Glenns Creek Pollutant Load Allocation and Causes and Source Analysis

Steven J. Evans[1], Lee Moser[2], and James Shelley[1]
[1]Kentucky Water Research Institute, [2] Cooperative Extension Service
233 Mining and Mineral Resources Building, University of Kentucky, Lexington, KY 40506-0107

Kentucky Water Research Institute

January 2025

Report to: Kentucky Division of Water, 300 Sower Blvd, Frankfort, KY 40601

Title: Glenns Creek Pollutant Loading and Cause and Source Analysis
Date: January 2025
Prepared by:

- Steven J. Evans, Associate Director, University of Kentucky, Kentucky Water Research Institute, Lead author
- Lee Moser, Agriculture Extension Associate Senior at University of Kentucky Cooperative Extension Service, Summaries of agricultural pollution generating activities, editorial review
- J. Adam Shelley, Research Communications Specialist at UK KWRI, Summaries of erosion impacts, calculation of land use statistics, load allocation consultation

Funding for this project was provided in part by a grant from the U.S. Environmental Protection Agency (USEPA) through the Kentucky Division of Water, Nonpoint Source Section, to KWRRI as authorized by the Clean Water Act Amendments of 1987, §319(h) Nonpoint Source Implementation Grant #PON2-129-2200000339. Mention of trade names or commercial products, if any, does not constitute endorsement.

Executive Summary

The *Glenns Creek Pollutant Load Allocation and Cause and Source Analysis* report provides a summary of watershed health impacts, identifies the causes and sources of those impacts, and allocates the pollution reductions necessary to achieve watershed health benchmarks to specific sources.

Monitoring efforts conducted by the Kentucky Water Research Institute and the Kentucky Division of Water identified chemical, biological, and habitat impacts to Glenns Creek and its tributaries. Results showed concerns with fecal indicator bacteria, nutrients, aquatic life, habitat and erosion, trash and litter, and dissolved solids.

***E. coli* bacteria** should be reduced from sources in all subwatersheds upstream of Steele Road, as well as along the Grassy Spring Tributary to achieve safe levels for swimming and wading uses. In urban sites, human waste is the most dominant source at over 83-84% while pet waste is also a notable contributor at 14-15%. In the agricultural areas, agricultural livestock sources generate the most *E. coli* in waste at 69 - 89%. For most subwatersheds, beef cattle are the most prominent source while the livestock wasteload is diversified in Camden Creek.

Nitrogen and **phosphorus** in the upper watershed (southeastern region) were found to regularly exceed protective levels and heavy algal blooms were regularly observed. In urban areas, contributing sources include wastewater treatment plant effluent, human sewage, pet waste, and lawn fertilization and yard trimmings. In rural areas, legacy nutrients stored in groundwater reservoirs, farm animal manure, agricultural fertilization, septic systems, bank erosion, and wildlife are sources.

To achieve the allocated loads for animals and human waste, the total reduction in loading is the equivalent to the waste generated by 225 beef cattle, 104 sheep, 45 horses, 63 swine, 22 dogs, and 61 households. Further reductions are achieved by wastewater nutrient optimization, fertilizer management on hay/pasture areas, or reducing streambank erosion.

In several areas of the watershed, achievement of nitrogen target reductions may be technically unfeasible. Technological limitations prevent reaching the goal at the wastewater treatment plant. Further, the contributions of elevated nitrogen from the groundwater reservoir, which is not treatable, may make reductions via other treatable sources (such as beef cattle) difficult to unfeasible.

The **biological diversity of the aquatic macroinvertebrate community** was found to be impacted in several areas of the watershed including a partial impact near the mouth of the Glenns Creek and non-supporting conditions in streams within Versailles. These impacts were caused, in part by degradation of stream habitat and stream erosion.

Stream habitat was found to be poor or fair at the majority of sites assessed. The lack of streamside vegetation, called the "riparian zone," was found to be a major cause of poor ratings. These impacts are typically due to mowing or livestock grazing to the edge of the stream. In total, 43% of stream bank riparian zones are highly impacted and 14% are moderately impacted. The impacted riparian zones occur on 215 land parcels in the watershed, of which 18 properties contain 46% of all impacts were prioritized for improvements. In addition to the need to expand these riparian zones, invasive plant species also contribute to the degradation of existing riparian habitat.

Streambank erosion was field measured along most of Glenns Creek and estimated for other reaches where access with restricted. While some erosion is natural, excessive erosion in Glenns Creek streams is caused by a variety of factors including excess runoff from impervious surfaces, livestock stream access, channelization, and bank or channel destabilization. A total of 1.6 miles of bank erosion were directly measured in the watershed with 14 miles of bank landscape loss (9%). Most erosion along tributaries to Glenns Creek occurred near pipe outfalls, walls, or low head dams. On Glenns Creek, near its entry to the Kentucky River, extensive bank scour and channel widening was observed, causing collapse of edge-of-bank trees into the stream. Bank erosion in this area is due to increased stormwater runoff volumes traveling at high velocities through the stream system. A total of 125 properties were found to contain eroded reaches. Fourteen (14) properties were identified as containing 46% of all erosion in the watershed and prioritized for improvement.

Streambank erosion allows sediment to enter the stream, adding phosphorus and covering over streambed habitat. Substantial sediment has accumulated behind the series of low-head dams in the watershed, which also act as barriers for fish passage and a safety hazard for boaters.

To minimize further impacts from erosion, green infrastructure practices should be implemented in highly urbanized areas of Versailles. **Impervious surfaces**, or surfaces that do not allow rainwater to soak into the ground, such as roofs, parking lots, and roads, increase the volume and speed of runoff, which can lead to flooding and erosion.

In the Versailles area, **trash and litter** accumulated along the stream after heavy rain events. Plastic bottles, Styrofoam cups, plastic bags and other litter can be blown out of overfilled trash bins and transported into streams. Litter in parking lots, commercial, areas, and roadside is another common source. Installation of a hydrodynamic separator as well as catch basin inserts would capture this trash from the systems.

Urban stream areas were also impacted by excessive application of **road salts** and **deicers**.

Table of Contents

Figures

Tables

1 Watershed and land use

The Glenns Creek Watershed, located in Woodford and Franklin Counties, Kentucky, is a mix of urban areas, pasture, cropland, and forest. As shown in Figure 1, the urban area is primarily located in the headwaters, with the City of Versailles to the southeast with ribbons of development located along the stream in Millville and along McCracken Pike. Near the mouth to the northwest where Glenns Creek flows into the Kentucky River, the topography is more rugged, and the land cover is dominated by forest. The remainder of the watershed is dominated by pastureland with some pockets of row crop agriculture.

To characterize potential pollutant sources within the Glenns Creek Watershed, nine (9) sites were sampled as shown in Figure 1. The land use in each site drainage area, according to the 2019 National Land Cover Database, is shown in Table 1. The land use within each site drainage area can be used to determine the types of potential pollutant sources that contribute to each site.

Figure 1 - Glenns Creek Watershed land use

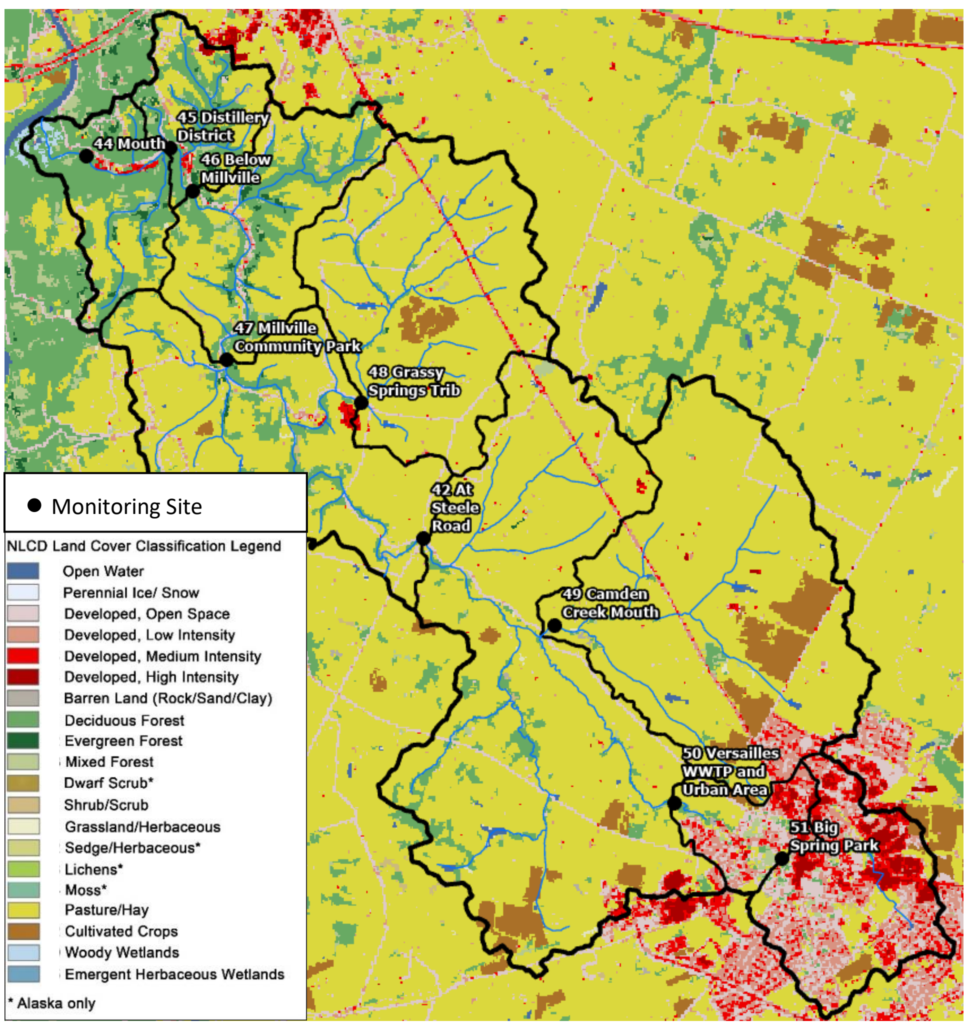


Table 1 - Glenns Creek Watershed site drainage area land use

Site ID	Site Description	% Urban	% Pastureland	% Cropland	% Forest	% Other
51	Big Springs Park	79.9	13.8	2.9	3.3	0.1
50	Versailles Wastewater Treatment Plant and Urban Area	60.6	24.6	2.0	12.5	0.3
49	Camden Creek Mouth	7.1	81.8	8.6	1.8	0.7
42	Steele Road	5.4	84.4	3.9	5.7	0.6
48	Grassy Springs Tributary	5.6	89.8	2.7	1.4	0.5
47	Millville Community Park	7.1	79.2	0.4	13.0	0.4
46	Below Millville	5.7	57.6	0.0	36.3	0.2
45	Distillery District	8.9	42.1	0.0	48.4	0.6
44	Glenns Creek Mouth	7.2	25.8	2.8	63.5	0.7

Source: NCLD 2019. Urban includes Developed, Open Space; Developed, Low Intensity; Developed, Medium Intensity; and Developed, High Intensity. Forested includes Deciduous Forest, Evergreen Forest, Mixed Forest, Shrub/Scrub, and Woody Wetlands.

2 Pollutant loading reductions

As detailed in the Glenns Creek Water Quality Data Analysis Report (Evans 2023), pollutant load reductions to meet targets were calculated. Table 2 summarizes the percent reductions by site to achieve the specified target concentrations. Table 3 converts the current loads into yields by dividing by the site area. Figures 2 – 5 display these pollutant yields.

Table 2 – Summary annual pollutant loads, target loads, and percentage reductions by site

Parameter	Unit	Site 44	Site 45	Site 46	Site 47	Site 48	Site 42	Site 49	Site 50	Site 51
E. coli (Trillion/year) 240 MPN/100mL	Actual	352.5	278.9	377.7	376.0	17.4	401.8	273.6	39.4	16.7
	Target	86.2	82.4	83.4	82.5	8.9	61.9	24.6	13.5	3.7
	% Reduction	76%	70%	78%	78%	49%	85%	91%	66%	89%
Ammonia (tons/year) 0.05 mg/L	Actual	1.57	1.64	1.77	2.02	0.16	1.01	0.46	1.31	0.09
	Target	2.22	2.03	2.1	2.07	0.23	1.56	0.63	0.36	0.1
	% Reduction	0%	0%	0%	0%	0%	0%	0%	73%	0%
Nitrogen, Nitrate + Nitrite (tons/year) 2.0 mg/L	Actual	89.14	85.05	89.65	93.09	7.4	85.44	39.39	18.13	4
	Target	88.96	81.35	84.14	82.89	9.36	62.45	25.23	14.23	3.82
	% Reduction	0%	4%	6%	11%	0%	27%	36%	21%	4%
Phosphorus, Total (tons/year) 0.35 mg/L	Actual	22.03	19.93	20.57	21.4	1.42	17.67	4.65	5.91	0.65
	Target	15.57	14.24	14.72	14.51	1.64	10.93	4.41	2.49	0.67
	% Reduction	29%	29%	28%	32%	0%	38%	5%	58%	0%
Solids, Total Dissolved (tons/year) 300 mg/L	Actual	12354	11537	11572	11507	1203	8820	3343	2540	885
	Target	13344	12203	12621	12434	1404	9368	3784	2135	573
	% Reduction	0%	0%	0%	0%	0%	0%	0%	16%	35%

NOTE: Red shading indicates the magnitude of the percentage load reduction required at the site.

Table 3 – Pollutant yields by site.

