some uncertainty exists about the flow conditions associated with the samples. Very large

TSS values likely occurred during very high flow events, which may be less responsive to restoration efforts (Meals, 1990). Previous research (unpublished) by KDHE has indicated that median values are strong descriptors of nutrient related impairments, even in the absence of flow data, when large sample records exist. At this level of analysis it is not possible to determine the relative contributions of overland flow and in-stream processes, including collapsing streambanks. Elevated nitrogen levels could also be indicative of failing on-site wastewater systems, which cannot be ruled out as a potential contributor at this level of analysis. Future restoration efforts in this area would benefit from more water quality data throughout the watershed, to pinpoint potential sources of pollution, and better define the spatial and temporal variation in water quality. Additionally, surveys of stream channel morphology will locate potential sources of major bank instability.

Adaptive Implementation Strategies-

Because this stream exhibits characteristics that are consistent with both overland flow and unstable streambank sources near the KDHE monitoring station, initial efforts could be focused on the lower reaches of Clarks Creek and Humboldt Creek. These areas epitomize the use of alluvial valleys for row crop production, and show significant signs of poor buffering around the streams. While a bacteria TMDL exists for this watershed, the TMDL was developed under the previous water quality criteria, which dealt with fecal coliform bacteria. The current *E. coli* data show relatively good conditions at the monitoring station, though improvements could be made. Provisions for alternate watering sites, livestock exclusion from streams and ponds, and other efforts to separate the cattle from the streams could prove beneficial to reducing sediment, nutrient and pathogen loading to the streams. Manure management plans for the confined animal operations may also have benefits, depending on their proximity to the stream system.

Because riparian buffering activities typically take three or more years to fully establish themselves, monitoring of post-implementation water quality should be a long-term objective. The existing monitoring record is unlikely to have many high-flow events, due to the design of the sampling program. Because the majority of loads of suspended solids and total phosphorus are likely to occur during a few, relatively large events, a before-and after- sampling program focused on high flow events would determine if efforts lead to significant improvements to water quality. For dissolved inorganic nitrogen, a significant time lag can occur due to elevated groundwater concentrations, which can take many years to reduce. If nitrogen is a priority issue, a groundwater sampling program may be needed to identify critical areas of elevated nitrogen. A less expensive strategy would be to increase the use of soil sampling to target fertilizer delivery to fields at rates unlikely to leach into the groundwater.

It should be noted that some strategies to reduce nutrient pollution have confounding effects. Tillage and cover strategies that reduce runoff and increase infiltration have been documented in some cases to increase nitrogen infiltration to groundwater. Increased infiltration should reduce phosphorus and sediment loading, and riparian planting of forest areas are likely to reduce groundwater loading of nitrogen to the stream, while increasing bank stability. Therefore, implementing strategies should target field runoff for sediment and phosphorus loading, and simultaneously implement riparian restoration.

Should streambank stabilization, riparian planting, and other buffering activities in the lower reaches not reduce sediment and nutrient loading to acceptable levels, targeted monitoring may be required to determine sources more accurately. Funding for practices to improve water quality should focus on lands adjacent to streams in HUC 102701010101, which are more likely to contribute to water quality problems monitored at station 517.

Wildcat Creek-

Monitoring Station- SC652
USGS Gaging Station- None
Included area-
HUC 8: 10270101
HUC 10: 02
HUC 12: 04, 05

Streams flowing to monitoring station-

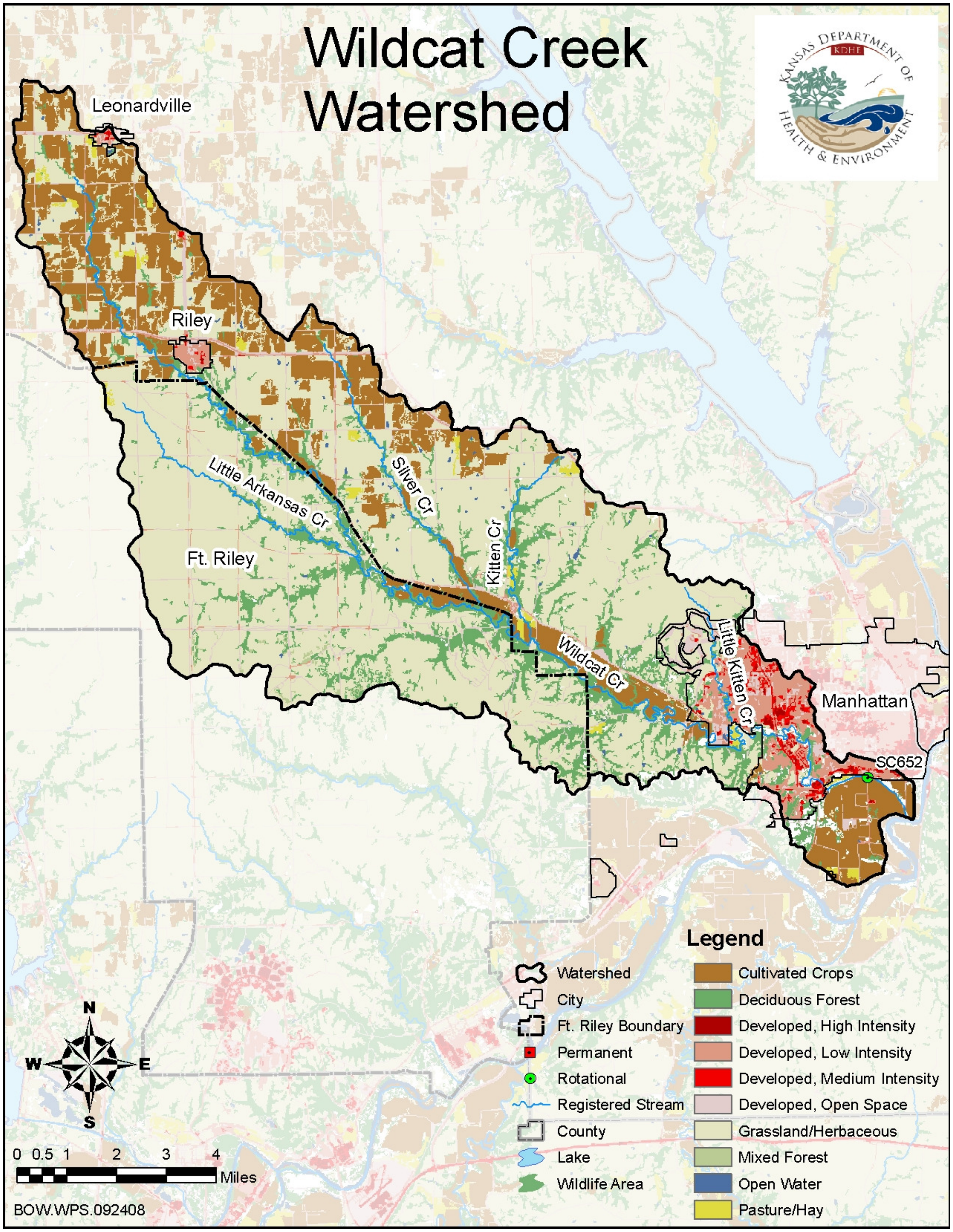
Name	Segment #
Wildcat Creek-	2
Silver Creek-	12
Little Arkansas Creek-	13
Kitten Creek-	14
Little Kitten Creek-	16

Land use-

Permanent Grass	55.61%
Cropland	18.84%
Forest	14.56%
Developed Land	10.68%

Counties- Riley
Cities- Manhattan, Riley, Leonardville, Ft. Riley housing lies outside the watershed, but significant training areas lie within
2000 Population- 21,545
Kansas House Districts-64, 66, 67, 106
Kansas Senate Districts- 21 & 22
Monitored Watershed Size- 98 square miles
2008 303(d) impaired waters- None
TMDLs- Bacteria, Dissolved Oxygen, approved 1/26/2000
NPDES Permitted Facilities- Riley MWTP (M-KS62-OO02), Leonardville MWTP (M-KS35-OO01), Manhattan MSSSS (Stormwater) (M-KS38-SN01)
Threatened and Endangered Species- Topeka Shiner (*Notropis topeka*)
Permitted Confined Animal Feeding Operations-7

Animal Type	Total Animals
Beef	130
Dairy	300
Swine	1,254



Stream Chemistry-

Wildcat Creek has a very poor ranking for total phosphorus, poor ranking for *E. coli*, and moderate rankings for total nitrogen and total suspended solids. Wildcat Creek experiences its highest pollutant concentrations during the spring season (April-July) some reductions during the summer/fall (August- October), and the lowest concentrations during the winter (November-March). While Wildcat Creek does not have a gaging station, these results are consistent with similar results in other gaged watersheds for areas experiencing runoff and high flow event contamination for sediment, phosphorus and organic nitrogen. However, not all pollutants share this trend. Inorganic nitrogen shows no seasonal behavior, with high concentrations occurring throughout the year, suggesting a groundwater input that leaches into these streams throughout the year. Total phosphorus shows low seasonality, suggesting that its loading may be decoupled from the suspended solids entering these streams. Total nitrogen, *E. coli*, and TSS show stronger signs of seasonality, consistent with runoff related pollution.

Wildcat Creek has an active TMDL for inadequate dissolved oxygen, based on a recorded sample at 4.5 mg/L in early August, 1997. State water quality standards mandate dissolved oxygen concentrations exceed 5 mg/L at all times to support aquatic life. Because Wildcat Creek is only monitored on the rotational schedule, less data are available to assess the compliance of the creek with water quality standards. In spite of the limited data, in early August, 2007, KDHE again recorded dissolved oxygen concentrations below water quality standards, this time at 4.95 mg/L. The sample, by chance, was subject to a quality control duplicate sample, which indicated a concentration of 5.29 mg/L. However, it should be noted that the sample was collected at 11:30 am, suggesting that dissolved oxygen concentrations during the night-time hours may be failing to meet water quality standards, given how close the late summer mid-day samples are to the minimum acceptable levels. Some speculation regarding the original low dissolved oxygen sample from 1997 focused on a low-water crossing bridge that created a large log jam and impeded the flow of the stream. The 2007 sample was taken after the crossing and the log jam were removed, suggesting that some causes of low dissolved oxygen remain.

Riley & Leonardville operate small lagoon wastewater treatment plants, which combined discharge about 160,000 gallons of wastewater per day. This is approximately 2.8% of the median estimated flow at the KDHE sampling point. BOD treatment from these facilities has been variable, but the distance between their outfalls and the KDHE sampling point suggest that other causes are larger factors influencing the swings in the dissolved oxygen in the downstream reaches of this stream. They may have larger effects in the upper reaches, but this has not been investigated. Dissolved oxygen is less soluble as water temperature increases, resulting in the typical U-shaped distribution of concentrations during the year. Late July and early August, when air temperatures are highest, are when we expect to see the lowest concentrations of dissolved oxygen.

A fecal coliform bacteria TMDL was established for this watershed in 2000. Recent sampling by KDHE crews was conducted to determine if this stream was in compliance with the new standard for *E. coli*, which requires five samples to be taken within 30 days. The stream consistently failed to meet expectations, and is confirmed as impaired by *E. coli* bacteria under current water quality standards.

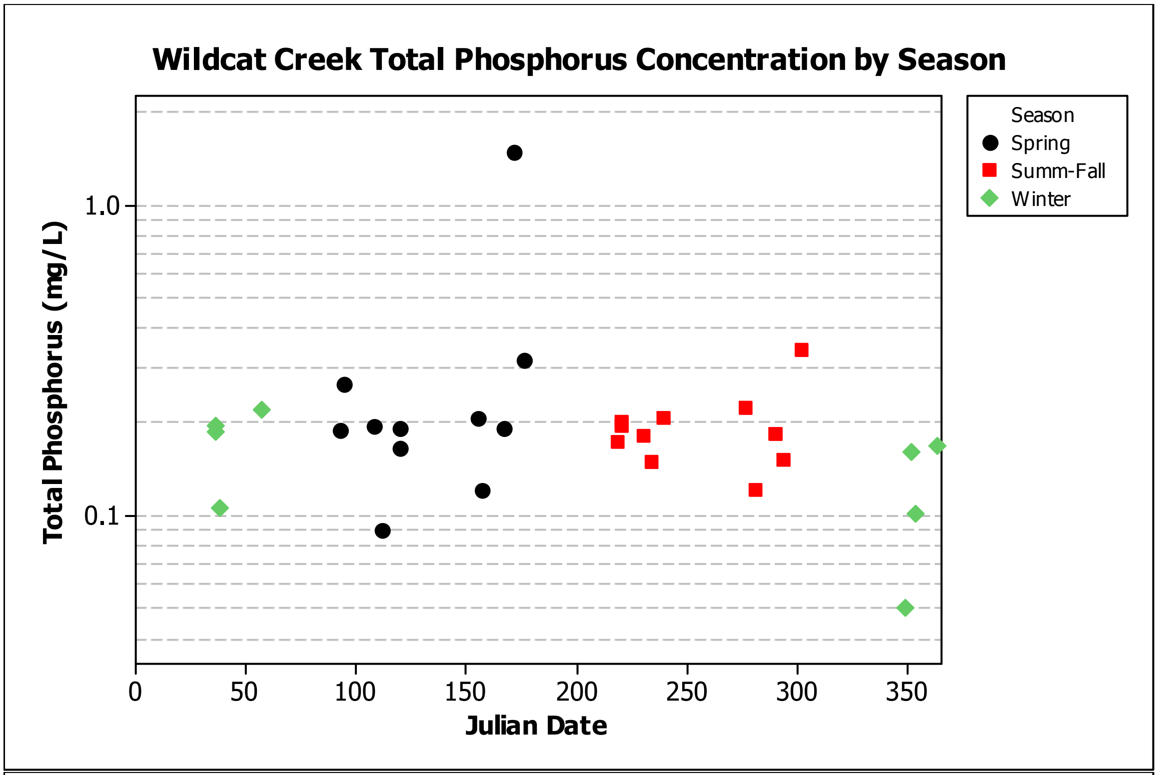
The strong seasonal nature of some of the contaminants suggests that measures targeting soil erosion, including stream bank stabilization, and buffering of streams from cropland will have significant beneficial impacts. Strategies for reducing livestock interaction with streams will likely have positive impacts on the observed bacteria levels. While no data was available to us, previous studies in areas with heavy track-vehicle use, as might be expected in the areas of the watershed used by Ft. Riley for training, have documented increased sediment loads from erosion on both upland areas and stream crossing sites.

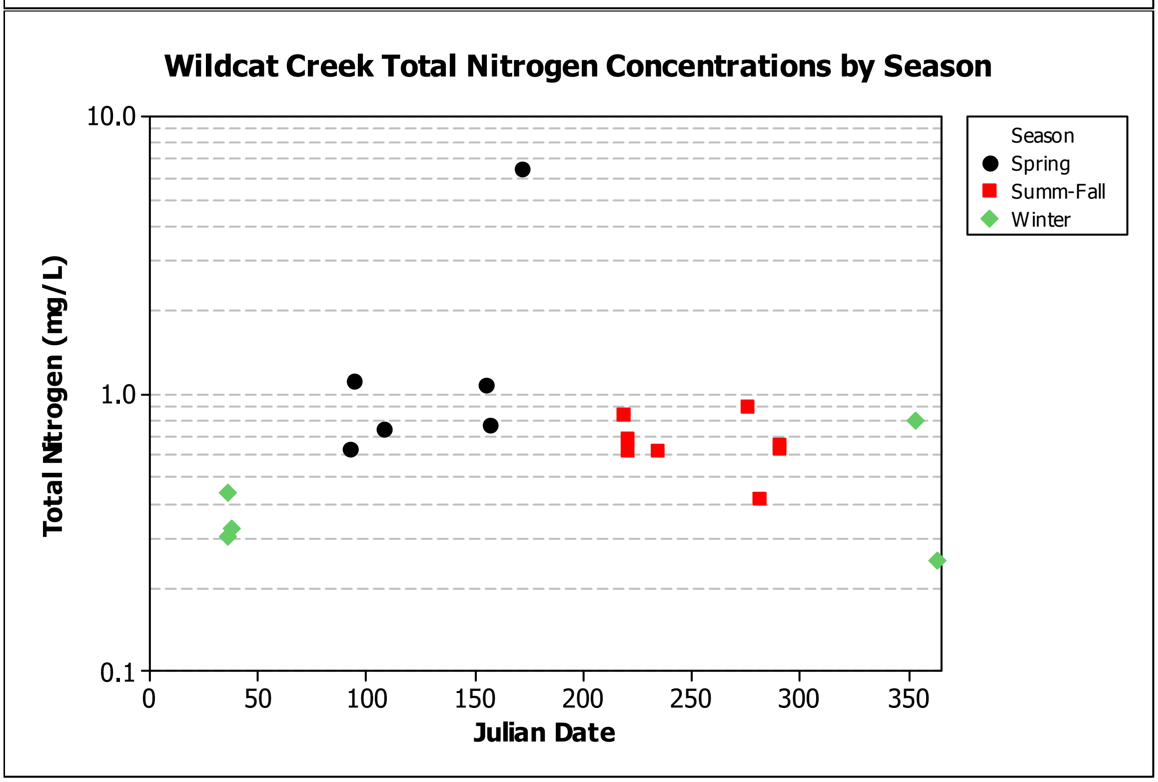
Wildcat Creek is unique in the project area for its combination of urban land use, federal lands, and the lack of major wastewater discharges. Anecdotal accounts of litter and trash in the stream reaches flowing through Manhattan suggest that efforts to improve water quality in this area will require support from urban residents and government. Concentrated urban populations, and the presence of a major state university present an opportunity to partner on efforts to improve water quality along Wildcat Creek, and ensure that ongoing development in the western part of Manhattan occurs in a manner that is consistent with long-term protection of water quality in this stream.

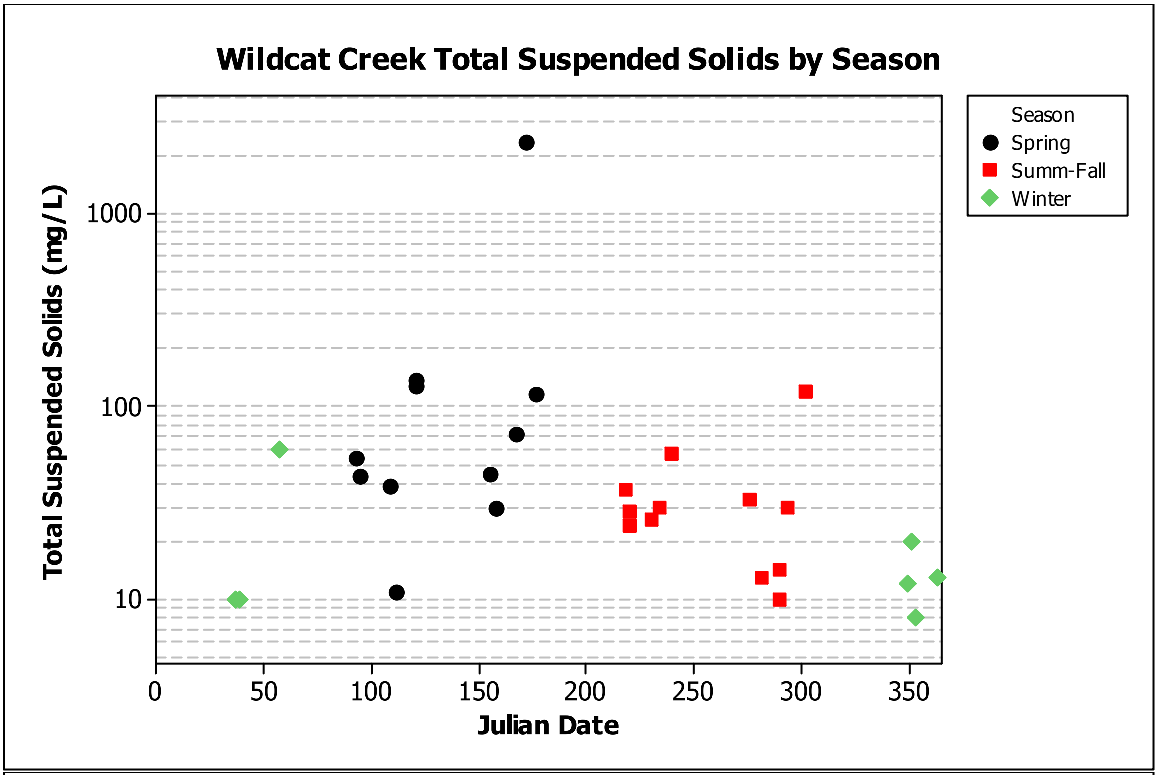
Long-term reductions in dissolved inorganic nitrogen levels may be produced by increased riparian buffering with forest. Once trees develop deep root systems that intercept groundwater flows reductions in inorganic nitrogen loads can be expected. Long-term results may occur with increased use of soil testing to ensure that fertilizer application rates do not exceed crop and urban turf grass needs.

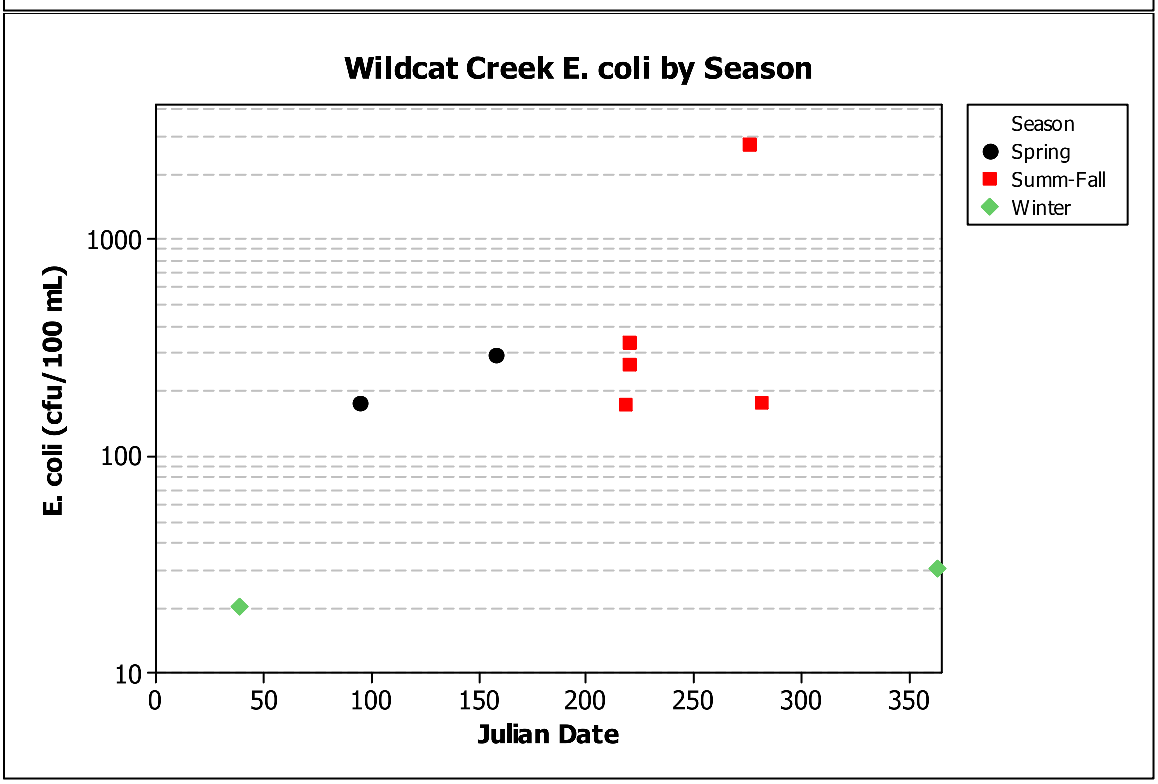
	TP Median	TSS Median	Turbidity Median	TOC Median	Kjeldahl Median	*E.coli* Median	TN Median
Overall	0.185 (31)	30 (31)	14 (31)	3.674 (18)	0.434 (19)	175 (9)	0.658 (19)
Spring	0.191 (11)	54 (11)	20 (11)	5.7595 (6)	0.6355 (6)	235 (2)	0.9225 (6)
Summer Fall	0.1825 (12)	29 (12)	17.35 (12)	4.1865 (8)	0.436 (8)	262 (5)	0.643 (8)
Winter	0.163 (8)	11 (8)	5.63 (8)	3.382 (4)	0.176 (5)	25 (2)	0.326 (5)

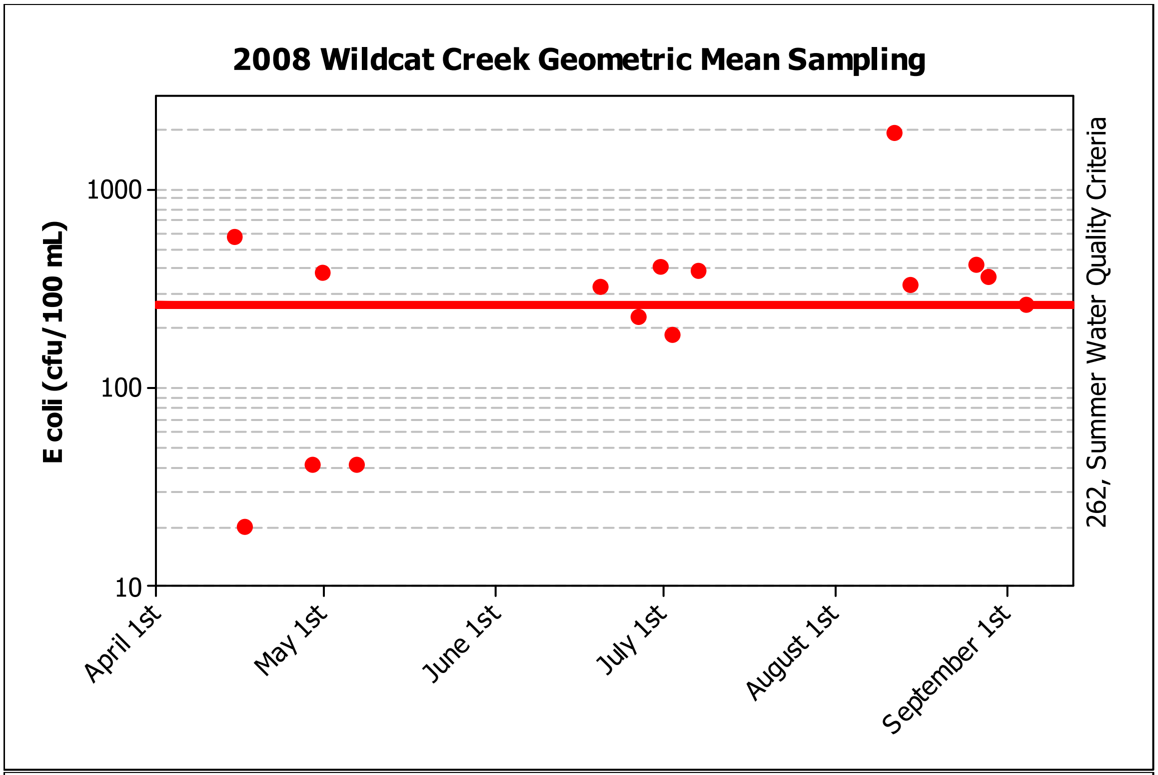
Numbers in parenthesis indicate sample size.

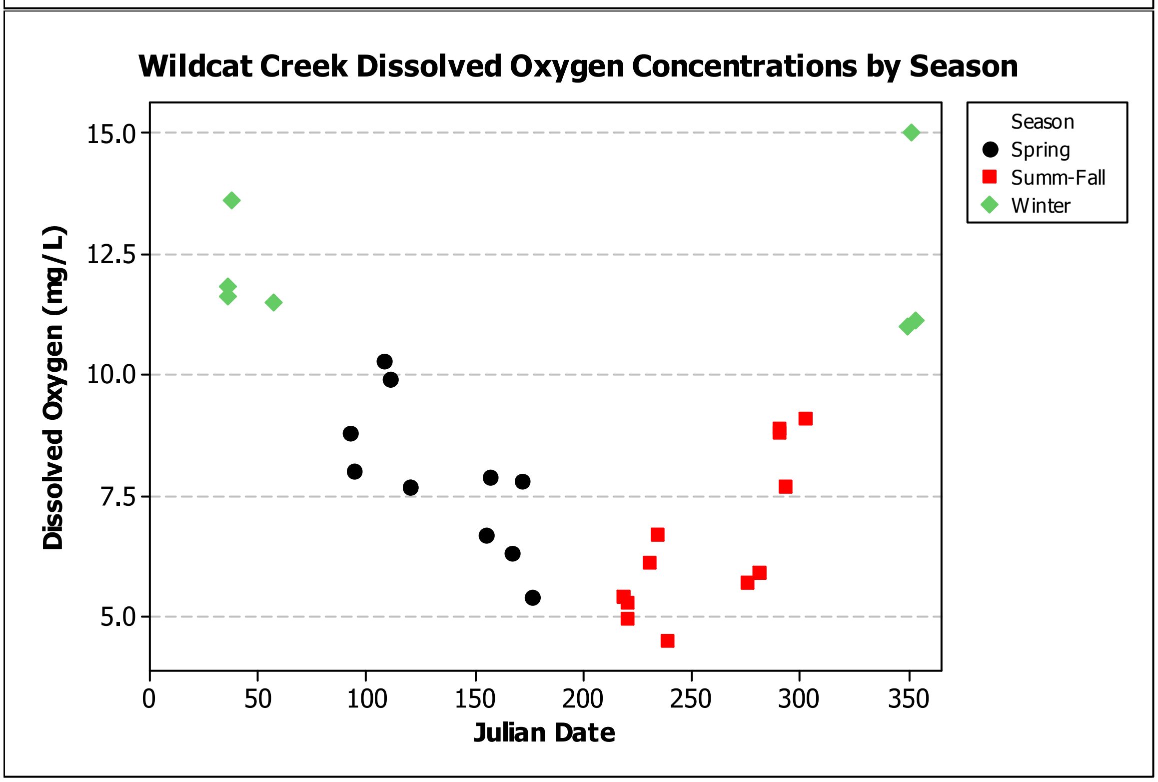

Wildcat Creek Total Phosphorus Concentration by Season
Total Phosphorus (mg/L)
1.0
0.1
0
50
100
150
200
250
300
350
Julian Date
Season
Spring
Summ-Fall
Winter


Wildcat Creek Total Nitrogen Concentrations by Season
Total Ntrogen (mg/L)
10.0
1.0
0.1
0
50
100
150
200
250
300
350
Julian Date
Season
Spring
Summ-Fall
Winter


Wildcat Creek Total Suspended Solids by Season
Total Suspended Solids (mg/L)
1000
100
10
0
50
100
150
200
250
300
350
Julian Date
Season
Spring
Summ-Fall
Winter

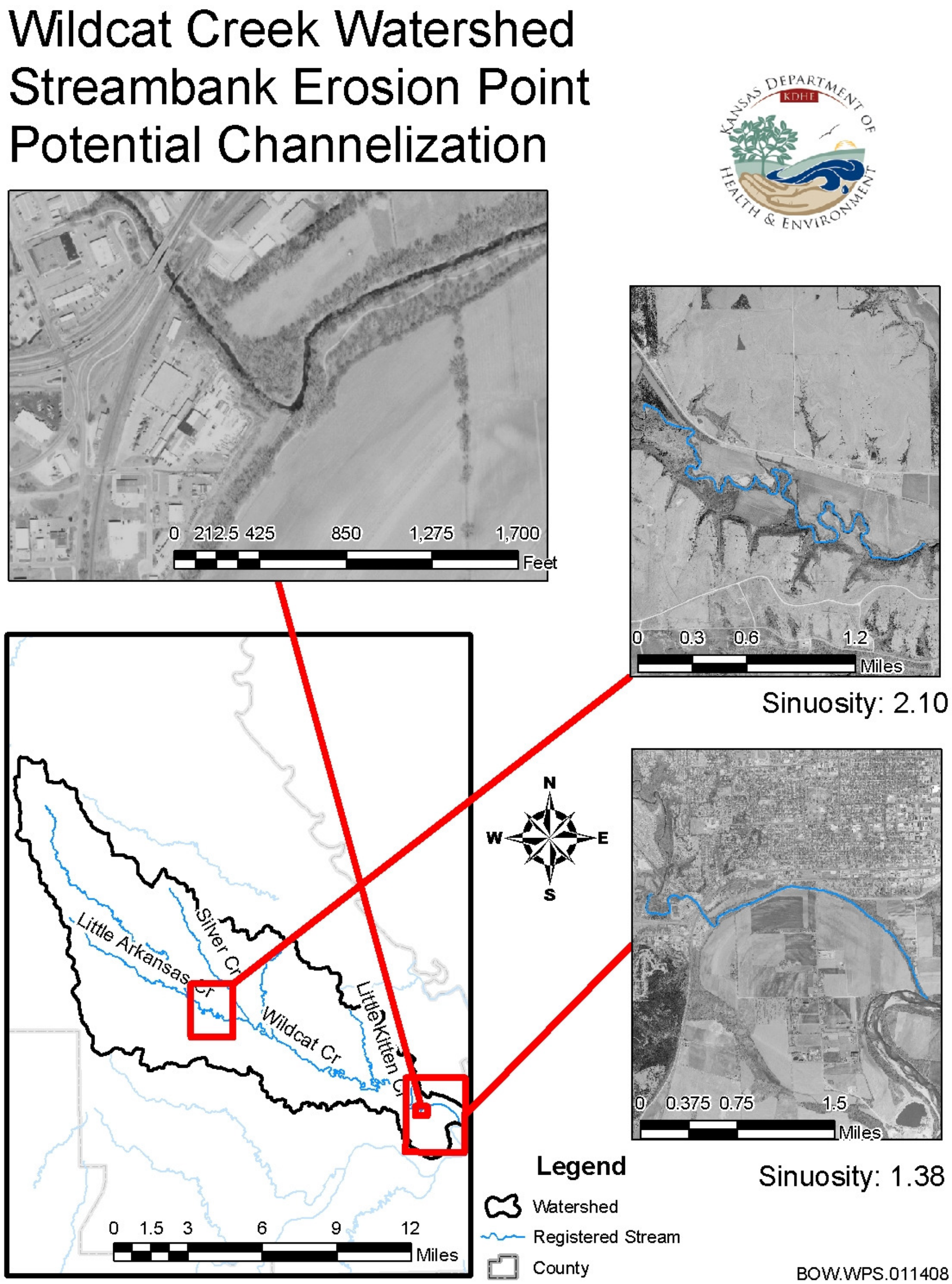

Wildcat Creek E. coli by Season
E. coli (cfu/100 mL)
1000
100
10
0
50
100
150
200
250
300
350
Julian Date
Season
Spring
Summ-Fall
Winter





Streambank stabilization may play an important role in improving water quality in the Wildcat Creek watershed. One meter resolution aerial photographs were used to identify a number of potential unstable streambanks in the lower reaches of the watershed.

Inspection of stream channel sinuosity also suggests that channelization has occurred, and may be contributing to the observed water quality.



Uncertainty-

Because no gage data are available for this stream, some uncertainty exists about the flow conditions associated with the samples. Very large TSS values likely occurred during very high flow events, which may be less responsive to restoration efforts (Meals, 1990). Previous research (unpublished) by KDHE has indicated that median values are strong descriptors of nutrient related impairments, even in the absence of flow data, when large sample records exist. At this level of analysis it is not possible to determine the relative contributions of overland flow, in-stream processes, including collapsing streambanks, and urban specific influences. Nitrogen concentrations are relatively low in comparison to recommended levels for this area, suggesting that groundwater and failing on-site wastewater systems are low concerns for these streams. Future restoration efforts in this area would benefit from more water quality data throughout the watershed to pinpoint potential sources of pollution, and better define the spatial and temporal variation in water quality. Additionally, surveys of stream channel morphology would locate potential sources of major bank instability.

Adapative Implementation Strategies-

Because this stream exhibits characteristics that are consistent with livestock waste loading, unstable streambanks and urban runoff, initial efforts could be focused on working with managers at Ft. Riley, the city of Manhattan, and cattle producers in the watershed. While a large concentration of cropland exists in the upper reaches of this watershed, their apparent contribution to the conditions observed at the monitoring station is low.

Currently a bacteria TMDL exists for this watershed, though it was developed under the previous fecal coliform criteria. Existing data indicate an April through October *E. coli* geometric mean of 324, which exceeds the water quality criteria for primary B waters, though this value is driven by a single sample taken in October of 2007. Without the October 2007 value the geometric mean is 227. However, as noted above, more intensive sampling has confirmed that Wildcat Creek has excessive levels of *E. coli*, and efforts to locate specific sources of the bacteria in the watershed should undertaken to target restoration efforts.

Bacteria may be of particular concern due to the presence of known primary contact recreational activity along the mainstem of Wildcat Creek west of Manhattan. Provision of alternate watering sites, livestock exclusion from streams and ponds, and other efforts to separate cattle from the streams may prove beneficial to reducing the sediment, nutrient and pathogen loading to the streams. Manure management plans for the confined animal operations may also have benefits, depending on their proximity to the stream system.

Because riparian buffering activities typically take three or more years to fully establish themselves, monitoring of post-implementation water quality should be a long-term objective. The existing monitoring record is unlikely to have many high-flow events, due to the design of the sampling program. Because the majority of loads of suspended solids, and total nitrogen are likely to occur during a few, relatively large events, a before- and after- sampling program focused on high flow events would determine if efforts lead to significant improvements to water quality. As is typically the case in the absence of direct inputs nearby, ammonia levels in Wildcat Creek are almost always below KDHE detection limits. Kjeldahl nitrogen typically constitutes 2/3rds of the total nitrogen load, suggesting that measures targeting surface sources of nitrogen, rather than groundwater sources, are most likely to have an impact on conditions seen in these streams. These measures can be expected to be most effective when they intercept or exclude nitrogen sources from sensitive riparian areas.

The lack of strong seasonality to total phosphorus concentrations should not be seen as an indicator that phosphorus concentrations occur at acceptable levels in these streams. Year round concentrations are typically more than twice the concentrations regarded as signifying acceptable water quality. The lack of seasonality leaves some uncertainty about which efforts are most likely to reduce concentrations in this watershed. As mentioned previously, more water quality data from throughout the watershed would help pinpoint the sources of phosphorus contributing to the conditions observed at the monitoring station. Once sources of phosphorus are identified, appropriate strategies for loading reductions can be developed.

This complex watershed has numerous opportunities and challenges urban population centers and federal lands. Efforts to improve water quality are most likely to be successful when a combination of government, private land owner, and urban stakeholder interests work together on this watershed. The involvement of Kansas State University would be beneficial, due to the proximity of both students and researchers within the watershed. The watershed will face ongoing stresses as the city of Manhattan continues to expand westward. Design plans for new developments need to be consistent with water quality protection goals.

Resources for watershed planning in urban watersheds are available at
http://www.cwp.org/PublicationStore/USRM.htm

Cross Creek-

Monitoring Station- SC551
USGS Gaging Station- None
Included area-
HUC 8: 10270102
HUC 10: 06
HUC 12: 01, 02, 03, 04

Streams Flowing to Monitoring Station-

Name	Segment #
Cross Creek-	12
Bartlett Creek-	55
Little Cross Creek-	61
Illinois Creek-	62
Salt Creek-	88
Sullivan Creek-	89
Coryell Creek-	94

Unmonitored Downstream-

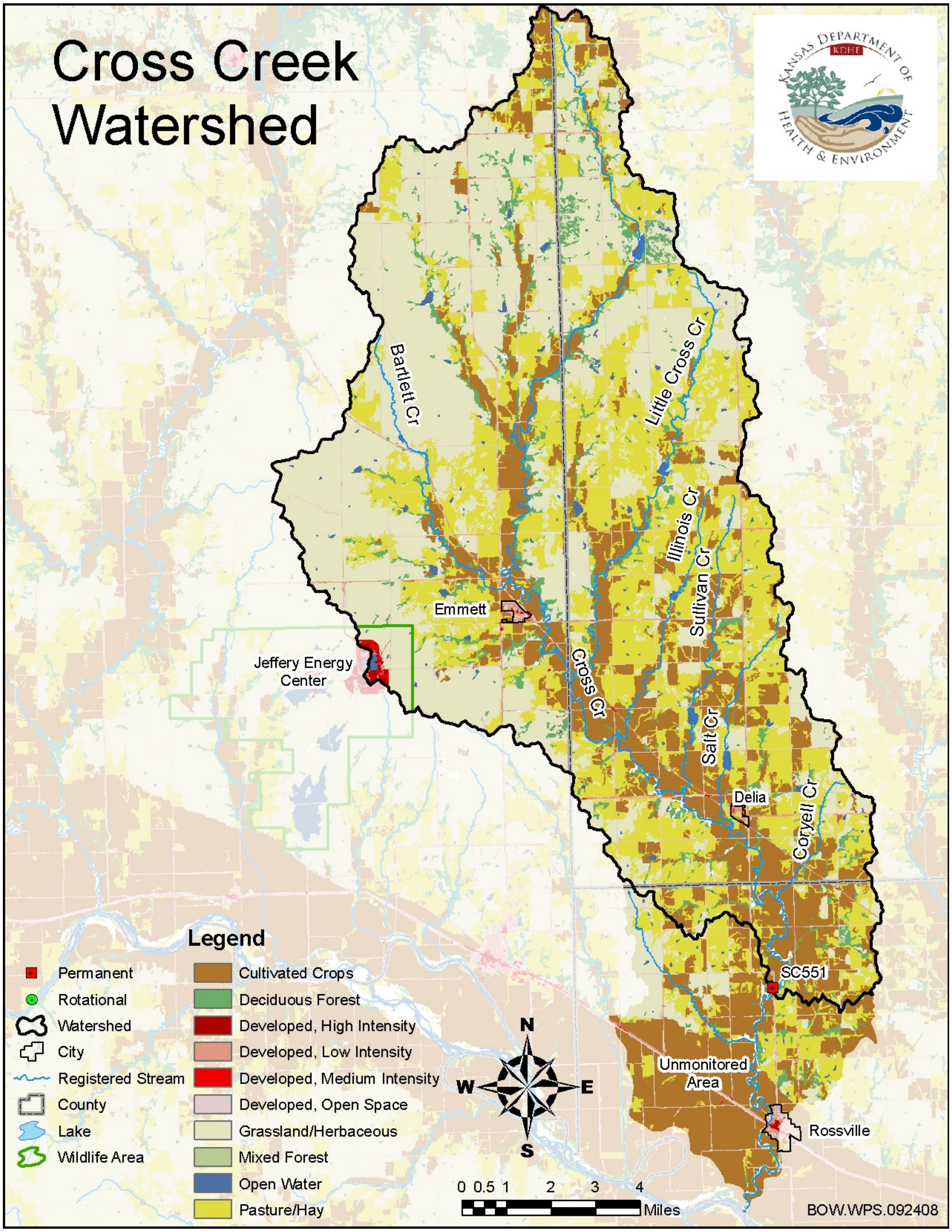
Cross Creek-	12
Snake Creek-	95

Land use in Monitored Area-

Permanent Grass	69.98%
Cropland	18.63%
Forest	6.22%
Developed Land	4.25%

Counties- Jackson, Pottawatomie, Shawnee
Cities- Delia, Emmett; Rossville lies along Cross Creek downstream of the monitored area
Cross Creek Watershed District – Includes the entire watershed
2000 Population- 1,660
Kansas House Districts-50, 51 & 61
Kansas Senate Districts- 1 & 18
Monitored Watershed Size- 154 square miles
Unmonitored Downstream Area- 21.5 square miles
2008 303(d) impaired waters- *E. coli* Category 3 (some evidence of impairment, but insufficient data to determine if water quality criteria are met)
TMDLs- None
NPDES Permitted Facilities- Delia MWTP (M-KS10-OO01), Emmett MWTP (M-KS16-NO01), Cross Creek Estates Mobile Home Park (C-KS16-NO02), Hamm (I-KS10-PO02)
Permitted Confined Animal Feeding Operations-2

Animal Type	Total Animals
Beef	600
Swine	510



Overview map of the Cross Creek watershed. Land use from the 2001 National Land Cover Dataset.

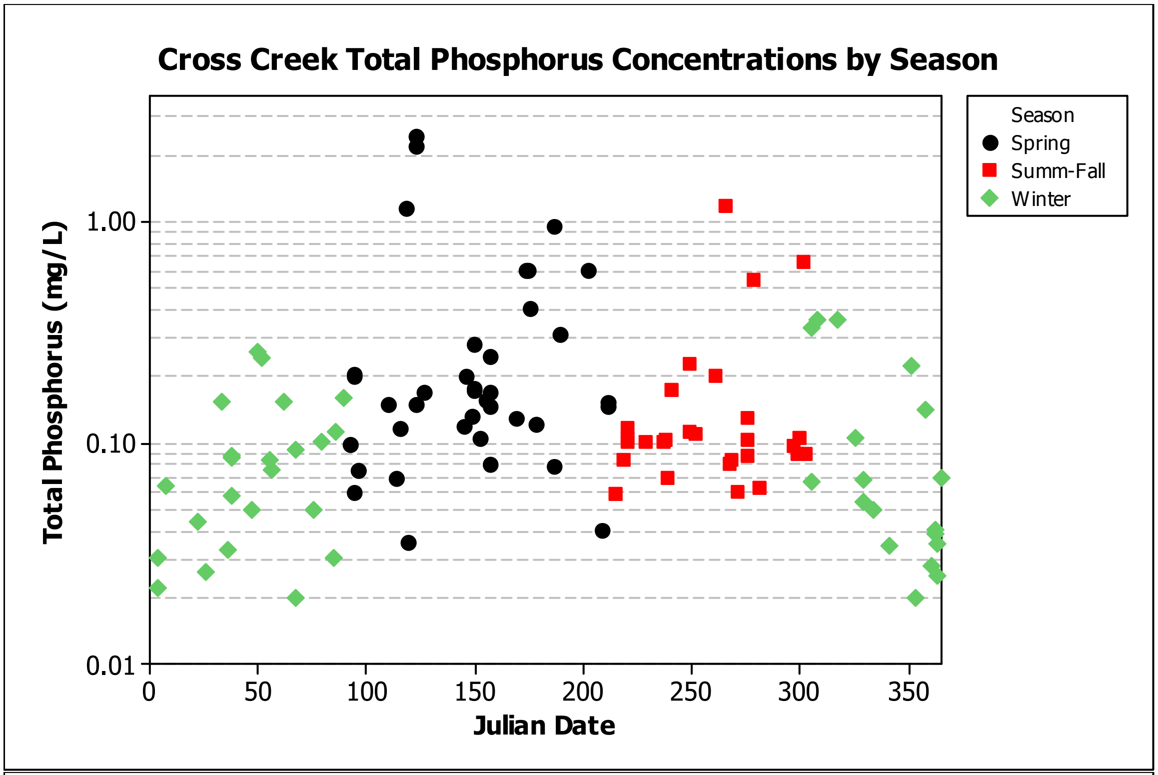
Stream Chemistry-

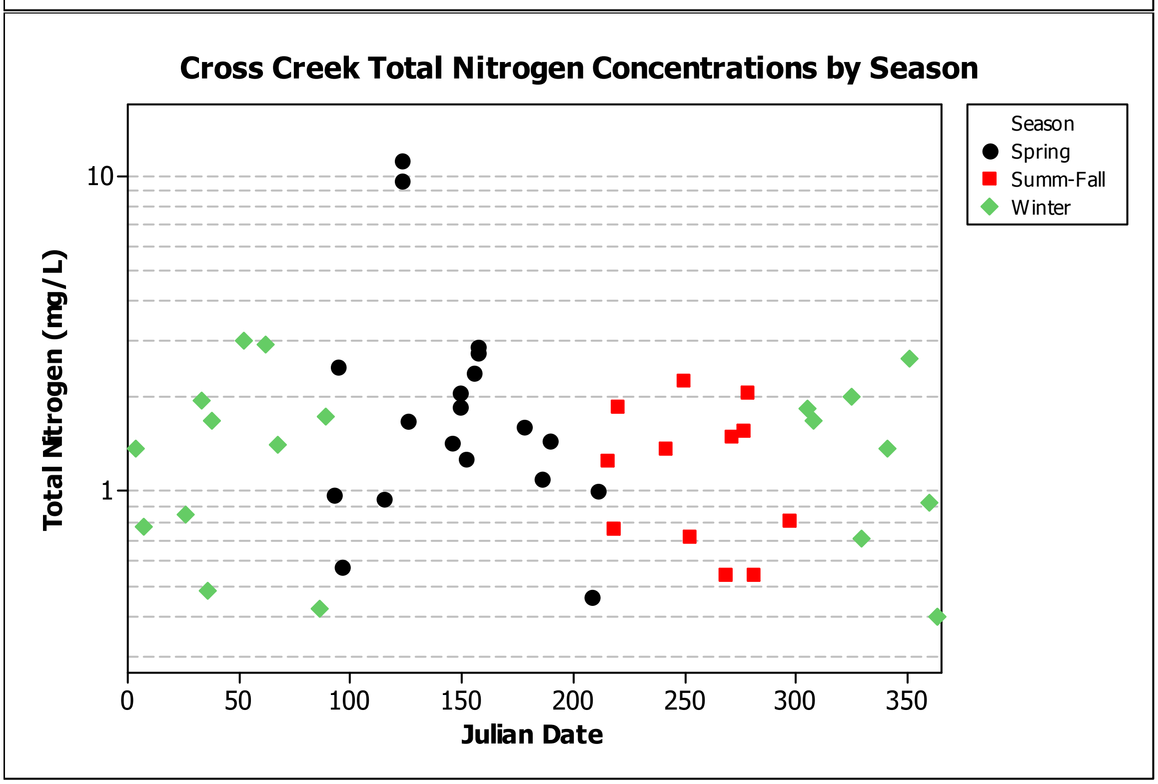
Cross Creek has a very poor ranking for TSS and TN when compared to other stations in the Upper and Middle Kansas, and moderate rankings for *E. coli* and TP. Cross Creek experiences its highest pollutant concentrations during the spring season (April-July) some reductions during the summer/fall (August- October), and the lowest concentrations during the winter (November-March). The seasonality is strongest for TP & TSS, while TN & *E. coli* show elevated spring concentrations with wide variation across the remainder of the year. While Cross Creek does not have an active gaging station, these results are consistent with similar results in other gaged watersheds for areas experiencing runoff and high flow event contamination for sediment and phosphorus. Inorganic nitrogen (NO_2 + NO_3) shows low seasonal behavior, with high concentrations occurring throughout the year, though spring coincides with a period where fewer low concentration samples are taken, suggesting a groundwater input that leaches into these streams throughout the year with some increases occurring during spring application season.

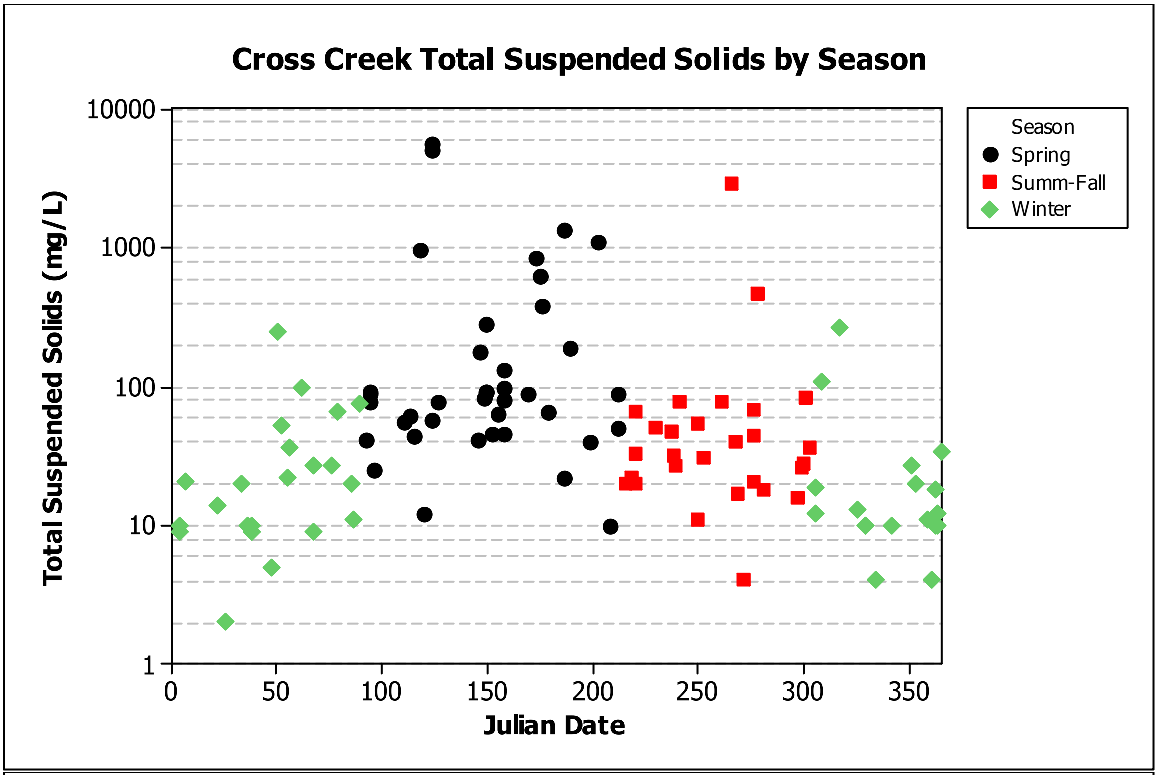
The strong seasonal nature of most of the contaminants suggests that measures targeting soil erosion, including stream bank stabilization, and buffering of streams from cropland will have large impacts. Bacteria appears to be an issue of limited concern in this watershed, as seasonal medians all fall below the most stringent contract recreation criteria for these streams. New data collected in accordance with current water quality criteria, which call for a 5 sample 30 day geometric mean, over the next few years should verify this conclusion. Long-term reductions in dissolved inorganic nitrogen levels may be produced by increased riparian buffer forest width. Once trees develop deep root systems that intercept groundwater flows reductions in inorganic nitrogen loads can be expected. Long-term results may occur with increased use of soil testing to ensure that fertilizer application rates do not exceed crop needs.

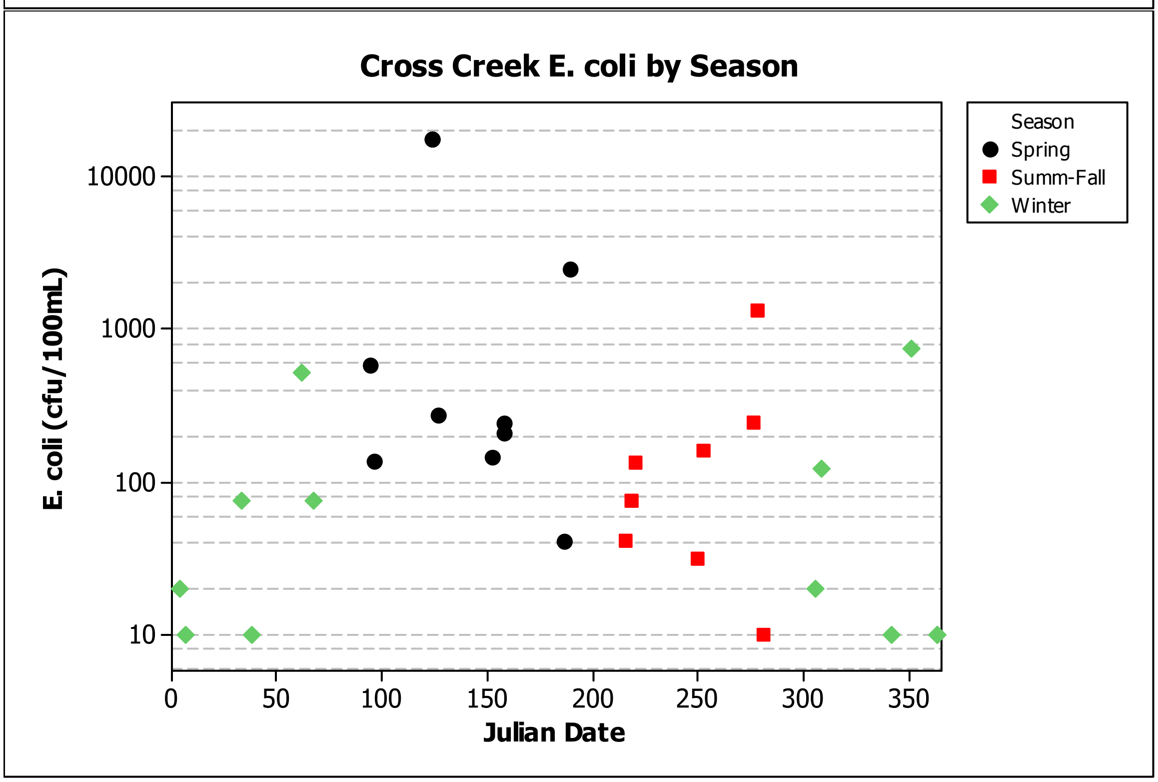
	TP Median	TSS Median	Turbidity Median	TOC Median	Kjeldahl Median	*E.coli* Median	TN Median
Overall	0.105 (107)	38.5 (108)	18 (108)	5.1775 (44)	0.605 (51)	127.5 (30)	1.42 (51)
Spring	0.155 (38)	84 (39)	34 (39)	6.506 (17)	0.671 (19)	256.5 (10)	1.59 (19)
Summer Fall	0.1015 (28)	32.5 (28)	18 (28)	4.462 (11)	0.535 (12)	104.5 (8)	1.2995 (12)
Winter	0.067 (41)	13 (41)	6 (41)	4.6295 (16)	0.4925 (20)	20 (12)	1.383 (20)

Numbers in parenthesis indicate sample size.


Cross Creek Total Phosphorus Concentrations by Season
Total Phosphorus (mg/L)
1.00
0.10
0.01
0
50
100
150
200
250
300
350
Julian Date
Season
Spring
Summ-Fall
Winter

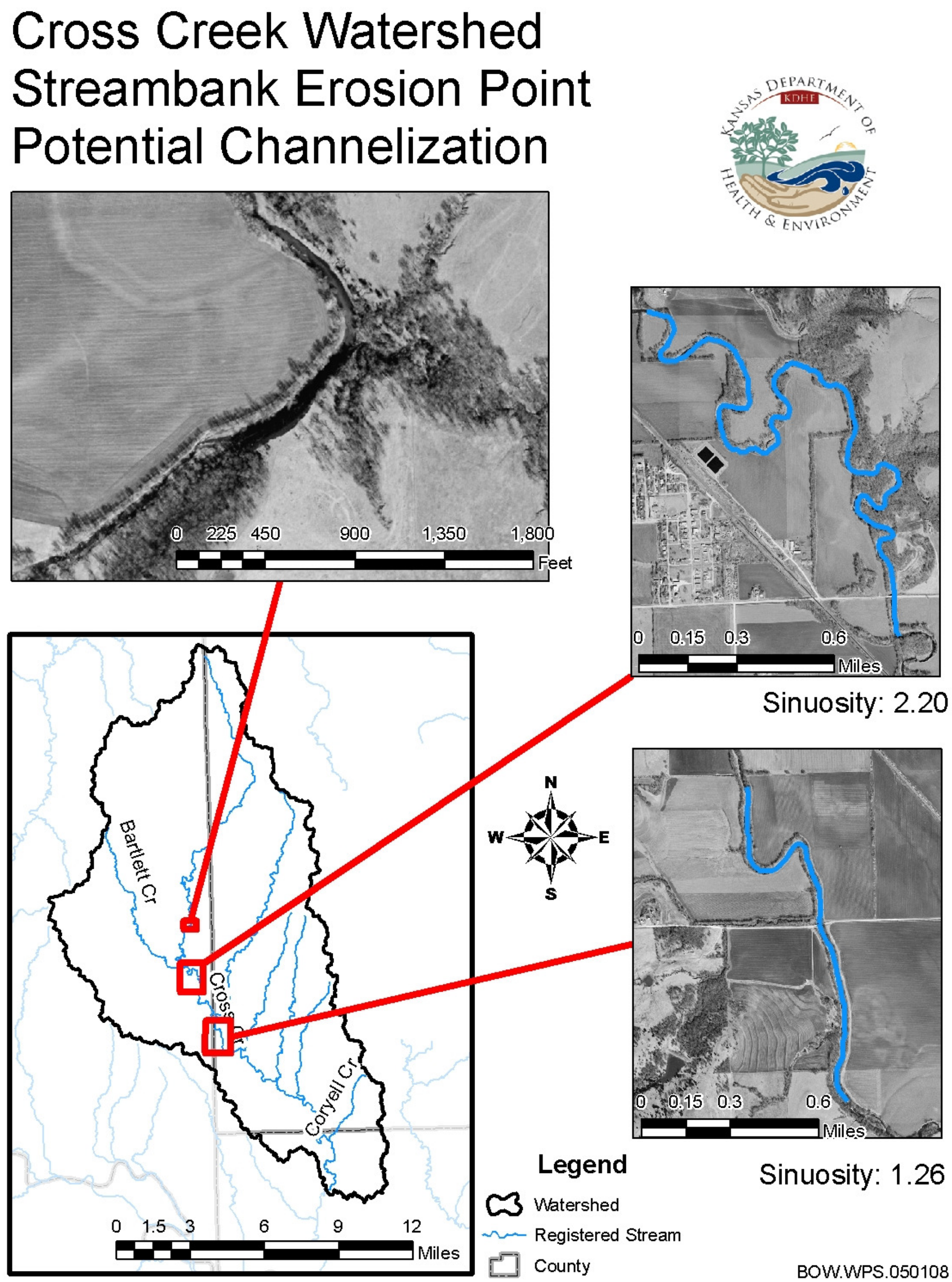

Cross Creek Total Nitrogen Concentrations by Season
Total Nitrogen (mg/L)
10
1
0
50
100
150
200
250
300
350
Julian Date
Season
Spring
Summ-Fall
Winter





Streambank stabilization may play an important role in improving water quality in the Clarks Creek watershed. One meter resolution aerial photographs were used to identify a number of potential unstable streambanks in the lower reaches of the watershed.

Inspection of stream channel sinuosity also suggests that channelization has occurred, and may be contributing to the observed water quality.



Uncertainty-

Because no gage data are available concurrently with the stream chemistry data, some uncertainty exists about the flow conditions associated with the samples. Very large

TSS values likely occurred during very high flow events, which may be less responsive to restoration efforts (Meals, 1990). Previous research (unpublished) by KDHE has indicated that median values are strong descriptors of nutrient related impairments, even in the absence of flow data, when large sample records exist. At this level of analysis it is not possible to determine the relative contributions of overland flow and in-stream processes, including collapsing streambanks. Elevated nitrogen levels could also be indicative of failing on-site wastewater systems, which cannot be ruled out as a potential contributor at this level of analysis. Future restoration efforts in this area would benefit from more water quality data throughout the watershed, to pinpoint potential sources of pollution, and better define the spatial and temporal variation in water quality. Additionally, surveys of stream channel morphology will locate potential sources of major bank instability.

Adaptive Implementation Strategies-

Because this stream exhibits characteristics that are consistent with both overland flow and unstable streambank sources, initial efforts could be focused on the lower reaches of Cross Creek and Coryell Creek. This watershed epitomizes the use of alluvial valleys for row crop production, and shows some signs of poor buffering around the streams. While forest buffers along major streams are present throughout the watershed, the buffers tend to be narrow, and would benefit streams more with additional width. The moderate TP concentrations appear to track the loading pattern of TSS, suggesting improvements in conservation practices may reduce both of these contaminants. Preservation and expansion of the existing buffer zone will likely have beneficial effects for all pollutants for many years to come. Some evidence of terracing is apparent from aerial photography, which can reduce erosion on steeply sloping soils. Evaluation of overall condition of existing terraces may identify areas where rebuilds are needed to ensure proper functioning. Placement of grassed waterways and other upland erosion control measures may also reduce the concentrations of TSS in Cross Creek and its tributaries. While permanent grassland is the major land use in this watershed, a large portion of that grass is pasture/hay, rather than grazing land. Little research has been done on the impacts of pasture land uses in Kansas, and a more detailed evaluation of the management of these lands may be helpful in understanding sources of pollution.

Cross Creek has had a number of historically notable floods. As recently as October 2, 2005 portions of Rossville were under water. Flooding during the last few decades has led to consideration of constructing an earthen levy and re-location of the channel of lower Cross Creek. However, structural solutions have not been implemented because of community concerns related to costs. Some strategies that would improve water quality, such as off-channel storage in riparian wetlands, may provide some level of protection by reducing the peak discharge volumes traveling down Cross Creek. It is likely such low-lying wetlands existed historically, and their re-establishment may offer an opportunity to improve water quality while reducing risks associated with intermittent flooding. Further study of this option will be required to determine costs and viability.

Because riparian buffering activities typically take three or more years to fully establish themselves, monitoring of post-implementation water quality should be a long-term objective. The existing monitoring record is unlikely to have many high-flow events, due to the design of the sampling program. Because the majority of loads of suspended solids and total phosphorus are likely to occur during a few, relatively large events, a before-and after- sampling program focused on high flow events would determine if efforts lead to significant improvements to water quality. Nitrogen concentrations appear to be less variable than TSS and TP, though concentrations still exceed regional guidance by large amounts, year round. Wintertime concentrations that usually exceed summer-fall concentrations suggest that groundwater loading is a probable source of nitrogen, because wintertime flows are typically driven by baseflow from groundwater sources, while some dilution may be occurring during summer when flows are usually somewhat higher than winter flows.

It should be noted that some strategies to reduce nutrient pollution have confounding effects. Tillage and cover strategies that reduce runoff and increase infiltration have been documented in some cases to increase nitrogen infiltration to groundwater. Increased infiltration should reduce phosphorus and sediment loading, and improvements to riparian forest areas are likely to reduce groundwater loading of nitrogen to the stream, while increasing bank stability. Therefore, implementing strategies should target field runoff for sediment and phosphorus loading, and simultaneously implement riparian restoration.

Should streambank stabilization, riparian planting, and other buffering activities in the lower reaches not reduce sediment and nutrient loading to acceptable levels, targeted monitoring may be required to determine sources more accurately. Funding for practices to improve water quality should focus on lands adjacent to streams where cropland is completely unbuffered, and implementation of erosion control practices in the valley along Cross Creek, because these areas are more likely to contribute to water quality problems monitored at station 551.

Cross Creek presents moderate challenges to implementation of protection and expansion of the existing riparian buffer, which has significant potential to improve water quality. While unverified at this level of analysis, the low sinuosity of some of the mainstem segments of Cross Creek suggests that channelization has occurred in this area, and unstable banks may be contributing to the concentrations observed. Increasing the streams’ connection with its flood plain and widening of permanent vegetation buffers along the streams could require some reductions of current cropland uses by area landowners. Further evaluation will need to be completed to determine the extent of the problem, and establish the costs for implementing conservation activities.

Vermillion Creek-

Monitoring Stations- SC520, SC645 & SC681
USGS Gaging Station- 06888000 (Vermillion Creek) 4/22/1936-6/30/1946, 1/1/1954-6/30/1972, & 2/1/2002-Current; 06888300 (Rock Creek) 10/1/1958-9/30/1965
Included area-

HUC 8: 10270102

HUC 10: 01; 02

HUC 12: 01, 02, 03, 04, 05, 06, 07, 08, 09; 01, 02, 03, 04, 05

Streams Flowing to Monitoring Station-

Station	Name	Segment #
SC520	Vermillion Creek-	16
Lower Vermillion	Vermillion Creek-	17
	Indian Creek-	20
	Jim Creek-	52
	Adams Creek-	53
	Spring Creek-	54
	Pomeroy Creek-	59
SC645	Rock Cr-	21
Rock Creek	Rock Cr, E Fork-	22
	Pleasant Hill Run-	23
	Wilson Cr-	50
	Darnells Cr-	51
	Mud Cr-	56
	Brush Cr-	57
	Elm Slough-	58
SC681	Vermillion Cr-	17
Upper Vermillion	Vermillion Cr-	18
	French Cr-	19
	Mulberry Cr-	42
	Hise Cr-	43
	Mud Cr-	44
	Cow Cr-	45
	Coal Cr-	46
	Gilson Cr-	47
	Spring Cr-	48

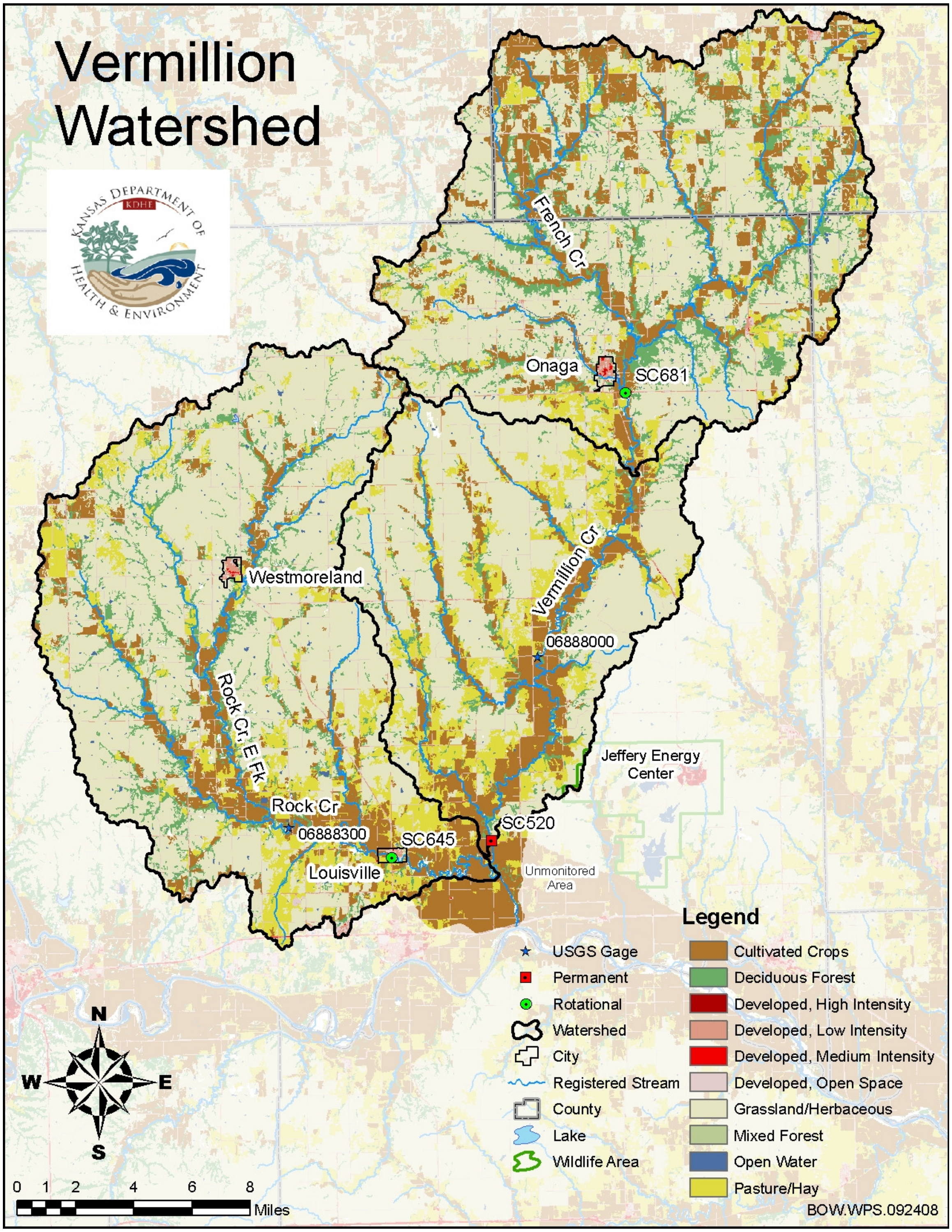
Monitored Watershed Size- 506.5 square miles
SC520- 124.5 square miles
SC645- 193.8 square miles
SC681- 188.2 square miles
Unmonitored Downstream Area – 8.1 square miles
Land use-

	Lower Vermillion	Rock Creek	Upper Vermillion
Permanent Grass	73.56%	71.97%	61.44%
Cropland	16.34%	13.16%	19.19%
Forest	6.41%	10.24%	14.59%
Developed Land	3.35%	4.09%	4.31%

Counties- Pottawatomie, Nemaha, Jackson & Marshall
Cities- Westmoreland, Onaga, Louisville
Rock Creek Watershed District- Includes only the streams draining to Rock Creek (HUC10 – 1027010201); does not include Vermillion Creek or streams monitored by SC520 or SC681 (HUC10 – 1027010202)
2000 Population- Overall- 5,880[1]
Lower Vermillion - 595
Rock Creek - 3,370
Upper Vermillion - 2,184
Kansas House Districts-50, 61, 62, 106
Kansas Senate Districts- 1 & 21
2008 303(d) impaired waters- Biology (SB520, High Priority) *E. coli* Category 3 (some evidence of impairment, but insufficient data to determine if water quality criteria are met) (SC645)
TMDLs- Bacteria, approved 1/26/2000 (SC520, SC681) (High Priority)
NPDES Permitted Facilities- Corning MWTP (M-KS94-OO01), Havensville MWTP (M-KS22-OO01), Louisville MWTP (M-KS37-NO01), Onaga MWTP (M-KS53-OO01), Westmoreland MWTP (M-KS75-OO01), Wheaton MWTP (M-KS79-OO01), Pottawatomie Co. S.D. – Fostoria (M-KS93-NO01), Rock Creek High School (M-KS75-NO04), Hamm (I-KS79-PO02)
Permitted Confined Animal Feeding Operations-30

Animal Type	Total Animals
Beef	8,547
Chickens Dry	600000
Dairy	362
Swine	23,338
Swine, misc. others	14,066

[1] Individual monitoring station populations add up to greater than the total population due to census boundaries that cross watershed boundaries.



Overview map of the Vermillion Creek watershed. Land use from the 2001 National Land Cover Dataset.

Stream Chemistry-

The monitoring stations in the Vermillion Creek area have moderate to poor overall rankings. Rock Creek has the second-to-worst overall condition, with the worst overall rank of all stations for *E. coli*, and poor rankings for nutrients and suspended solids. Upper Vermillion Creek has a very poor ranking for total phosphorus, and moderate to poor rankings for the other parameters. Lower Vermillion Creek appears to be benefiting from some dilution or in-stream processing of nutrients and bacteria reduction, with better rankings for these parameters than the upstream station. However, lower Vermillion Creek has a very poor ranking for suspended solids, suggesting some increase in sediment loading in the area monitored by SC520. The elevated TSS values seen at SC520 may be related to the impairment listing for biology at that site, particularly if the springtime TSS concentrations inhibit the reproduction and colonization of species that reproduce only once per year.

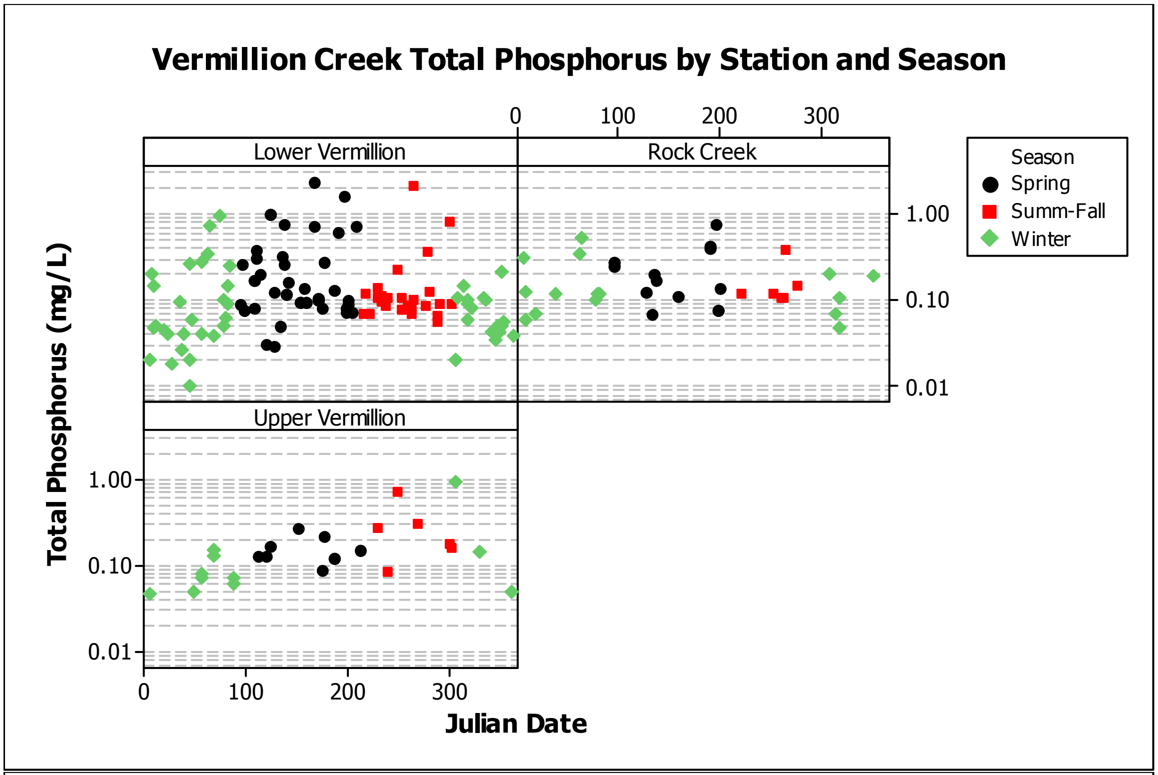
Rock Creek and Lower Vermillion Creek experience their highest pollutant concentrations during the spring season (April – July), with some reductions during summer/fall (August – October), and the lowest concentrations during the winter (November – March). The seasonality is strongest for TP, TSS & *E. coli*, and more moderate for TN. Rock Creek has relatively little variation between the summer/fall and winter for TP, TSS, kjeldahl nitrogen, and total organic carbon, though turbidity is notably higher during the summer/fall than the winter. Upper Vermillion Creek shows a somewhat different pattern, with elevated concentrations of nitrogen, phosphorus and organic carbon during the summer/fall period. Caution should be used when interpreting these results for nitrogen and carbon, due to their small sample size, though they appear consistent with phosphorus results which have a larger sample size over a longer period of time. Similar caution should be applied to the *E. coli* results for both Rock Creek and Upper Vermillion, where very small sample sizes limit our ability to reach significant conclusions. More detailed monitoring of *E. coli* at Rock Creek is being done, consistent with the current water quality criteria, which require a 5 sample, 30 day geometric mean be calculated, and these results should improve our understand of this pollutant.