Parameter	Unit	Site 44	Site 45	Site 46	Site 47	Site 48	Site 42	Site 49	Site 50	Site 51
Drainage Area	acre	21634	20585	19741	18082	3094	12272	4257	2183	1569
E. coli	billion/year/acre	16.3	13.5	19.1	20.8	5.6	32.7	64.3	18.0	10.6
Ammonia	lbs./year/acre	0.15	0.16	0.18	0.22	0.10	0.16	0.22	1.20	0.11
Nitrogen, Nitrate+Nitrite	lbs./year/acre	8.24	8.26	9.08	10.30	4.78	13.92	18.51	16.61	5.10
Phosphorus, Total	lbs./year/acre	2.04	1.94	2.08	2.37	0.92	2.88	2.18	5.41	0.83
Solids, Total Dissolved	tons/year/acre	0.57	0.56	0.59	0.64	0.39	0.72	0.79	1.16	0.56

Table 4 shows the calculated incremental load reductions necessary to achieve the target reductions. These incremental load reductions assume that if the load is reduced at upstream sites, it will also be reflected downstream. Zeros indicate areas in which either the site did not exceed benchmarks or the incremental load reductions at upstream sites were sufficient to meet benchmarks. No load reductions are required below Millville Community Park (Site 47), but all sites above require reductions to one or more parameters.

Table 4 – Incremental load reductions by site drainage area to achieve targets.

Parameter	**Site 44**	**Site 45**	**Site 46**	**Site 47**	**Site 48**	**Site 42**	**Site 49**	**Site 50**	**Site 51**
E. coli (Count/year)	0	0	0	0	8.5E+12	6.5E+13	2.49E+14	1.29E+13	1.3E+13
Ammonia (lbs./year)	0	0	0	0	0	0	0	1,900	0
Nitrogen, Nitrate+Nitrite (lbs./year)	0	0	0	0	0	9,860	28,400	7,440	360
Phosphorus, Total (lbs./year)	0	0	0	300	0	6,160	480	6,840	0
Solids, Total Dissolved (lbs./year)	0	0	0	0	0	0	0	186,000	624,000

Figure 2 – E. coli yield by site drainage

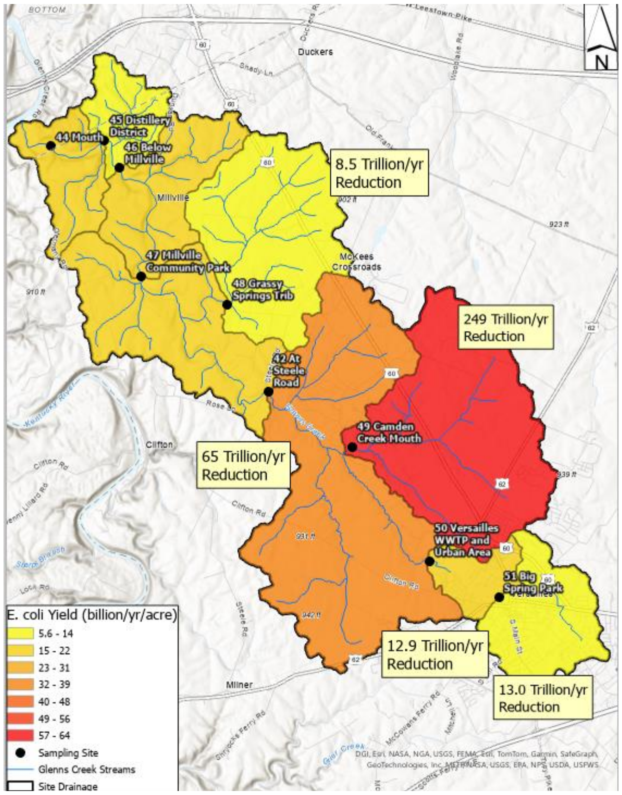


Figure 3 – Nitrate + nitrite yield by site drainage

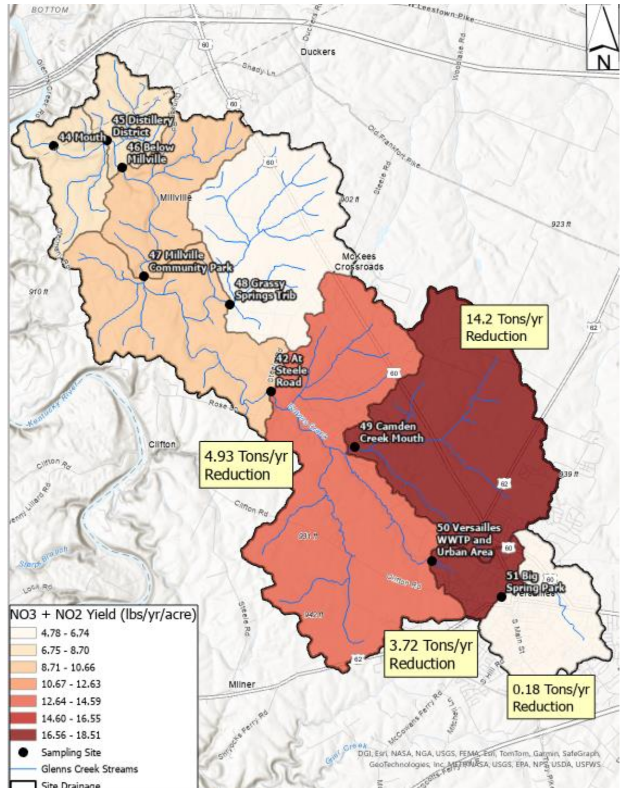


Figure 4 – Ammonia yield by site drainage

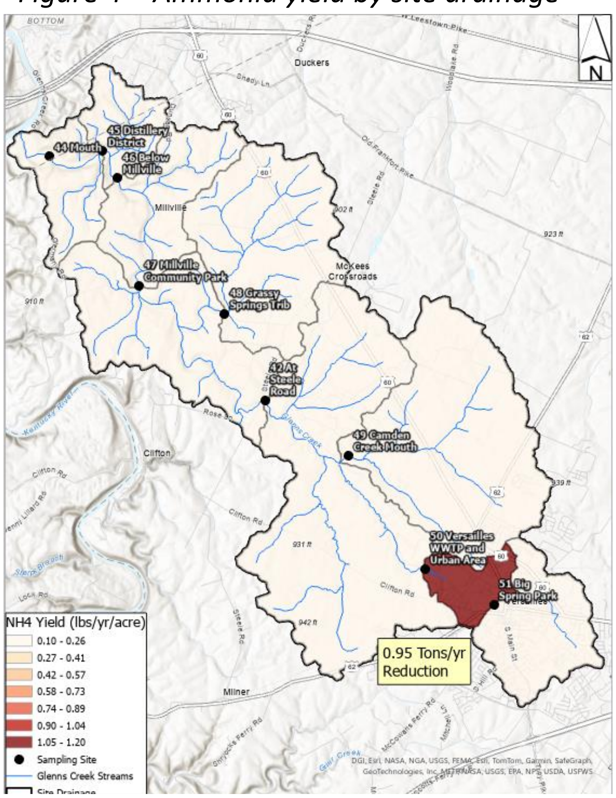


Figure 5 – Phosphorus yield by site drainage

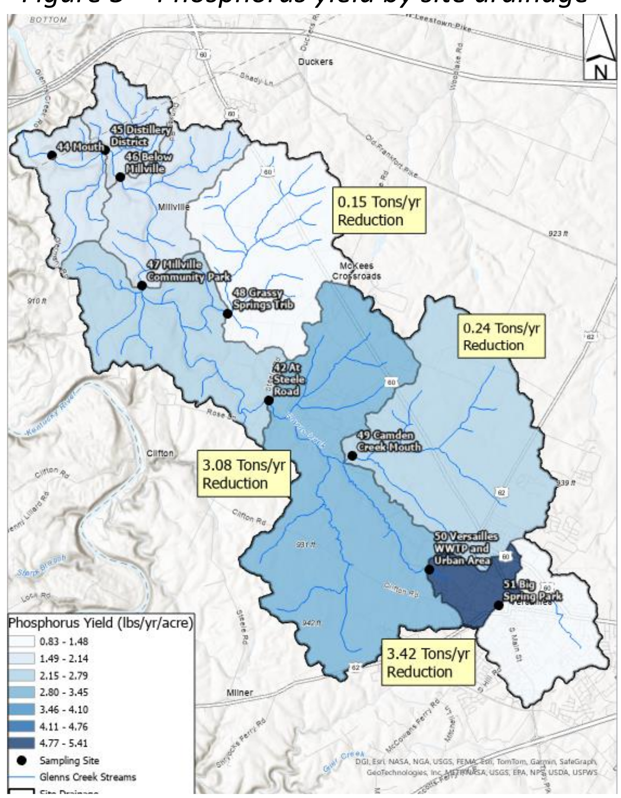
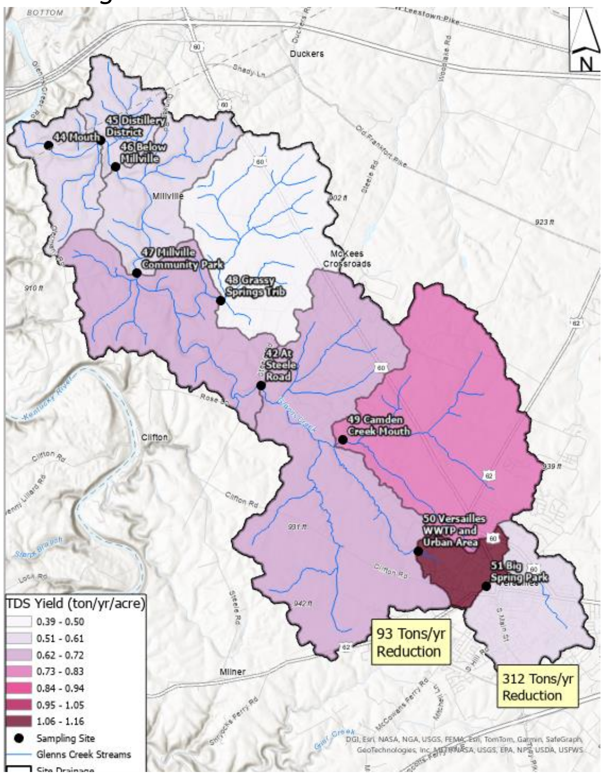


Figure 6 – Total dissolved solids yield by site drainage



3 Aquatic ecosystem and habitat

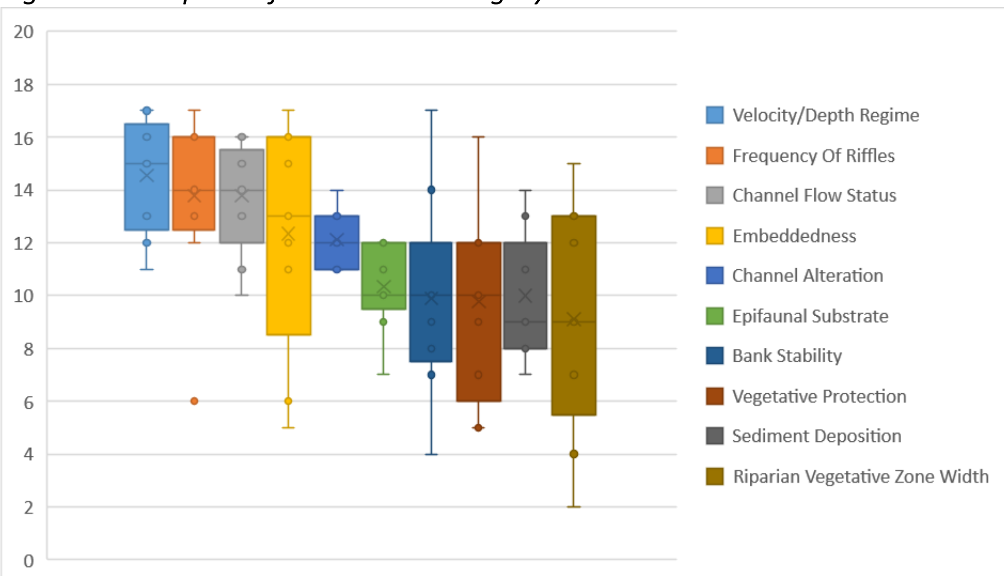
The Kentucky Division of Water (KDOW) conducted a macroinvertebrate survey and identification and a rapid habitat assessment (RBP) at all sites between April and July 2021. These results were compared against the KDOW bioregional criteria for the macroinvertebrate biotic index (MBI) and RBP at each site. These indices are different for wadeable and headwater streams, with headwater streams having higher criteria. The results are shown in Table 5.

Table 5 – Macroinvertebrate and habitat scores and ratings by site

Site	44	45	46	47	48	42	49	50	51
Headwater (H) or Wadeable (W)	W	W	W	W	H	W	W	H	H
Macroinvertebrate Biotic Index Score	52	61	68	60	55	59	61	29	23
Macroinvertebrate Index Rating	Fair	Fair/ Good	Good	Fair/ Good	Good	Fair/ Good	Fair/ Good	Poor	Poor
Habitat (RBP) Score	145	123	121	136	119	115	103	92	87
Habitat Rating	Good	Fair	Fair	Good	Poor	Fair	Poor	Poor	Poor

The macroinvertebrate community is partially impacted in the watershed near the mouth and fully impacted in the headwaters in the urban area of Versailles. Habitat scores showed impacts in the headwaters with fair ratings below Millville in the Distillery District. Two sites also scored good for habitat, located in large forest blocks. Figure 7 shows a breakdown of the habitat subcategories at all sites. The channel velocity/depth regime, frequency of riffles, and channel flow status were high at all sites, but bank vegetative protection, sediment deposition, and riparian zone width were often marginal or poor.

Figure 7 – Boxplots of habitat subcategory results.



Because the riparian zone width was one of the most impacted habitat subcategories, an aerial assessment of the width of riparian zone analysis was conducted by KWRI. The stream banks were delineated using aerial imagery, infrared imagery, and lidar data, and then buffered at widths of 10 and 30 feet. Widths of less than 10 feet were categorized at "high impact," between 10 and 30 feet as "moderate impact," and greater than 30 feet as "low impact," as shown in Figure 8. The percentage for each site drainage area for each impact category are summarized in Table 6. In total, 43% of stream bank riparian zones are highly impacted and 14% are moderately impacted. By weighing the relative percentage impact in each stream reach, a riparian impact index (RI) was developed according to the following equation with H as the length of highly impacted riparian stream bank, M as moderately impacted, and L as low impact. Letter grades were established at each 20-point interval, with 0 indicating the completely impacted and 100 indicating no impacts. Results point to the need to plant trees and native riparian species in the waterways upstream of Millville Community Park.

$$RI = 100 * \{1 - \left[\frac{(2H + M)}{2(H + M + L)}\right]\}$$

Figure 8 – Riparian zone impact analysis of Glenns Creek and its tributaries based on aerial imagery.