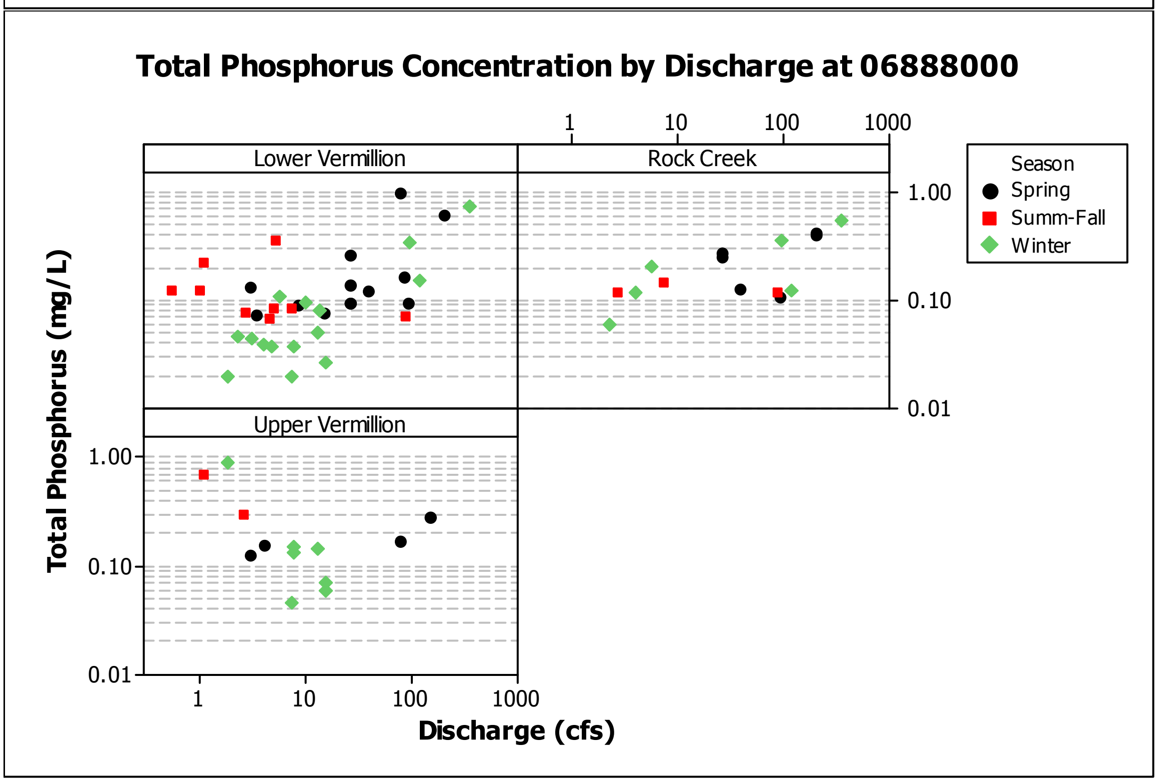
Due to the short recent record at the USGS gaging station, limited conclusions can be drawn regarding the linkage between flow and pollutant concentration. However, some significant indicators are already visible, even with only five years of discharge data. For example, total phosphorus concentrations at the three monitoring sites have different patterns. Stations SC520 (Lower Vermillion) & SC645 (Rock Creek) fit the overall pattern observed in Kansas waters where nonpoint sources are significant. There is variation around the median, and seasonal variation consistent with flow patterns expected based on regional climate. However, SC681 (Upper Vermillion) has a U-shaped curve, indicating high concentrations at low flow, with some dilution at moderate flows, and increases in concentration again at high flows. This pattern is typical of streams under the influence of point source discharge, where concentrated waste streams strongly influence concentrations at low flows, become diluted as flows increase, until high flows introduce non-point sources and loads into the stream. The city of Onaga has a four-cell lagoon system that discharges not far upstream from SC681, however they are not required to monitor phosphorus at this time, nor are they required to monitor discharge volume, so no estimate of their contribution to the load at SC681 can be made. While mechanical plant wastewater systems typically remove most of the suspended load prior to discharge, lagoons sometimes do not effectively remove suspended algae, which could explain why TSS values at SC681 also demonstrate a U-shaped pattern. This is also consistent with the high correlation between total nitrogen and kjeldahl nitrogen observed at SC681, where discharged algae might be expected to contribute a larger portion of the overall nitrogen load. Lower Vermillion Creek (SC520) may be showing some signs of a U-shaped distribution, but any such effect appears to be diluted by the time the stream reaches that station. Caution should be used when applying gage data to sites other than those which are co-located with the chemistry collection point. In the absence of co-located sites, nearby gages can provide a general understanding of the likely flow conditions at independently located sites.

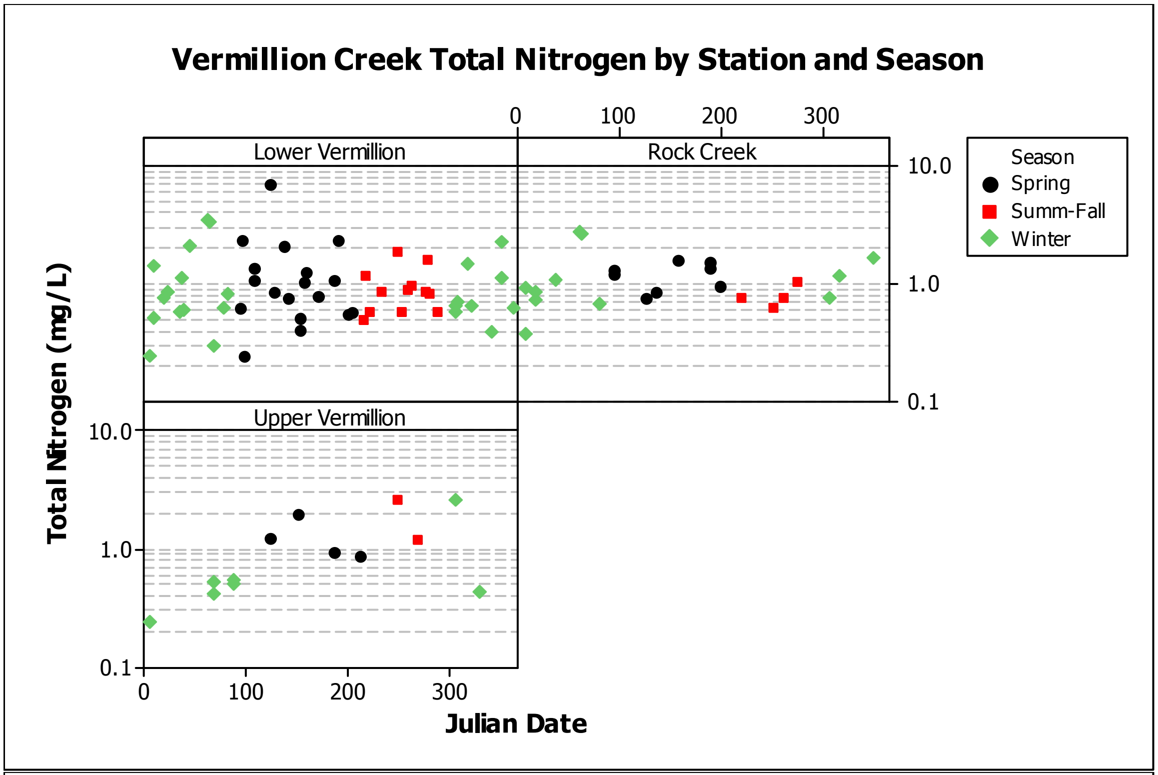
Biological monitoring data collected in Vermillion Creek indicates that most of the samples do not indicate a fully supported biological (macroinvertebrate) community. Some caution may be noted due to the poor distribution of sample dates, where the two recent (since 1999) samples collected in mid-summer have the best overall rankings, while many of the poorly performing samples were collected in May (4) or late fall (2). This could indicate a seasonal impairment occurring during the spring. Until there are more comprehensive data, no such determination can be made. The presence of elevated spring TSS loads may also be related to the poor scores from May. The recent scores still indicate some level of impairment of aquatic life in Vermillion Creek. Improvements from pollutant reductions might generate more suitable habitat.

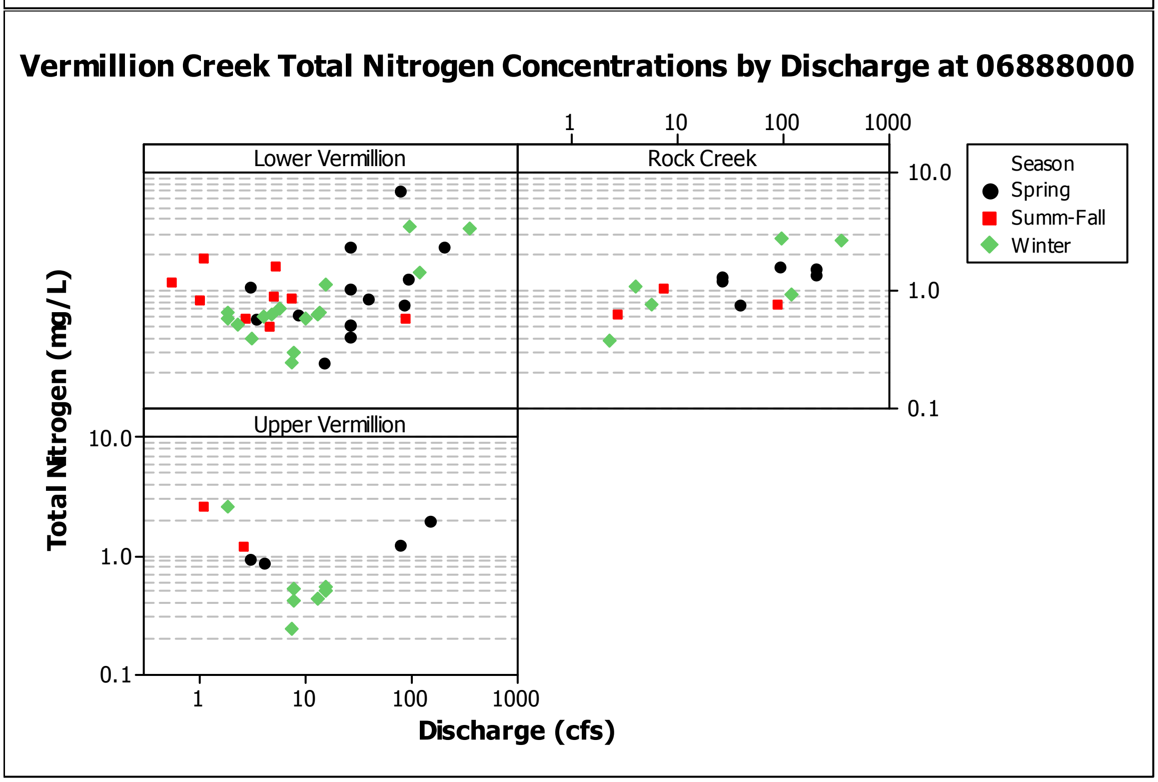
Site	Season	Turbidity Median	TSS Median	TP Median	TN Median	Kjeldahl Median	*E.coli* Median	TOC Median
Lower Vermillion SC520	Overall	16.5 (112)	38.5 (112)	0.095 (111)	0.825 (53)	0.508 (53)	98 (31)	4.903 (46)
SC520	Spring	33.9 (39)	56 (39)	0.124 (39)	0.96 (18)	0.516 (18)	156 (9)	5.5235 (16)
SC520	Summer-Fall	18.2 (28)	38.5 (28)	0.09 (27)	0.8525 (12)	0.7245 (12)	82.5 (8)	4.97 (11)
SC520	Winter	9.31 (45)	16 (45)	0.06 (45)	0.705 (23)	0.478 (23)	36 (14)	4.191 (19)
Rock Creek SC645	Overall	21.5 (34)	33.5 (34)	0.1215 (34)	0.984 (23)	0.607 (23)	433 (16)	5.4515 (16)
SC645	Spring	37.25 (12)	44.5 (12)	0.189 (12)	1.289 (8)	0.894 (8)	3165.5 (6)	6.7375 (6)
SC645	Summer-Fall	20.05 (6)	25 (6)	0.117 (6)	0.7625 (4)	0.557 (4)	110 (3)	4.054 (3)
SC645	Winter	11.15 (16)	23.5 (16)	0.119 (16)	0.941 (11)	0.519 (11)	86 (7)	5.371 (7)
Upper Vermillion SC681	Overall	15 (25)	34 (25)	0.136 (25)	0.89 (13)	0.74 (13)	108 (7)	4.721 (13)
SC681	Spring	30.8 (8)	60 (8)	0.1455 (8)	1.1085 (4)	0.7795 (4)	635 (2)	5.5605 (4)
SC681	Summer-Fall	15.5 (6)	55 (6)	0.23 (6)	1.9715 (2)	1.8215 (2)	108 (1)	7.818 (2)
SC681	Winter	7.4 (11)	16 (11)	0.072 (11)	0.51 (7)	0.36 (7)	30.5 (4)	4.241 (7)

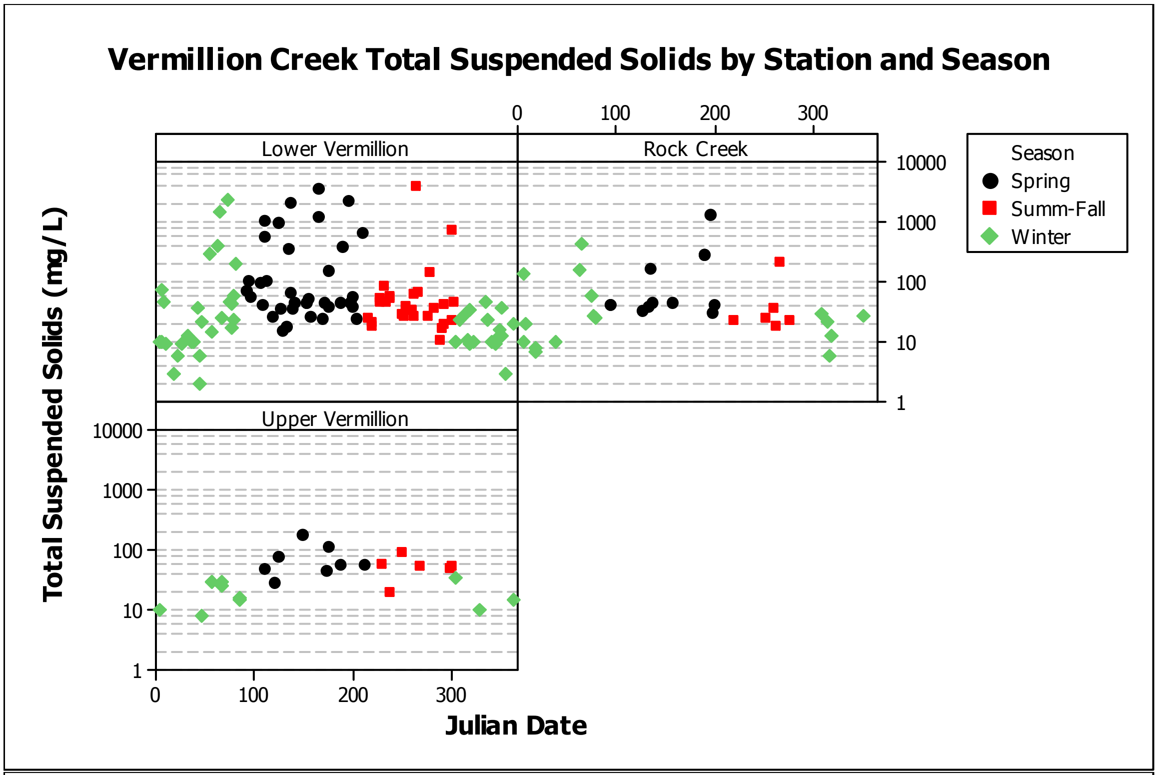
Numbers in parenthesis indicate sample size.

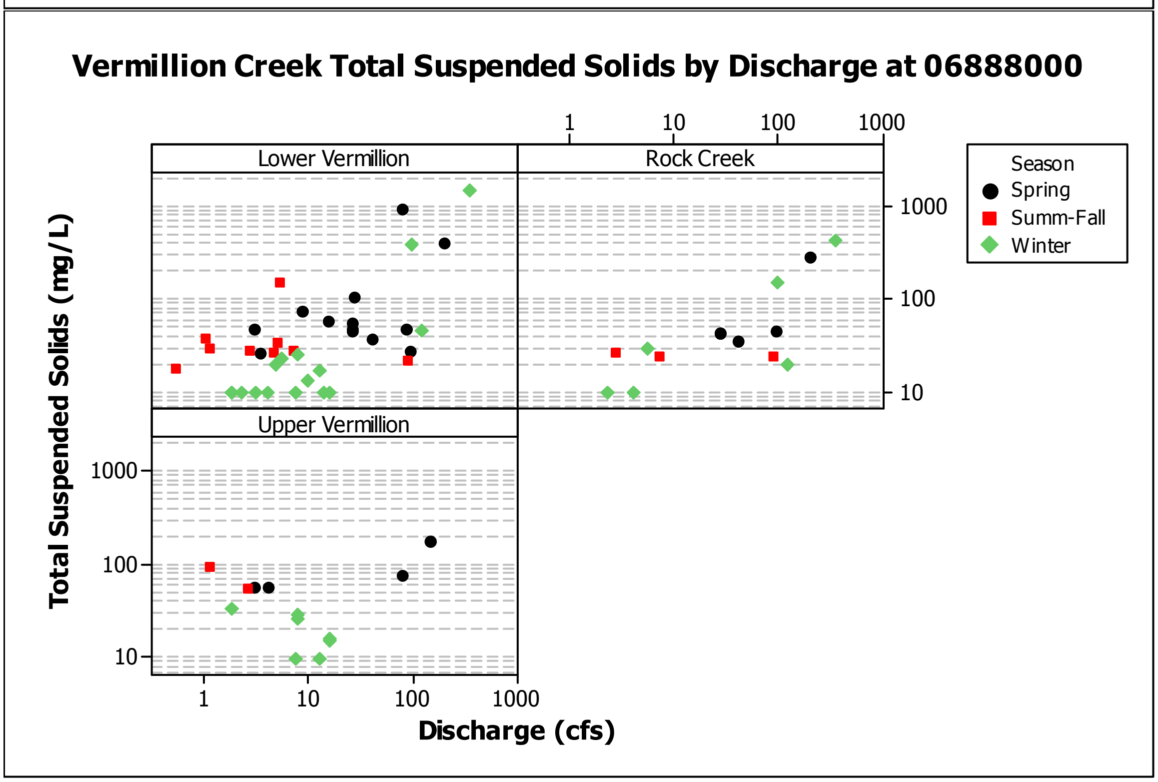

Vermillion Creek Total Phosphorus by Station and Season
Lower Vermillion
Rock Creek
Upper Vermillion
Season
Spring
Summ-Fall
Winter
Total Phosphorus (mg/L)
1.00
0.10
0.01
0
100
200
300
Julian Date

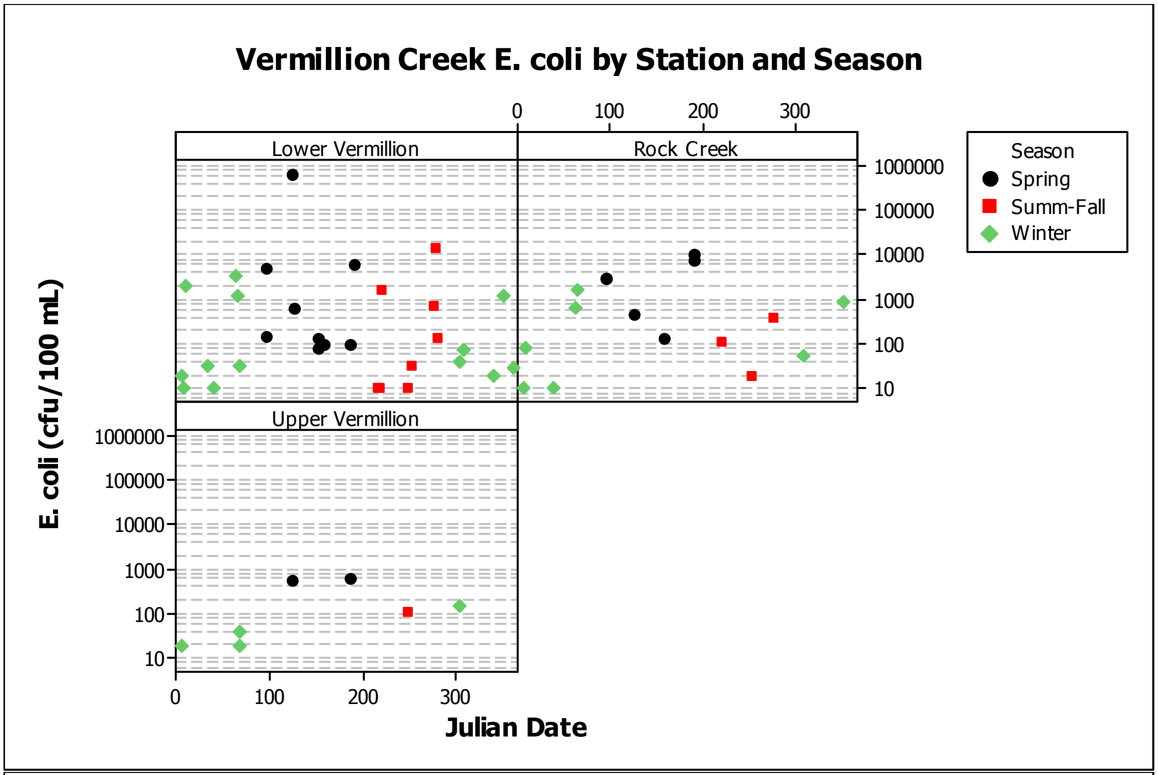

Total Phosphorus Concentration by Discharge at 06888000
Lower Vermillion
Rock Creek
Upper Vermillion
Season
Spring
Summ-Fall
Winter
Total Phosphorus (mg/L)
1.00
0.10
0.01
1
10
100
1000
Discharge (cfs)

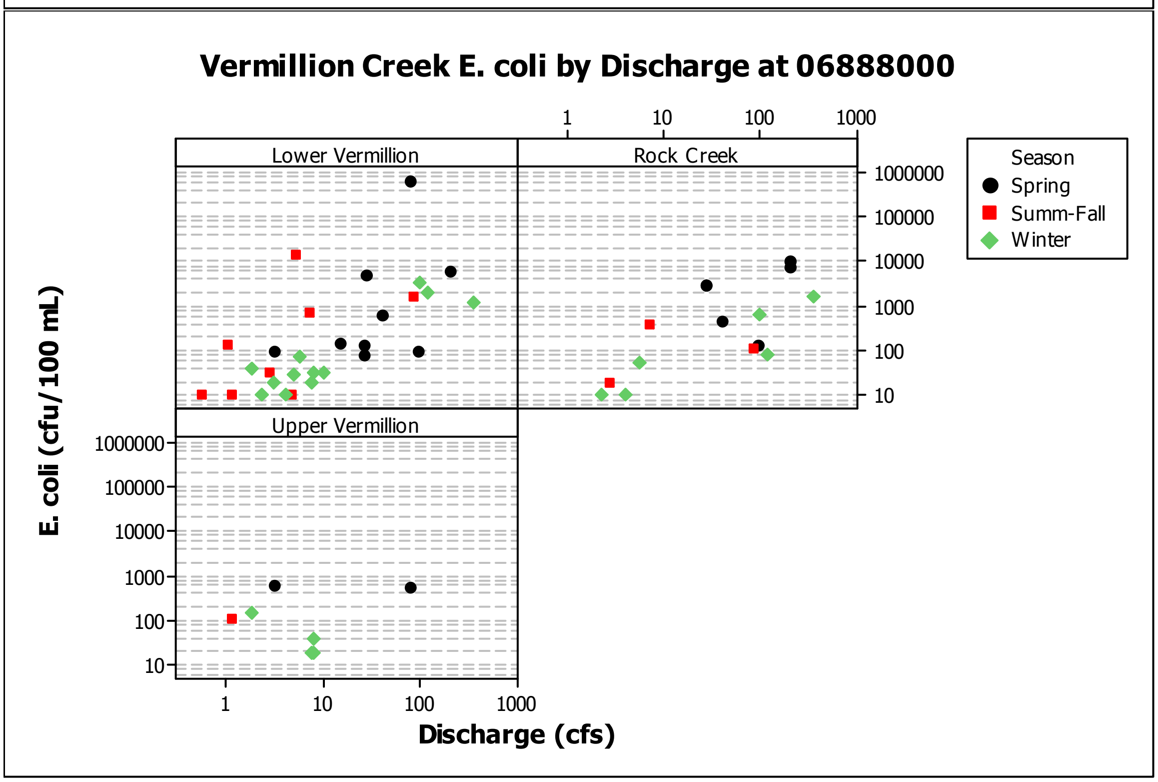

Vermillion Creek Total Nitrogen by Station and Season
Lower Vermillion
Rock Creek
Upper Vermillion
Total Nitrogen (mg/L)
Julian Date
Season
Spring
Summ-Fall
Winter
0
100
200
300
10.0
1.0
0.1

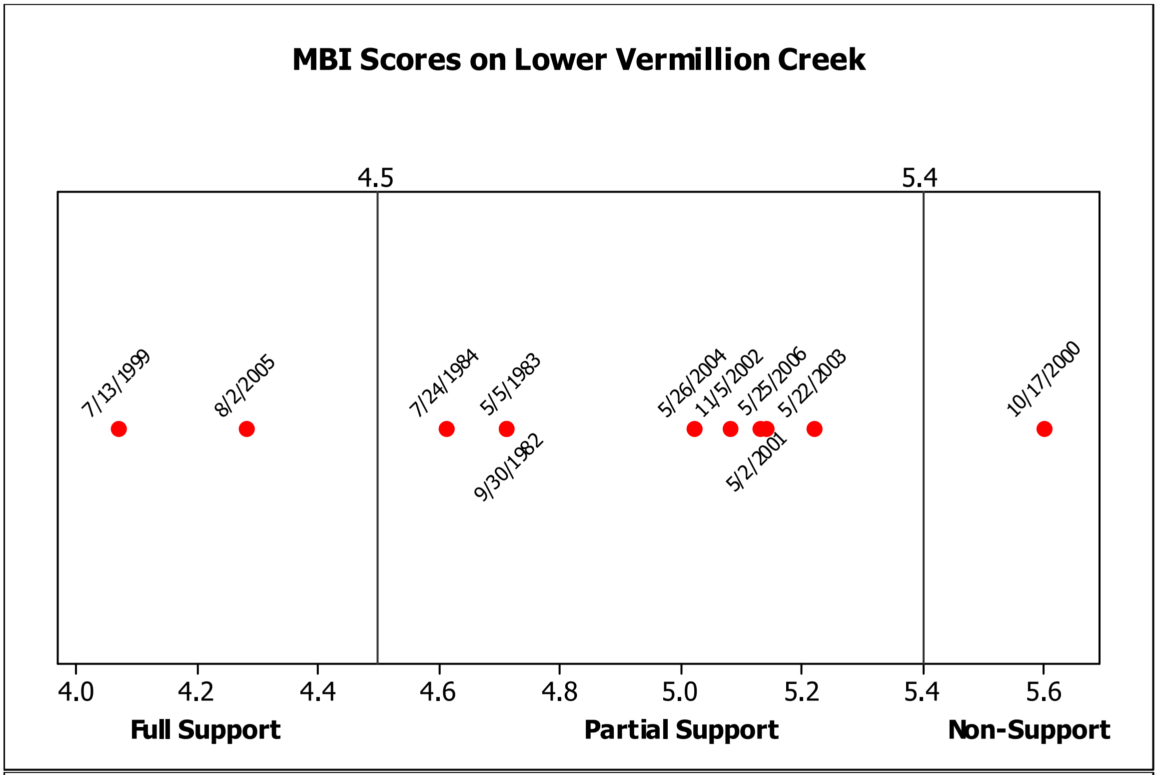

Vermillion Creek Total Nitrogen Concentrations by Discharge at 06888000
Lower Vermillion
Rock Creek
Upper Vermillion
Total Nitrogen (mg/L)
Discharge (cfs)
Season
Spring
Summ-Fall
Winter
1
10
100
1000
10.0
1.0
0.1

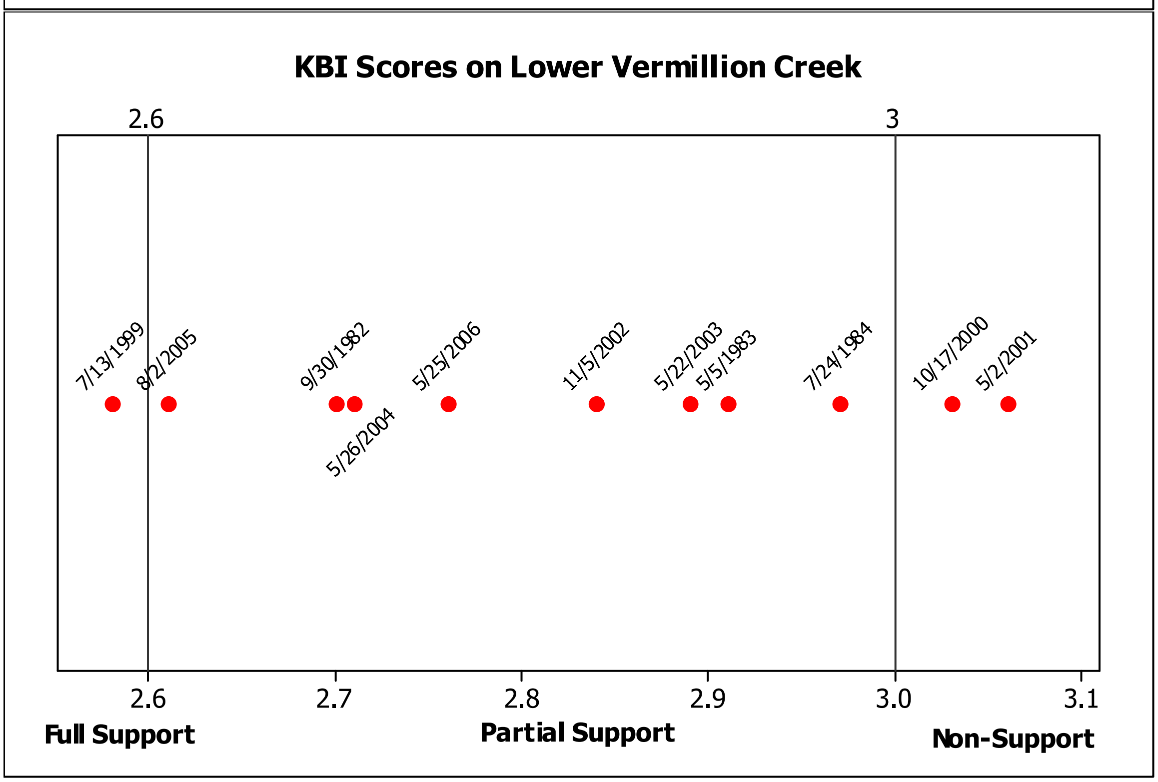

Vermillion Creek Total Suspended Solids by Station and Season
Lower Vermillion
Rock Creek
Upper Vermillion
Season
Spring
Summ-Fall
Winter
Total Suspended Solids (mg/L)
Julian Date
0
100
200
300
1
10
100
1000
10000

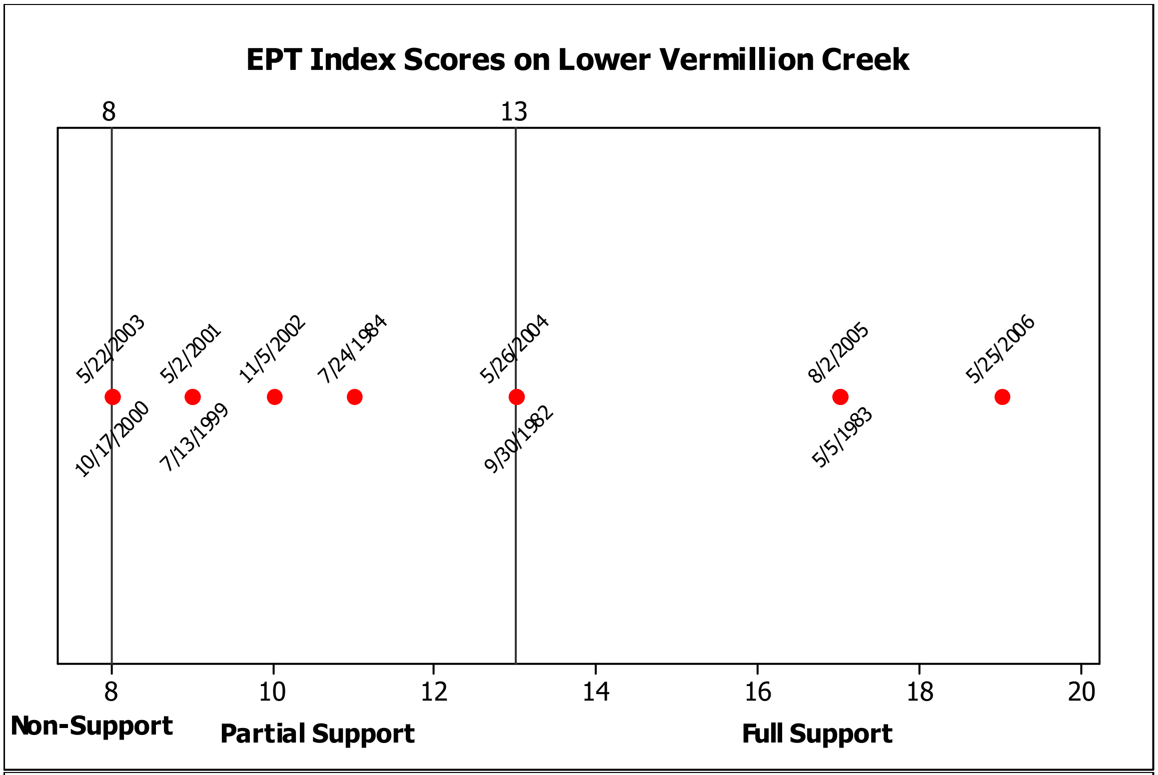

Vermillion Creek Total Suspended Solids by Discharge at 06888000
Lower Vermillion
Rock Creek
Upper Vermillion
Season
Spring
Summ-Fall
Winter
Total Suspended Solids (mg/L)
Discharge (cfs)
1
10
100
1000

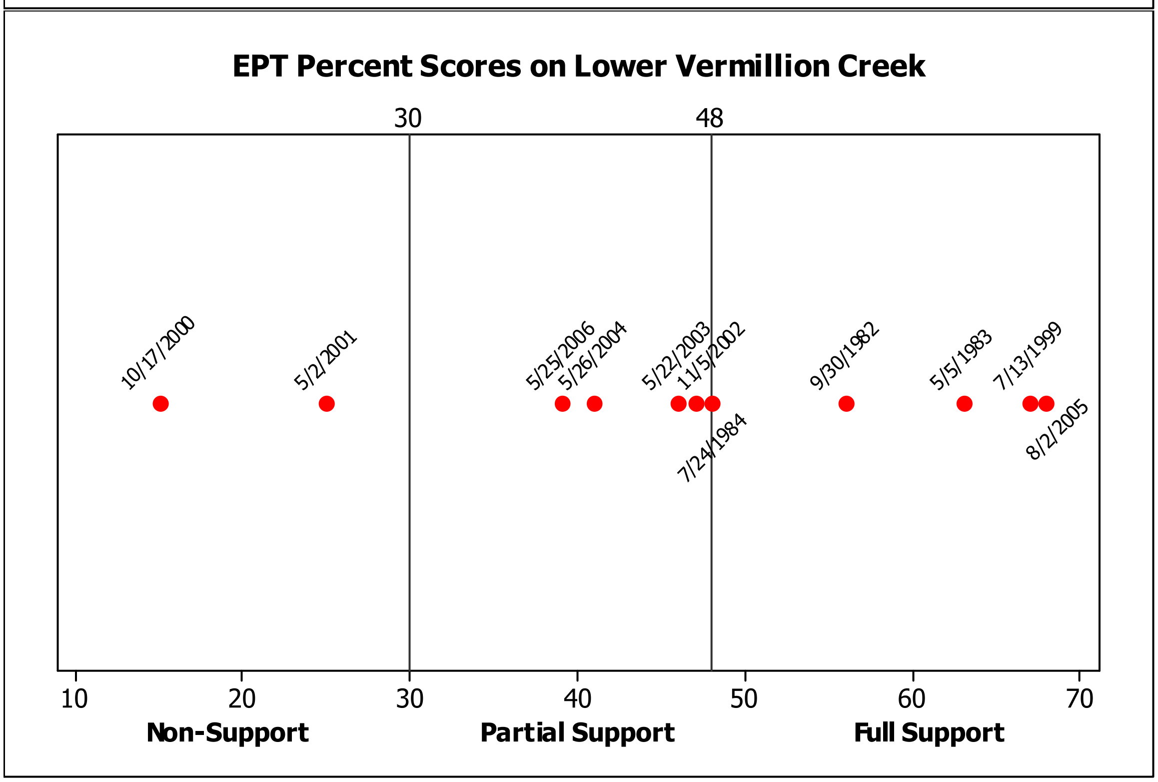

Vermillion Creek E. coli by Station and Season
Lower Vermillion
Rock Creek
Upper Vermillion
Season
Spring
Summ-Fall
Winter
E. coli (cfu/100 mL)
1000000
100000
10000
1000
100
10
0
100
200
300
Julian Date


Vermillion Creek E. coli by Discharge at 06888000
Lower Vermillion
Rock Creek
Upper Vermillion
Season
Spring
Summ-Fall
Winter
E. coli (cfu/100 mL)
1000000
100000
10000
1000
100
10
1
10
100
1000
Discharge (cfs)


MBI Scores on Lower Vermillion Creek
4.5
5.4
7/13/1999
8/2/2005
7/24/1984
5/5/1983
9/30/1982
5/26/2004
11/5/2002
5/25/2006
5/22/2003
5/2/2001
10/17/2000
4.0
4.2
4.4
4.6
4.8
5.0
5.2
5.4
5.6
Full Support
Partial Support
Non-Support

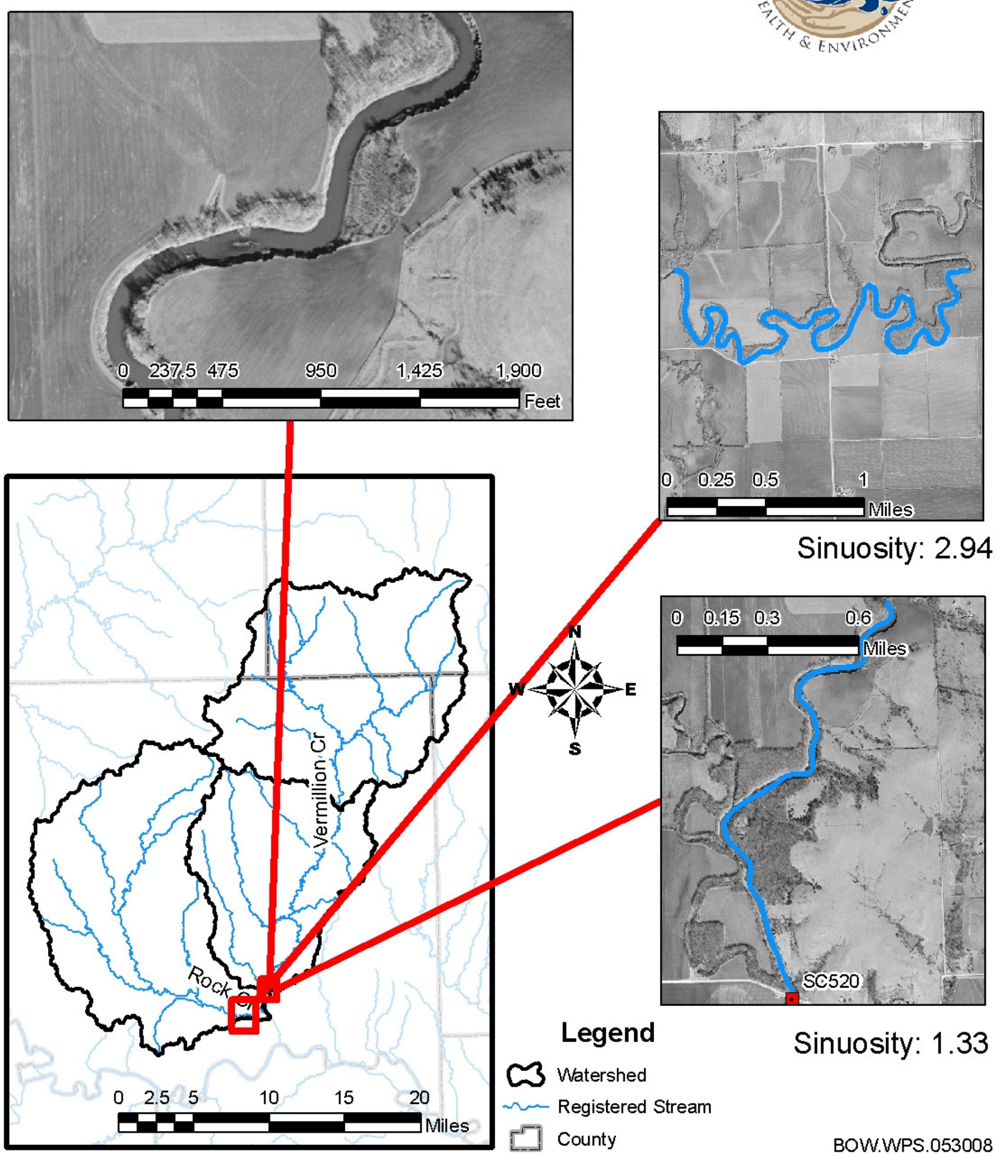

KBI Scores on Lower Vermillion Creek
2.6
3
7/13/1999
8/2/2005
9/30/1982
5/26/2004
5/25/2006
11/5/2002
5/22/2003
5/5/1983
7/24/1984
10/17/2000
5/2/2001
2.6
2.7
2.8
2.9
3.0
3.1
Full Support
Partial Support
Non-Support





Streambank stabilization may play an important role in improving water quality in the Vermillion Creek watershed. One meter resolution aerial photographs were used to identify a number of potential unstable streambanks in the lower reaches of the watershed. Inspection of stream channel sinuosity also suggests that channelization has occurred, and may be contributing to the observed water quality.