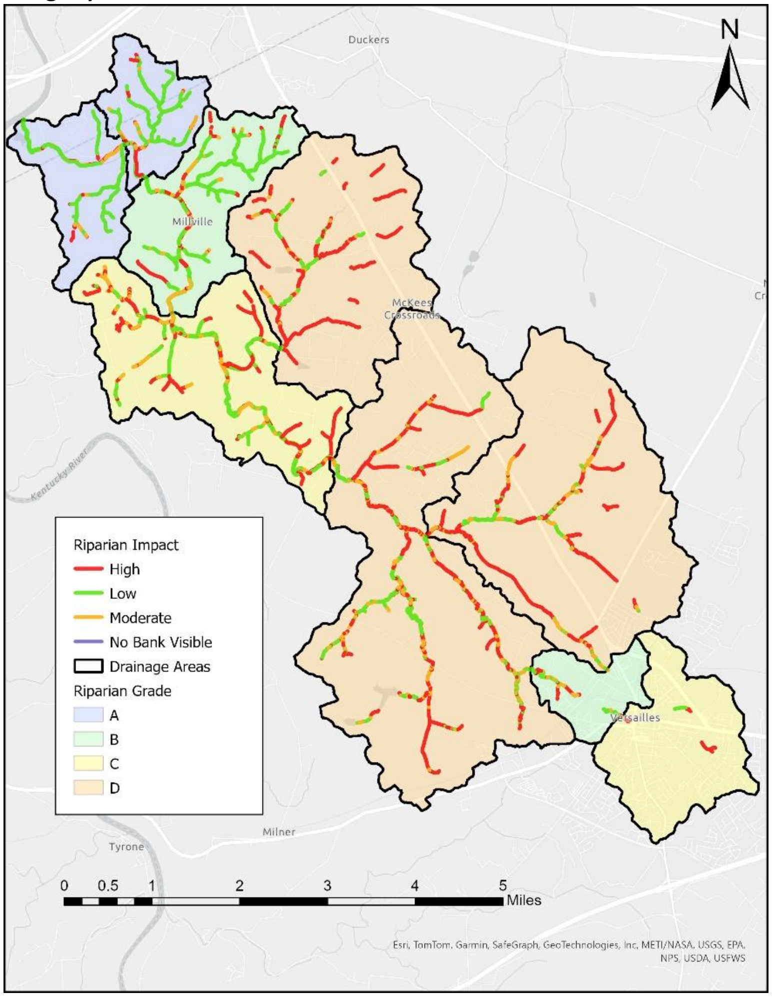


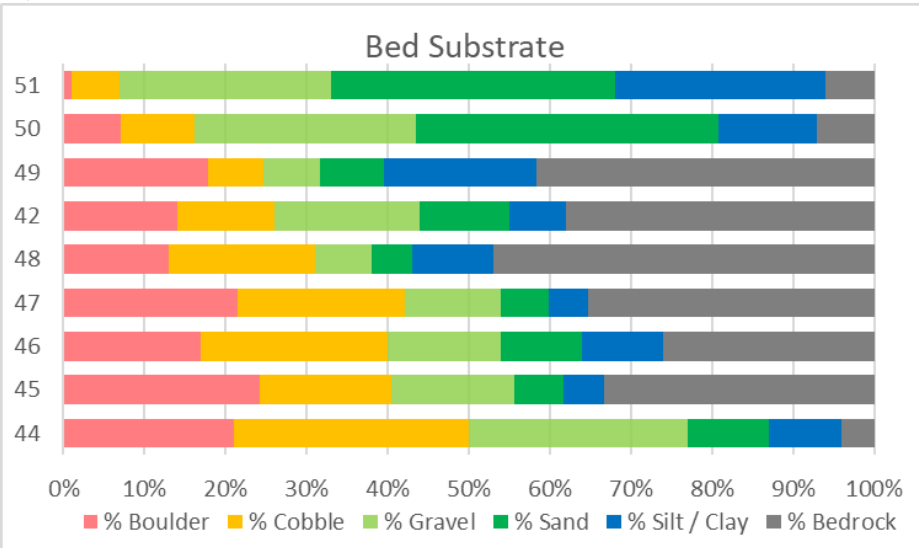
Table 6 – Riparian zone impact percentages by site drainage

Catchment	Total Bank Length (ft)	No Bank (piped or crossing)	Low Impact	Moderate Impact	High Impact	Riparian Impact Index	Riparian Impact Rating
44	53,862	0%	81%	9%	10%	86	A
45	64,015	0%	82%	9%	10%	86	A
46	106,764	0%	70%	12%	18%	76	B
47	139,812	0%	37%	19%	44%	47	C
48	86,821	1%	22%	5%	72%	24	D
42	181,396	6%	25%	17%	52%	35	D
49	107,616	1%	17%	18%	64%	26	D
50	15,496	0%	49%	21%	30%	60	C+
51	6,744	3%	37%	3%	57%	40	D+

4 Streambed, bank erosion and runoff volume

KDOW also performed visual assessments of the bed substrate during their monitoring visits. The results of these assessments are shown in Figure 9. In the urban area of Versailles (Sites 50 and 51), the streams are dominated by sand, gravel, and silt. The mouth of the stream is dominated by cobbles and boulders. For much of the rest of the streams, the stream bed is dominated by bedrock with channels becoming over-widened due to scour.

Figure 9 – Bed substrate characterization based visual assessment.

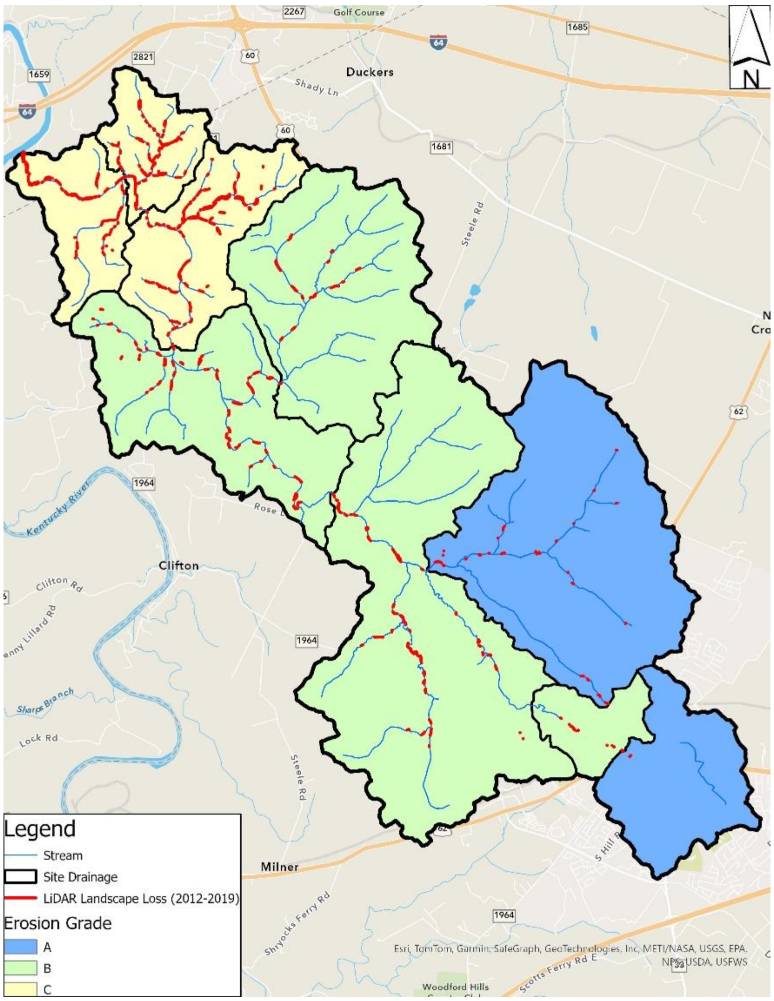


A visual assessment was conducted by KWRI staff of streams where access was granted by the property owners. Streams were walked and surveyed using Maryland's "Stream Corridor Assessment Survey" (Yetman 2001). Bank erosion length and height were measured as well as the severity of the erosion. The results are summarized in Table 7. A total of 1.6 miles of bank erosion were directly measured.

Most erosion along tributaries occurred near pipe outfalls, walls, or low head dams. On Glenns Creek near the mouth, extensive bank scour was observed due to stream channelization down to the bedrock and subsequent widening. This widening caused the collapse of edge-of-bank trees into the stream and their transport downstream, particularly evident near the confluence with the Kentucky River. This bank erosion is due to increased runoff volume traveling at increased velocities through the stream system.

Because access was not permitted in many areas of the watershed, the amount of erosion was estimated by using changes in the landscape riparian area between the two LIDAR surveys, 2012 and 2019. Because the 2019 survey has increased resolution, it was down-sampled to match the 5-ft resolution of the 2012 survey. Loss was counted if it was greater than half a foot to eliminate noise in the dataset. The results were digitized from an area to a line along the stream bank edge. The results, shown in Figure 10, show that 14 miles of bank had landscape loss. These estimates correlate well with direct measurements in those areas directly observed and show that most erosion is occurring on the steeper ground near the mouth of Glenns Creek. An erosion grading index was established using breakpoints at 3%, 7%, 10%, and 30% bank erosion to define letter grades for each site drainage area. The results are summarized in Table 7 and Figure 10.

Figure 10 – Locations of bank landscape loss based on comparison of changes in LiDAR data.



To determine areas where the runoff volume is highest and increased detention and infiltration would be beneficial, the National Land Cover Dataset was intersected with the Hydrologic Soil Group to determine the TR-55 Curve Number associated with each area, as shown in Table 8. A runoff index was developed by converting the curve number ratings to a 0-100 scale with a curve number of 50 equal to 100 and a curve number of 90 or greater equal to 0. Area-weighted composite curve numbers were then developed for each site's drainage area, as summarized in Table 9. Because watersheds are relatively similar, increased detention, infiltration, or tree planting would be most beneficial in the headwaters of the watershed as increased infiltration upstream will benefit downstream sites.

Table 7 – Bank erosion by site drainage based on field assessment and LiDAR calculation.

		Field Measured				LiDAR Landscape Loss			
Site	Total Bank Length (feet)	% Stream Accessed	Total Bank Assessed (feet)	Total Bank Erosion (feet)	% Erosion on Assessed Reaches	Bank Land-scape Loss (feet)	% Bank Land-scape Loss	Erosion Index	Erosion Rating
44	53,862	100	53,862	5,940	11%	12,675	24%	46	C
45	67,725	15	10,159	738	7%	13,353	20%	50	C
46	116,756	12	14,011	527	4%	19,475	17%	53	C
47	152,040	38	57,775	86	0%	12,023	8%	74	B
42	88,103	0	0	0	N/A	3,571	4%	75	B
48	185,674	0	0	0	N/A	10,364	6%	67	B
49	107,616	54	58,112	556	1%	2,711	3%	83	A
50	16,486	100	16,486	454	3%	737	4%	73	B
51	7,734	100	7,734	135	2%	67	1%	88	A
Total	**795,996**	**27**	**218,139**	**8,436**	**4%**	**74,977**	**9%**	**64**	**B-**

Table 8 – USDA TR-55 curve numbers by hydrologic soil group and land cover and associated runoff index

NLCD Code	NLCD Description	Hydrologic Soil Group				Runoff Index			
		A	B	C	D	A	B	C	D
11	Open Water	98	98	98	98	0	0	0	0
21	Developed, Open Space	45	65	76	82	100	70	48	36
22	Developed, Low Intensity	60	74	82	86	80	52	36	28
23	Developed, Medium Intensity	77	85	90	92	46	30	20	15
24	Developed, High Intensity	92	94	96	96	15	10	5	5
31	Barren Land	77	86	91	94	46	28	18	10
41	Deciduous Forest	36	60	73	79	100	80	54	42
42	Evergreen Forest	30	55	70	77	100	90	60	46
43	Mixed Forest	30	55	70	77	100	90	60	46
52	Shrub/Scrub	35	56	70	77	100	88	60	46
71	Grassland/Herb	49	69	79	84	100	62	42	32
81	Pasture/Hay	49	69	79	84	100	62	42	32
82	Cultivated Crops	62	71	78	81	76	58	44	38
90	Woody Wetlands	45	66	77	83	100	68	46	34
95	Emergent Herbaceous Wetlands	49	69	79	84	100	62	42	32

Table 9 – Runoff volumes and composite curve numbers by site drainage area

Site	Area (Acres)	Composite Curve Number	Runoff (in)	Runoff Volume (Acre-in)	Normalized Runoff Volume	Runoff Index	Runoff Index Rating
44	1049	65.67	1.29	1356	0.15	69	B
45	844	67.46	1.41	1191	0.12	65	B
46	1659	65.91	1.31	2171	0.31	68	B
47	2716	63.95	1.18	3214	0.51	72	B
48	3095	62.47	1.09	3384	0.54	75	B+
42	5833	60.65	0.99	5757	1.00	79	B+
49	4258	60.77	1.00	4239	0.71	78	B+
50	614	60.05	0.95	585	0.00	80	B+
51	1569	66.08	1.32	2070	0.29	68	B

5 Trash and Litter

To quantify observations of trash and litter, a trash index was developed based on the amount of trash observed on each field visit according to the criteria shown in Table 10. Narratives and photos were utilized to generate scores for each field visit and then average scored were utilized to generate the overall index score for each site. Results shown in Table 11 reveal that trash accumulation was the greatest in Big Spring Park and downstream of Millville. It is noted that values for Big Spring Park would be higher if not for regular efforts by park staff to pick up trash after precipitation events.

Table 10 – Trash index

Visual Indicator	Trash Index Score
No trash visible	100
Trash in minor amounts (trash bag)	75
Trash in moderate amounts (multiple bags)	50
Trash blocking or affecting flow of stream, (large or abundance trash / debris)	25
Trash abundant and unsightly; dumping site	0

Table 11 – Trash index scores by site

Site	44	45	46	47	48	42	49	50	51
Trash Index	91	75	77	98	100	95	97	91	69

6 Causes and sources of pollution and waterway impacts

In evaluating the causes and sources of these impacts to the waterways, a number of pollution generating activities and other activities causing stream impacts were identified. These activities are divided between urban and rural sources in Table 12. These activities are described in the following sections.

Table 12 – Urban and rural pollution-generating or waterway-impacting activities

Pollution Generating Activity	*E. coli*	Nutrients	Dissolved Solids	Habitat	Trash	Erosion and Runoff
Urban						
Human Sewage						
Private sewer connections	X	X				
Public sewer infrastructure	X	X				
Treated water from public treatment plant		X				
Pet waste	X	X				
Waterfowl	X	X				
Lawn fertilization and yard trimmings		X				
Road and parking lot salt / deicer			X			
Litter, dumping, and overfilling trash bins					X	
Runoff from paved and compacted surfaces						X
Mowing streamside vegetation				X		
Invasive species in streamside vegetation				X		
Rural						
Horse / cattle manure management	X	X				
Livestock stocking, feeding, and heavy use areas	X	X				X
Fertilizer management		X				
Legacy soil nutrients		X				
Wildfowl	X	X				
Wildlife (Deer, Coyotes, Raccoons)	X	X				
Livestock stream access	X	X		X		X
Streambank erosion						X
Invasive species in riparian zone				X		
Mowing or grazing riparian zone				X		
Row crop runoff		X				
Septic systems drainage to karst	X	X				
Low-head dams				X		X

6.1 Human sewage sources

Human sanitary wastewater in the watershed is treated either by a sanitary sewer system or by septic systems.

6.1.1 Sanitary sewer system

Within the urban service area of Versailles, properties are serviced by a sanitary sewer system that is comprised of three different parts (Figure 10), 1) private lateral lines that connect the property to 2) the public sewer lines that transport the wastewater to 3) the wastewater treatment plant. The Versailles Wastewater Treatment Plant was upgraded in 2020 to improve emergency backup power, add ultraviolet disinfection, increase the capacity, and modernize the plant. The City of Versailles has almost 100 miles of sewer line, 2,225 manholes, and 24 sewer lift stations in its sewer collection system. Versailles Municipal Wastewater has conducted extensive sewer rehabilitation work at a cost of over $7 million over the past ten years with three phases of rehabilitation projects being implemented. On an ongoing basis, they video-inspect lines and conduct maintenance as issues are identified. These efforts have dramatically improved the performance of the system and eliminated most sanitary sewer overflows. However, repair and improvement work still remain.

Both the private and public lines can be harmed by breaks, cracks, root intrusion, clogs, and other problems that can cause exfiltration or overflows. In older neighborhoods, built prior to the 1970s when PVC pipe became widely used in construction, clay pipe or Orangeburg pipe may still be in use and increasingly susceptible to exfiltration. In karst areas like Versailles, broken pipes may not resurface or back up into homes but may instead leach into the groundwater where sewage is quickly transported to springs, the stormwater system, or to streams (Figure 11). A pathogen indicator study (Reed et al. 2011) inferred that leakage from sanitary sewers was contributing to elevated concentrations at the Blue Hole Spring in Versailles just upstream of the wastewater treatment plant.

Figure 11 – Diagram of private and public portions of the sanitary sewer system.

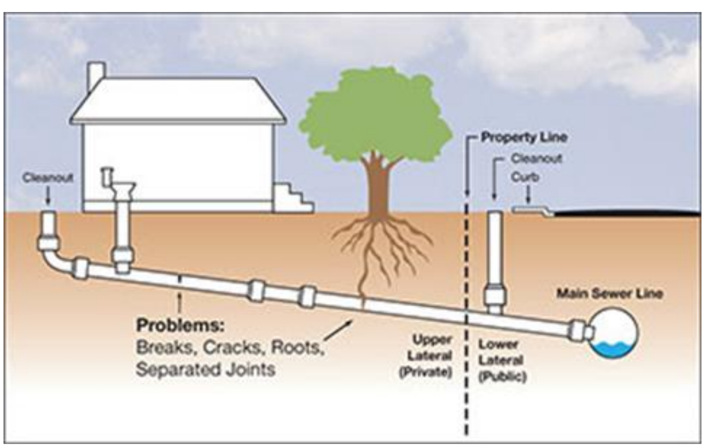
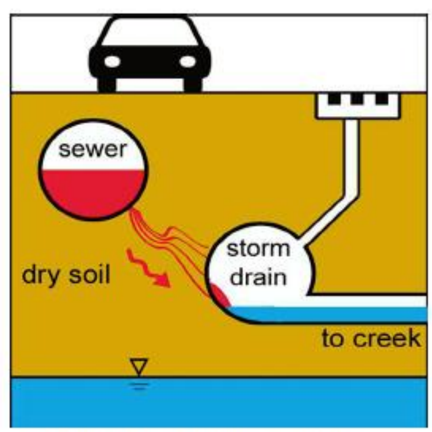


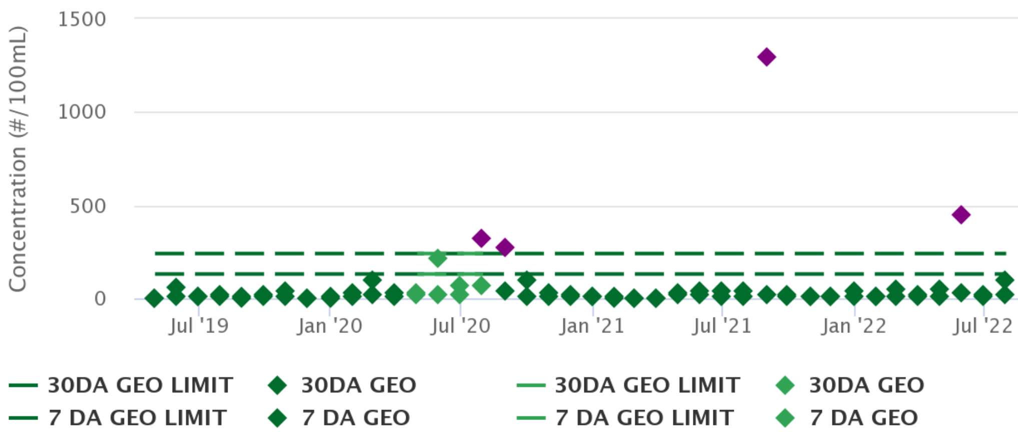
Figure 12 – Diagram of exfiltration from sanitary sewer to storm sewer during low groundwater condition.



The City of Versailles conducted a series of *E. coli* sampling events from November 2023 to April 2024 to gradually trace the source upstream from Big Spring Park. Their investigation identified a hotspot at the CharMil pump station near Bryanwood Drive and Tichner Drive. This pump station serves roughly 335 homes and is undersized causing wet weather exfiltration. Preliminary engineering reports estimate the improvement cost at near $1 million. Other unidentified overflows or exfiltration from the system may be occurring from public lines or from older private lateral lines. This known issue should be addressed then the need for additional projects reassessed based on subsequent monitoring in an iterative manner.

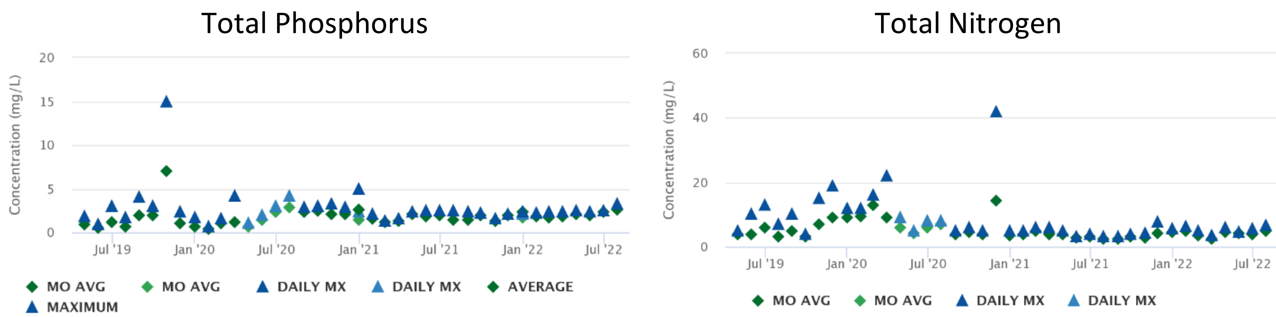
While the wastewater treatment plant is performing proficiently in *E. coli* treatment, opportunities for nutrient reduction by optimization or biological or chemical control can help to reduce exports. As shown in Figure 13, the *E. coli* concentrations in the effluent were below required permit limits for almost the entire project monitoring period (March 2021 to February 2022) with one exception. For nitrogen and phosphorus, the plant does not have specified permit limits. As shown in Figures 14, total phosphorus and total nitrogen concentrations in treated effluent averaged around 2 mg/L and 4.5 mg/L, respectively. Calculating loading from weekly plant reporting (Figure 15), the wastewater plant contributed an estimated 25,159 lbs. of nitrogen and 10,773 lbs. of phosphorus with an average daily flow of 2.461 million gallons per day of discharge to Glenns Creek during the project period.

Figure 13 – Versailles STP (KY0020621) effluent concentrations for E. coli, 2019-2022.



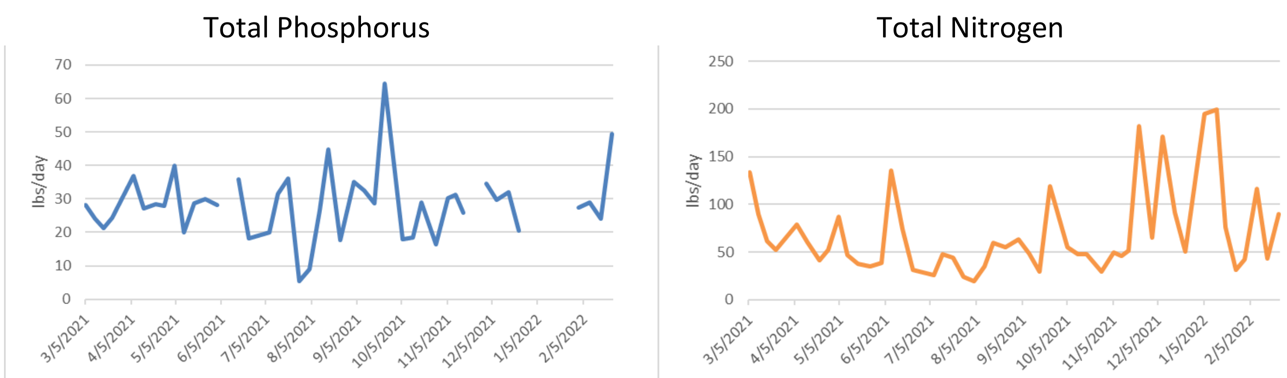
Source: US EPA ECHO

Figure 14 – Versailles STP (KY0020621) effluent concentrations for total phosphorus and total nitrogen, 2019-2022.



Source: US EPA ECHO

Figure 15 – Versailles STP (KY0020621) effluent load of total phosphorus and total nitrogen, March 2021-February 2022



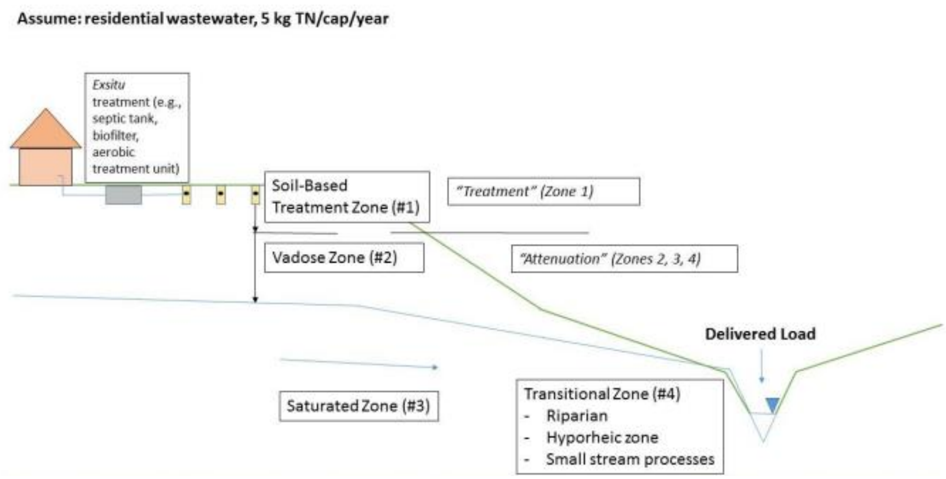
Source: Versailles Wastewater Plant

6.1.2 Septic systems

Outside of the urban service area, properties are serviced by onsite septic systems. Septic systems are effective methods of treating sanitary waste. To maintain optimal performance, these systems require inspection at least every 3 years and pumping every three to five years. Homeowners should also utilize best management practices (BMPs) to ensure proper functioning of their systems, such as avoiding overloading their systems with household wastewater and ensuring that certain types of items are not flushed or washed down drains (e.g., disposable wipes, toxic cleaning agents, etc.).