Vermillion Creek Watershed
Streambank Erosion Point
Potential Channelization



Vermillion Creek has also been channelized downstream of the junction of Vermillion Creek and Rock Creek, visible in this image from the 2006 NAIP photograph. The historic channel is located as a wooded belt just to the east of the current channel, and provides a case study in the reduction of channel complexity that typically occurs during channelization. This area is part of the unmonitored portion of the watershed, and the land use in this part of the watershed is essentially all row crop production. A similar channelization effort on Soldier Creek has resulted in well documented head-cutting of the stream, lowering the base elevation of the creek bed, substantially increasing bank instability, eroding large quantities of bed and bank material and potentially leading to lower groundwater levels.

Uncertainty-

Because concurrent gage data are only available recently with the stream chemistry data, some uncertainty exists about the flow conditions associated with the earlier samples. Very large TSS values likely occurred during very high flow events, which may be less responsive to restoration efforts (Meals, 1990). Previous research (unpublished) by KDHE has indicated that median values are strong descriptors of nutrient related impairments, even in the absence of flow data, when large sample records exist. At this level of analysis it is not possible to determine the relative contributions of overland flow and in-stream processes, including collapsing streambanks. Elevated nitrogen levels could also be indicative of failing on-site wastewater systems, which cannot be ruled out as a potential contributor at this level of analysis. Future restoration efforts in this area would benefit from more water quality data throughout the watershed, to pinpoint potential sources of pollution, and better define the spatial and temporal variation in water quality. Additionally, surveys of stream channel morphology will locate potential sources of major bank instability.

Adaptive Implementation Strategies-

Because this stream exhibits characteristics that are consistent with point source pollution, overland flow and unstable streambank sources, initial efforts could be focused on the lower reaches of Vermillion Creek for streambank efforts, the Rock Creek watershed for bacteria reductions, and below the city of Onaga for the upper reaches of Vermillion Creek. Evaluation of the potential to restore the most downstream reach of Vermillion Creek to its historic channel would help establish the amount of pollutant loading to the Kansas River from this unmonitored lowest segment of Vermillion Creek. Any movement of the channel of this creek would have to evaluate costs associated with major infrastructure, including the Highway 24 and adjacent Union Pacific railroad bridge near the outlet of Vermillion Creek. This watershed shows extensive use of alluvial valleys for row crop production, and shows some signs of poor buffering around the streams, along the lower reaches of Rock & Vermillion Creeks. While forest buffers along major streams are present in some locations in the watershed, they tend to be narrow, and would benefit streams more with additional width. The moderate TP concentrations appear to track the loading pattern of TSS, suggesting improvements in conservation practices may reduce both these contaminants. Preservation and expansion of the existing buffer zone will likely have beneficial effects for all pollutants for many years to come. Placement of grassed waterways and other upland erosion control measures may also reduce the concentrations of TSS in Vermillion Creek and its tributaries.

Because riparian buffering activities typically take three or more years to fully establish themselves, monitoring of post-implementation water quality should be a long-term objective. The existing monitoring record is unlikely to have many high-flow events, due to the design of the sampling program. Because the majority of loads of suspended solids and total phosphorus are likely to occur during a few, relatively large events, a before-and-after sampling program focused on high flow events would determine if efforts lead to significant improvements to water quality. Nitrogen concentrations appear to be less variable than TSS and TP, though concentrations still exceed regional guidance. Wintertime concentrations that usually exceed summer-fall concentrations, as is the case on Rock Creek, suggest that groundwater loading is a probable source of nitrogen, because wintertime flows are typically driven by baseflow from groundwater sources, while some dilution may be occurring during summer when flows are usually somewhat higher than winter flows.

It should be noted that some strategies to reduce nutrient pollution have confounding effects. Tillage and cover strategies that reduce runoff and increase infiltration have been documented in some cases to increase nitrogen infiltration to groundwater. Increased infiltration should reduce phosphorus and sediment loading, and improvements to riparian forest areas are likely to reduce groundwater loading of nitrogen to the stream, while increasing bank stability. Therefore, implementing strategies should target field runoff for sediment and phosphorus loading, and simultaneously implement riparian restoration.

Should streambank stabilization, riparian planting, and other buffering activities in the lower reaches not reduce sediment and nutrient loading to acceptable levels, targeted monitoring may be required to determine sources more accurately. Funding for practices to improve water quality should focus on lands adjacent to streams where cropland is completely unbuffered, and implementation of erosion control practices in the valley along Vermillion Creek, because these areas are more likely to contribute to water quality problems monitored at station 520. Provision of alternate watering sites, and exclusion of cattle from direct access to streams has numerous benefits, and may prove an important component of watershed restoration in this area. Reduced bank trampling increases the stability of streambanks, while also improving the growth and health of riparian trees. Keeping cattle out of streams also reduces direct inputs of nutrients and bacteria to the stream, and buffer areas can filter overland flow reducing pollutant loading from that source as well.

Vermillion Creek and its tributaries presents significant challenges to implementat protection and expansion of the existing riparian buffer has significant potential to improve water quality. While unverified at this level of analysis, the low sinuosity of some of the mainstem segments of Vermillion Creek suggests that channelization has occurred in this area, and unstable banks may be contributing to the concentrations observed. Increasing the streams' connection with its flood plain and widening of permanent vegetation buffers along the streams could require some reductions of current cropland uses by area landowners. Further evaluation will need to be completed to determine the extent of the problem, and establish the costs for implementing conservation activities.

Mill Creek-

Monitoring Stations- SC506, SC519, SC521, SC726 & SC727
USGS Gaging Station- 06888500 (Mill Creek) 12/18/1953-Current
Included area-
HUC 8: 10270102
HUC 10: 03; 04
HUC 12: 01, 02, 03, 04, 05; 01, 02, 03, 04
Streams Flowing to Monitoring Station-

Station	Name	Segment #
SC506	Mill Creek, W Br-	28
West Branch Mill Creek	Mill Creek, W Br-	29
	Loire Creek-	80
SC519	Mill Cr, E Br-	31
South Branch Mill Creek	Mill Cr, S Br-	32
	Mill Cr, E Br-	33
	Unnamed Stream-	693
	Nehring Cr-	81
SC521	Mill Cr-	27
Lower Mill Creek	Hendricks Cr-	73
	Pretty Cr-	74
	Paw Paw Cr-	75
	Spring Cr-	76
	Mulberry Cr-	77
	Dog Cr-	78
	Dry Cr-	79
	Kuenzli Cr-	82
	Snokomo Cr-	85
SC726	Illinois Cr-	30
Illinois Creek		
SC727	Nehring Cr-	81
Nehring Creek		

Monitored Watershed Size- 416.1 square miles
West Branch Mill Creek (SC506) – 107.2 square miles
South Branch Mill Creek (SC519) – 90.2 square miles
Lower Mill Creek (SC521) – 171.5 square miles
Illinois Creek (SC726) – 34.7 square miles
Nehring Creek (SC727) – 12.5 square miles

Land use-

	West Branch Mill Creek	South Branch Mill Creek	Lower Mill Creek	Illinois Creek	Nehring Creek
Permanent Grass	87.98%	90.54%	79.29%	90.85%	93.24%
Cropland	4.35%	2.58%	10.55%	1.91%	0.91%
Forest	4.51%	3.96%	4.73%	5.04%	3.27%
Developed Land	2.87%	2.26%	4.87%	2.02%	2.51%

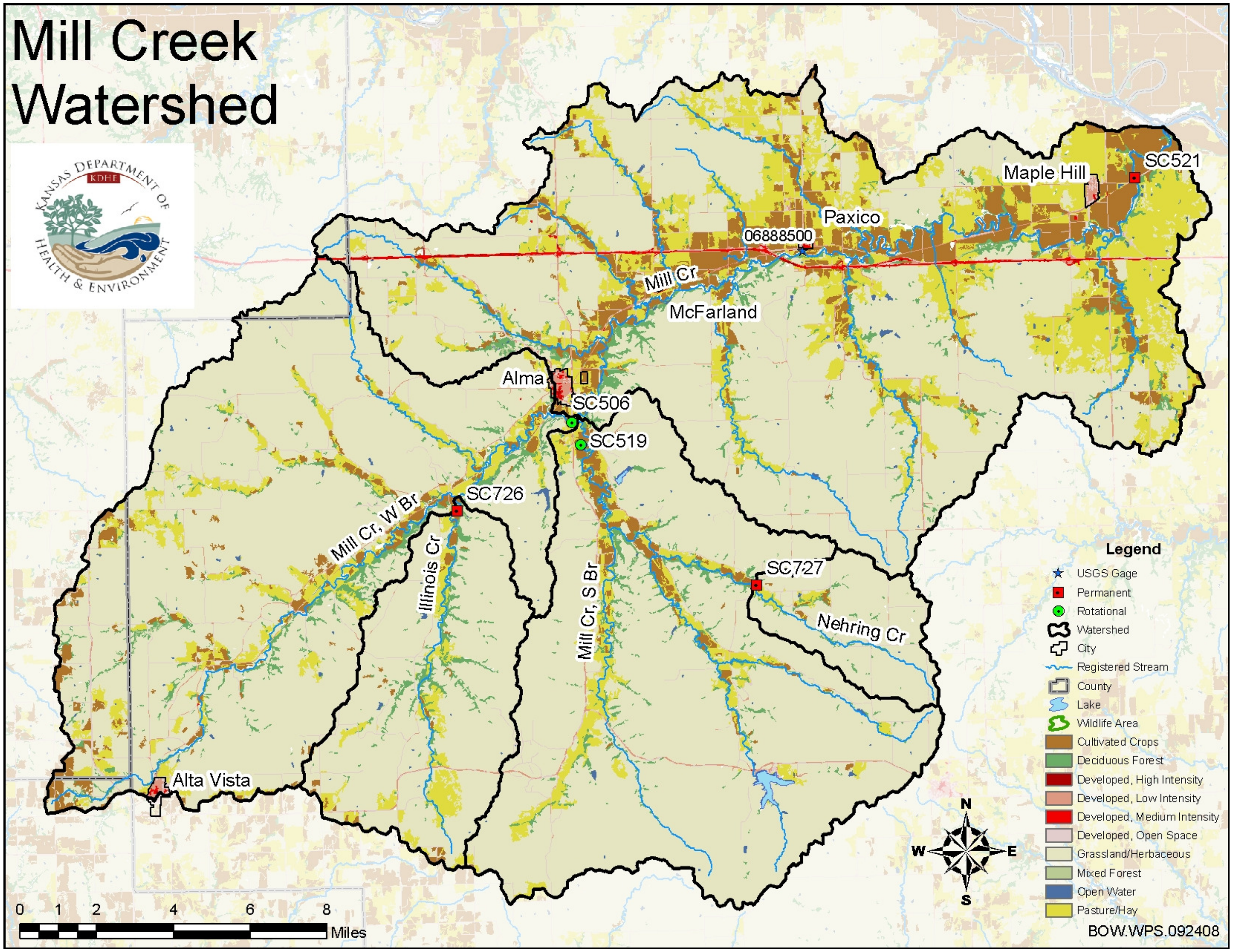
Counties- Wabaunsee, Morris, Geary & Riley
Cities- Alma, Alta Vista, McFarland, Paxico & Maple Hill
Mill Creek Watershed District- Includes the entire watershed
2000 Population- Overall- 4,453[2]
West Branch Mill Creek (SC506) - 1,090
South Branch Mill Creek (SC519) - 447
Lower Mill Creek (SC521) - 3,320
Illinois Creek (SC726) – 71
Nehring Creek (SC726) - 73
Kansas House Districts – 51, 61, 65, 67, 68
Kansas Senate Districts – 17, 18 & 22

2008 303(d) impaired waters- None
TMDLs- Bacteria, approved 1/26/2000 (SC506, SC519, SC521)
NPDES Permitted Facilities- Alma MWTP (M-KS01-IO01), Maple Hill MWTP (M-KS39-OO01), McFarland MWTP (M-KS41-OO01), Wabaunsee County S.D. #1 (M-KS57-NO01), Paxico MWTP (M-KS57-OO01), KDOT Rest Area (M-KS57-OO02), Lake Wabaunsee Improvement District (M-KS92-OO02), Granma Hoerner's (C-KS01-NO01), Quality Gas & Shop (C-KS01-NO01), Maple Hill Truck Stop (C-KS39-NO01), Wyldewood Cellars Winery (C-KS57-NO01), Stuckey's (C-KS57-NO03), Keith Scott & Co. (Maginley)(I-KS57-PO02), Keith Scott & Co. (Heigert)(I-KS57-PO02)

Permitted Confined Animal Feeding Operations-11

Animal Type	Total Animals
Beef	10,126
Dairy	189
Swine	1115

[2] Individual monitoring station populations add up to greater than the total population due to census boundaries that cross watershed boundaries.



Overview map of the Mill Creek watershed. Land use from the 2001 National Land Cover Dataset.

Stream Chemistry-

The monitoring stations in the Mill Creek watershed have the top four ranked stations in the Middle & Upper Kansas sub-basins, and five of the top six. In other analyses, this watershed has had some of the best overall water quality in the state. The worst individual rank in this area was for TSS at Lower Mill Creek (SC521), with a ranking of 9 out of 19, or better than half of all monitoring stations included in this analysis. The best ranks go to the more upstream areas, suggesting some level of degradation occurring as water moves downstream. Nehring Creek is ranked more poorly than might be expected for TN and E. coli, suggesting that some level of livestock related reduction in water quality may be occurring in that small area of the watershed, relative to the other stations. Overall, the concentrations of pollutants in the Mill Creek watershed fall below levels of concern based on ecoregional guidance, contact recreation criteria, and state water quality standards, with one possible seasonal exception at the most downstream monitoring station.

More downstream stations show increasing evidence of non-point source pollution, seasonally varying concentrations of pollutants, particularly turbidity, TSS and TP. The highest overall concentrations occur in spring time for most metrics for all stations in the watershed. The arch shaped graphs for TP and TSS are examples of this pattern. Exceptions are the higher median concentrations of TP and TN at Nehring Creek during the summer-fall, the higher kjeldahl nitrogen concentrations at the most downstream station during summer-fall, and the higher *E. coli* concentrations on Illinois Creek during the summer-fall. Spring concentrations of TSS on Lower Mill Creek exceed those previously thought to impair aquatic life as a long-term concentration, and may be cause for some concern regarding the management of lands in the alluvial valley along Mill Creek. While not shown in summary statistics, the highest *E. coli* concentration in the KDHE database occurred at Lower Mill Creek, visible on the far right of the *E. coli*/discharge graph, and high flows can contribute greatly to the absolute loads of pollutants like TP and TSS, as seen in their respective graphs. These very high concentrations tend to occur during the spring, and only at the most downstream station in the watershed.

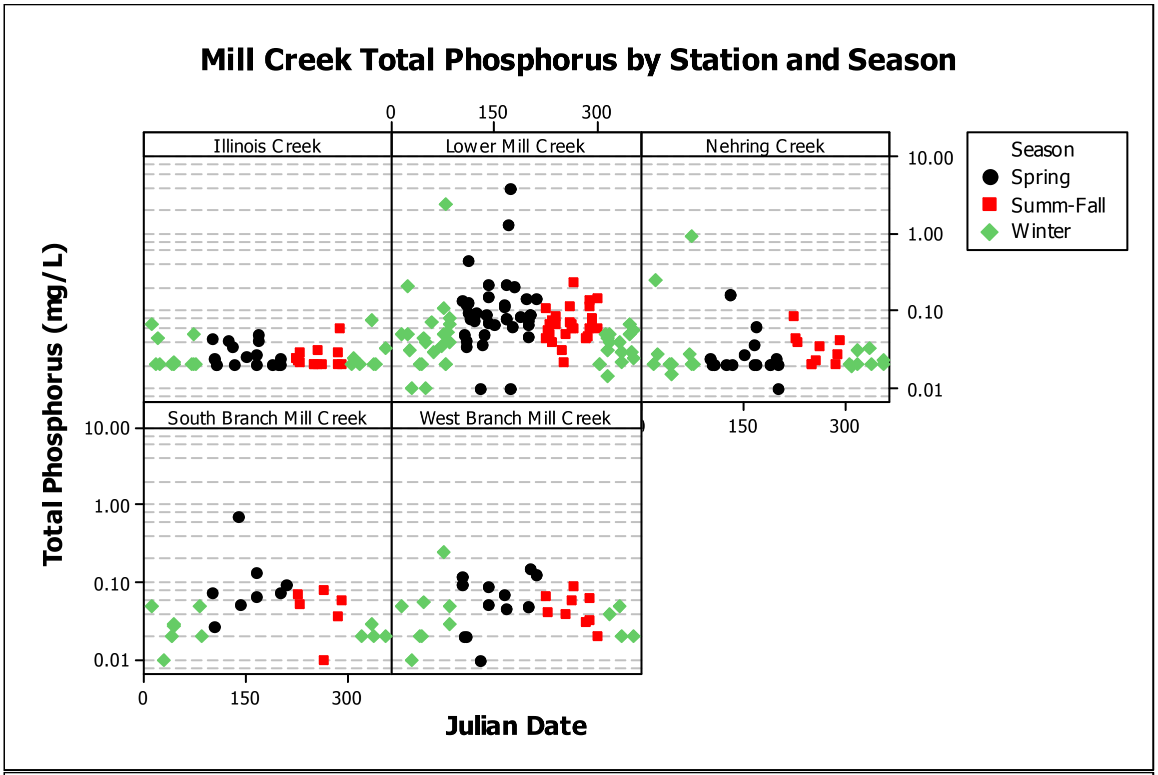
The Mill Creek watershed is fortunate to have long-term gage records that coincide with the chemical and biological monitoring data. The discharge data indicates that, to the extent that any concern is warranted at all, most pollutants are entering the streams in this watershed during high flow events, and that under ambient conditions water quality is consistently good. One possible exception to that generalization is the very low flow conditions on Nehring Creek, where the beginnings of a U-shapped curve are occurring on *E. coli* and TN graphs. As noted elsewhere, a U-shaped curve tends to indicate that very low flows have somewhat elevated concentrations, which can be a sign of direct loading from point sources or livestock in the stream, with low flows unable to dilute the impact of the source. While point sources, such as municipal discharge are not present in the Nehring Creek watershed, there may be direct inputs of animal waste as livestock congregate in wetted areas during low flow periods. If this is the case, some provision for alternative watering sites and other exclusion activities may ensure that the exceptional water quality observed elsewhere in the Mill Creek watershed is maintained in Nehring Creek. Additionally, the rapidly rising TSS & TP concentrations during high flow events in Nehring Creek are not seen in Illinois Creek, suggesting some localized source that is contributing at high flows. While the total cropland in this area is low, a few small fields may have sections of poor buffering just upstream of the Nehring Creek station (SC727), which could be contributing to this pattern.

Biological monitoring data indicate an overall picture of relatively good support for aquatic life, with moderately impaired values some of the time. Previous work on the data from this watershed indicates that for as much as 60 days following a major storm even the macroinvertebrate community is impaired, likely due to the washing out of both mature adults and juveniles needed to recolonize the area. Work at Konza Prairie demonstrated that the distance to a source of replacement macroinvertebrates, such as a less-effected downstream water, is an important part of the recolonization rate for macroinvertebrates in prairie streams. While not analyzed here, it is possible that some of the partially-supporting designations at SB521 are correlated with the elevated spring concentrations of TSS, which could impair species dependent on gills for breathing and possibly impair species that reproduce once per year if they reproduce primarily during the spring.

Site	Season	Turbidity Median	TSS Median	TP Median	TN Median	Kjeldahl Median	*E.coli* Median	TOC Median
West Branch Mill SC506	Overall	5.2 (33)	12 (33)	0.05 (33)	0.4085 (16)	0.299 (16)	≤10 (8)	2.4835 (16)
SC506	Spring	7.25 (12)	20 (12)	0.0625 (12)	0.4865 (6)	0.3365 (6)	≤10 (3)	2.667 (6)
SC506	Summer-Fall	3.5 (9)	≤10 (9)	0.043 (9)	0.565 (5)	0.415 (5)	15.5 (2)	2.088 (5)
SC506	Winter	2.49 (12)	≤10 (12)	0.035 (12)	0.352 (5)	0.171 (5)	≤10 (3)	2.388 (5)
South Branch Mill SC519	Overall	4.05 (26)	10.5 (26)	0.0435 (26)	0.3895 (14)	0.1385 (14)	≤10 (7)	2.0935 (14)
SC519	Spring	11.7 (8)	30.5 (8)	0.0765 (8)	0.6665 (4)	0.2415 (4)	58.5 (2)	3.315 (4)
SC519	Summer-Fall	4.03 (6)	11.5 (6)	0.0575 (6)	0.366 (4)	0.161 (4)	20 (2)	2.366 (4)
SC519	Winter	2.2 (12)	≤10 (12)	0.02 (12)	0.2885 (6)	0.1385 (6)	≤10 (3)	1.827 (6)
Lower Mill SC521	Overall	12.1 (107)	26 (107)	0.063 (104)	0.536 (51)	0.291 (51)	31 (29)	3.234 (43)
SC521	Spring	20 (39)	52 (39)	0.09 (39)	0.66 (19)	0.43 (19)	35.5 (10)	3.719 (16)
SC521	Summer-Fall	11.55 (28)	25.5 (28)	0.07 (27)	0.669 (12)	0.539 (12)	41 (7)	3.234 (11)
SC521	Winter	5.3 (40)	12 (40)	0.04 (38)	0.4135 (20)	0.2535 (20)	15 (12)	2.8935 (16)
Illinois SC726	Overall	0.71 (48)	≤10 (48)	0.021 (48)	0.271 (48)	0.104 (48)	31 (28)	1.657 (45)
SC726	Spring	0.77 (16)	≤10 (16)	0.0245 (16)	0.286 (16)	0.1135 (16)	41.5 (10)	2.092 (15)
SC726	Summer-Fall	0.65 (13)	≤10 (13)	0.022 (13)	0.25 (13)	0.1 (13)	86 (7)	1.494 (11)
SC726	Winter	0.7 (19)	≤10 (19)	≤0.02 (19)	0.27 (19)	0.103 (19)	≤10 (11)	1.508 (19)
Nehring SC727	Overall	1.06 (47)	≤10 (47)	≤0.02 (47)	0.479 (47)	0.137 (47)	74 (29)	1.81 (45)
SC727	Spring	1.845 (18)	≤10 (18)	≤0.02 (18)	0.461 (18)	0.1295 (18)	146 (11)	2.26 (17)
SC727	Summer-Fall	1.365 (10)	≤10 (10)	0.031 (10)	0.8135 (10)	0.124 (10)	30 (6)	1.265 (9)
SC727	Winter	0.78 (19)	≤10 (19)	≤0.02 (19)	0.468 (19)	0.137 (19)	47 (12)	1.596 (19)

Stream chemistry data for all five KDHE monitoring sites in the Mill Creek Watershed by season and overall. Number in parenthesis is sample size.

This aerial photograph, from the 2006 NAIP, shows the location of row crop fields somewhat upstream from the KDHE monitoring station. The fields are visible in light brown, and can be seen in some locations directly adjacent to the creek.


Mill Creek Total Phosphorus by Station and Season
Illinois Creek
Lower Mill Creek
Nehring Creek
South Branch Mill Creek
West Branch Mill Creek
Total Phosphorus (mg/L)
Julian Date
0
150
300
10.00
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0.10
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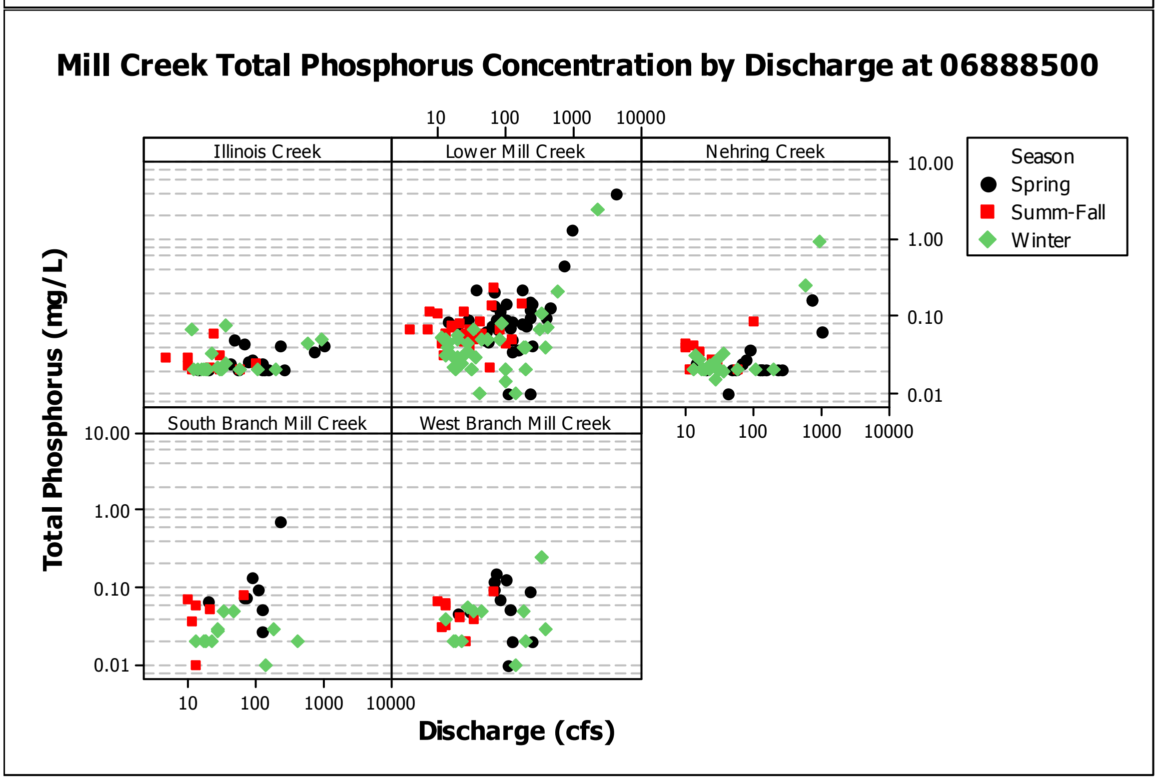
Season
Spring
Summ-Fall
Winter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South Branch Mill Creek
West Branch Mill Creek
Total Phosphorus (mg/L)
Discharge (cfs)
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10.00
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Season
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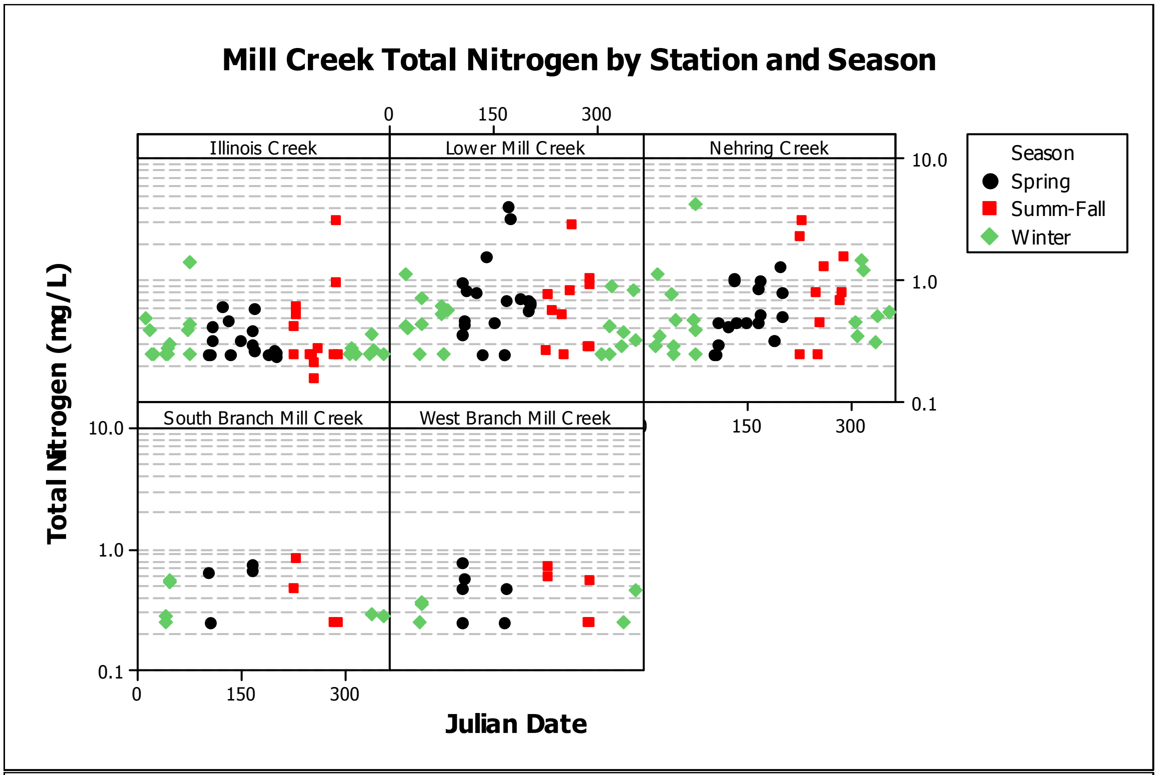
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Julian Date
0
150
300
10.0
1.0
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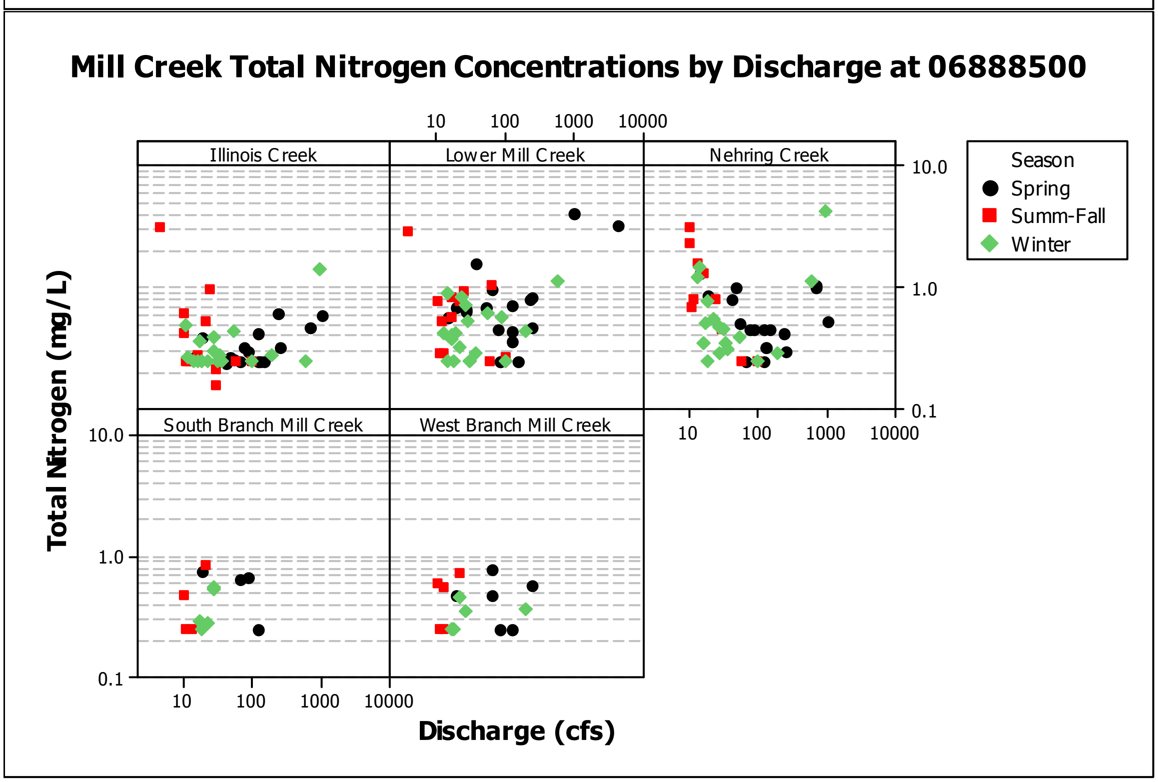
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Total Nitrogen (mg/L)
Discharge (cfs)
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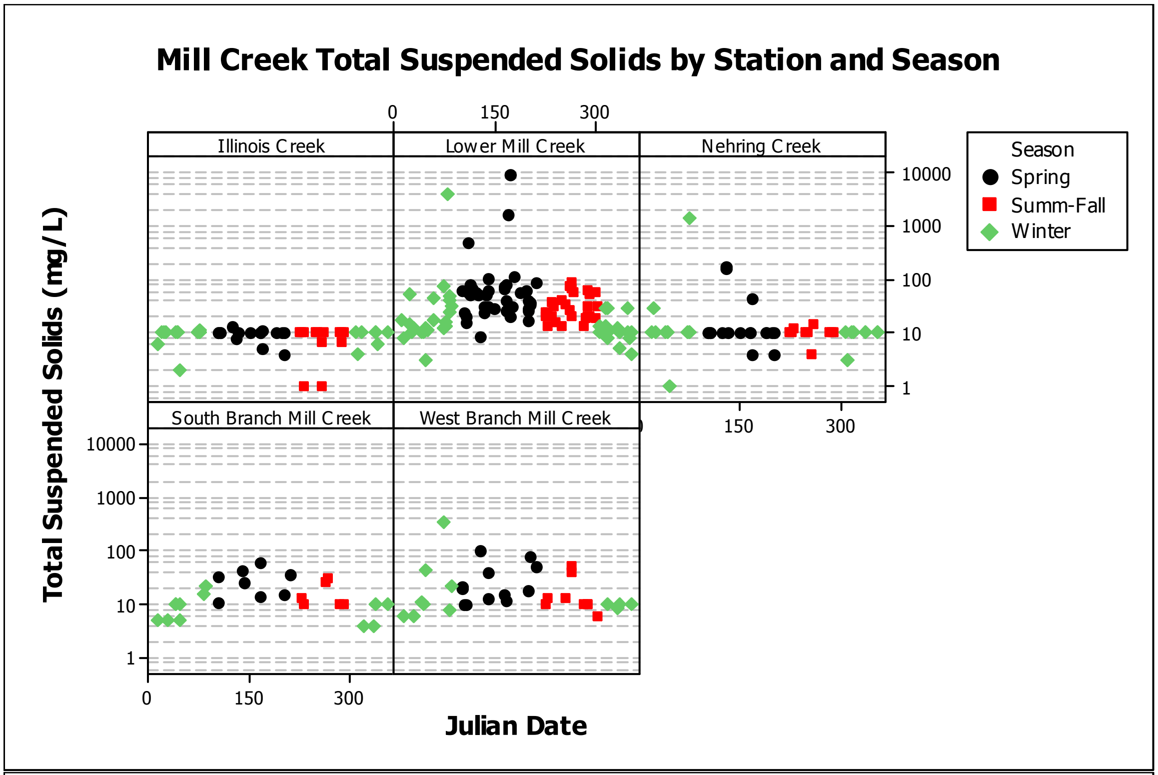
100
1000
10000
10.0
1.0
0.1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150
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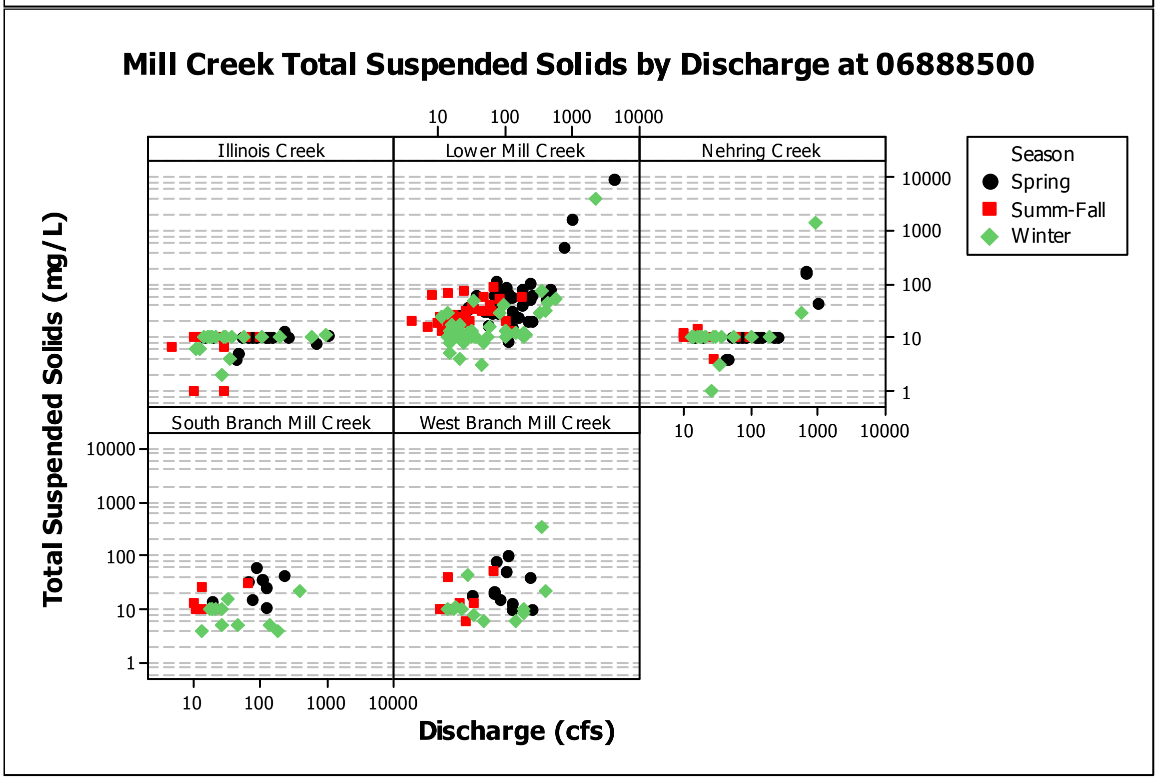
10000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West Branch Mill Creek
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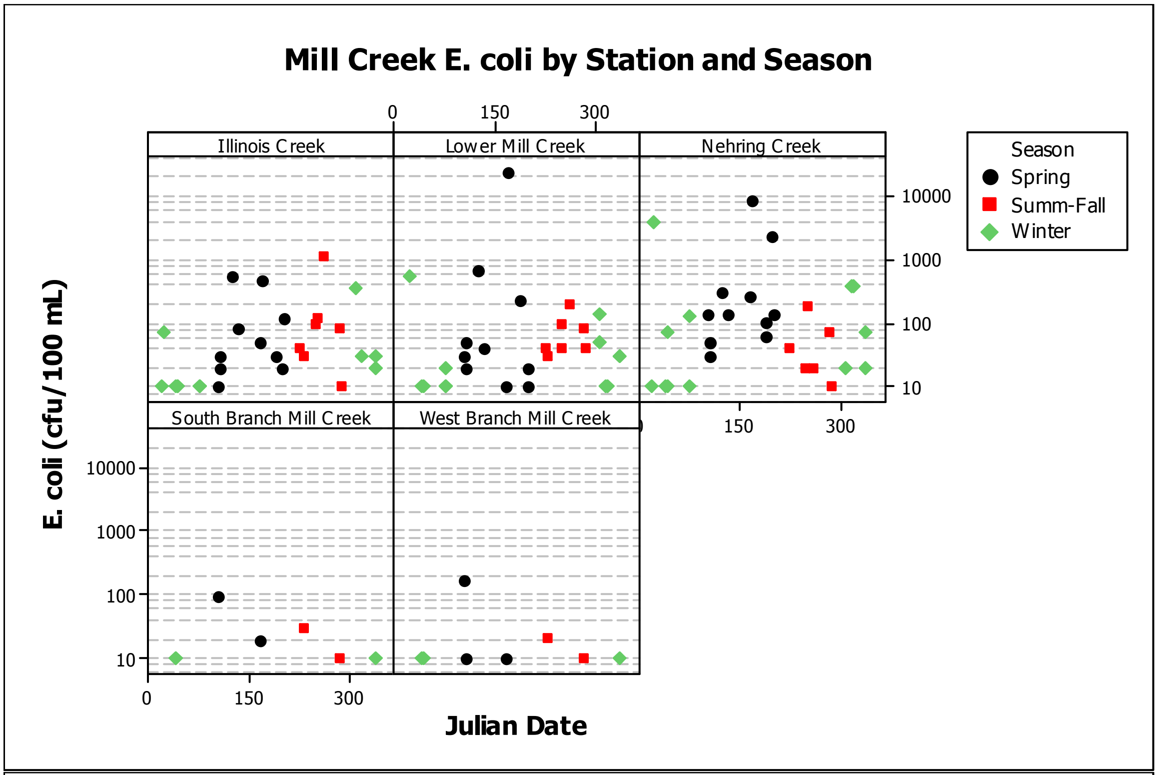
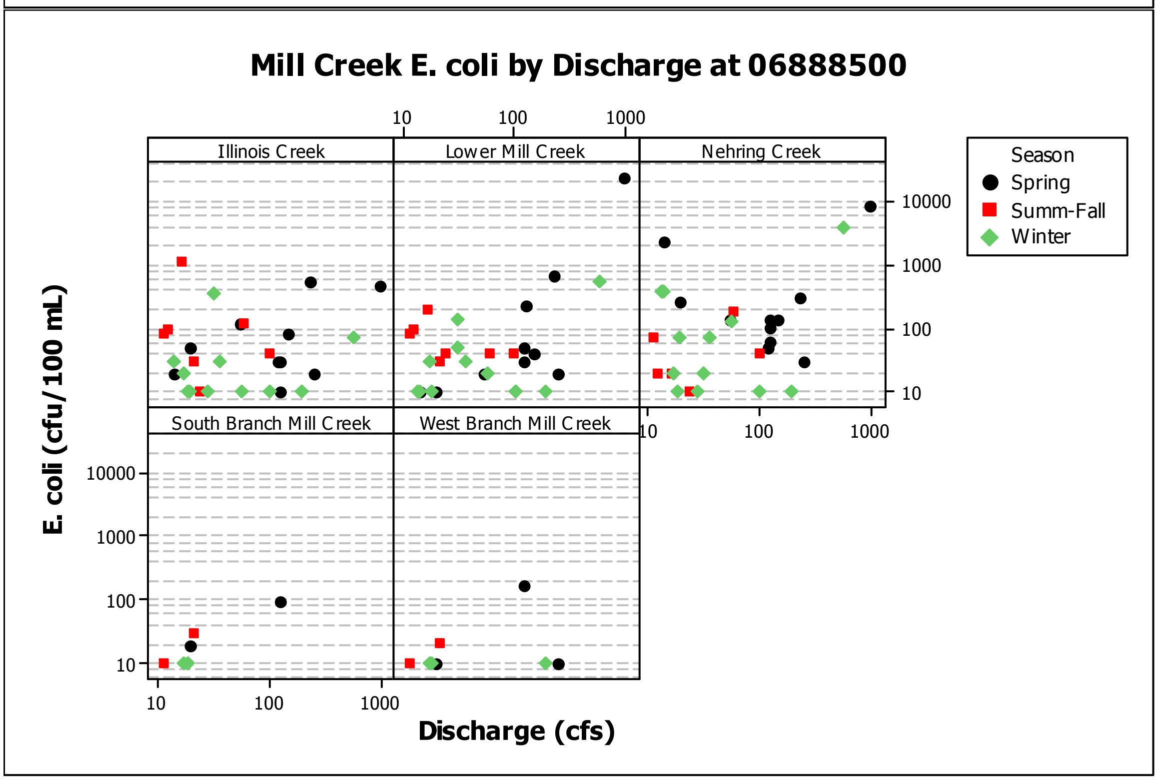
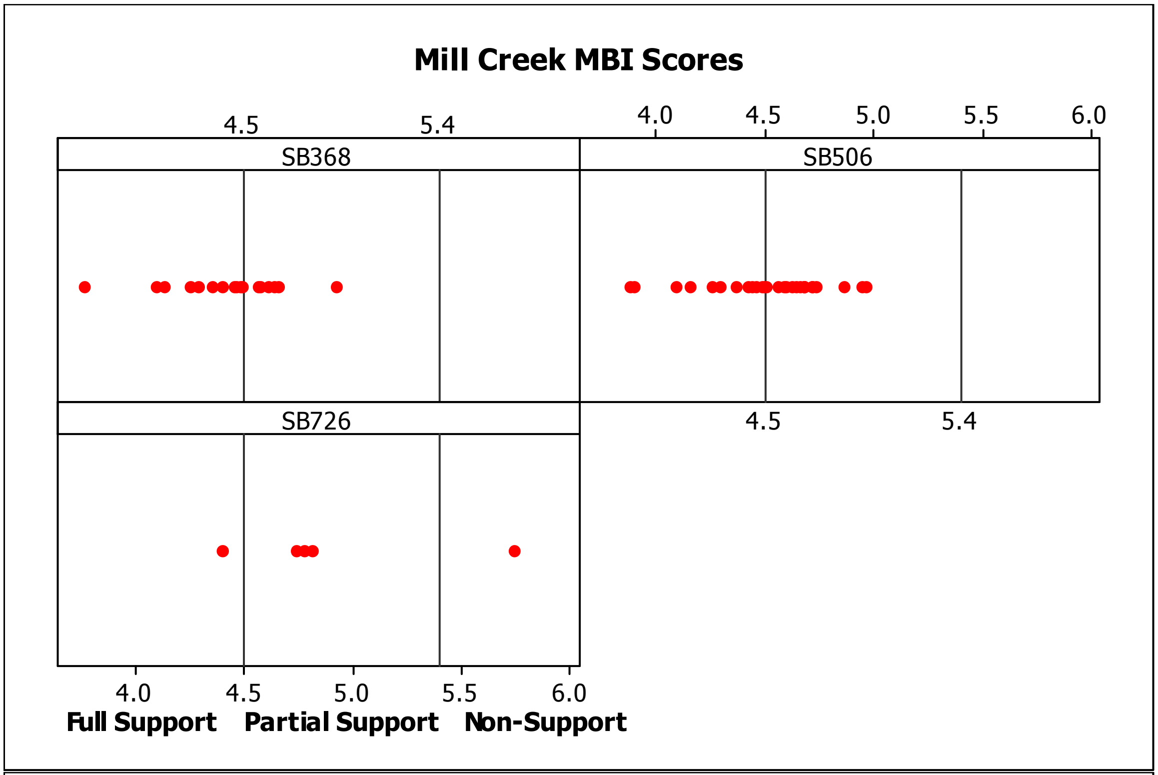
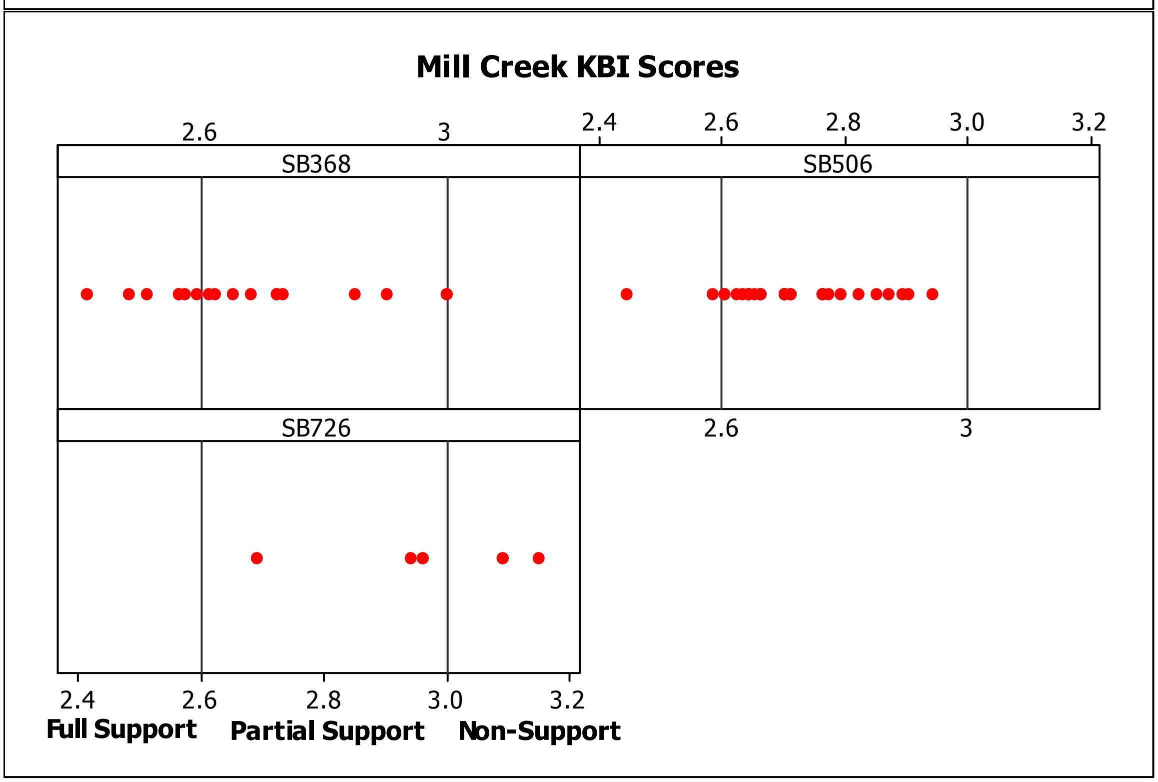
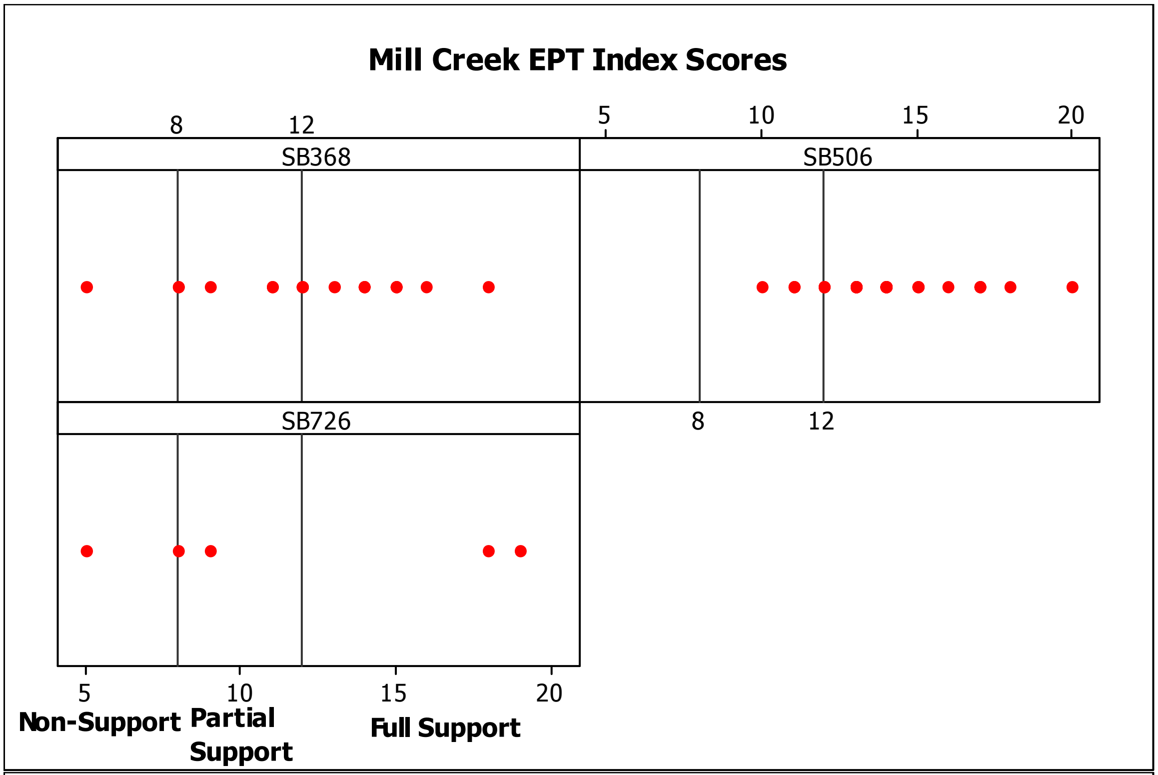
Spring
Summ-Fall
Winter
Total Suspended Solids (mg/L)
Discharge (cfs)
10
100
1000
10000
1

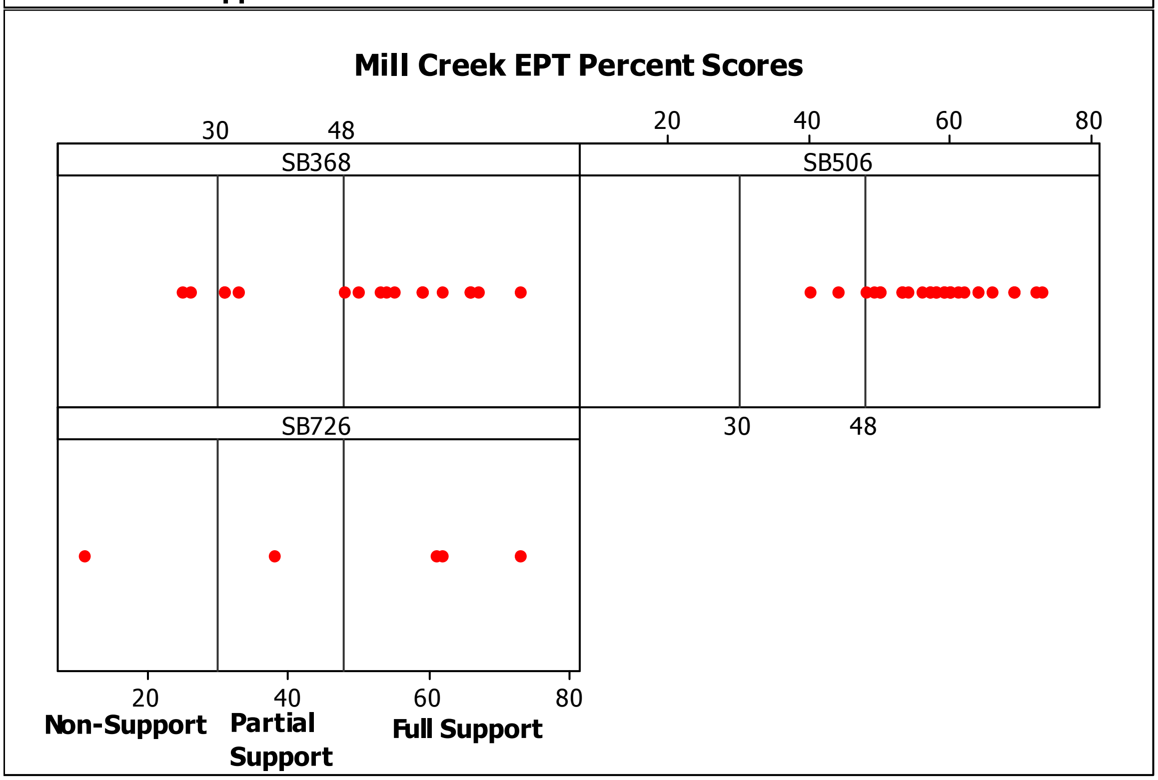

Mill Creek E. coli by Station and Season
Illinois Creek
Lower Mill Creek
Nehring Creek
South Branch Mill Creek
West Branch Mill Creek
Season
Spring
Summ-Fall
Winter
E. coli (cfu/100 mL)
Julian Date


Mill Creek E. coli by Discharge at 06888500
Illinois Creek
Lower Mill Creek
Nehring Creek
South Branch Mill Creek
West Branch Mill Creek
Season
Spring
Summ-Fall
Winter
E. coli (cfu/100 mL)
Discharge (cfs)

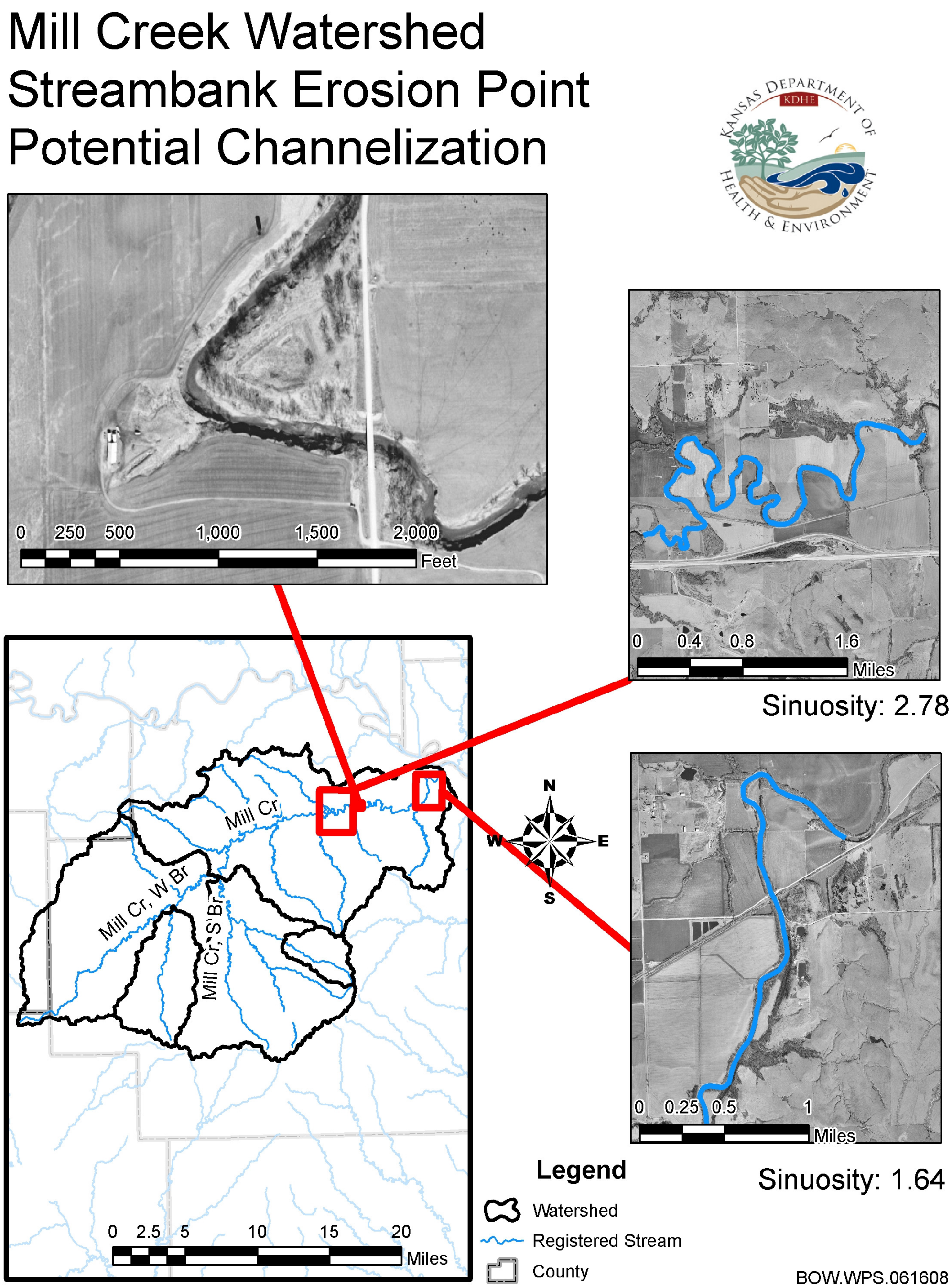

Mill Creek MBI Scores
SB368
SB506
SB726
4.5
5.4
4.0
4.5
5.0
5.5
6.0
Full Support
Partial Support
Non-Support


Mill Creek KBI Scores
SB368
SB506
SB726
2.6
3
2.4
2.6
2.8
3.0
3.2
Full Support
Partial Support
Non-Support





Streambank stabilization may play an important role in improving water quality in the lower Mill Creek watershed. One meter resolution aerial photographs were used to identify a number of potential unstable streambanks in the lower reaches of the watershed. Inspection of stream channel sinuosity also suggests that channelization has occurred, and may be contributing to the observed water quality.



Uncertainty-

The availability of gage data concurrent with all the stream chemistry data and biology data reduce some of the uncertainty regarding water quality in this watershed. While the gage is not directly co-located with any of the stream chemistry sites, it is likely to be a good indicator of the relative flow conditions occurring in this watershed at the time of sampling. Because biology data are collected annually or less frequently, there is less certainty regarding the applicability of the data across time. Previous research on this, and other similar watersheds in Kansas, have noted a strong "harshness" effect of rapidly rising and falling floods, as occur in areas with relatively shallow soils. This harshness can result in temporary reductions in the observed biotic indexes as macroinvertebrates are dislodged during large storm events. Other uncertainty exists due to maximum/minimum reporting limits on chemical parameters monitored by KDHE. For some time TSS concentrations have been measured only down to 10 mg/L, and TP concentrations down only to 0.02 mg/L. In exceptional areas, like the upstream waters of the Mill Creek drainage, data are often recorded at the reporting limit, leaving uncertainty regarding the actual concentrations of these constituents. At this level of analysis we cannot assign sources to particular pollutants, though increasing nutrient and TSS concentrations moving downstream are correlated with increasing row-crop production. It is also not possible at this level of analysis to determine the source of bacteria, leaving uncertainty regarding the relative contributions from cattle and wildlife.

Adaptive Implementation Strategies-

The Mill Creek watershed has among the finest water quality in Kansas. Adaptive implementation in this watershed can be divided into two major areas, protection of existing water quality in the upper reaches and improving water quality in the downstream reaches. In the upper reaches of Mill Creek, as noted in the Nehring Creek data, there may be some localized or seasonal water quality concerns that can be addressed by ensuring appropriate buffering of the areas in row crop production and by working to reduce direct impacts of cattle grazing on the streams and streambanks. These efforts may reduce the limited impacts observed in the upper reaches. The upper reaches also pose an opportunity to provide education and outreach to other grassland watersheds in the WRAPS area, and other parts of the state, to help reduce the impacts of livestock grazing on Kansas Streams. Land managers and owners in the upper reaches of Mill Creek have done an admirable job of protecting water quality and should be recognized for their work to ensure that continued high quality grazing management occurs.

The lower reaches of Mill Creek, generally the area east of Alma, and more specifically the valley along Mill Creek itself could benefit from improved buffering of the creek from row crop production. The rich valley soils provide ideal conditions for raising a variety of row crops, and the continued success of these farms will benefit from preserving available farmland by reducing both overland and streambank erosion. Water quality notably declines, particularly sediment and phosphorus concentrations along this stretch of Mill Creek, and that is likely to be linked to inputs of soil during wet periods of the year. Expansion of, or establishment of, wooded riparian corridors along the entire creek will reduce sediment loading, particularly from stream bank sources. Overland flow may be a smaller component of the conditions experienced along the lower reaches of Mill Creek due to the minimally sloping soils. Efforts to identify eroding streambanks and establish effective riparian buffers are likely to have the largest beneficial effects on water quality in this area.

Some elevated *E. coli* concentrations have been observed in Mill Creek. However, under ambient conditions, *E. coli* concentrations fall below levels of concern for primary contact recreation such as swimming.

Mill Creek and its tributaries are a valuable water quality resource in the Middle Kansas, and of statewide significance with regard to baseline conditions that allow us to better understand what kind of high quality water we can expect in our streams and rivers. Efforts to protect and preserve the water quality in this watershed may be justified as a high priority, given the statewide significance of their ambient conditions when establishing goals for other areas.

Soldier Creek-

Monitoring Stations- SC101, SC239, SC685
Biology Stations- SB299, Upper Soldier Creek; SB376, Halfday Creek
USGS Gaging Station- 06889200 (Lower Soldier) 10/1/1958-Current
Included area-
HUC 8: 10270102
HUC 10: 08
HUC 12: 01, 02, 03, 04, 05, 06, 07, 08
Streams Flowing to Monitoring Station-

Station	Name	Segment #
SC101	Soldier Cr-	9
Middle Soldier Creek	Soldier Cr-	9009
	James Creek-	87
	Dutch Cr-	92
	Crow Cr-	Tribal Stream
	S Br Soldier Creek-	Tribal Stream
SC239	Soldier Cr-	5
Lower Soldier Creek	Soldier Cr-	9
	Little Soldier Cr-	6
	Little Soldier Cr-	7
	Unnamed Stream-	8
	Walnut Cr-	91
	Messhoss Cr-	96
SC685	Little Soldier Cr-	7
Little Soldier Creek	Big Elm Cr-	90
Unmonitored Downstream	Soldier Cr-	5
	Halfday Cr-	97
	Indian Cr-	1365
	Unnamed Stream-	1367
	Unnamed Stream-	1389

Monitored Watershed Size- 339.2 square miles
Lower Soldier Creek (SC239) – 78.2 square miles
Middle Soldier Creek (SC101) – 155.3 square miles
Little Soldier Creek (SC685) – 60.9 square miles
Unmonitored Area – 40.4 square miles

Land use-

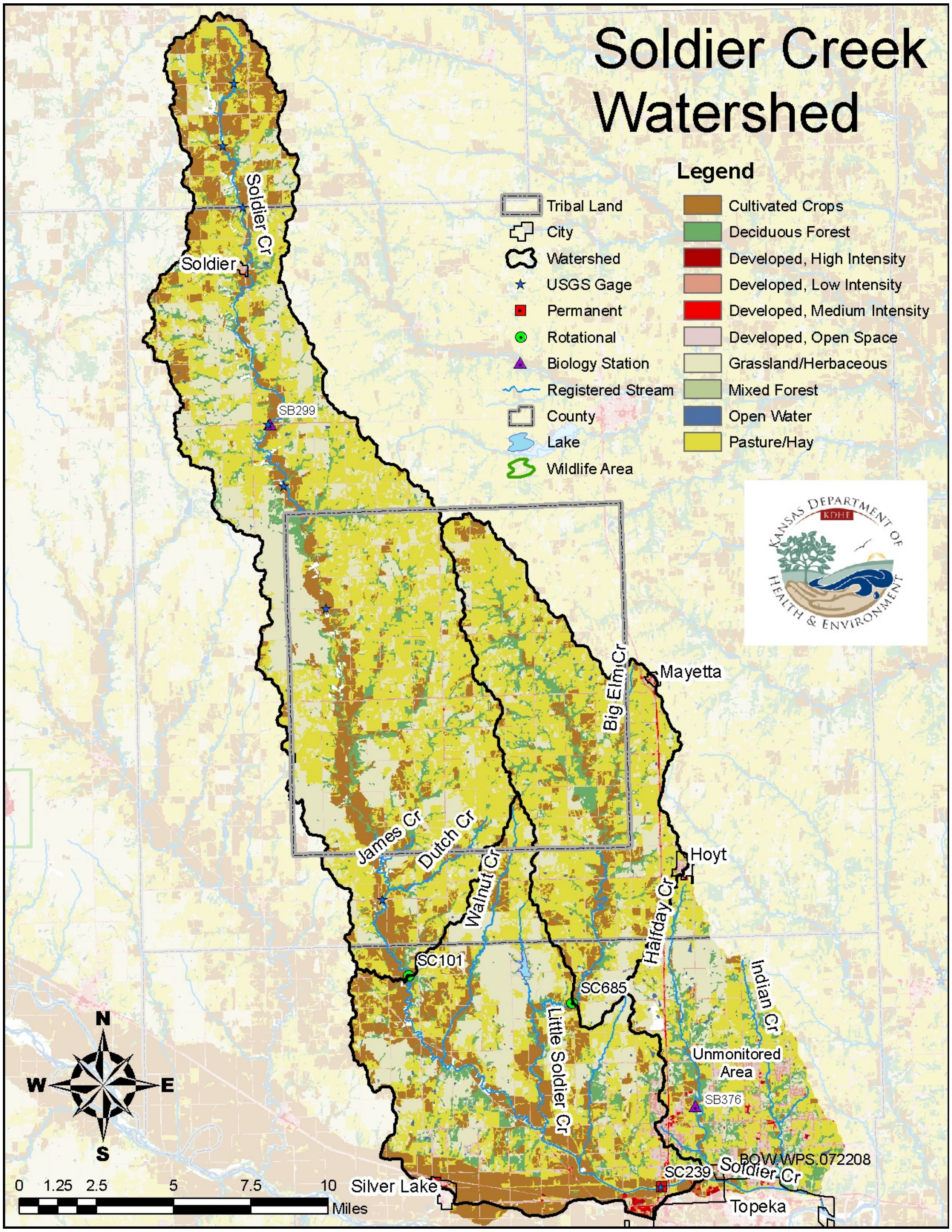
	Lower Soldier Creek	Middle Soldier Creek	Little Soldier Creek	Unmonitored Downstream Area
Permanent Grass	54.45%	69.69%	71.36%	58.42%
Cropland	26.65%	16.79%	11.78%	4.36%
Forest	10.08%	9.62%	11.35%	17.29%
Developed Land	7.86%	3.54%	4.93%	18.18%

Counties- Shawnee, Jackson & Nemaha
Cities- Soldier; Portions of Topeka, Silver Lake, Mayetta & Hoyt
2000 Population- Overall- 19,173[3]
Lower Soldier Creek (SC239) – 4,987
Middle Soldier Creek (SC101) – 1,482
Little Soldier Creek (SC685) – 2,330
Unmonitored Area – 12,027
Kansas House Districts – 50, 51, 57, 62
Kansas Senate Districts – 1, 18, 21

2008 303(d) impaired waters- Lower Soldier Creek, Biology
TMDLs- Biology, approved 8/3/2007 (SC101, SB299)
NPDES Permitted Facilities- Soldier MWTP (M-KS70-OO01), Soldier stormwater (M-KS87-SU01), Fairview North School (M-KS72-NO04), Northern Hills Jr./Sr. High (M-KS72-NO13), Seaman Sr. High (M-KS72-OO18), Shawnee North Community Center (M-KS72-OO06), Shawnee Co. M.S.D. #2- Indian Creek (M-KS72-OO24), Fairview Farms (I-KS72-NO01), Hill's (I-KS72-NO23), Hamm- Rolling Meadows #11 (I-KS72-PO20), KSNT (C-KS72-NO14), Northside Church of Christ (C-KS72-NO17), Northview Mobile Home Park (C-KS72-OO03)
Permitted Confined Animal Feeding Operations-12

Animal Type	Total Animals
Beef	1300
Dairy	390
Swine	10,295

[3] Individual monitoring station populations add up to greater than the total population due to census boundaries that cross watershed boundaries.



Overview map of the Soldier Creek watershed. Land use from the 2001 National Land Cover Dataset.

Stream Chemistry-

Water quality in the Soldier Creek drainage is consistently poor across all sites, parameters and seasons. The monitoring stations in the Soldier Creek watershed had overall ranks of 10 (Little Soldier), 13 (Lower Soldier) and 17 (Middle Soldier), placing them solidly in the lower half of streams included in this analysis. Middle Soldier has the worst water quality from a sediment/nutrient point of view during the summer-fall months, while Lower Soldier and Little Soldier show a more typical patterns with the worst water quality in the spring and relatively better quality during the summer-fall and winter months.

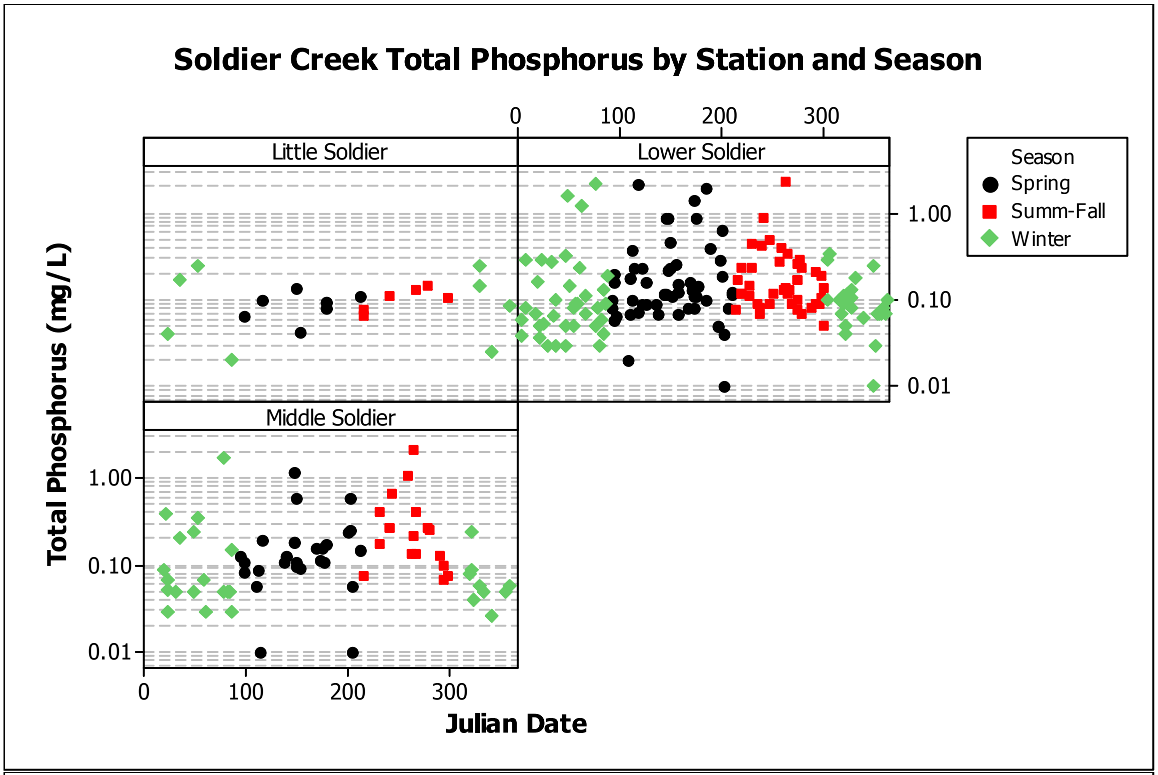
Middle Soldier has exceptionally high total suspended solids (TSS) concentrations for the Mid-Kansas area during both spring and summer-fall, with substantially lower concentrations during the winter. This is also somewhat apparent on the discharge graphs, where the winter data points tend to fall below the other seasons at lower flows, even as some of the highest recorded concentrations occurred during winter months when high discharge events occurred. This suggests that overland flow sources may be secondary to erosional bank areas for this stream, consistent with the work done previously to identify sources of sediment on Soldier Creek. More information regarding winter ground cover practices in the watershed would be helpful in assessing the relative potential of these two sources of sediments and nutrients. Bacteria data for Middle Soldier are limited, but at least some high bacteria events have occurred during the spring, and these appear to be unlinked to discharge at this location. There is some evidence that groundwater may be contributing to increases in nitrogen concentrations during low flow periods.