Nitrogen in human waste has been found to have limited reduction by septic systems. Experts (D'Amato 2016) have determined that nitrogen reduction by a septic system is a factor of four zones of treatment and attenuation (Figure 12). A rate of 5 kg nitrogen/person/year is assumed for residential wastewater. For loamy soils (the most common type for the Glenns Creek Watershed), Zone 1 soil-based treatment achieves a 34% reduction (3.3 kg/cap/year) in total nitrogen. Zone 1 and 3 achieve a reduction to between 0.8 and 2.1 kg/cap/year (58%-84% reduction). In areas of karst, septic systems may only provide Zone 1 reduction levels as the groundwater moves through quick-flow or moderate-flow systems. Further, experts recognized that nitrogen delivery is a function of distance with a recommended setback from streams of 1,000 feet.

Figure 16 – Diagram of onsite wastewater treatment and attenuation zones.



Source: D'Amato 2016.

6.2 Pet waste

Pet waste, specifically dog waste, can be a significant source of *E. coli* and nutrient pollution in waterways. According to the 2022 Census, Versailles has a population of 10,416 in 4,243 households. According to the US American Veterinary Medical Association (2024), 45.5% of households own dogs, with an average of 1.5 dogs per household. This means that about 2,900 dogs are located in Versailles, KY. According to the USDA (2005), the average dog excretes 274 pounds of waste per year. Therefore, dogs of Versailles excrete almost 400 tons of waste each year. While much of this waste is collected and disposed of in a landfill, a portion of this waste is left on lawns where it contributes to the pollutant load via runoff. By encouraging dog waste pick up, this source can be reduced.

Cats are also a contributor of *E. coli* and nutrient pollution with 32.1% of households owning an average of 1.8 cats (AVMA 2024). However, most cats tend to reside completely indoors where their waste is collected for transport to the landfill. For outdoor cats, the size of the waste makes pick up programs unfeasible. Nevertheless, this source was considered in loading calculations.

6.3 Waterfowl

Waterfowl were observed at multiple sites during multiple monitoring visits, as shown in Figure 17. Geese and ducks can contribute to the *E. coli* and nutrient loads due to their tendency to flock together and generate prolific waste near waterbodies. According to the Audubon Christmas Bird Count (2021) in Frankfort (the closest count location), 348 Canada geese and 23

Mallard ducks were observed. These populations represent independent confirmations of the wildlife estimates calculated by land use for the Glenns Creek Watershed.

Figure 17 – Canada geese spotted in the Glenns Creek Watershed above Site 48 (left) and at Site 44 (right)

Source: Steve Evans

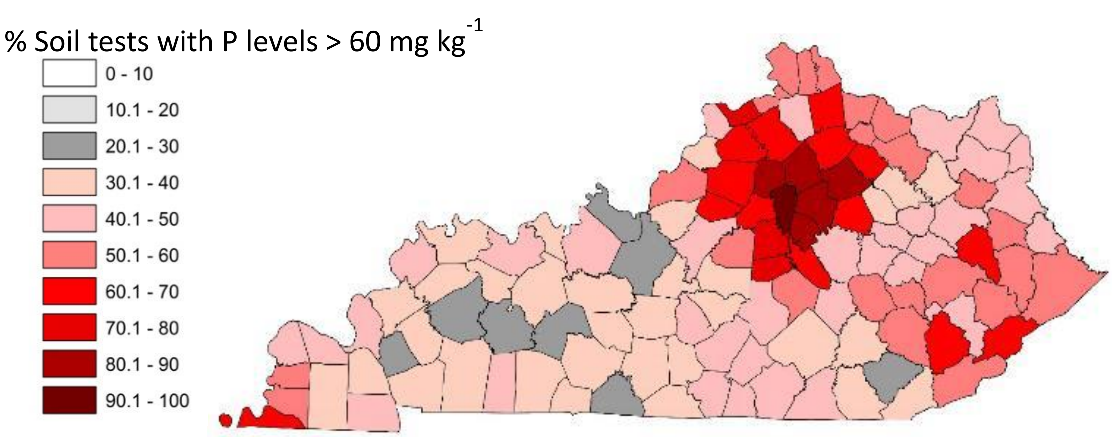
Other birds were also noted during monitoring and surveys, including turkey vulture, black vulture, great blue heron, and songbirds.

6.4 Lawn fertilization and yard trimmings

Lawn fertilization, grass clippings, and fallen leaves can represent large nutrient inputs to the stream system.

Because the soils of Woodford County have naturally high levels of phosphorus, lawn fertilization with additional phosphorus results in leaching and runoff to streams. According to Kentucky home and garden phosphorus test results over 25 years (Figure 18), Woodford County was more frequently in the high-risk category than any other county in Kentucky. Education and outreach on not applying phosphorus to lawn and gardens would help reduce this source.

Figure 18 – Percent of soil test phosphorus from Kentucky home lawn and gardens greater than 60 mg/kg (High Risk) in Kentucky counties summarized from 25 years of data (1990-2014)



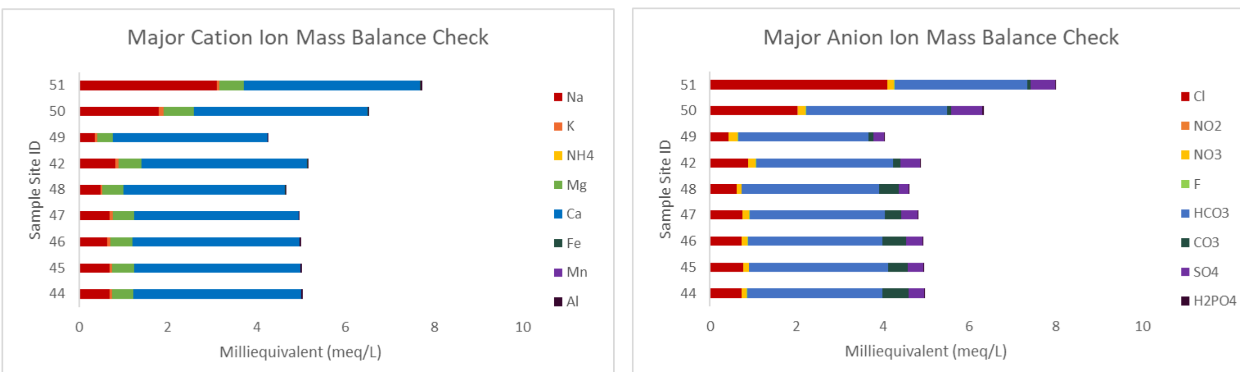
Source: Brad Lee

Further, yard trimmings from mowing and weed eating down to the edge of the stream were observed both in urban and rural locations in the watershed. Grass clippings, as well as leaves that are blown into the stormwater system, can be significant sources of nutrient input to streams. A Florida study (Lusk et al. 2020) found that 25% of the nitrogen concentration of residential stormwater was particulate organic nitrogen and this nitrogen originated from oak leaves (76%) and lawn grass clippings (24%).

6.5 Road and parking lot salt and deicer

As shown in Figure 19, sodium chloride loads are responsible for the difference in the higher conductivity and dissolved solids concentrations from the urban City of Versailles (sites 50-51) as compared to the remainder of the watershed. Road salt and deicer applications are major sources of sodium chloride input. Education and outreach on proper application rates for roads, parking lots, and driveways may help to reduce this input.

Figure 19 – Mass balance of cations and anions shows excess sodium chloride as contributing to high loads from the urban sites draining the City of Versailles (Sites 50-51)



6.6 Litter, dumping, and overfilling trash bins.

Trash and debris can reach the stream from multiple sources. No dump sites were observed in the creek during monitoring visits. Several farm dumps were observed on aerial images near the back of properties, but these sites were not immediately adjacent to the streams, and so do not appear to be large sources of trash in the waterways.

At Big Spring Park, trash and litter was observed to be primarily plastic bottles, Styrofoam cups, plastic bags, and other floatable litter (See Figure 20). This may be due to litter along roadways and parking lots. It may also be due to overfilling residential trash bins and wind transporting the litter into the storm sewer system. In either case, the installation of catch basin inserts at large parking lots and hydrodynamic separators in the storm sewer system would help to collect these sources. Visual encouragement to use available trash receptacles, such as signage and bin placement, would also help address the trash issue.

Figure 20 – Accumulated trash and debris in sinkhole in Big Spring Park

Source: Alan Fryar

Downstream of Millville, observed trash included clothing and children's toys, bottles, Styrofoam, and plastic. Sources of this litter may include flooding of backyards adjacent to the creek, as well as road litter or overfilling trash bins. Organizing regular stream cleanups along Glenns Creek in Millville may help raise awareness and reduce littering in this area of the stream.

6.7 Impervious surface runoff and soil compaction

Impervious surfaces can increase the velocity and volume of runoff leading to impacts to streams. Further, soil compaction during construction can lead to increased runoff by limiting the capacity for soil absorption. According to a recent study (Blum et al. 2020), for every 1% increase in impervious surface area, there is a 3.3% increase in annual flood magnitude.

Major hotspots for impervious surfaces include the downtown area and the industrial / commercial zone along U.S. Hwy 60 (see Figure 21). Several large industrial facilities, including Sheridan Kentucky, Pilkington North America, and Ruggles Sign, have large roof footprints. Encouraging capture and reuse or extended detention of storm water runoff from these facilities could help reduce the impacts of storm water runoff.

In residential areas, rain gardens, rain barrels, or rainwater cistern implementation can help capture stormwater for later use or release. Methods to encourage infill of vacant parking lots may help to limit the impacts of future development by reducing the amount of additional impervious area added. The use of green infrastructure in future developments and stormwater retrofits of existing basins may help to limit the impacts of existing and future development.

Figure 21 – Land use map showing hot spot for impervious surface along U.S. 60 corridor.

6.8 Mowed or grazed riparian zones.

As shown in Figure 8, streams in both urban and rural areas have their riparian zones impacted due to mowing or grazing. In total, 43% of stream bank riparian zones are highly impacted and 14% are moderately impacted. The mowing can also add grass clippings to the stream, increasing nutrient loading. Restoration of riparian zones along the stream will require a combination of mowing setbacks from the stream and tree and native vegetation plantings. In some cases, as shown in Figure 22, livestock restrictions will be required in addition to plantings to ensure restoration.

Figure 22 – Glenns Creek tributary in cattle field shows evidence of sedimentation and erosion with the absence of a riparian zone

Source: KyFromAbove Oblique Imagery

Figure 23 – Paddock in Glenns Creek Watershed with intersecting ephemeral stream historically graded to protect horse health

Source: KyFromAbove Oblique Imagery

In rural areas in some horse farm paddocks (Figure 23), the land surface of ephemeral streams has been smoothed such that the landowners may not be aware of the presence of a "stream" but just an area floods during rain. Near some horse farms, riparian zones may be mowed to protect horse health or to accommodate existing paddock shapes. Programs to educate landowners on the value of riparian zones and incentivize restoration where feasible should be pursued.

6.9 Invasive species in the riparian zone

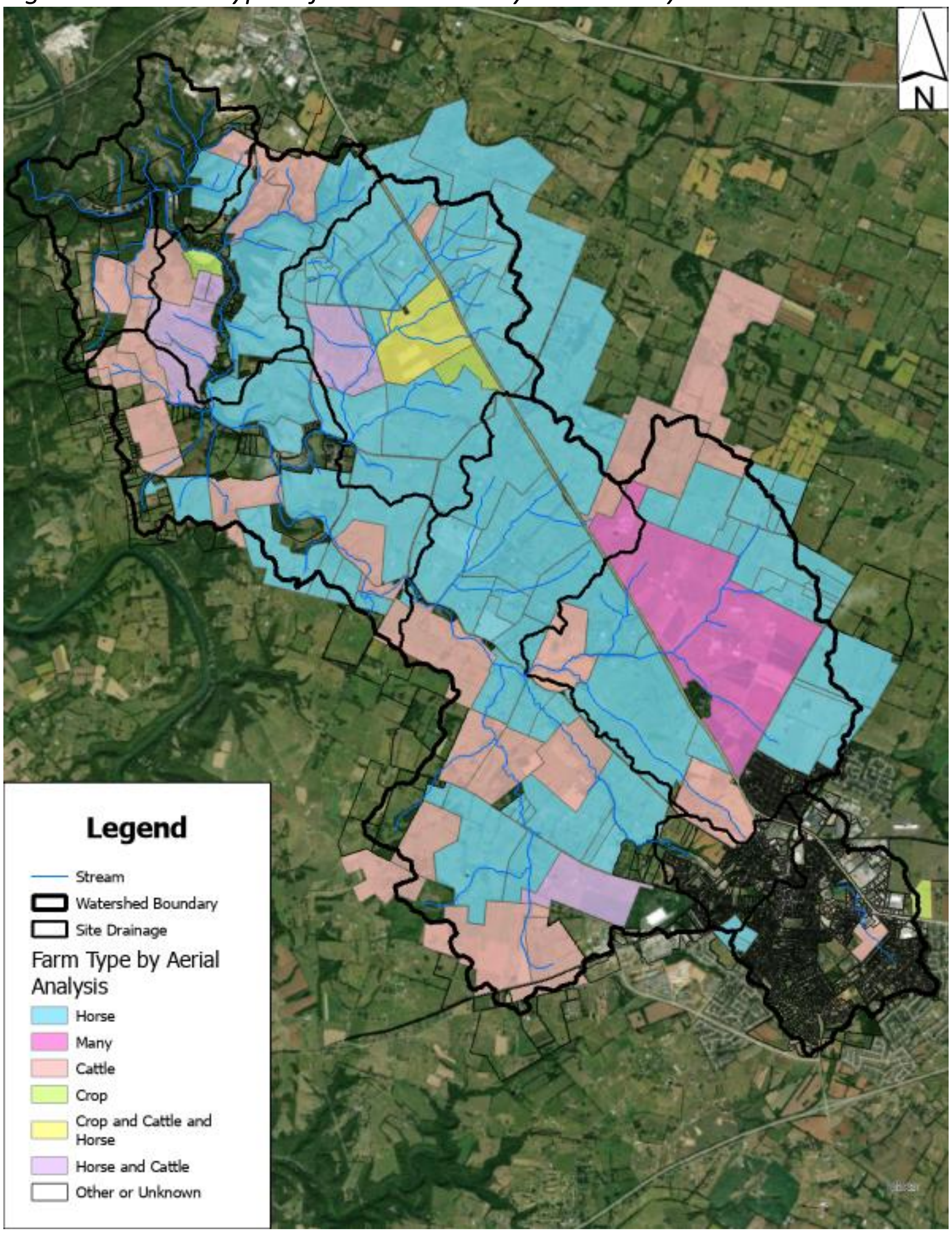
In some areas where riparian zones are present, they are dominated by invasive species. As shown in Figure 24, bush honeysuckle and wintercreeper were frequently found in the riparian zone throughout the watershed while Japanese knotweed is currently only observed in Big Spring Park. Treatment of these invasive species and replanting of native species will help recover the habitat value of these riparian corridors.

Figure 24 – Dominant invasive riparian species in the Glenns Creek Watershed including Japanese knotweed (left), bush honeysuckle (top right), and wintercreeper (bottom right)

6.10 Livestock stocking, feeding, and high-use areas

A review of aerial oblique imagery was conducted to identify the animals managed by farms within the watershed area and potential watershed impacts of farm management. As shown in Figure 25, a total of 119 parcels were identified as farms with 86 containing horses, 38 with cattle, five (5) with cropland, and one (1) with additional livestock types including swine and sheep.

Figure 25 – Farm types of Glenns Creek by aerial analysis



Based on a review of these farms, most are maintaining their properties with effective management practices. However, some of these farms showed evidence of impacts due to overstocking of livestock, improper siting of feeding areas, mud and erosion in heavy use areas, and excess nutrient inputs from bale grazing.

On average, one mature horse will require 2-3 acres of managed pasture (Teutsch et al.). Similarly, two acres per cow is often used as a rule-of-thumb although the most profitable stocking rate may be 3-4 acres per cow depending on the soil type, soil health, hay nutrient value, and hay cost (Halich 2020). On several farms, stocking rates for horses or cattle were observed much higher than recommended rates causing impacts to the land and water resources.

On one horse farm (Figure 26), multiple horses were kept in 0.5-acre paddocks which showed evidence of bare ground with erosion gully formation and heavy land application of manure and grazing in an adjacent field with ephemeral drainage. Such management may contribute to *E.coli*, nutrient, and sediment impacts on downstream waterways. The use of proper stocking rates, a designated sacrifice lots for winter feeding, feeding structures with heavy use pads, and pasture renovation or re-establishment are best management practices that could be used to address the management impacts.

Figure 26 – Horse farm with multiple land and water impacts due to overstocking

Source: KyFromAbove Oblique Imagery

Similarly Figures 27 shows examples of cattle farms in the Glenns Creek Watershed with impacts from overstocking. Here similar impacts are occurring including bare ground with erosion potential in heavy use areas, erosion impacts to streams due to cattle access and multiple crossing points, a lack of a riparian vegetated buffer, and heavy bale grazing. In one case, the bale feeding was sited in close proximity to the stream increasing the impacts to these waterbodies.

In many cases, mud formation was observed in heavy-uses areas along fence rows or near feeding structures, such as in Figure 28. Heavy-use area hardening to reduce mud accumulation has environmental benefits but also benefits for animal health and farm profitability (Higgins et al. 2024). Mud can increase animal stress, increase the risk of injury due to falls, and increase opportunities for infection and disease. Mud reduction improves cattle's weight gain increasing profitability.

Figure 27 – Cattle fields in Glenns Creek Watershed with land and water impacts due to overstocking

Source: KyFromAbove Oblique Imagery

Figure 28 – Mud formation in heavy-use areas along a fence line on a horse farm (left) and near a feeding structure on a cattle farm (right)

Source: KyFromAbove Oblique Imagery

While bale feeding is used in some areas to increase pasture fertility (Manitoba Agriculture 2008), even in these areas intensive management is recommended due to risks of nutrient export from the bales into the soil. Because soils in Woodford County are naturally rich in nitrogen and phosphorus, bale grazing can be a contributor to excess nutrient loading in the watershed. Siting bale feeding on harden structures away from streams and sinkholes can reduce the export of nutrients to waterways.

6.11 Manure management

Within the Camden Creek subwatershed of the Glenns Creek watershed, The University of Kentucky Martin-Gatton College of Agriculture, Food and Environment's C. Oran Little Research Center operates as a multi-species livestock and crop research farm. The various livestock research units on the farm produce a variety of manures that are managed using several specific techniques that vary by species. The farm has a large composting facility that is utilized for management of many manure and bedding products. A specific area of animal mortality composting is designated and land applied on-site with no export. All land applications of compost and animal manure are guided by AGR1 recommendations (McGrath and Ritchey 2023) on fertilizer and lime applications based on soil sample analysis.

The poultry research unit produces a mixture of litter and poultry manure that is composted at the on-farm composting facility. The poultry unit is relatively low volume in terms of the number of research specimens and produces a modest amount of litter and manure annually. The composted product is then land applied on-farm based on nutrient management plan recommendations.

The swine research unit produces dilute liquid swine manure that is captured in pits below the swine research facility. The dilute liquid manure is then pumped and transported to storage tanks to stage for land application. When land application of dilute liquid swine manure occurs, it is injected into crop fields on the UK farm property in the spring and fall.

A large portion of the beef unit manure is distributed on-pasture during livestock grazing. Bedding and manure from the research buildings associated with the beef unit are stockpiled and composted for volume reduction. A portion of this manure is co-composted with food waste from UK dining facilities. The majority of the composted product is exported and used offsite on campus or the UK South Farm. However, prevention of impacts to near by drainages could be improved on this unit, as shown in Figure 29.

Figure 29 – Drainage near beef unit on University of Kentucky's C. Oran Little Research Center

Source: KyFromAbove Oblique Imagery

The UK equine unit is primarily pasture-based with generation of manure and spent hay around feeding areas. Accumulations of manure and spent hay or any bedding are composted at the on-farm composting facility and exported offsite.

The sheep unit on the research farm is mostly pasture-based, with bedded pack in the barn. Bedding and manure from the barn are composted and exported offsite.

Based on conversations with Extension professionals that have worked in the watershed, some farms in the watershed utilize soil sample and animal waste analysis services and manure management recommendations through UK Cooperative Extension/Regulatory Services to guide manure management decisions. There is limited land application from stockpiling of manure associated with winter feeding for beef cattle operations within the watershed. This is primarily due to the pasture-based nature of the majority of beef operations within the watershed, which means that most do not accumulate significant quantities of manure from confinement feeding situations that would dictate widespread manure application from stockpiles. However, areas with excessive land applications of manure from both horse an cattle farms were observed in the watershed, as shown in Figure 30.

Figure 30 – Excessive land application of manure adjacent to a stream on cattle (left) and horse (right) farms in the Glenns Creek Watershed

Source: KyFromAbove Oblique Imagery

Equine operations in the watershed often utilize barn cleanout with stockpiling for land applications onsite. Some utilize the stockpiling method with removal by a contract manure management service that transports the muck offsite. Creech Services and Blue Horse Ventures are available composting services in the area. A small number of equine producers stockpile equine manure/bedding/hay mixtures from barn cleanouts and export the product to beef cattle producers for use as a feed product. Through stakeholder interviews, historic issues with stockpiling manure adjacent to sensitive karst features was identified as an occasional issue in the watershed. Additional concerns have been expressed through stakeholder interviews associated with land application of manures/bedding near and within sinkholes.

For proper siting of manure management and fields for land application, farms should ideally select locations at the top of a slope with filters located below. Because of the high karst potential of the watershed, land application in sinkholes or karst prone areas can impact stream

E.coli and nutrient concentrations. Farmer education should be provided on proper manure management and risk assessment using the karst mapping resources available through the Kentucky Geological Survey.

6.12 Fertilizer management

Within the Camden Creek subwatershed of the Glenns Creek watershed at the University of Kentucky Martin-Gatton College of Agriculture, Food and Environment's C. Oran Little Research Center, all land applications of fertilizer are guided by AGR1 recommendations (McGrath and Ritchey 2023) on fertilizer and lime applications based on soil sample analysis. Applications of nutrients generally occur in split applications to reduce environmental loss and improve crop uptake. A comprehensive assessment of fertilization at the farm over a multi-year period may be found in McGill (2022).

Within the Glenns Creek Watershed, some large equine operations utilize contract fertilizer application and pasture management through private contractor services. There is limited fertilizer management practiced in the watershed on beef cattle operations. Crop operations in the watershed focus on corn or corn/soybean rotation through the use of crop advisors and contract nutrient applicators. Some operations utilize soil sample analysis through UK Extension/Regulatory Services and Extension provides fertilization recommendations based on current agronomic guidelines presented in AGR1 (McGrath and Ritchey 2023). There is some fertilization of hay/pasture ground that may or may not be based on soil sample results and current agronomic recommendations.

6.13 Legacy soil nutrients

Studies (see **Appendix A**) at the C. Oran Little Research Farm indicate that slow flow through the soil pores and small fissures accounts for 75% of the stream flow, 70% of dissolved phosphorus load, and 80% of nitrate load. It was found that fertilization with no tillage is contributing to accumulation of high concentration of legacy soil nutrient levels which can persist for decades in the subsurface. These legacy soil nutrients become disconnected from the effective root zone and uptake during the summer but reconnect during the winter month and during periods of high soil moisture elevating nutrient levels at springs. A survey was conducted on C. Oran Little streams (**Appendix B**) and confirmed that spring sources of nitrogen are significant contributors to the loading in the area.

6.14 Wildlife

Numerous wildlife or their scat were observed during field visits including deer, raccoon, coyote, beaver, and mink (see Figure 31). This wildlife can represent background fecal inputs into the waterways via direct deposition of via runoff.

Figure 31 – Raccoon scat on rocks in middle of small named tributary to Camden Creek (left) and a beaver den near U.S. 60 crossing of Camden Creek (right)

Source: Steve Evans

6.15 Cattle streambank access

Livestock hoof traffic can have significant impacts on streambank stability and erosion rates. Cattle access to streams and subsequent impacts on streambanks is common on operations throughout the watershed, which reflects trends throughout the greater region. In a few cases, such as shown in Figure 32, erosion impacts and loafing in the stream could be observed in aerial imagery. Some use of livestock fencing for stream and riparian exclusion is employed throughout the watershed, however, it is generally limited. A notable exception includes the nearly comprehensive riparian exclusion fencing system throughout the pastures at the C. Oran Little Research Center within the Camden Creek subwatershed. The impacts of cattle access to streams and streambanks in the watershed could be reduced through additional adoption of exclusion fencing of waterways along with the riparian buffer establishment.

Figure 32 – Impacts of cattle access to a stream in the Glenns Creek Watershed

Source: KyFromAbove Oblique Imagery

6.16 Streambank erosion

As observed in the assessment, the causes of streambank erosion in the Glenns Creek watershed can be attributed primarily to anthropogenic influences, notably stream infrastructure such as weirs, low-head dams, pipes, culverts, and retaining walls. These structures can significantly alter natural water flow patterns, leading to several key issues that may be contributing to or exacerbating erosion at or near these locations:

<u>Altered Flow Dynamics:</u> Stream infrastructure can change the velocity and direction of water flow. For example, structures like weirs and low-head dams can create areas of accelerated flow downstream, which can scour the streambed and banks, leading to erosion. Similarly, pipes and culverts can concentrate flow, increasing the force of water against the bank. Generally, these alterations and hydraulic changes in the watershed contribute to infrastructure undermining and failure. Erosion exacerbated by or attributed to flow alteration was more prevalent and severe in agricultural, commercial, or industrial areas. The Outstanding State Resource Water, located in the watershed on unnamed tributaries near the distilleries, retained relic infrastructure from probable early attempts of flow redirection that directly contributed to erosion.

<u>Increased Runoff Volume:</u> Increased runoff volume from impervious surfaces, such as roads, buildings, and parking lots, can overwhelm streams, particularly where infrastructure like culverts and pipes discharge into the stream, leading to higher velocities and more severe bank erosion. Again, erosion exacerbated by increased runoff was more prevalent and severe in agricultural, commercial, or industrial areas.

<u>Channel and Bed Alteration:</u> Channelization, deepening streams, and bed alteration for drainage improvement or land development—can lead to increased flow speeds. Faster water has a greater capacity to erode streambanks, particularly where the channel has been narrowed or where natural meanders have been removed. Again, erosion exacerbated by or attributed to channel and bed alteration was more prevalent and severe in agricultural, commercial, or industrial areas.

<u>Reduced Vegetative Buffer:</u> Stream infrastructure often correlates with reduced riparian vegetation. Vegetation plays a crucial role in stabilizing banks through its root systems. Banks become more susceptible to erosion when vegetation is removed to construct or maintain these structures. Erosion exacerbated by the absence or reduction of a vegetative buffer was ubiquitous throughout the watershed but more prevalent and severe in agricultural, commercial, or industrial areas where stream infrastructure is located.

In summary, most streambank erosion observed in Glenns Creek is associated with the presence and influence of stream infrastructure and other anthropogenic modifications to the watershed. These modifications disrupt natural processes, increasing and accelerating erosion at critical points along the stream. Addressing these issues may require a combination of restoring natural flow patterns, reinforcing or redesigning infrastructure to reduce its impact, and enhancing riparian buffers to stabilize banks and absorb flow energy.

6.17 Row crop runoff

Row crop operations throughout the watershed commonly grow corn or a corn/soybean rotation. Row crop operations can be vulnerable to issues with runoff and erosion when fields are unprotected by living roots and growing plants, especially in areas of highly erodible soil or on sloping ground. Practices like cover crops, reduced/no-till, filter strips, and many of the other crop best management practices included in the Kentucky Agriculture Water Quality Plan are indicated to address issues with row crop runoff and infield erosion. The adoption rate of runoff and erosion mitigating best management practices on crop operations within the watershed is currently unknown.

6.18 Low-head dams

Low-head dams extend across the width of the stream, partially blocking the waterflow, creating a small reservoir of water of sufficient water depth for water withdrawals. When the water level exceeds the height of the dam, it flows over the top. Historically they were installed along Glenns Creek to support distillery water supply.