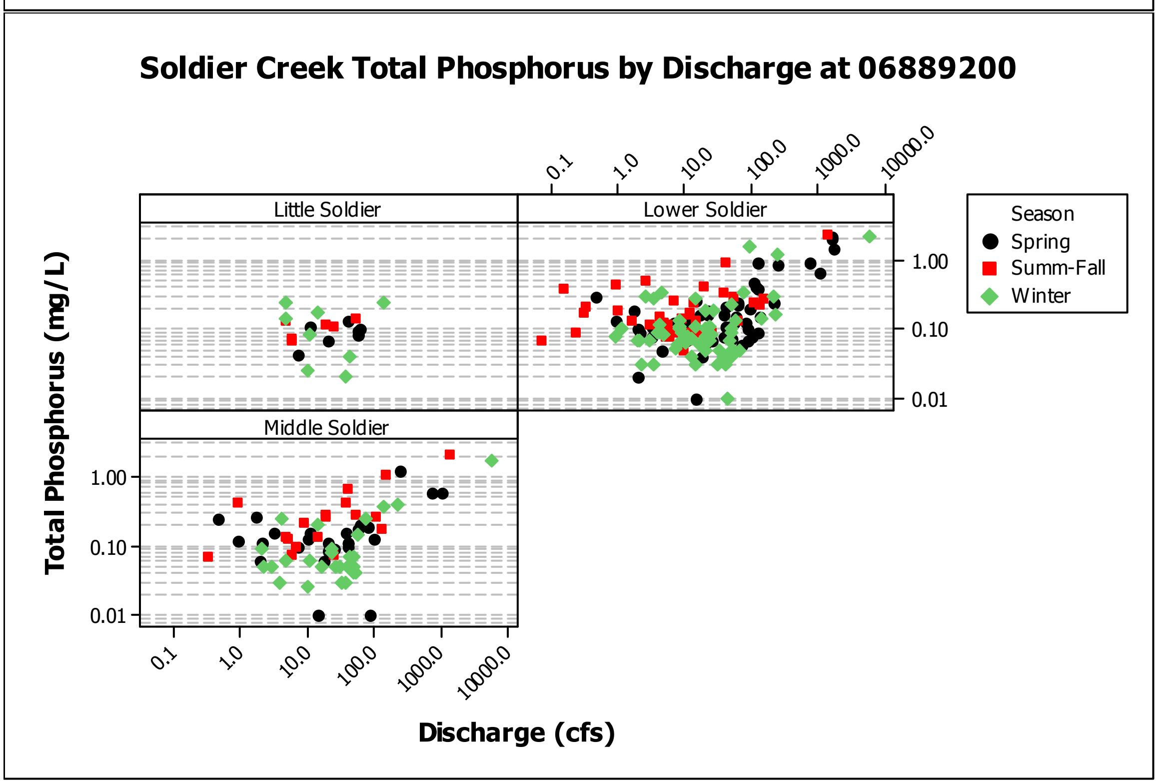
Little Soldier has a fairly small monitoring record, and shows some unusual patterns of water quality. Turbidity and TSS are not as strongly linked in this portion of the watershed as they are in other areas. Winter nitrogen concentrations are much greater than summer concentrations, suggesting either point source discharges or groundwater loading. Even in areas with riparian forests, groundwater nitrogen leaching can be higher in winter, a time when relatively little growth is occurring, reducing the effectiveness of trees at removing nitrogen from the groundwater. Total phosphorus appears to be non-seasonal, with stable, and moderately elevated concentrations, throughout the year. Spring and summer-fall bacteria concentrations show some evidence of elevated levels, but data are limited and more samples will need to be taken to confirm this finding.

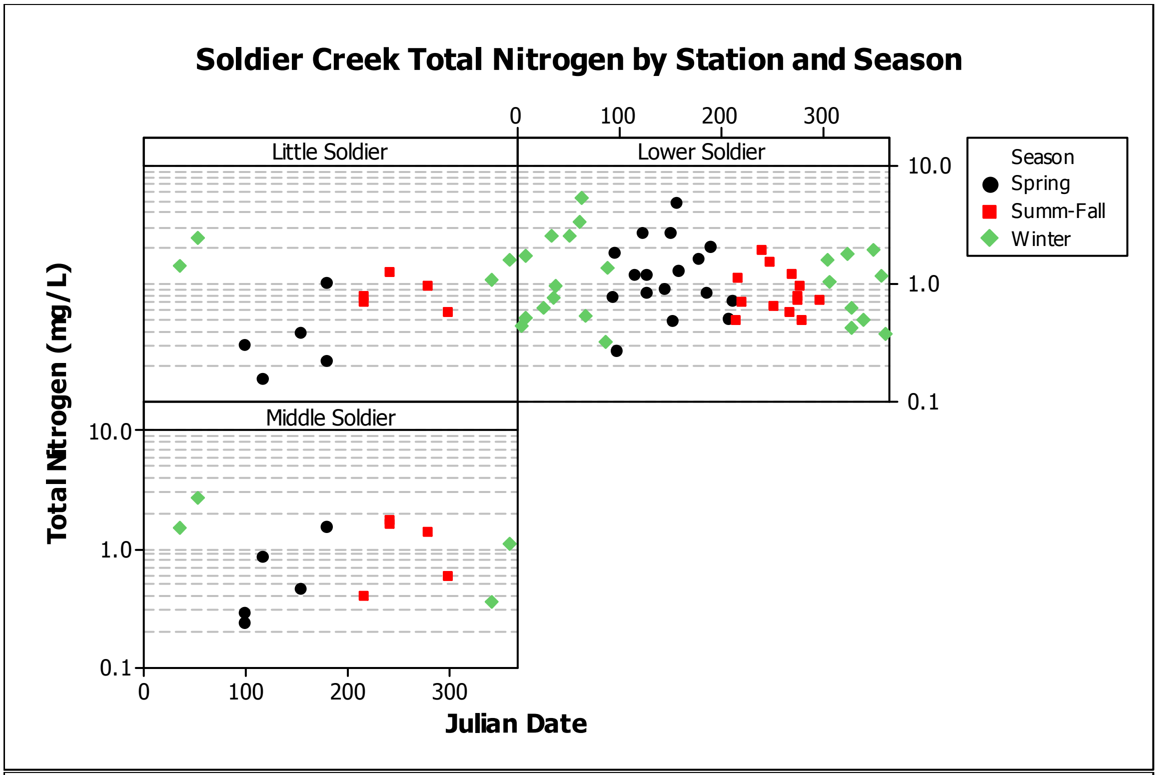
Lower Soldier Creek appears to be benefiting from some improvement relative to the Middle Soldier monitoring station with regards to TSS, turbidity, total phosphorus (except during the winter), bacteria, and total nitrogen (except during the spring). The largest and most robust dataset for this watershed exists at this monitoring station, and it shows the typical non-point arch-type graphs when plotted by the Julian Date of sample collection. High flow events are associated with elevated concentrations of pollutants, regardless of season, with more high flow events during the spring and winter than the summer.

Site	Season	Turbidity Median	TSS Median	TP Median	TN Median	Kjeldahl Median	*E.coli* Median	TOC Median
Middle Soldier SC101	Overall	31.95 (72)	70 (69)	0.112 (72)	0.9975 (14)	0.5085 (14)	153 (7)	6.087 (13)
SC101	Spring	38 (26)	88 (25)	0.125 (26)	0.477 (5)	0.196 (5)	591 (3)	6.087 (5)
SC101	Summer-Fall	43 (18)	95.5 (18)	0.24 (18)	1.409 (5)	0.799 (5)	212 (2)	4.882 (5)
SC101	Winter	10 (28)	25 (26)	0.0555 (28)	1.324 (4)	0.654 (4)	81.5 (2)	8.054 (3)
Lower Soldier SC239	Overall	18 (157)	36.5 (154)	0.11 (157)	0.9455 (52)	0.64 (52)	132 (31)	5.36 (45)
SC239	Spring	22 (53)	49.5 (52)	0.123 (53)	1.212 (17)	0.693 (17)	132 (9)	6.211 (15)
SC239	Summer-Fall	21.35 (42)	40 (42)	0.135 (42)	0.742 (13)	0.587 (13)	146 (9)	4.29 (12)
SC239	Winter	9.15 (62)	20.5 (60)	0.0805 (62)	1.014 (22)	0.605 (22)	52 (13)	5.713 (18)
Little Soldier SC685	Overall	15.2 (21)	24 (21)	0.101 (21)	0.8835 (14)	0.2935 (14)	393 (7)	5.083 (13)
SC685	Spring	10.4 (7)	26 (7)	0.093 (7)	0.313 (5)	0.163 (5)	458 (2)	5.083 (5)
SC685	Summer-Fall	29.6 (6)	21.5 (6)	0.1105 (6)	0.784 (5)	0.463 (5)	441 (3)	3.873 (5)
SC685	Winter	8.9 (8)	18.5 (8)	0.113 (8)	1.521 (4)	0.771 (4)	10 (2)	8.18 (3)

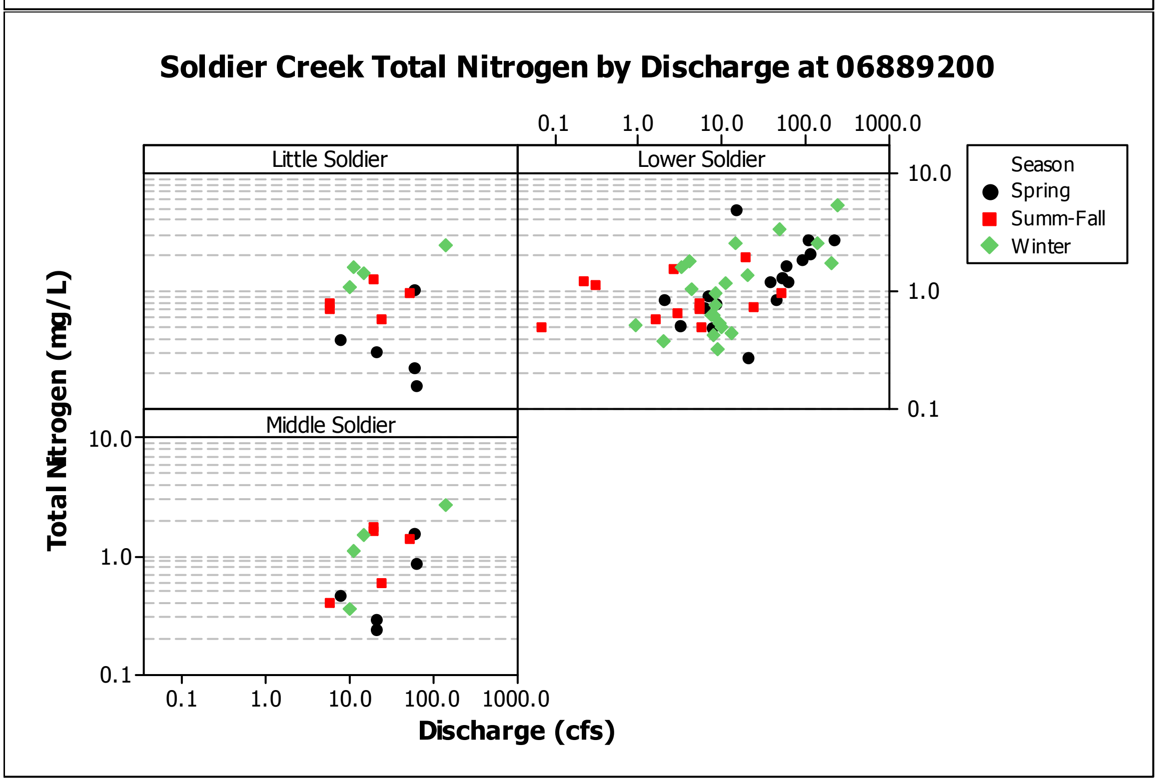
Soldier Creek stream chemistry data by season and overall at all three KDHE monitoring stations in the watershed. Number in parenthesis is sample size.


Soldier Creek Total Phosphorus by Station and Season
Little Soldier
Lower Soldier
Middle Soldier
Season
Spring
Summ-Fall
Winter
Total Phosphorus (mg/L)
1.00
0.10
0.01
0
100
200
300
Julian Date


Soldier Creek Total Phosphorus by Discharge at 06889200
Little Soldier
Lower Soldier
Middle Soldier
Season
Spring
Summ-Fall
Winter
Total Phosphorus (mg/L)
1.00
0.10
0.01
0.1
1.0
10.0
100.0
1000.0
10000.0
Discharge (cfs)

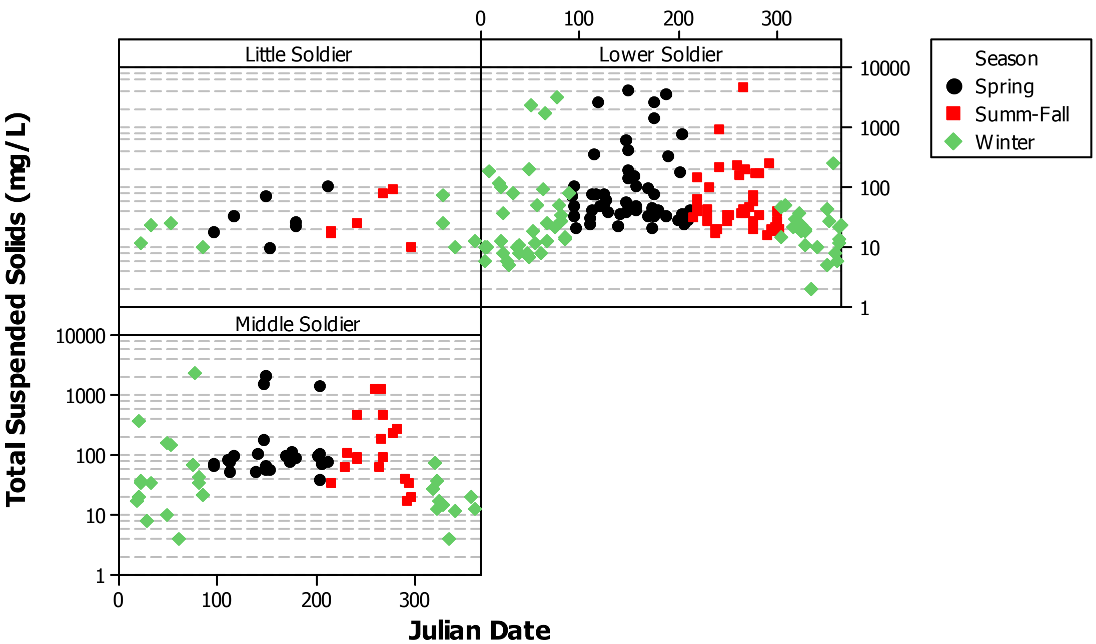


Soldier Creek Total Nitrogen by Station and Season
Little Soldier
Lower Soldier
Middle Soldier
Season
Spring
Summ-Fall
Winter
Total Nitrogen (mg/L)
Julian Date
0
100
200
300
10.0
1.0
0.1

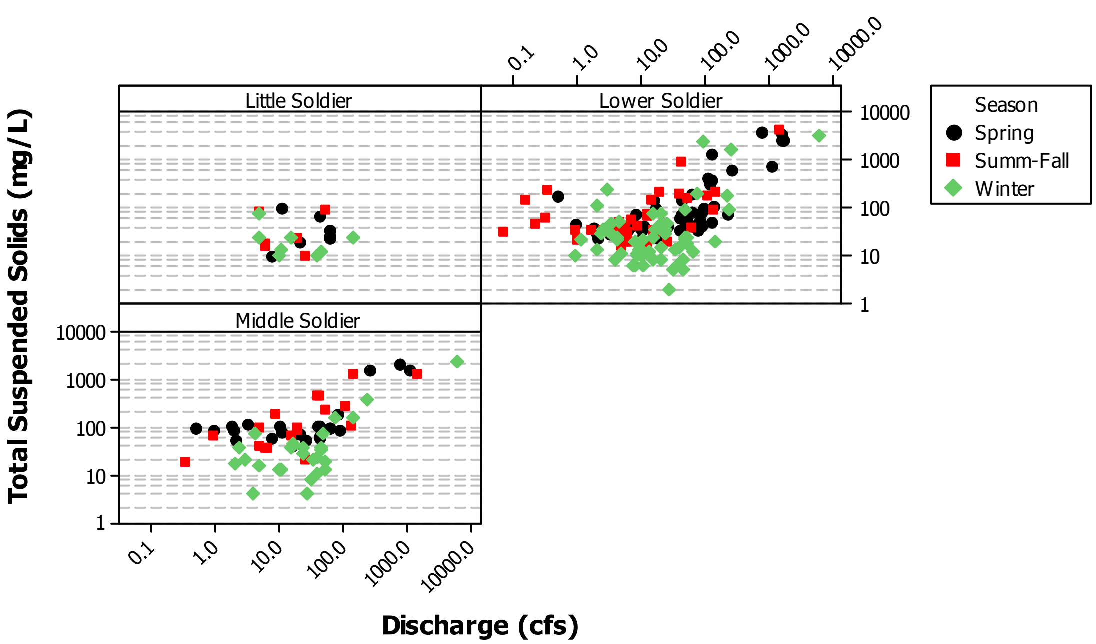


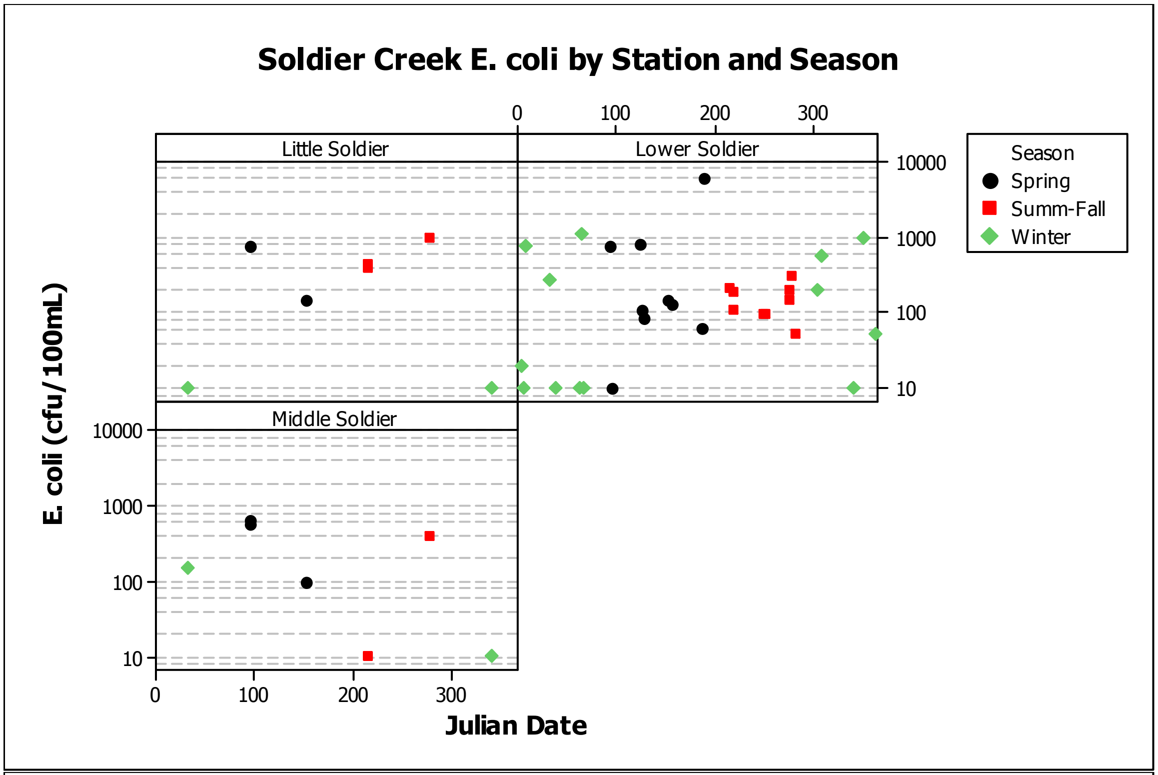
Soldier Creek Total Nitrogen by Discharge at 06889200
Little Soldier
Lower Soldier
Middle Soldier
Season
Spring
Summ-Fall
Winter
Total Nitrogen (mg/L)
Discharge (cfs)
0.1
1.0
10.0
100.0
1000.0

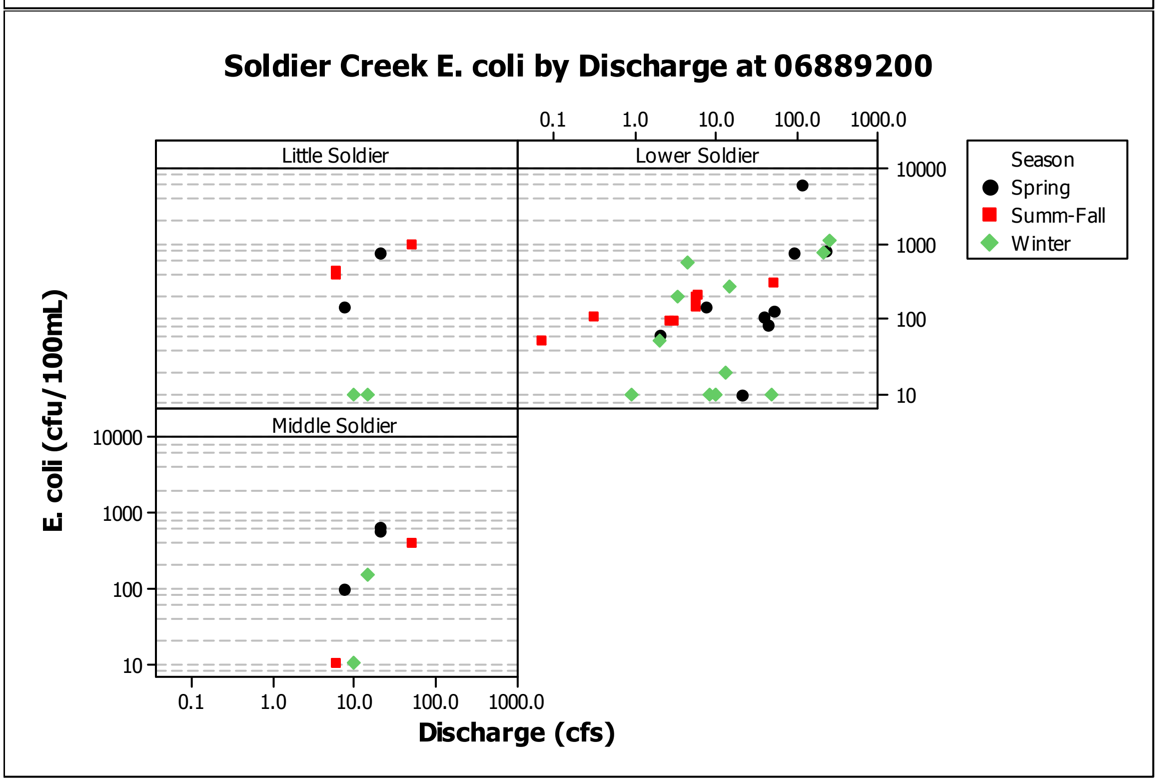
Soldier Creek Total Suspended Solids by Station and Season

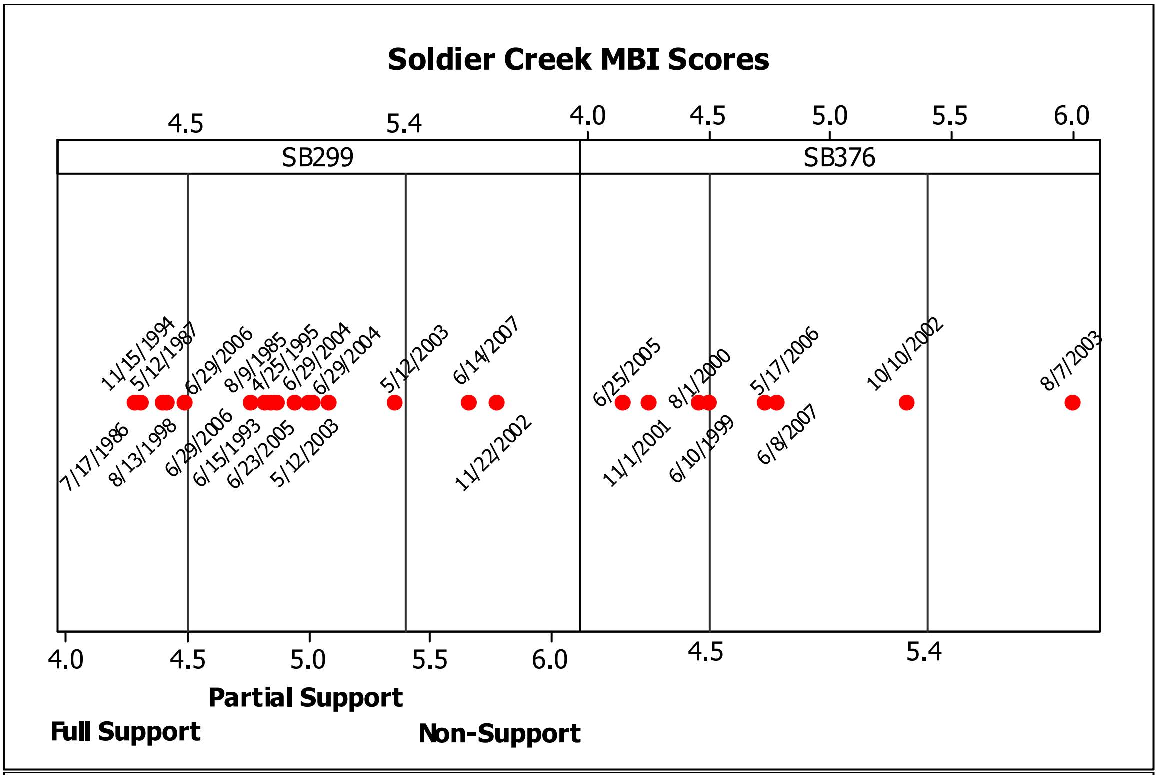


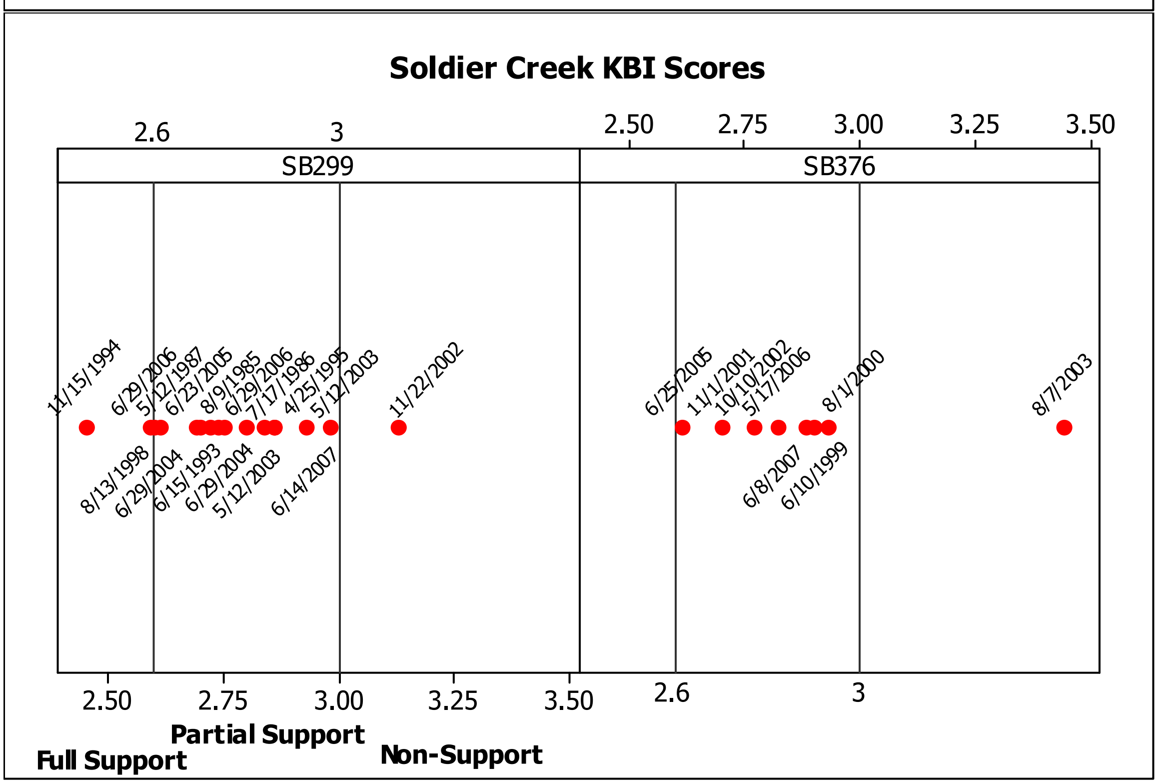
Soldier Creek Total Suspended Solids by Discharge at 06889200

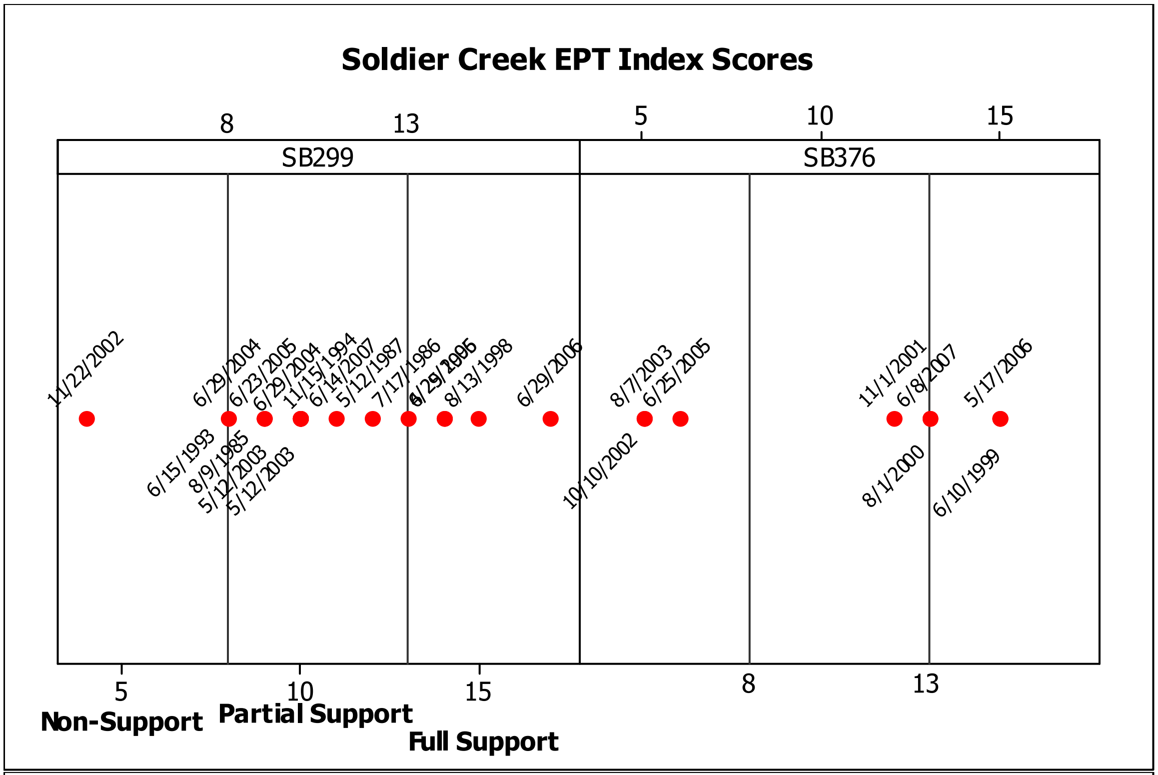


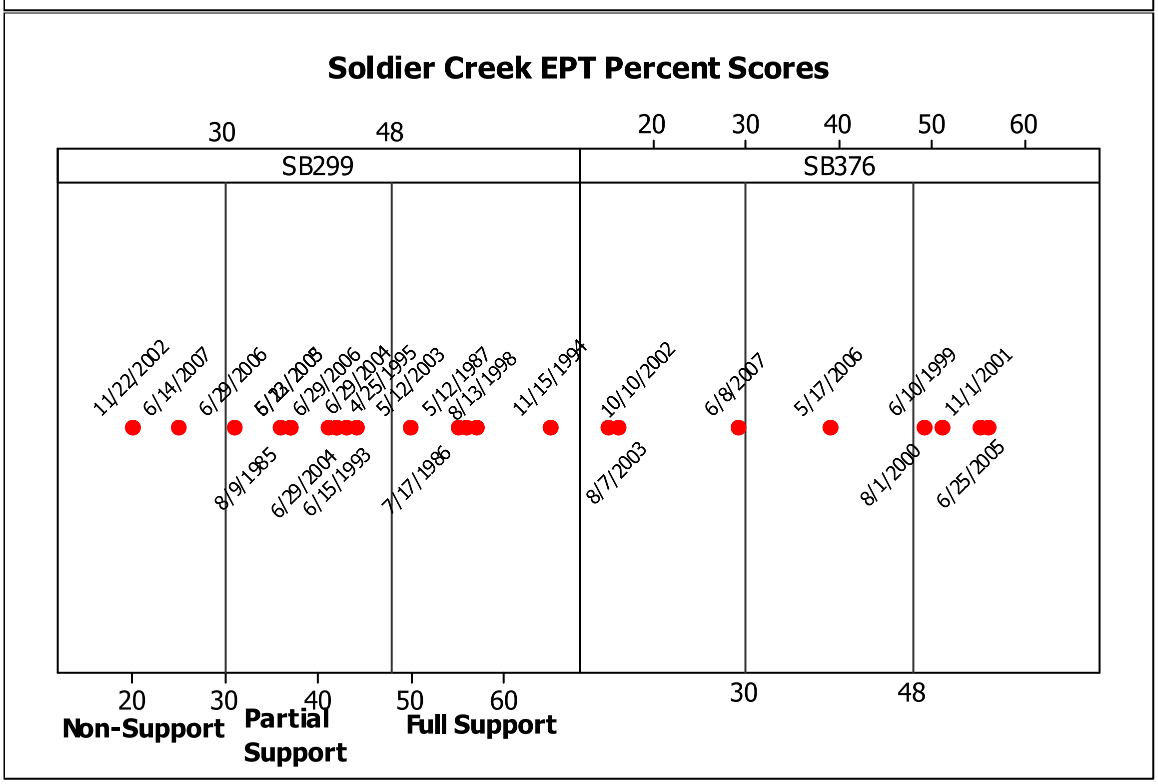

Soldier Creek E. coli by Station and Season
Little Soldier
Lower Soldier
Middle Soldier
E. coli (cfu/100mL)
Julian Date
0
100
200
300
10
100
1000
10000
Season
Spring
Summ-Fall
Winter


Soldier Creek E. coli by Discharge at 06889200
Little Soldier
Lower Soldier
Middle Soldier
E. coli (cfu/100mL)
Discharge (cfs)
0.1
1.0
10.0
100.0
1000.0
10
100
1000
10000
Season
Spring
Summ-Fall
Winter

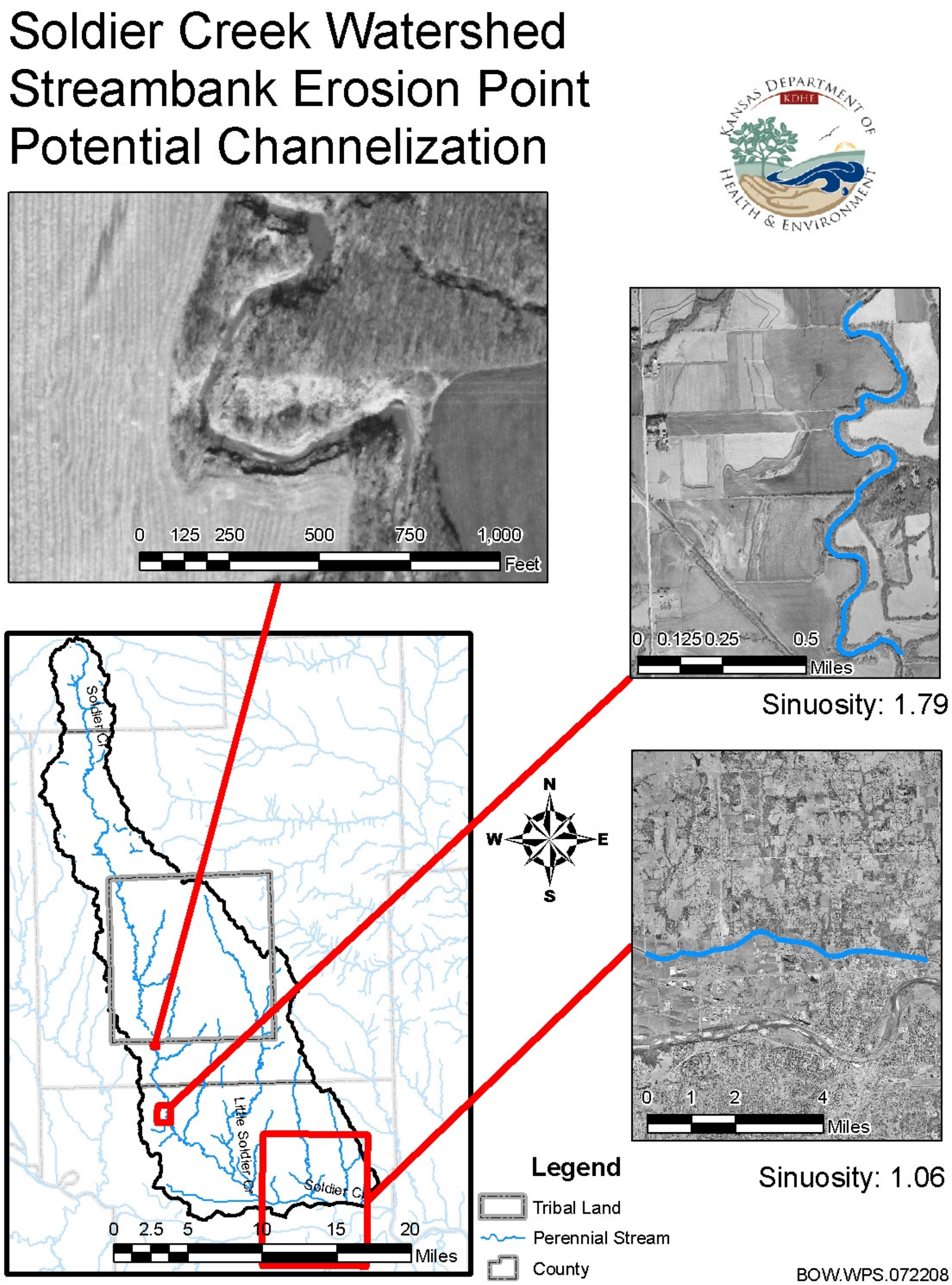

Soldier Creek MBI Scores
4.5
5.4
4.0
4.5
5.0
5.5
6.0
SB299
SB376
11/15/1994
5/12/1987
6/29/2006
8/9/1985
4/25/1995
6/29/2004
6/29/2004
5/12/2003
6/14/2007
7/17/1986
8/13/1998
6/29/2006
6/15/1993
6/23/2005
5/12/2003
11/22/2002
6/25/2005
8/1/2000
5/17/2006
10/10/2002
8/7/2003
11/1/2001
6/10/1999
6/8/2007
4.0
4.5
5.0
5.5
6.0
4.5
5.4
Partial Support
Full Support
Non-Support


Soldier Creek KBI Scores
2.6
3
2.50
2.75
3.00
3.25
3.50
SB299
SB376
11/15/1994
6/29/2006
5/12/1987
6/23/2005
8/9/1985
6/29/2006
7/17/1986
4/25/1995
5/12/2003
11/22/2002
8/13/1998
6/29/2004
6/15/1993
6/29/2004
5/12/2003
6/14/2007
6/25/2005
11/1/2001
10/10/2002
5/17/2006
8/1/2000
8/7/2003
6/8/2007
6/10/1999
2.50
2.75
3.00
3.25
3.50
2.6
3
Partial Support
Full Support
Non-Support





Streambank stabilization may play an important role in improving water quality in the Soldier Creek watershed. Previous studies have documented the extensive channelization of the lower reaches of Soldier Creek, and subsequent headcutting along the main channel. In areas with poor buffering channelized reaches are particularly susceptible to collapse. One meter resolution aerial photographs were used to identify a number of potential unstable streambanks in the lower reaches of the watershed



Uncertainty-

The availability of gage data concurrent with all the stream chemistry data and biology data reduce some of the uncertainty regarding water quality in this watershed.