Long-term, low-head dams can present a safety hazard to boaters and swimmers and can also impact stream habitat and water quality. The recirculating currents at the base of dams can be difficult to escape and can cause death. The dams have ecological impacts, converting a stream ecosystem into an ecosystem more typical of a series of ponds. Dams can serve as barriers to fish passage and can impact the types of aquatic species found both upstream and downstream of the dams (Smith et al. 2017).

As the infrastructure ages, erosion can occur around these dams causing further stream impacts. Upstream of dams, heavy sedimentation typically occurs, algae or aquatic plant growth may increase, and water quality may be impacted by decreased dissolved oxygen.

Because of these impacts, a nationwide movement has been underway over the last 25 years to remove low-head dams and allow waterways to flow freely (American Rivers 2022).

7 Pollutant load allocation

To develop an implementation plan to achieve load reductions, pollutant loads must be allocated to sources and then best management practices applied to these sources until benchmarks are achieved. To determine the source load allocations, a baseline model of watershed pollution sources must be developed based on land use, loading rates of pollutants, and known inputs, and estimated process contributions.

7.1 Watershed Multi-Year Model for nutrient load estimation

To provide an estimate of source allocation for nitrogen and phosphorus, the “Watershed Multi-Year Model” in Model My Watershed (https://modelmywatershed.org/) was utilized (Stroud Water Research Center 2024). This model simulates 30 years of daily water, nutrient and sediment fluxes using the Generalized Watershed Loading Function Enhanced (GWLF-E) model. This model automatically aggregates multiple datasets including 2019 National Land Cover Dataset, gridded soil surveys (gSSURGO), 30-m elevation data, climate data (1960 to 1990), estimated baseflow, estimated soil nitrogen and phosphorus, county-level farm animal populations, and discharge monitoring reports. It also allows for customized input of land use areas, septic systems and failure estimates, agricultural statistics, and point source contributions. The model exports the relative load contributions in terms of land use, farm animals, erosion, subsurface flow, point sources, and septic systems. These relative source contributions can be utilized for allocations even though the model is based on 30-years of climate data as opposed to one year of measured watershed data. A complete description of the model with technical manuals can be found online.

The Watershed Multi-Year Model was used to provide estimates for the entire Glenns Creek Watershed, as well as for sites in which load reductions were necessary to achieve benchmarks. Because of complexities in the groundwater flow paths, Sites 50 and 51 (urban Versailles) were modeled together. To improve model estimates, inputs for agricultural statistics, septic systems, and point sources were input into the model. Default values were utilized for other inputs. The total loading of each subwatershed was computed by the model, and then incremental loads were calculated by subtracting out upstream contributions.

To estimate agricultural animal sources, the 2017 Census of Agriculture for Woodford County were utilized (USDA 2017). To estimate the portion of the livestock and poultry, the nonurban acres of the Glenns Creek Watershed (15,941 acres) was divided by the total land in farms for Woodford County (112,190 acres). Where these estimates were lower than actual 2023 livestock and poultry counts from the Oran C. Little Research Farm, the larger value was utilized. The counts were then divided into subwatershed based on the percentage of pastureland. The results are shown in Table 13.

To evaluate potential human sources located in each site drainage area, the property parcels were joined to the site drainage area in which their centroid was located. Parcels with access to sanitary sewers were then separated from those without access. A total of 4,838 parcels are located in the Glenns Creek Watershed with Table 13 summarizing the site drainage area breakdown. For unsewered properties, a septic system failure rate of 20% was assumed (Lee 2012). For the wastewater treatment plant, the weekly plant effluent measurements for the project period (25,159 lbs. of nitrogen, 10,773 lbs. of phosphorus, average daily flow of 2.461 million gallons per day) were utilized.

Although not considered as input for the Watershed Multi-Year Model, subwatershed pet and wildlife estimates were computed for use in source allocations. To estimate the number of dogs in each drainage area, the American Veterinary Medical Association (2018) rates of dog ownership were applied to the residential or rural parcels in each site drainage area. To estimate the amount of wildlife, the EPA's Bacterial Indicator Tool (2001) rates for wildlife in cropland, pastureland, and forest were applied to each subwatershed (Table 13).

Table 13 – Estimated animal and human sources by site drainage area

Source	Count	Site 44	Site 45	Site 46	Site 47	Site 48	Site 42	Site 49	Site 50	Site 51
Agricultural[1]										
Beef Cattle	3111	55	72	195	438	565	1002	709	31	44
Sheep	518	0	0	0	0	0	0	518	0	0
Horse	984	17	23	62	138	179	317	224	10	14
Chicken	1169	0	0	0	0	0	0	1169	0	0
Swine	311	0	0	0	0	0	0	311	0	0
Human[2]										
Unsewered Parcels	467	60	64	113	102	25	65	35	3	0
Sewered Parcels	4007	0	0	0	0	0	96	557	872	2482
Pet Waste[3]										
Dog	2587	41	44	77	70	17	44	379	479	1437
Cat	2190	35	37	65	59	14	38	321	406	1216
Wildlife[4]										
Duck	330	25	18	34	44	46	90	62	5	6
Geese	165	13	9	17	22	23	45	31	2	3
Deer	165	13	9	17	22	23	45	31	2	3
Beaver	33	3	2	3	4	5	9	6	0	1
Raccoon	165	13	9	17	22	23	45	31	2	3

[1]Numbers derived from 2017 Census of Agriculture with adjustments for known farm counts.
[2]Parcels were counted for the site drainage in which the centroid of their parcel was located within.
[3]Estimates ownership rates from American Veterinary Medical Association (2024) applied to zoned residential or rural parcels. For dogs, 45.5% of households own an average of 1.5 dogs. For cats, 32.1% of households own an average of 1.8 cats.
[4]Generated using EPA's Bacterial Indicator Tool (2001) rates for cropland, pastureland, and forest.

The results of the watershed multi-year model are shown in Tables 14 and 15 for the incremental subwatershed area for each source.

For nitrogen, farm animals, hay/pasture, and subsurface flow were the most dominant sources in that order. Hay/pasture loads includes dissolved and solid nitrogen forms transported in runoff or via soil erosion. The wastewater treatment plant accounted for over 70% of the nitrogen contribution in urban Versailles. Even though 20% of septic systems were modeled as failing, septic contributions were estimated to be a small contributor. Due to the low overall percentage of cropland in the watershed (2.6%), the model predicted a minor contribution to nitrogen loading from this source.

Table 14 – Watershed multi-year model nitrogen source load percentage estimation by incremental subwatershed

Sources	Site 44 Mouth	Site 47 Millville	Site 48 Grassy Springs	Site 42 Steele Road	Site 49 Camden Creek	Site 50-51 Versailles
Hay/Pasture	57%	20%	34%	19%	20%	3%
Farm Animals	23%	46%	38%	43%	45%	2%
Point Sources	0%	0%	0%	0%	0%	77%
Subsurface Flow	8%	25%	24%	31%	25%	8%
Stream Bank Erosion	7%	6%	1%	3%	1%	2%
Cropland	0%	2%	2%	2%	6%	1%
Developed Areas	1%	0%	1%	1%	1%	3%
Septic Systems	2%	0%	1%	1%	2%	3%
Natural Areas	2%	0%	0%	0%	0%	0%

Table 15 – Watershed multi-year model phosphorus source load percentage estimation by incremental subwatershed

Sources	Site 44 Mouth	Site 47 Millville	Site 48 Grassy Springs	Site 42 Steele Road	Site 49 Camden Creek	Site 50-51 Versailles
Hay/Pasture	70%	50%	68%	59%	61%	10%
Farm Animals	19%	30%	26%	28%	24%	2%
Point Sources	0%	0%	0%	0%	0%	79%
Subsurface Flow	1%	3%	2%	2%	2%	1%
Stream Bank Erosion	11%	15%	1%	8%	2%	6%
Cropland	0%	1%	3%	3%	12%	2%
Developed Areas	0%	0%	0%	0%	0%	1%
Septic Systems	1%	1%	0%	0%	0%	0%
Natural Areas	0%	0%	0%	0%	0%	0%

For phosphorus, the percentage of land use in each area had a strong influence on the load contribution. Hay/pasture was the most dominant source. Farm animals were also a large contributor and to a lesser degree stream bank erosion. As with nitrogen, the wastewater treatment plant accounted for over 70% of the phosphorus contribution in urban Versailles.

Based on prior research at the C. Oran Little Agricultural Research Center **(Appendix A)** and the field survey conducted there as part of this project **(Appendix B)**, the nitrogen and phosphorus allocations to subsurface flow are likely underpredicted in this model, at least in the Camden Creek subwatershed. Using a decade of data, Ford and others (2019) predicted that slow flow from the groundwater reservoir comprised 70% of phosphorus load, and 80% of nitrate load.

Further, Radcliff and others (2021) found that phosphorus increased in the soil profile below the root zone where it was unavailable for uptake. This reservoir of nutrients may be challenging to improve via conservation practices though vegetative buffers, livestock exclusion, vegetative uptake, and constructed wetlands are proposed as potential solutions.

7.2 Literature-based loading rates

To estimate the loading rates of *E. coli*, literature values for fecal coliform from the American Society of Civil Engineers (ASCE 2014) and mean values from U.S. EPA Bacterial Indicator Tool (US EPA 2001) were converted into *E. coli* counts using the ratio of fecal coliform to *E. coli* (200:130) utilized by the KDOW when regulatory criteria were published for both standards. Rates for human and animal sources are reflected in Table 16.

Table 16 – Fecal coliform and E. coli human and animal loading rates

Category	Source	Fecal Coliform (Count/Day)	*E. coli*[1] (Count/Day)	Reference
Human	Household septic / sewage / straight pipe (direct)	1.00E+06	3.28E+09	US EPA 2001
Human	Household septic (surcharge reaching stream)	1.00E+04	3.28E+07	US EPA 2001
Agriculture	Dairy Cow	5.36E+10	3.48E+10	US EPA 2001
Agriculture	Beef Cattle	5.49E+10	3.57E+10	US EPA 2001
Agriculture	Horse	4.19E+08	2.72E+08	US EPA 2001
Agriculture	Chicken (Layer)	1.88E+08	1.22E+08	US EPA 2001
Agriculture	Sheep	1.41E+10	9.13E+09	US EPA 2001
Agriculture	Swine	1.02E+10	6.66E+09	US EPA 2001
Pet	Dog	1.41E+09	9.19E+08	ASCE 2014
Pet	Cat	5.53E+08	3.59E+08	ASCE 2014
Wildlife	Songbird	9.38E+05	6.09E+05	ASCE 2014
Wildlife	Duck	2.31E+09	1.50E+09	ASCE 2014
Wildlife	Goose	5.04E+08	3.28E+08	ASCE 2014
Wildlife	Rat	8.93E+06	5.80E+06	ASCE 2014
Wildlife	Beaver	5.00E+08	3.25E+08	US EPA 2001
Wildlife	Raccoon	2.50E+08	1.63E+08	US EPA 2001
Wildlife	Deer	1.25E+08	8.13E+07	US EPA 2001

[1]*E. coli* daily load rates calculated from fecal coliform using a ratio of 200 fecal coliform to 130 *E. coli* based on prior Kentucky regulatory limits.

To calculate the daily loading rates for nutrients (Table 17), the default rates from the Map My Watershed BMP Tool (Evans et al 2023) were utilized for agricultural animals and literature values for pets (Cowan 2024). To convert animal loading rates into stream load allocations, manure must be assigned into one of three categories: 1) manure in pasture, 2) manure directly to stream, and 3) confined manure available for land application or transport. For agricultural animals, default rates from the US EPA (2001) were adjusted with the best estimates with input from local extension agents as shown in Table 19. For pasture runoff and direct instream loads, the fraction of time is multiplied by the rate and number of animals. For the confined load, both the fraction of time confined (C) and the fraction available for runoff (D) are multiplied by the rate and number of animals. For pets, a Lexington survey (Raabe 2022) was used to evaluate the percentage of owners that collected dog waste from their dog and for cats an evaluation of the number of cats that are exclusively indoors was utilized.

Combining the results of Tables 16, 17, and 18, annual loading rates per human and animal were calculated and are shown in Table 19. These values can be utilized to help estimate and approximate number of human or animal sources that need to be addressed.

Table 17 – Animal nutrient and manure loading rates.

Animal	Average Weight (kg)	Total Animal Equivalent Units (kg)	Nitrogen Rate (kg N/AEU/day)	Phosphorus Rate (kg P/AEU/day)	Total Nitrogen (lbs./day)	Total Phosphorus (lbs./day)
Dairy Cow	640	0.64	0.44	0.07	0.62093	0.09878
Beef Cattle	360	0.36	0.31	0.09	0.24608	0.07144
Horse	500	0.5	0.28	0.06	0.30870	0.06615
Chicken (broiler)	0.9	0.0009	1.07	0.3	0.00212	0.00060
Chicken (layer)	1.8	0.0018	0.85	0.29	0.00337	0.00115
Sheep	50	0.05	0.37	0.1	0.04079	0.01103
Swine	61	0.061	0.48	0.15	0.06456	0.02018
Cat[1]	3.75	NA	0.6 (urine) 0.15 (feces)	0.554 (urine) 0.586 (feces)	0.029 (total) 0.005 (feces)	0.038 (total) 0.028 (feces)
Dog[1]	21.6	NA	0.50 (urine) 0.10 (feces)	0.22 (urine) 0.586 (feces)	0.006 (total) 0.001 (feces)	0.009 (total) 0.005 (feces)

[1] Cowan 2024. Rates are per body mass (kg) rather than Animal Equivalent Unit (AEU). Only the feces portion would be available for removal.

Table 18 – Livestock runoff loading variables.