The gage is co-located with only the most downstream of the stream chemistry sites, it is likely to be a good indicator of the relative flow conditions occurring in this watershed at the time of sampling. Because biology data is collected annually or less frequently there is less certainty regarding the applicability of the data across time. At this level of analysis we cannot assign sources to particular pollutants, though increasing nutrient and TSS concentrations moving downstream are correlated with increasing row-crop production, increasing population, and channelized stream reaches. It is also not possible at this level of analysis to determine the source of bacteria, leaving uncertainty regarding the relative contributions from septic systems, cattle and wildlife.

Adaptive Implementation Strategies-

Soldier Creek has a number of challenges facing the stakeholders in its watershed. The need to work with tribal government to coordinate water quality improvement measures is unique in the Mid-Kansas sub-basin. As noted previously, water quality is poor around the watershed, and the ongoing impacts of previous management decisions, particularly the channelization of the lower reaches of Soldier Creek, pose significant difficulties. In addition, the majority of the population in this watershed lives in and along the lower reaches of Soldier Creek, where significant semi-urban development is occurring, with the associated water quality concerns, including impacts from 5-20 acre ranchettes and management of on-site sanitary waste needs.

Reductions in sediment loading should provide concurrent relief from phosphorus loading, though nitrogen and bacteria appear to result from alternate sources. Reductions in sediment and phosphorus can be expected by improved management of riparian areas, and construction sites during development, as well as management activities that reduce the prevalence of bare ground. Promotion of reduced tillage strategies to row crop producers in the Soldier Creek watershed is one way to reduce surface runoff. Restoration of riparian buffers, designed with both heavily treed areas near the stream and permanent grass between the trees and any other activity will begin to provide some relief from near stream sources in this watershed. Over extended periods of time Soldier Creek will likely attempt to regain some of the channel length lost during the channelization of the lower reaches, absent any active attempts to constrain the stream to its existing channel.

Little Soldier and Middle Soldier show some potential evidence of bacteria contamination during spring and summer periods. Provision of alternative watering sites and exclusion of cattle from streams will likely reduce the bacteria concentrations observed in these areas. Other beneficial effects may be noted from reduction to livestock access, including reduced bank trampling, which may also improve water quality with regards to sediment and nutrients.

Nitrogen concentrations in this watershed show some evidence of elevated groundwater concentrations, with regard to acceptable surface water quality. While no evidence is currently available to suggest a problem with drink water supply needs, nitrogen concentrations during winter periods are elevated relative to spring and summer, suggesting a groundwater source. Improved soil testing and targeted application rates of nitrogen fertilizers by agricultural producers can be expected to provide some reduction in this regard, though changes typically occur over a period of decades, as groundwater transport is slow. With the growing population in the lower reaches of Soldier Creek, proper management of on-site sanitary waste systems by residential homeowners will take an increasingly important role in managing loading of nutrients to groundwater.

Outreach and education efforts targeted at residential homeowners will likely be needed to ensure that these stakeholders engage in responsible land management, including pest control, turf management and fertilizer usage. Some anecdotal accounts suggest that improvements could also be made at the Shawnee County landfill, which has been identified as a potential source of sediment to nearby streams.

While tribal lands fall outside the jurisdiction of the state of Kansas, the residents of those areas are integral parts of improved conditions in this watershed. All of the general comments noted above apply equally to tribal lands, though mechanisms to implement them may differ due to alternative oversight and implementation sources.

Shunganunga Creek-

Monitoring Stations- SC238
USGS Gaging Station- 06889700 (Rice Rd.) 10/1/1979-9/30/1981, 10/1/1993-9/30/1996
Included area-
HUC 8: 10270102
HUC 10: 09
HUC 12: 01, 02
Streams Flowing to Monitoring Station-

Station	Name	Segment #
SC238	Shunganunga Cr-	39
	Shunganunga Cr-	40
	S. Br. Shunganunga Cr -	87
	Deer Cr-	92
Unmonitored Downstream		
	Stinson Cr-	394

Watershed Size- 73.7 square miles
Monitored Area (SC239) – 62.3 square miles
Land use-

Permanent Grass	27.6%
Cropland	6.9%
Forest	10.6%
Open Water	1.8%
Developed, <20% impervious	16.8%
Developed, 20-49% impervious	24.5%
Developed, 50-79% impervious	8.6%
Developed, 80-100% impervious	3.3%

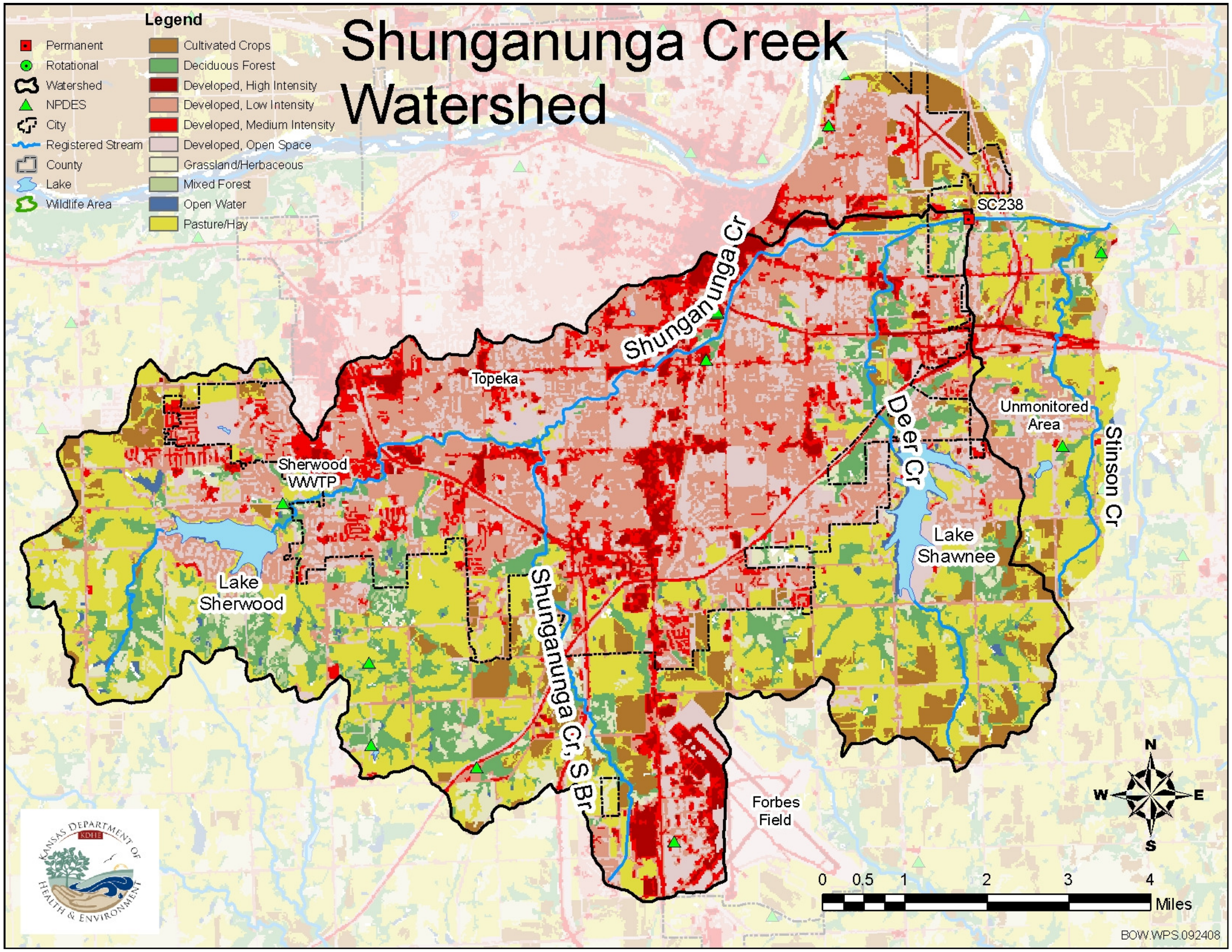
Counties- Shawnee
Cities- Topeka
2000 Population- 103,459
Kansas House Districts –51, 52, 53, 54, 55, 56, 57, 58
Kansas Senate Districts – 18, 19, 20

2008 303(d) impaired waters listing- Total phosphorus
TMDLs- Dissolved Oxygen, approved 8/3/2007, High Priority; Bacteria, approved 1/26/2000, High Priority

NPDES Permitted Facilities- Sherwood WWTP (M-KS72-OO27), Topeka Stormwater (M-KS72-SO01), Shawnee County Stormwater (M-KS72-SU01), KDOT Stormwater (M-KS72-SU02), Tecumseh Township Stormwater (M-KS98-SU01), Jay Shideler School (M-KS72-OO11), Washburn Rural Jr./Sr. High (M-KS72-OO16), Meier's Ready Mix (I-KS72-PR01, I-KS72-PR02), East Side Baptist Church (C-KS72-NO16), Shawnee Hills Mobile Home Park (C-KS72-OO11)

Permitted Confined Animal Feeding Operations-1

Animal Type	Total Animals
Dairy	180



Shunganunga Creek Watershed
Legend
Permanent
Rotational
Watershed
NPDES
City
Registered Stream
County
Lake
Wildlife Area
Cultivated Crops
Deciduous Forest
Developed, High Intensity
Developed, Low Intensity
Developed, Medium Intensity
Developed, Open Space
Grassland/Herbaceous
Mixed Forest
Open Water
Pasture/Hay
SC238
Shunganunga Cr
Topeka
Sherwood WWTP
Lake Sherwood
Deer Cr
Unmonitored Area
Stinson Cr
Lake Shawnee
Shunganunga Cr, S Br
Forbes Field
N
W
E
S
0 0.5 1 2 3 4
Miles
BOW.WPS.092408

Stream Chemistry-

Shunganunga Creek has the worst overall ranking of all the monitoring stations in the Mid-Kansas area, with the worst rankings for nutrients (both total phosphorus and total nitrogen) and very poor rankings for total suspended solids and bacteria. Suspended solids are decoupled from total phosphorus, as would be expected in a point-source impacted stream. The large discharge (1 million gallons/day average) from the Sherwood Improvement District has a significant negative impact on water quality in the mainstem of Shunganunga Creek. As expected under these circumstances, winter nutrient concentrations are higher than spring and summer concentrations. Elevated bacteria levels during spring months were noted under the previous fecal colifrom bacteria criteria, and appear to be exceeding expectations under the current *E. coli* criteria as well.

Shunganunga Creek is a largely urban stream, and is more disconnected from many typical sources of sediment, such as row crop production. During development periods streams in urban areas may experience temporary increases in sediment load, followed by a period of reduced sediment supply as impervious cover becomes responsible for an increasing amount of the runoff from the watershed. These pressures are reflected in the lower overall median concentration of suspended solids and the overall turbidity. However, spring samples show concentrations that are more than twice those of the wintertime, suggesting that other sources may still be playing an important role. Eroding streambanks would not be uncommon in a heavily urbanized area, and may be contributing sediment at higher rates during water spring periods, especially during significant storm events.

Bacteria concentrations in Shunganunga Creek remain a concern eight years after the establishment of a high priority TMDL for bacteria, especially during the spring months, when concentrations are consistently high. Over a quarter of the watershed remains in permanent grassland usage, and these areas may be contributing to the observed spring bacteria load. However, in a complex urbanizing watershed, other potential sources cannot be ruled out, including pet waste and failing on-site wastewater systems. The Sherwood wastewater treatment plant operates a UV disinfection bank, and can be ruled out as a potential contributor to this problem.

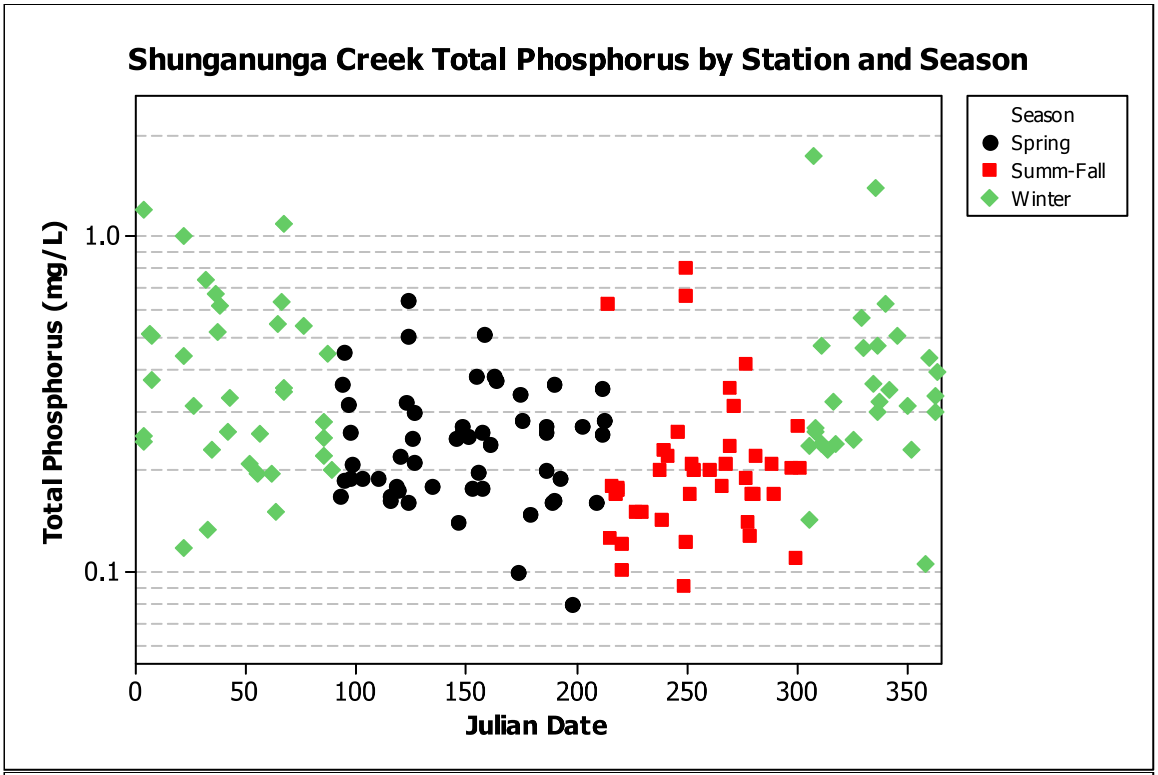
Nutrient concentrations in Shunganunga Creek are consistently elevated over levels that signify acceptable water quality measures throughout all seasons. The highest observed concentrations are noted during winter months, when relatively little precipitation occurs, in-stream nutrient processing by biofilms and other microbial processes slows, and the Sherwood wastewater treatment plant contributes most significantly to the flow of the stream. Nutrient discharge from the treatment plant typically contribute large percentages of the observed concentrations at the KDHE monitoring station, which is located 10 miles downstream (at Rice Rd.), and also receives water from the South Branch and Deer Creek.

A high priority TMDL was established for inadequate dissolved oxygen in Shunganunga Creek in 2007. Critical periods for dissolved oxygen concentrations are the summer and fall, when low flow conditions can be expected. The TMDL identified organic loading, or biological oxygen demand (BOD) as the pollutant of concern. The observed nutrient concentrations may also be contributing to low dissolved oxygen concentrations during low flow, warm periods, as increased algal productivity results in wider swings of dissolved oxygen and pH through the day, with low concentrations typically occurring during the late night hours as oxygen demand from these organisms exceeds available production and re-aeration rates As noted elsewhere, oxygen concentrations are expected to be highest during winter months when gas solubility is highest due to lower water temperatures.

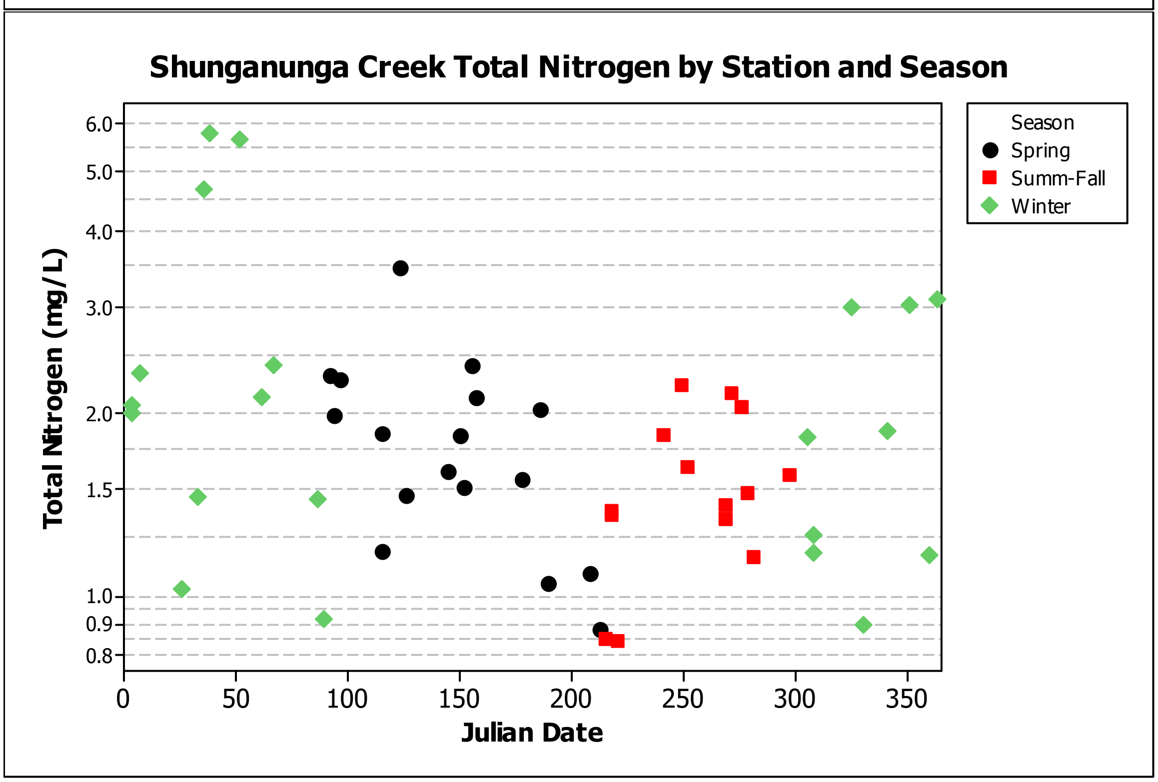
While not a stream chemistry measure, it is worth noting that urbanization and channelization, both of which are present in this watershed, contribute to predictable changes in stream hydrographs. A hydrograph, or a graph of the discharge of a stream over time, shows how quickly a stream responds to storms, and what non-stormflow conditions exist during the rest of the year. The existing gage record is too small to draw conclusions regarding the impact of urban expansion within this watershed. However, most streams undergoing urbanization experience lower base flow rates, due to reduced groundwater recharge because impervious surfaces (roofs, parking lots, roads, etc.) result in direct runoff to streams through stormwater sewers with reduced infiltration into the ground. At the same time increased peak flows, and often flooding, occur because major storms have less available infiltration surface area and more rapid delivery of storm water to the stream system. Channelization can also result in increased delivery rates for water from storm events, leading to more rapidly rising stream flows, and is often associated with reduced connectivity with the floodplain, where transient storage can slow stormwaters, reducing peak flows.

Site	Season	Turbidity Median	TSS Median	TP Median	TN Median	Kjeldahl Median	*E.coli* Median	TOC Median
Shunganunga Creek SC238	Overall	20.5 (157)	36 (153)	0.25 (157)	1.73 (52)	0.8365 (52)	172 (30)	6.808 (45)
SC238	Spring	24.3 (54)	48 (52)	0.245 (54)	1.84 (17)	0.9 (17)	577 (8)	7.29 (15)
SC238	Summer-Fall	21 (41)	36 (41)	0.19 (41)	1.4415 (14)	0.844 (14)	75 (9)	5.579 (13)
SC238	Winter	10.8 (62)	18 (60)	0.325 (62)	2.001 (21)	0.694 (21)	31 (13)	6.821 (17)

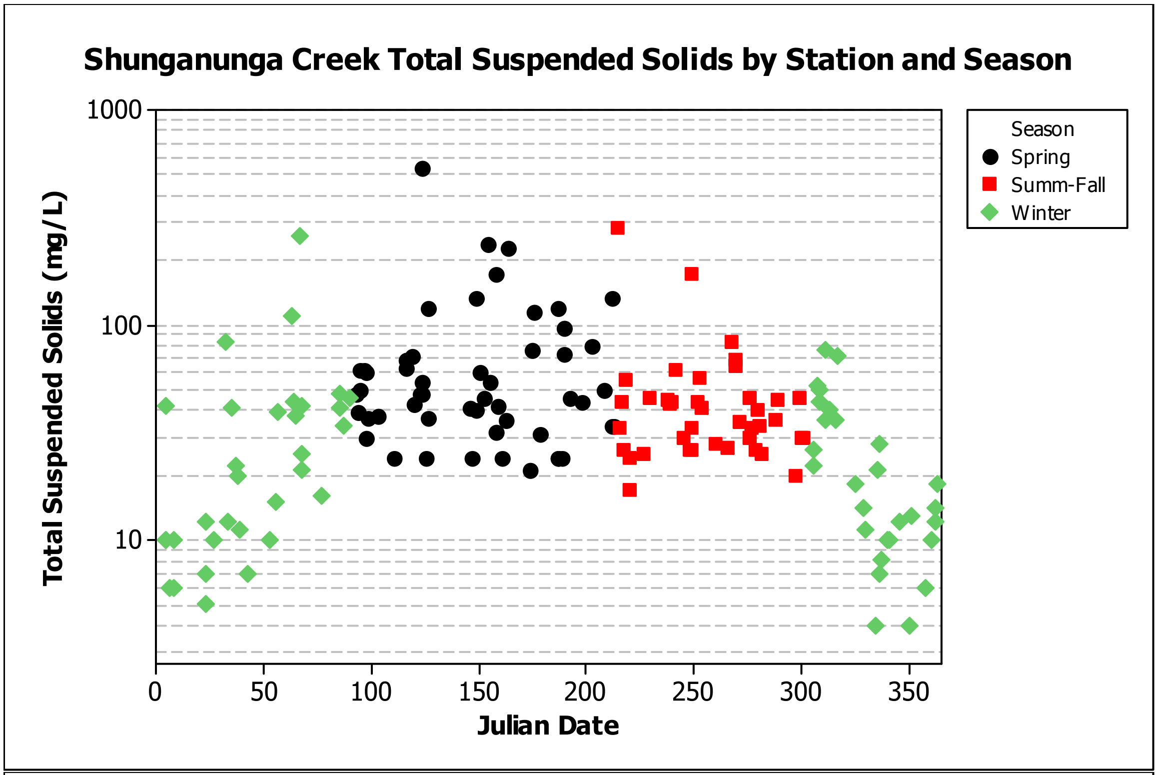
Shunganunga Creek stream chemistry data by season and overall. Number in parenthesis is sample size.

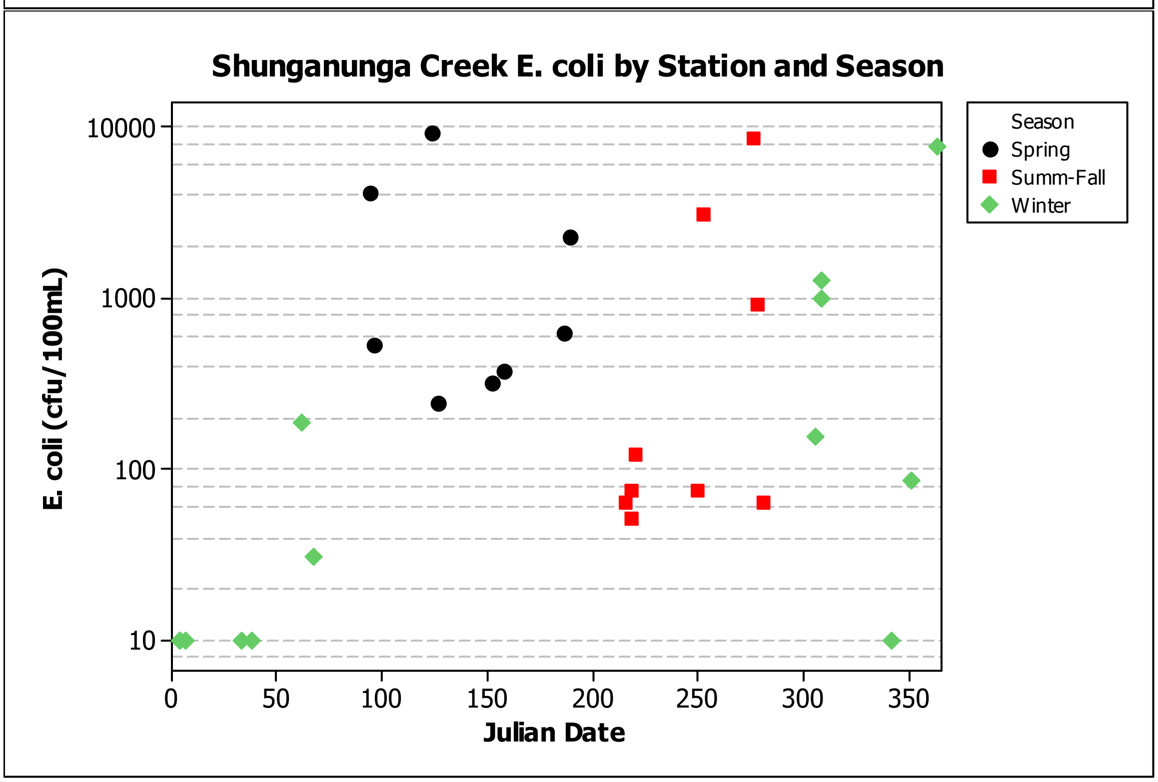


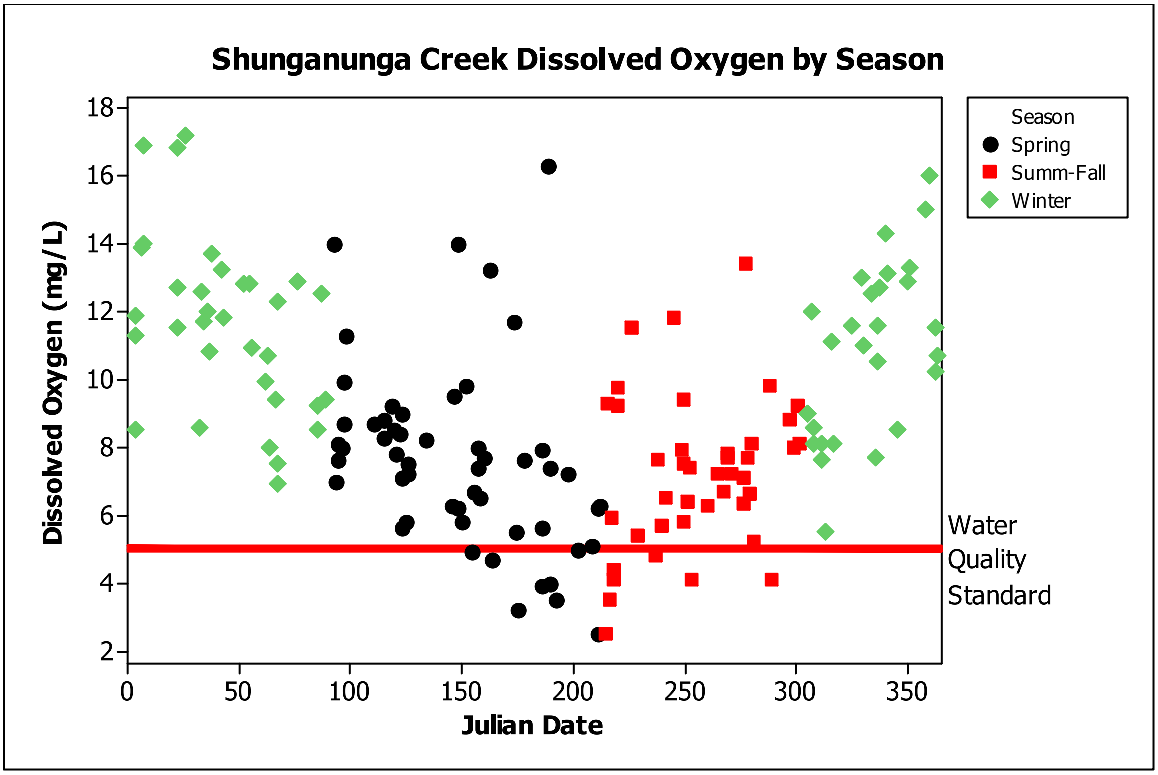
Shunganunga Creek Total Phosphorus by Station and Season
Total Phosphorus (mg/L)
1.0
0.1
0
50
100
150
200
250
300
350
Julian Date
Season
Spring
Summ-Fall
Winter



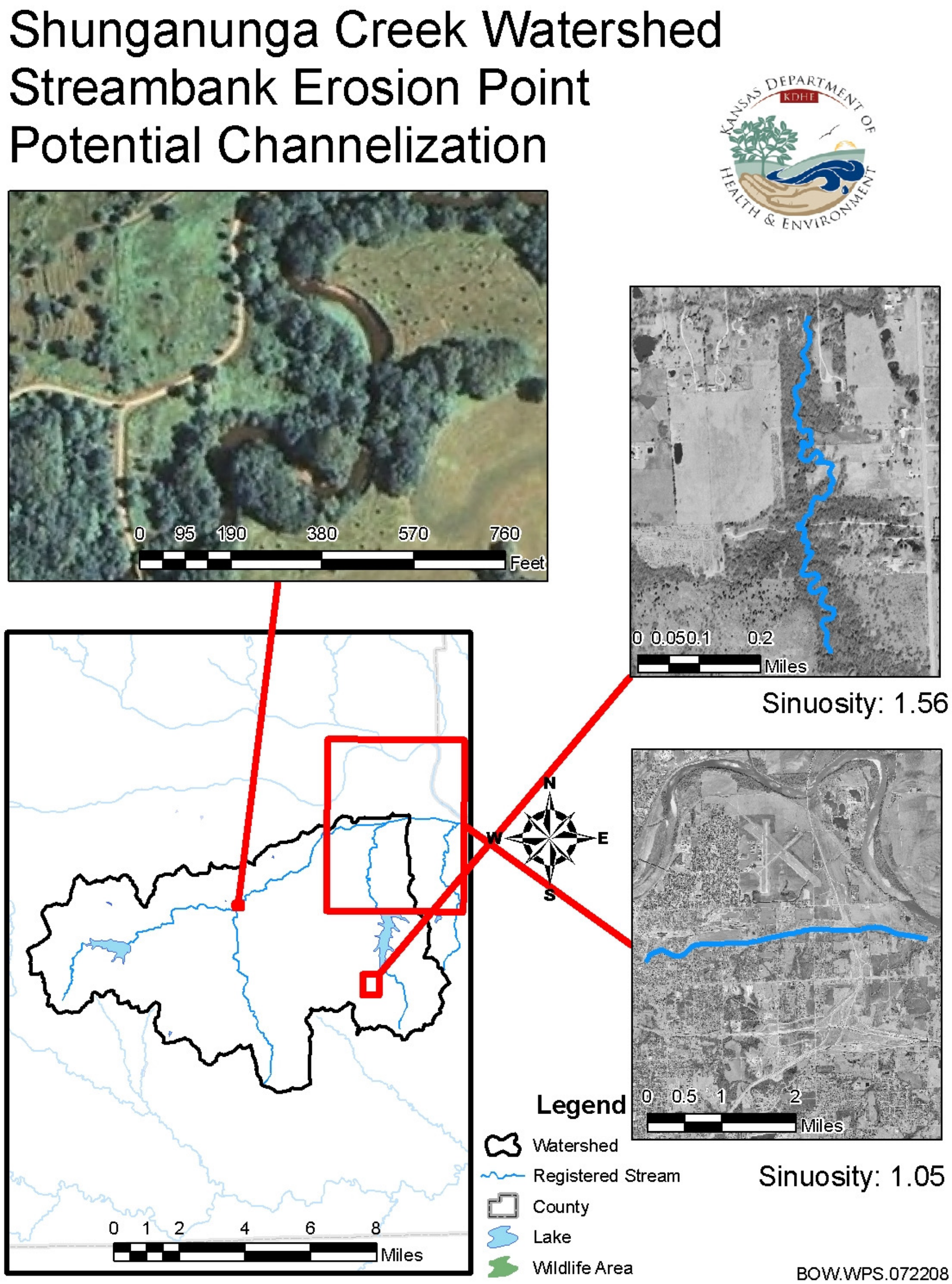
Shunganunga Creek Total Nitrogen by Station and Season
Total Nitrogen (mg/L)
6.0
5.0
4.0
3.0
2.0
1.5
1.0
0.9
0.8
0
50
100
150
200
250
300
350
Julian Date
Season
Spring
Summ-Fall
Winter


Shunganunga Creek Total Suspended Solids by Station and Season
Total Suspended Solids (mg/L)
1000
100
10
0
50
100
150
200
250
300
350
Julian Date
Season
Spring
Summ-Fall
Winter


Shunganunga Creek E. coli by Station and Season
E. coli (cfu/100mL)
10000
1000
100
10
0
50
100
150
200
250
300
350
Julian Date
Season
Spring
Summ-Fall
Winter



Relatively few points of seriously eroding stream banks are visibile in the 2002 DOQQ and 2006 NAIP 1 meter resolution photographs. While geomorphically stable streams are uncommon in urban areas, it is common for significant efforts to be made to reduce stream channel movement in an effort to protect property. Overall sinuosity is low in this watershed, and even candidate sites show lower sinuosity than adjacent watersheds. Encroachment of valuable infrastructure onto the floodplain is common in urban areas, and leaves relatively fewer options for improvement, due to the high costs associated with developed lands relative to more agricultural settings.



Uncertainty-

The lack of available gage data for most of the monitored period leaves some uncertainty regarding the interactions between discharge conditions and water quality measures. The lack of gage data also leaves uncertainty regarding the impacts of increased urbanization in this watershed over time. Changes to the pattern and magnitude of storm and base flows can be expected to have occurred in this watershed, however no data is available to us to quantify those changes. Biological sampling has been limited, and is not included here due to the lack of long-term or recent data. Reduced habitat and reduced stream complexity is often associated with reduced biological diversity, but we lacked sufficient data to assess that potential impact at this time. Because the KDHE monitoring station is located near the outlet of Shunganunga Creek, there remains uncertainty regarding the contributions of particular sub-watersheds to the overall condition seen at SC238. In addition, we do not have data available at this time regarding the potential contributions from illicit discharges and failing on-site wastewater treatment systems. Anecdotal accounts indicate that illegal dumping and other trash remain a problem in Shunganunga Creek, but we have insufficient data to quantify the potential impacts from this source.

Adaptive Implementation-

Shunganunga Creek faces many challenges to improved water quality. The challenges include channelization, altered hydrology and other typical urban non-point impacts as well as wastewater discharged by the Sherwood treatment facility on a daily basis. The costs and opportunities are both larger in urban areas, where high population density increases the number of individuals potentially interested in watershed restoration work and potential revenue sources from municipal residents that may not be available in more rural settings. In many ways Shunganunga Creek is typical of degraded urban streams, and opportunities for improvement of water quality within the Shunganunga Creek watershed can likely learn from other urban stream improvement projects, both in Kansas and nationally.

Of all the issues facing Shunganunga Creek stakeholders, sediment concentration is likely to be the lowest concern, not only because the absolute concentrations are lower than in other more agriculturally impacted watersheds, but also because the other problems facing this creek are of such a larger magnitude. KDHE data do show a typical non-point source pattern with regards to total suspended solids, as seen in the arch shaped graph of concentrations as a function of season. Recent research by KDHE has indicated that while the magnitude of discharge has an effect on the TSS concentration, it is also impacted by land use, particularly along the riparian corridor and seasonal factors. To the extent that seriously eroding streambanks exist within the watershed, addressing them may lead to some improvement in water quality, and may result in increased resident satisfaction for adjacent landowners. Stabilization is often understood, particularly in urban settings, to mean rip-rap and other bank hardening measures, however these are temporary features on the landscape that are eventually undercut by stream action. Bank hardening efforts are less preferable than riparian forestry approaches, because forested buffers become stronger over time as trees mature and improving nearby property values.

Nutrient concentrations in Shunganunga Creek are excessively high, and any effort to address them must take into account the impact of the discharge from the Sherwood treatment facility. Rough calculations based on estimates of stream discharge at median flow (5 cubic feet per second) indicate that the nutrient load from the treatment facility exceeds the load observed at Rice Rd by substantial amounts, suggesting some in-stream processing and removal of nutrients occur along the channel length. Should biological nutrient removal (BNR) be implemented at the treatment facility, median annual concentrations could be expected to fall significantly at both the treatment facility and downstream at the KDHE monitoring station. The impact of this reduction can be expected to be most significant during the winter when low microbial activity and reduced flows from the watershed result in the highest concentrations of TN and TP in Shunganunga Creek, visible in the U-shaped graphs of concentrations throughout the year. Assuming a similar reduction in the load is observed at Rice Rd. the concentrations (est. WWTP load w/ BNR/ current ext. WWTP load) * current Rice Rd. concentration) of both total phosphorus and total nitrogen will likely approach more acceptable levels. Use of treatment technologies with greater nutrient removal may be desirable for further improvement in water quality.

	Median Flow (gal./day)	Median Flow (cubic feet/second)	Current TP (mg/L)	Current TN (mg/L)	Current TP Daily Load (lbs/day)	Current TN Daily Load (lbs/day)	Est. TP Conc. (mg/L) w/ BNR	Est. TN Conc. (mg/L) w/ BNR	Est. TP Daily Load (lbs/day) at BNR conc. 1.5 mg/L	Est. TN Daily Load (lbs/day) at BNR conc. 6 mg/L
Sherwood WWTP	936,000	1.4	4.13	16.34	32.26	127.66	1.50	6.00	11.72	46.87
Rice Rd. Monitoring Station (SC238)	3,231,584	5	0.25	1.73	6.74	46.66	0.09	0.64	2.45	17.13

Other efforts to reduce the impact of nutrients on this stream may also have beneficial effects on water quality. Watershed wide efforts to reduce/eliminate illicit discharges, eliminate failing on-site waste systems, reduce fertilizer use by both urban and rural residents to recommended levels, and improvements to the riparian forest may also result in improvements to water quality in Shunganunga Creek. Education of urban residents on proper use and application of lawn chemicals has the potential to reduce nutrient impacts, to the extent that overuse is now occurring. Increased retention of water on the landscape, through both individual efforts, like raingardens, and municipal planned projects, like bio-retention cells, also have the potential to reduce nutrient concentrations and runoff into Shunganunga Creek.

Bacteria concentrations still exceed acceptable concentrations for the potential recreational uses of this stream many years after the adoption of a TMDL to address this issue. The Sherwood treatment facility has been successfully operating ultraviolet effluent disinfection for some years, and can therefore be eliminated as a major source of bacteria in the stream. Urban pet populations have been implicated in other areas as major sources of bacteria to streams, though genetic identification of bacterial strains is usually needed to link the bacteria to particular animal types. Stakeholders may wish to gather more detailed information regarding the relative concentrations of bacteria around the watershed, and identify the sources of those bacteria before deciding which efforts are most likely to reduce bacteria concentrations to acceptable levels. Improved pet waste management, identification and management of potential livestock sources in the more rural areas of the watershed, and increased retention of runoff on the landscape may all be steps residents wish to take to help decrease bacteria concentrations in this stream.

Dissolved oxygen concentrations in Shunganunga Creek have been, and continue to be cause for concern, particularly during summer months when low flows and high temperatures occur. Reductions of nutrient concentrations in this stream are likely to have major impacts on dissolved oxygen concentrations, as low concentrations are often linked to high in-stream productivity, and oxygen demand from algae and other micro-organisms during night-time hours. Increases in riparian canopy may also reduce the low dissolved oxygen events, by reducing available sunlight to in-stream photosynthetic organisms. Increases in riparian forestry in the lower reaches may not be desired by watershed residents if they also result in reduced conveyance during high flow events passing through the channelized and levied lower reaches.

Shunganunga Creek has many challenges to improved water quality. Coordinated efforts by the county and city, would be beneficial to upgrade the quality of this stream. Local residents will need to invest themselves into concern for the stream, especially if public financing for the restoration projects requires is necessary. Shunganunga Creek is severely mpaired by multiple pollutants, and has the potential to be a great success story through action taken over many years. Initial improvement efforts on Shunganunga Creek would address the impact of the Sherwood treatment plant, but other issues, such as urban stormwater impacts, will remain. Development of monitoring plans to track progress will help evaluate the success of efforts to improve water quality in this watershed, and should be a part of any plan to address the issues facing this stream.

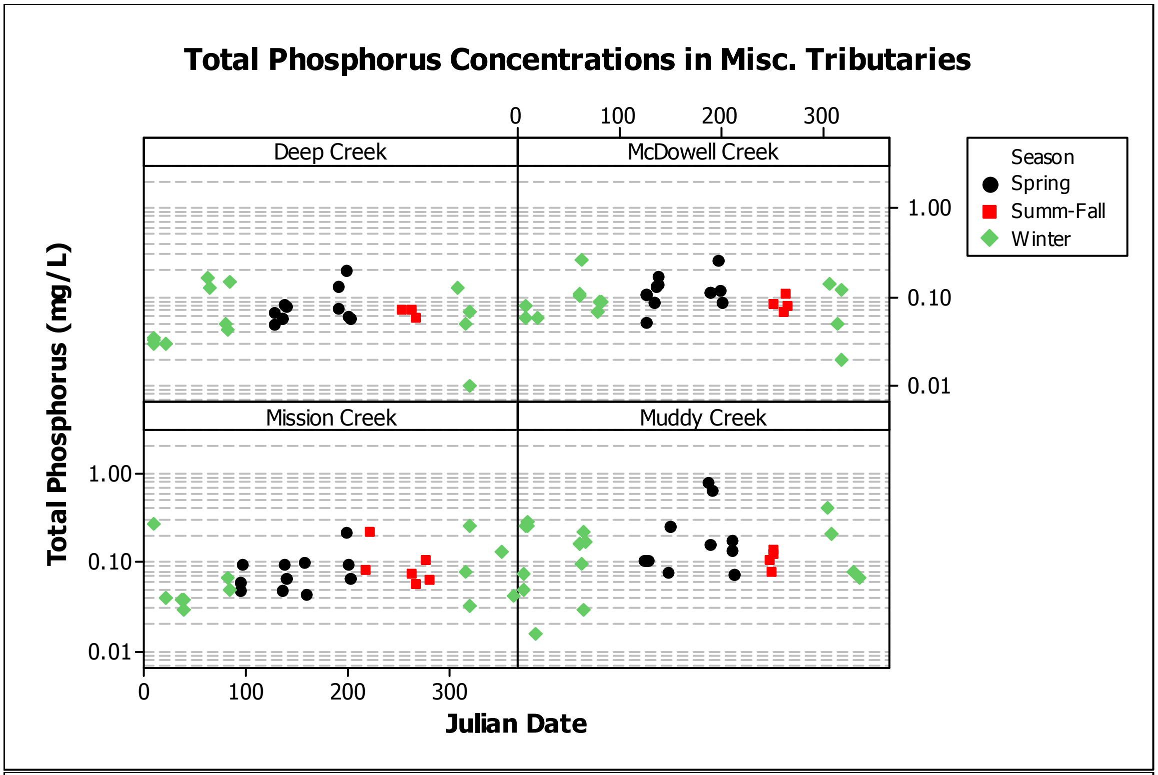
Resources for watershed planning in urban watersheds are available at http://www.cwp.org/PublicationStore/USRM.htm

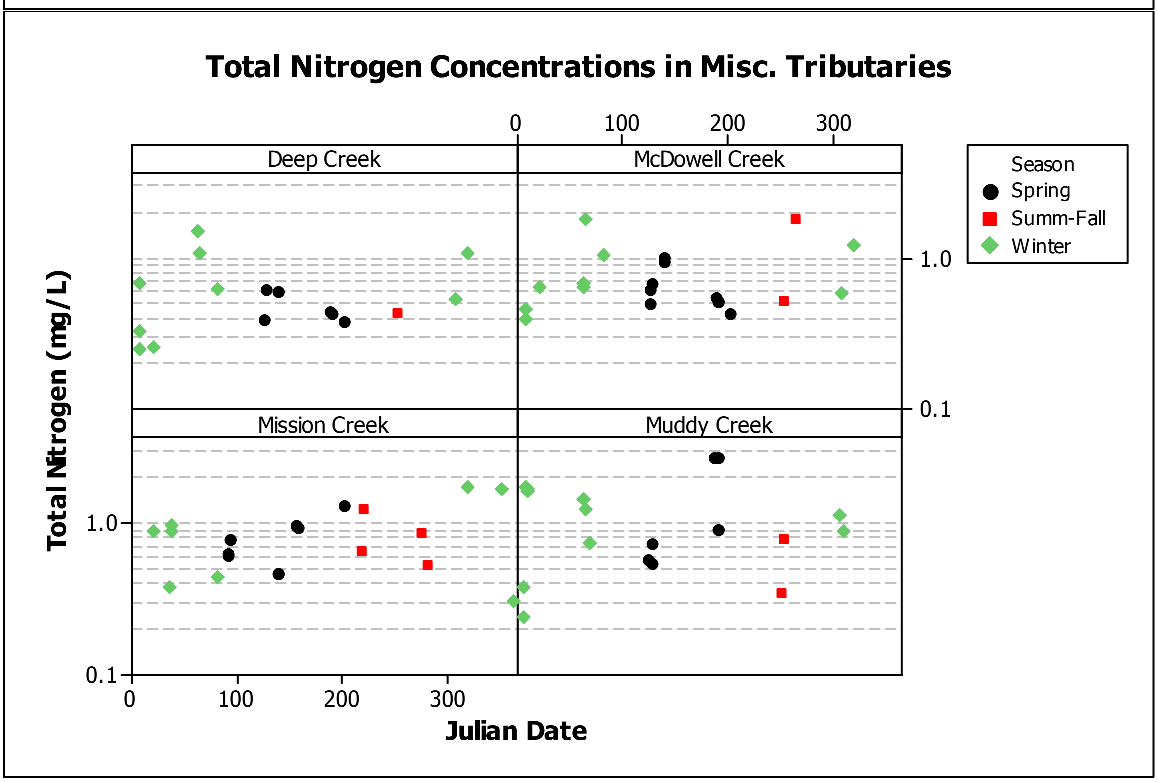
Appendix A: Miscellaneous monitored tributary streams

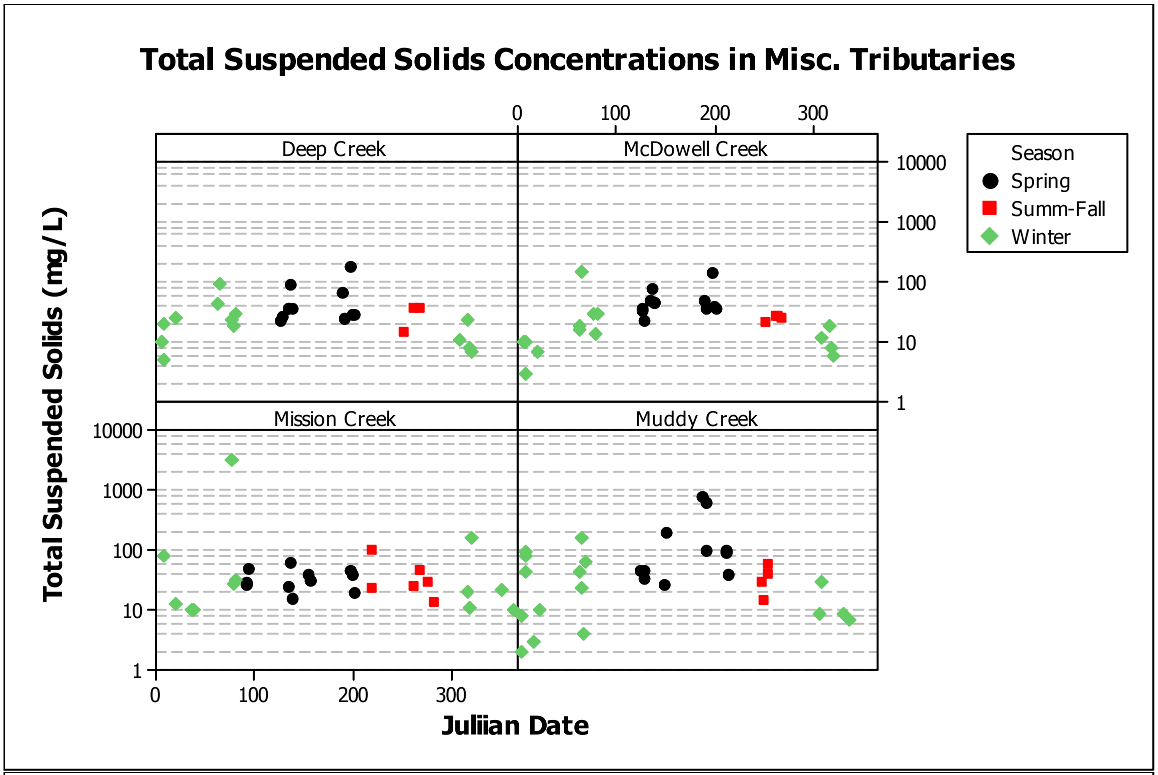
While this guide to watersheds will not provide detailed information on a number of smaller monitored streams, we do provide some limited data on water quality in these areas. Below are summary statistics tables and graphs similar to those presented above. The streams included in this appendix are Muddy Creek, Mission Creek, Deep Creek and McDowell Creek. All are monitored on a rotational basis, so data are limited. These streams are considered overall lower priorities for protection and restoration due to their small size, relatively good water quality, or a combination of both. Should stakeholders in the watershed express an interest in more detailed information regarding potential causes and sources in these areas, it will be provided as available.

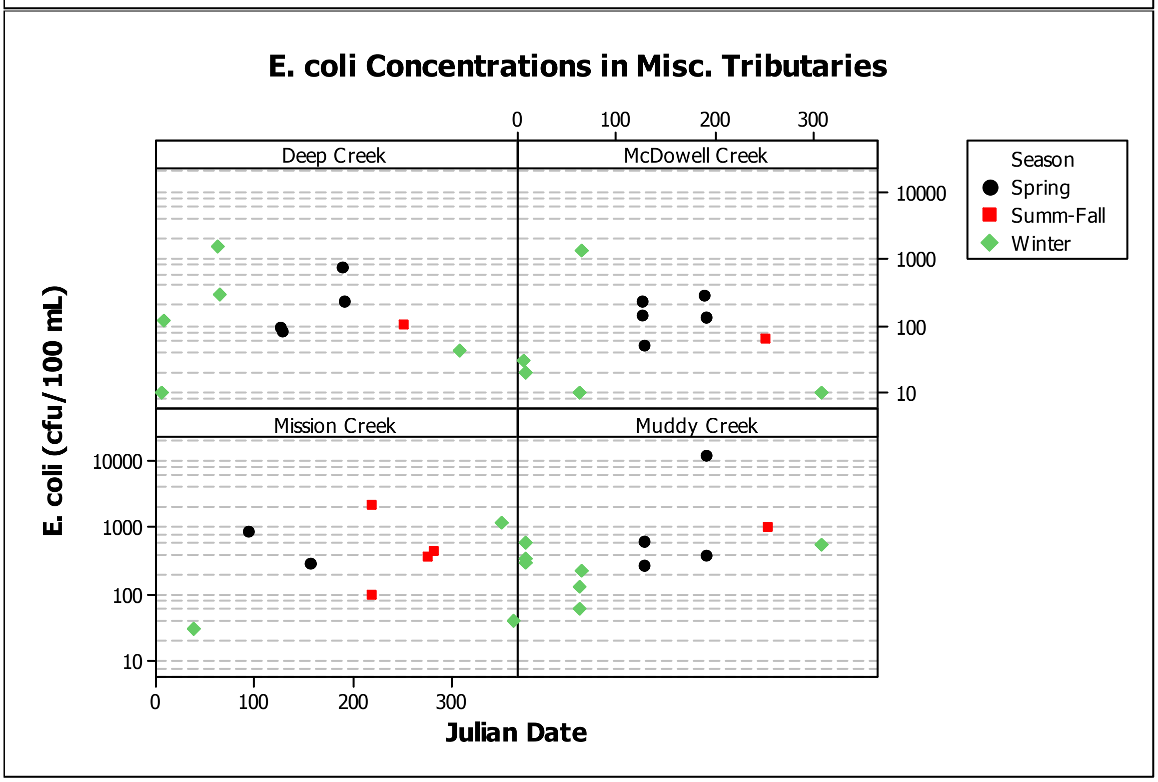
Muddy Creek (SC639)	TP Median	TSS Median	Turbidity Median	TOC Median	Kjeldahl Median	*E. coli* Median	TN Median
Overall	0.139 (31)	42.5 (32)	26.05 (32)	7.3805 (12)	0.758 (19)	368 (12)	0.922 (19)
Spring	0.14 (11)	99 (11)	41.2 (11)	5.929 (4)	0.6855 (6)	511 (4)	0.8355 (6)
Summer-Fall	0.12 (4)	35.5 (4)	19.15 (4)	4.214 (1)	0.317 (2)	1076 (1)	0.582 (2)
Winter	0.1625 (16)	24 (17)	10 (17)	8.427 (7)	0.974 (11)	301 (7)	1.278 (11)
McDowell Creek (SC646)	TP Median	TSS Median	Turbidity Median	TOC Median	Kjeldahl Median	*E. coli* Median	TN Median
Overall	0.104 (29)	26 (30)	12.1 (30)	2.827 (12)	0.468 (19)	57.5 (12)	0.64 (19)
Spring	0.1175 (12)	43.5 (12)	20.85 (12)	2.753 (5)	0.424 (8)	148 (5)	0.5885 (8)
Summer-Fall	0.0815 (4)	25.5 (4)	10 (4)	2.562 (1)	0.952 (2)	63 (1)	1.187 (2)
Winter	0.088 (13)	13 (14)	6.5 (14)	2.872 (6)	0.47 (9)	15 (6)	0.65 (9)
Deep Creek (SC647)	TP Median	TSS Median	Turbidity Median	TOC Median	Kjeldahl Median	*E. coli* Median	TN Median
Overall	0.062 (27)	26 (28)	14 (28)	2.682 (11)	0.325 (16)	107 (11)	0.497 (16)
Spring	0.068 (11)	37 (11)	23.4 (11)	2.7725 (4)	0.294 (6)	168 (4)	0.444 (6)
Summer-Fall	0.072 (3)	37 (3)	17 (3)	1.851 (1)	0.29 (1)	107 (1)	0.44 (1)
Winter	0.05 (13)	19.5 (14)	6 (14)	3.429 (6)	0.51 (9)	80.5 (6)	0.62 (9)
Mission Creek (SC648)	TP Median	TSS Median	Turbidity Median	TOC Median	Kjeldahl Median	*E. coli* Median	TN Median
Overall	0.07 (31)	28 (31)	12 (31)	4.157 (14)	0.47 (19)	337 (10)	0.89 (19)
Spring	0.07 (11)	32 (11)	12 (11)	4.028 (5)	0.488 (7)	606.5 (2)	0.804 (7)
Summer-Fall	0.08 (6)	27 (6)	11.25 (6)	4.702 (4)	0.6245 (4)	417 (4)	0.7745 (4)
Winter	0.06 (14)	21 (14)	11.85 (14)	4.098 (5)	0.293 (8)	36 (4)	0.908 (8)

Stream chemistry data from KDHE monitoring stations in the sub-basins by season and overall. Number in parenthesis is sample size.


Total Phosphorus Concentrations in Misc. Tributaries
Deep Creek
McDowell Creek
Mission Creek
Muddy Creek
Total Phosphorus (mg/L)
Julian Date
0
100
200
300
0.01
0.10
1.00
Season
Spring
Summ-Fall
Winter


Total Nitrogen Concentrations in Misc. Tributaries
Deep Creek
McDowell Creek
Mission Creek
Muddy Creek
Total Nitrogen (mg/L)
Julian Date
0
100
200
300
0.1
1.0
Season
Spring
Summ-Fall
Winter


Total Suspended Solids Concentrations in Misc. Tributaries
Deep Creek
McDowell Creek
Mission Creek
Muddy Creek
Season
Spring
Summ-Fall
Winter
Total Suspended Solids (mg/L)
Juliian Date
0
100
200
300
1
10
100
1000
10000


E. coli Concentrations in Misc. Tributaries
Deep Creek
McDowell Creek
Mission Creek
Muddy Creek
Season
Spring
Summ-Fall
Winter
E. coli (cfu/100 mL)
Julian Date
0
100
200
300
10
100
1000
10000

Appendix B: Mainstem Kansas River Water Quality

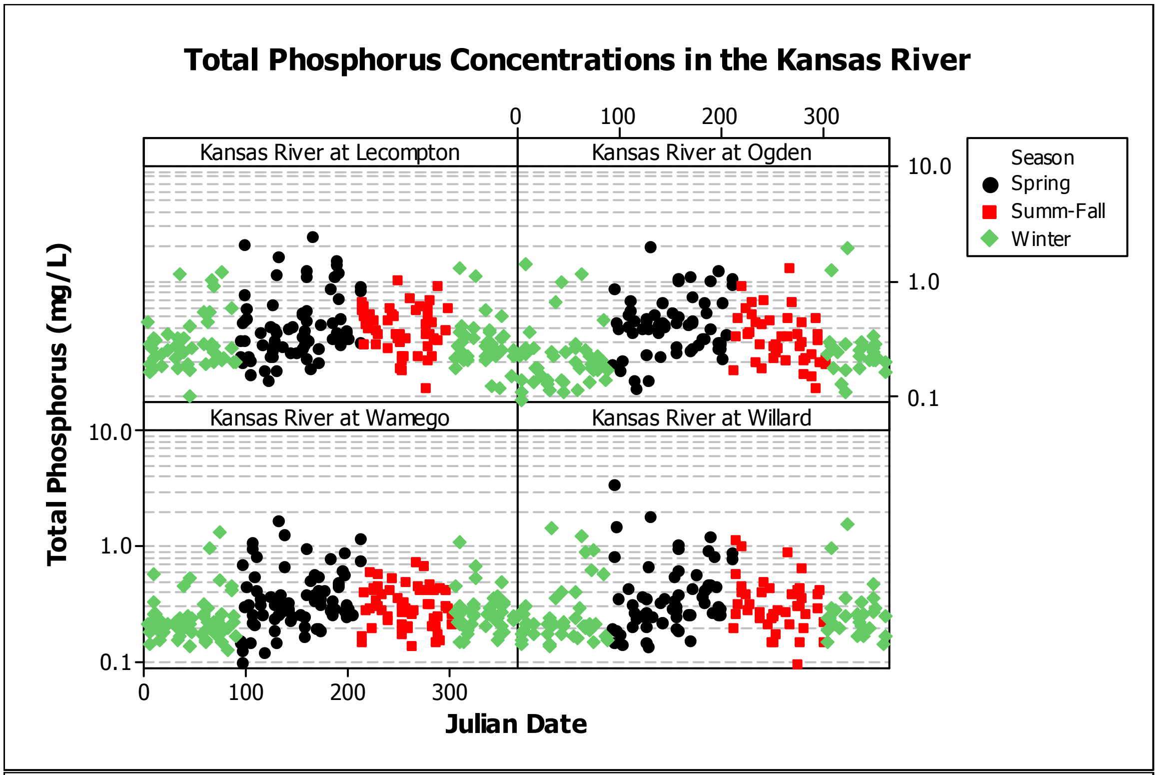
As noted in the summary information, the Kansas River is the eventual receiving stream for over 50,000 square miles of land stretching back Nebraska and Colorado. It is unreasonable to expect a volunteer watershed team to have a major impact on water quality in the river when so many upstream sources remain contributors. However some knowledge of the water quality in this important public recreational resource is useful to have on hand. Below is summary information for the four monitoring stations along the mainstem of the Kansas river within and just downstream of these two HUC 8s. No attempt has been made to link these concentrations to discharge, as has been done where available in the remainder of this document.

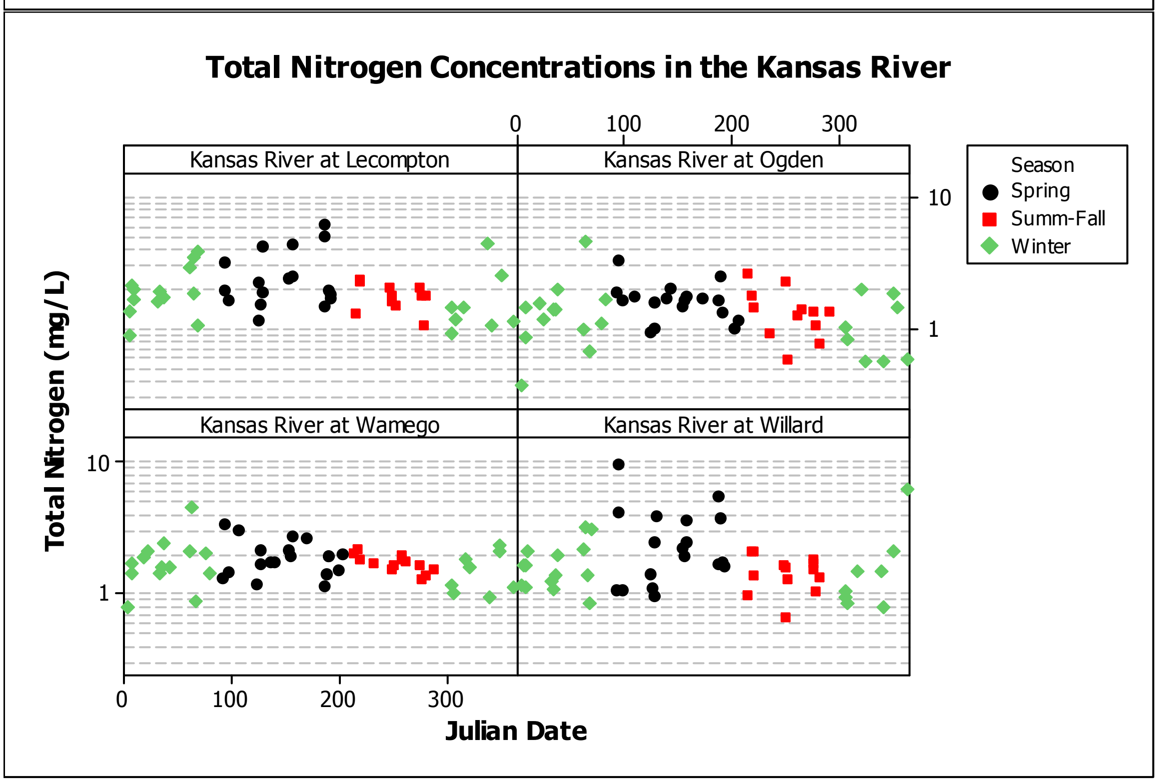
A number of active TMDLs exist on this stretch of river, as well as current 303(d) listings. Interested readers are referred to those documents for more detailed information on the sources and causes of pollution along the river. The data included in these tables are drawn from 1985 onward, a somewhat longer period of record than those available on most of the other monitoring stations. All data available in the KDHE database are included to provide the most complete picture of water quality possible. Over the last 20 years some major improvements have been made to wastewater treatment along the main river, particularly with regard to disinfection of effluent. Those impacts will be less apparent in our monitoring data because monitoring of E. coli began in 2003. Other major upgrades to major treatment plants have also had measurable effects on water quality, though improvements can still be made through increased adoption of biological nutrient removal (BNR).

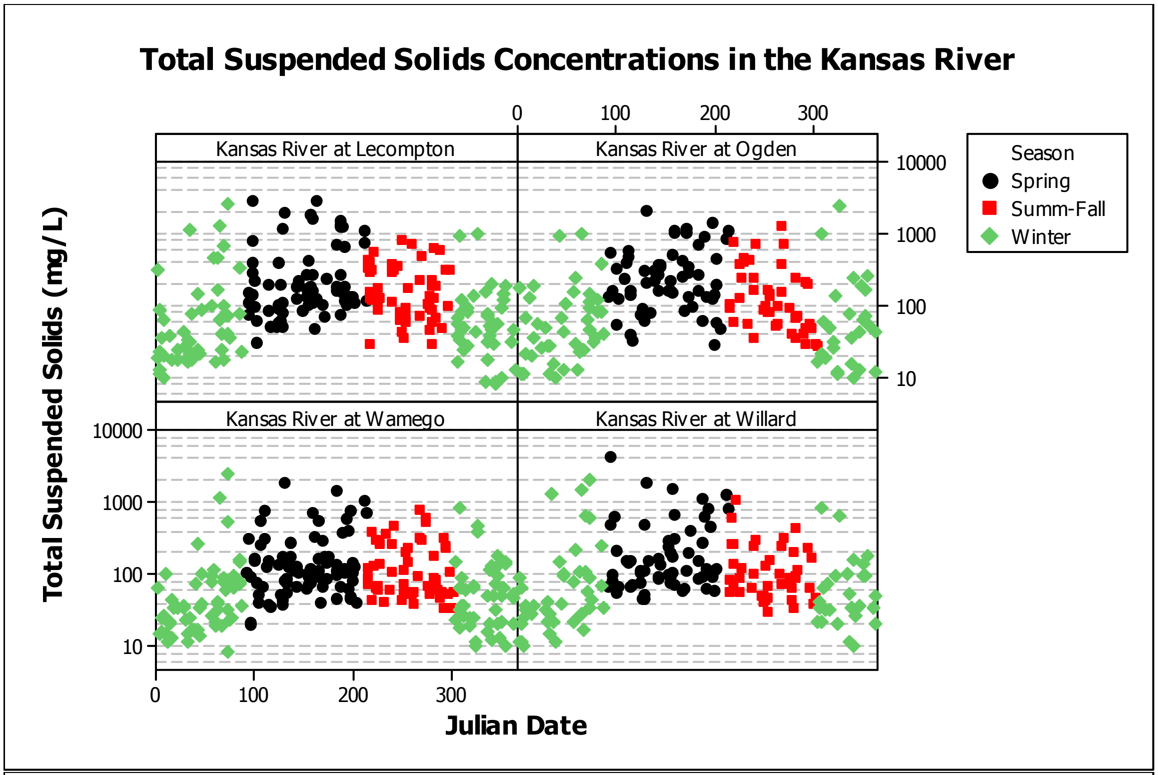
Non-point source reductions can also have some effect on the water quality in the mainstem Kansas River. The majority of the cropland in these two HUC 8s is located in the rich alluvial soils adjacent to the main river. Previous studies have documented the importance of riparian forestry in protecting the river banks, by comparing aerial photographs of the Kansas River before and after the 1993 flood in areas of differing forest density. Areas with greater forest density generally lost less land to the river than those areas with low riparian forest density. Appropriate use of agricultural chemicals and fertilizer may have some impact on the conditions observed in the river, though distinguishing such effects will be complicated because of the magnitude of other sources impacting the river.

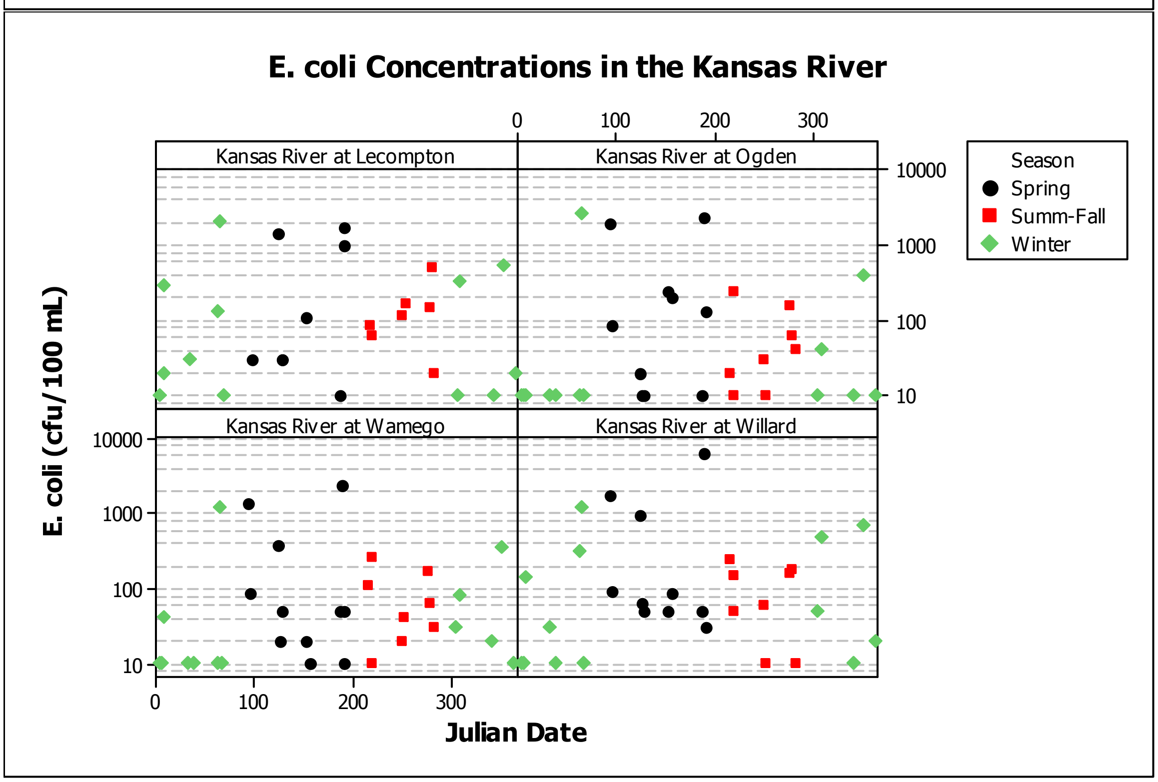
Kansas River at Ogden (SC518)	TP Median	TSS Median	Turbidity Median	TOC Median	Kjeldahl Median	*E. coli* Median	TN Median
Overall	0.2765 (180)	97 (180)	37 (180)	6.153 (44)	0.99 (51)	20 (31)	1.41 (51)
Spring	0.42 (62)	216.5 (62)	82 (62)	8.4195 (16)	1.307 (18)	108.5 (10)	1.708 (18)
Summer-Fall	0.296 (46)	95 (46)	42 (46)	5.924 (11)	1.0475 (12)	36 (8)	1.3625 (12)
Winter	0.2105 (72)	44.5 (72)	16.95 (72)	5.417 (17)	0.701 (21)	10 (13)	1.188 (21)
Kansas River at Wamego (SC260)	TP Median	TSS Median	Turbidity Median	TOC Median	Kjeldahl Median	*E. coli* Median	TN Median
Overall	0.279 (258)	74 (254)	31.95 (258)	5.913 (47)	0.992 (54)	36 (32)	1.778 (54)
Spring	0.32 (87)	118 (85)	58 (87)	7.08 (17)	1.16 (19)	52 (11)	1.97 (19)
Summer-Fall	0.31 (63)	80 (63)	38 (63)	5.507 (12)	1.074 (13)	52 (8)	1.766 (13)
Winter	0.2325 (108)	36 (106)	14.5 (108)	5.515 (18)	0.826 (22)	10 (13)	1.6115 (22)
Kansas River at Willard (SC259)	TP Median	TSS Median	Turbidity Median	TOC Median	Kjeldahl Median	*E. coli* Median	TN Median
Overall	0.27 (179)	88 (179)	35 (179)	5.996 (46)	0.948 (53)	62 (31)	1.676 (53)
Spring	0.33 (63)	122 (63)	53 (63)	7.282 (16)	1.5075 (18)	74.5 (10)	2.1385 (18)
Summer-Fall	0.3 (45)	88 (45)	44 (45)	6.004 (12)	0.973 (13)	110 (8)	1.582 (13)
Winter	0.22 (71)	37 (71)	16 (71)	5.1195 (18)	0.7215 (22)	31 (13)	1.4615 (22)
Kansas River at Lecompton (SC257)	TP Median	TSS Median	Turbidity Median	TOC Median	Kjeldahl Median	*E. coli* Median	TN Median
Overall	0.31 (221)	98 (217)	40 (221)	6.342 (41)	1.292 (49)	85 (27)	1.859 (49)
Spring	0.355 (74)	147.5 (72)	57.4 (74)	7.2775 (14)	1.672 (17)	70.5 (8)	1.985 (17)
Summer-Fall	0.38 (54)	132 (54)	84.5 (54)	6.7535 (10)	1.292 (11)	120 (7)	1.809 (11)
Winter	0.26 (93)	44 (91)	19 (93)	5.294 (17)	1.006 (21)	25.5 (12)	1.693 (21)

Stream chemistry data from KDHE monitoring stations on the Kansas River by season and overall. Number in parenthesis is sample size.


Total Phosphorus Concentrations in the Kansas River
Kansas River at Lecompton
Kansas River at Ogden
Kansas River at Wamego
Kansas River at Willard
Season
Spring
Summ-Fall
Winter
Total Phosphorus (mg/L)
10.0
1.0
0.1
0
100
200
300
Julian Date


Total Nitrogen Concentrations in the Kansas River
Kansas River at Lecompton
Kansas River at Ogden
Kansas River at Wamego
Kansas River at Willard
Season
Spring
Summ-Fall
Winter
Total Nitrogen (mg/L)
10
1
0
100
200
300
Julian Date


Total Suspended Solids Concentrations in the Kansas River
Kansas River at Lecompton
Kansas River at Ogden
Kansas River at Wamego
Kansas River at Willard
Season
Spring
Summ-Fall
Winter
Total Suspended Solids (mg/L)
10
100
1000
10000
0
100
200
300
Julian Date


E. coli Concentrations in the Kansas River
Kansas River at Lecompton
Kansas River at Ogden
Kansas River at Wamego
Kansas River at Willard
Season
Spring
Summ-Fall
Winter
E. coli (cfu/100 mL)
10
100
1000
10000
0
100
200
300
Julian Date

Appendix C: Explanation of the Biological Monitoring Metrics

MBI – Macroinvertebrate Biotic Index: Developed to assess the impact of oxygen demanding nutrients and organic enrichment on macroinvertebrate populations. Has a wider range of possible scores than the KBI, but the research basis for the larger number of values is lacking. Has more generalization into higher taxanomic units than the KBI. Includes many insect genera and species and other common macroinvertebrates, such as leaches, worms, snails, bivalves, flatworms, and crayfish; some of the insect species scored in the KBI are not scored in the MBI.
Scoring Range: 1 (intolerant) – 11 (tolerant)

Fully Supporting ≤ 4.5
Partially Supporting 4.51-5.39
Non-Supporting ≥ 5.4

KBI – Kansas Biotic Index: Reported here as the Nutrient Oxygen Demand component. Developed specifically for Kansas insects belonging to the 10 orders of insects known to occur in Kansas, this metric is primarily intended to capture the impact of elevated nutrient-oxygen demand. Species are assigned tolerance values and the composite score for the site is the abundance weighted average tolerance score for the population collected.
Scoring Range: 0 (intolerant) – 5 (tolerant)

Fully Supporting ≤ 2.6
Partially Supporting 2.61-2.99
Non-Supporting ≥ 3.0

EPT – Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies): The simple sum of the number of species collected belonging to these three orders. EPT are widely recognized as relatively intolerant to pollution, and generally the presence of greater numbers (both diversity and abundance) of these species is considered indicative of higher water quality.

Fully Supporting ≥ 13
Partially Supporting 8-12
Non-Supporting ≤ 8

EPT % Abundance: The percentage of all individuals collected belonging to these three orders. Large populations of a few species may swing this metric to fully supporting when the EPT index registers a partial or non-supporting condition. This metric does not measure diversity in community structure.

Fully Supporting ≥ 48%
Partially Supporting 31-47%
Non-Supporting ≤ 30%