Animal	% Time in Pasture / Field (A)	% Time in Stream (B)	% Time Confined (C)	% Confined Manure Available for Wash-off in Land Application (D)
Dairy Cattle	0	0	100	62.5
Beef Cattle	92	7	1	62.5
Horse	70	0	30	62.5
Chicken	0	0	100	36
Sheep	100	0	0	0
Swine	0	0	100	60
Dog	45[1]	0	0	0
Cat	37	0	63[2]	0

[1] Raabe 2022 – Percent that did not pick up in own yard.
[2] Foreman-Worsley et al 2021.

Table 19 – Summary of annual source loading rates for E. coli and nutrients

Category	Source	*E. coli* (Count/Year)	Total Nitrogen (lbs./yr)	Total Phosphorus (lbs./yr)
Human	Household septic / sewage / straight pipe (direct input)	1.20E+12	9.13[1]	2.15[1]
Human	Household septic (surcharge reaching stream)	1.20E+10	9.13[1]	2.15[1]
Agriculture	Dairy Cow	1.27E+13	227	36.1
Agriculture	Beef Cattle (Total Available)	1.30E+13	89	26.0
Agriculture	Beef Cattle Pasture	1.20E+13	83	24.0
Agriculture	Beef Cattle Instream	9.11E+11	6.3	1.83
Agriculture	Beef Cattle Land-Applied Manure	8.14E+10	0.6	0.16
Agriculture	Horse (Total Available)	3.95E+10	100.0	21.4
Agriculture	Horse Pasture	3.12E+10	78.9	16.90
Agriculture	Horse Land-Applied Manure	8.35E+09	21.13	4.53
Agriculture	Chicken Land-Applied Manure	1.20E+12	0.443	0.151
Agriculture	Sheep Pasture	9.94E+10	14.89	4.03
Agriculture	Swine Land-Applied Manure	1.46E+12	14.1	4.42
Pet	Dog (Total All Waste Outdoors)	3.35E+11	10.43	14.0
Pet	Dog Outdoor Uncollected Feces	1.51E+11	0.783	4.59
Pet	Cat (Total Available, All Waste)	4.85E+10	0.84	0.65
Wildlife	Songbird	5.48E+11	-	-
Wildlife	Duck	1.20E+11	-	-
Wildlife	Goose	2.97E+10	-	-
Wildlife	Rat	1.19E+11	-	-
Wildlife	Beaver	5.95E+10	-	-
Wildlife	Raccoon	5.48E+11	-	-
Wildlife	Deer	1.20E+11	-	-

[1] Loading rate of septic system effluent from U.S. EPA 2002.

7.3 *E. coli* load estimation

To calculate the *E. coli* load percentage of various sources in the watershed, the human and animal estimated counts (Table 13) were multiplied by the annual source loading rates (Table 19) to generate a potential *E. coli* wasteload being produced in excrement from each source type. In cases where several options were available for a source type, the total available rate was utilized. Totals were then aggregated, and percentage contributions calculated for each source category as shown in Table 20.

In urban sites (50 and 51), human waste is the most dominant overall *E. coli* wasteload at over 53-65% while pet waste is also a notable contributor at 9-12%. Although these subwatersheds are primarily urban, cattle on pastures within the drainage were predicted to contribute between 14 and 25%.

In the agricultural areas (Sites 47, 48, 42, and 49), agricultural livestock sources, specifically beef cattle, generate the most *E. coli* in waste at 77-99%. In the Camden Creek Watershed (Site 49), chicken (12%) and swine (4%) are predicted to be contributors. Because of the lower concentrations of *E. coli* in horse excrement, they were not predicted to be significant contributors to the bacterial load.

Table 20 – E. coli load percentage estimation based on annual waste generation rates of local populations.

Source	**Site 44**	**Site 45**	**Site 46**	**Site 47**	**Site 48**	**Site 42**	**Site 49**	**Site 50**	**Site 51**
Agricultural	87%	90%	93%	97%	99%	98%	93%	25%	14%
Beef Cattle	87%	90%	93%	97%	99%	98%	77%	25%	14%
Sheep	0%	0%	0%	0%	0%	0%	0%	0%	0%
Horse	0%	0%	0%	0%	0%	0%	0%	0%	0%
Chicken	0%	0%	0%	0%	0%	0%	12%	0%	0%
Swine	0%	0%	0%	0%	0%	0%	4%	0%	0%
Human	9%	7%	5%	2%	0%	1%	6%	64%	73%
Pet	2%	2%	1%	0.4%	0.1%	0.1%	1%	11%	13%
Dog	2%	1%	1%	0.4%	0.1%	0.1%	1%	10%	12%
Cat	0%	0%	0%	0.0%	0.0%	0.0%	0.1%	1%	1%
Wildlife	2%	1%	0.8%	0.5%	0.4%	0.5%	0.3%	0.2%	0.1%

Based on these allocations, load reductions will focus on human and pet waste sources in urban areas and agricultural and human sources in rural areas.

Utilizing the percentages of total *E. coli* load generated to allocate loading reductions does not account for the effectiveness of BMPs to treat specific loads, the bacterial die-off rates prior to runoff, the distance from waterways or other influencing factors. However, it provides a literature-based estimate of untreated loading rates that can be applied in an unbiased manner to sources. Therefore, it provides the best available allocation method based on the available information.

7.4 Load reduction allocation

To achieve load reductions, the estimated percentages from the Watershed Multi-Year Model for nutrients (Table 14 and 15) and the load rate-based percentage estimates of *E. coli* (Table 20) were used to allocate the reductions to feasible categories, as shown in Table 21. For nutrients, categories where reduction was possible included farm animals, hay/pasture, point sources, stream bank erosion, and cropland categories. For *E. coli*, beef cattle, sheep, swine, human, and pet waste sources were utilized for reductions.

To translate these loads into a count of animals and humans, the loading rates (Table 19) were used to estimate the count of animals to achieve the specific *E. coli* human and animal reductions, and the “farm animal” nitrogen, and phosphorus reductions. As shown in Table 22, nitrogen reductions required addressing the most animals in Sites 42 (Glenns Creek above Steele Road) and Site 49 (Camden Creek). As previously mentioned, the model may be underpredicting the accumulated load of nitrogen in the groundwater reservoir and thus overpredicting the allocations to farm animal sources in these areas.

For Camden Creek where the farm animal population is more diversified, the load portions from various animal sources were estimated from literature values and animal counts. Nitrogen allocations were assigned according to their estimated nitrogen load contribution in that subwatershed with beef cattle 65%, horses 23%, sheep 8%, and swine 4%.

To achieve the allocated loads for animals and human waste, the total reduction in loading is the equivalent to the waste generated by 225 beef cattle, 104 sheep, 45 horses, 25 chickens, 63 swine, 31 dogs, and 61 households. The projected loads associated with these counts are shown in Table 22. For cattle and horses, the number of animals to be addressed depends on the portion of the manure addressed – either portions in pasture, instream, land-applied manure from confinement, or the total amount produced by the animal. In subwatersheds of Sites 42 and 49, achieving load reductions from beef cattle via either restriction from instream deposition or ceasing land-application of the manure accumulated during confinement is not possible given that the cattle populations of these watersheds could do not produce sufficient loads in these methods. Thus, achievement of the nitrogen target goals in these watersheds may be difficult.

To achieve the remaining load reductions, three modeled additional sources were utilized: hay/pasture runoff, stream bank erosion, and wastewater treatment plant nutrient optimization. The load reductions associated with these sources are summarized in Table 23.

Table 21 – Allocation for load reductions by source

Parameter	Site 47	Site 48	Site 42	Site 49	Site 50	Site 51
***E. coli* (count/year)**	**0**	**8.5E+12**	**6.5E+13**	**2.49E+14**	**1.29E+13**	**1.3E+13**
Beef Cattle	NA	8.5E+12 (100%)	6.44E+13 (99%)	1.94E+14 (78%)	3.23E+12 (25%)	1.82E+12 (14%)
Chicken	NA	0%	0%	2.99E+13 (12%)	0%	0%
Swine	NA	0%	0%	9.96E+12 (4%)	0%	0%
Human	NA	0%	6.50E+11 (1%)	1.49E+13 (6%)	8.26E+12 (64%)	9.49E+12 (73%)
Pet	NA	0%	0%	0%	1.42E+12 (11%)	1.69E+12 (13%)
Nitrogen (lbs./year)	**0**	**0**	**9,860**	**28,400**	**7,440**	**360**
Farm Animals	NA	NA	6,800 (69%)	19,600 (69%)	0%	0%
Hay/Pasture	NA	NA	3,060 (31%)	8,800 (31%)	0%	0%
Point Sources	NA	NA	0%	0%	7,440 (100%)	360 (100%)
Phosphorus, Total (lbs./year)	**300**	**0**	**6,160**	**480**	**6,840**	**0**
Farm Animals	96 (32%)	NA	1,848 (30%)	120 (25%)	0%	NA
Hay/Pasture	159 (53%)	NA	3,819 (62%)	302 (63%)	0%	NA
Point Sources	0%	NA	0%	0%	6,840 (100%)	NA
Stream Bank Erosion	45 (15%)	NA	493 (8%)	0%	0%	NA
Cropland	0%	NA	0%	58 (12%)	0%	NA

Table 22 – Estimated count of animal and human waste sources to be addressed to achieve load reductions.

Source	Site 47	Site 48	Site 42	Site 49	Site 50	Site 51
Count of animals addressed:						
Beef Cattle (Total) [Pasture/Instream/Land-Applied Manure]	4 [5/53/590]	1 [1/5/56]	76 [83/*/*]	142 [154/*/*]	1 [1/2/21]	1 [1/2/12]
Sheep Pasture	0	0	0	104	0	0
Horse (Total) [Pasture/Land-Applied Manure]	0	0	0	45 [57/213]	0	0
Chicken Land-Applied Manure	0	0	0	25	0	0
Swine Land-Applied Manure	0	0	0	63	0	0
Household Sewage (Direct input)	0	0	1	13	7	40
Dog	0	0	0	0	10	12
***E. coli* Load Reduced (Count/Year)**						
Beef Cattle (Total)	9.83E+13	2.46E+13	1.87E+15	3.49E+15	2.46E+13	2.46E+13
Sheep Pasture	-	-	-	1.03E+13	-	-
Horse (Total)	-	-	-	3.98E+12	-	-
Chicken Land-Applied Manure	-	-	-	3.00E+13	-	-
Swine Land-Applied Manure	-	-	-	9.69E+13	-	-
Household Sewage (Direct input)	-	-	1.20E+12	1.56E+13	8.40E+12	4.80E+13
Dog	-	-	-	-	1.51E+12	1.81E+12
Total Reduced	**9.83E+13**	**2.46E+13**	**1.87E+15**	**3.65E+15**	**3.45E+13**	**7.44E+13**
Remaining Load	**0**	**0**	**0**	**0**	**0**	**0**
Nitrogen Reduced (lbs./year)						
Beef Cattle (Total)	358	89	6,801	12,706	89	89
Sheep Pasture	-	-	-	1,548	-	-
Horse (Total)	-	-	-	4,500	-	-
Chicken Land-Applied Manure	-	-	-	11	-	-
Swine Land-Applied Manure	-	-	-	891	-	-
Household Sewage (Direct input)	-	-	9	119	64	365
Dog	-	-	-	-	8	9
Total Reduced	**358**	**89**	**6,810**	**19,775**	**161**	**464**
Remaining Load	**0**	**0**	**3,050**	**8,625**	**7,279**	**0**
Phosphorus Reduced (lbs./year)						
Beef Cattle (Total)	104	26	1,974	3,689	26	26
Sheep Pasture	-	-	-	419	-	-
Horse (Total)	-	-	-	964	-	-
Chicken Land-Applied Manure	-	-	-	4	-	-
Swine Land-Applied Manure	-	-	-	278	-	-
Household Sewage (Direct input)	-	-	2	28	15	86
Dog	-	-	-	-	46	55
Total Reduced	**104**	**26**	**1,976**	**5,382**	**87**	**167**
Remaining Load	**196**	**0**	**4,184**	**0**	**6,753**	**0**

Note: Coloring of human and animal counts indicates that pollutant which required the maximum reduction with yellow indicating *E. coli*, orange for nitrogen, and blue for phosphorus.
*Site 42 contains an estimated 1,002 beef cattle, and Site 49 contains 709. To achieve beef cattle allocated load reductions by removal of either instream or land-applied manure portions alone is not feasible.

Table 23 – Load reductions associated non-animal sources.

Source	Site 47	Site 42	Site 49	Site 50
Hay/Pasture (lbs./year [lbs./acre])				
Acres available	14,326 acres	10,360 acres	3,484 acres	-
- Nitrogen	-	3,050 [0.29]	8,625 [2.48]	-
- Phosphorus	159 [0.011]	3,819 [0.37]	-	-
Stream Bank Erosion (lbs./year [% Reduction])				
Eroded stream length available (ft)	12,023 ft	3,571 ft	-	-
- Phosphorus	37 [5%]	365 [47%]	-	-
Wastewater Treatment Plant Optimization (lbs./year [% Reduction])				
- Nitrogen	-	-	-	2,768 [11%]]*
- Phosphorus	-	-	-	6,753 [63%]
Unallocated Load (total lbs./year)				
- Nitrogen	-	-	-	4,511

* Reduction percentage limited by technology and left unallocated.

The University of Kentucky Cooperative Extension Service (Teutsch et al. n.d, Schwab and Piersawl 2010) recommends nitrogen be applied to equine pastures at a rate of 40-60 lbs./acre and that no phosphorus be applied unless soil tests indicate a need. Reductions of nitrogen by 0.29 and 2.39 lbs./acre thus represents a minor reduction in the recommended application to achieve the nitrogen goals if spread across the entire pasture/hay acreage of farms throughout the area. However, if only a few farms participate in reduction efforts, larger reductions may be required. For phosphorus, it is assumed that not all farms are utilizing fertilizer without phosphorus. Therefore, the reduction in phosphorus may also be achieved via outreach on fertilizer application management.

The stream bank erosion percent reductions were estimated based on dividing the allocated percentage based on the Watershed Multi-Year Model output into the total output from that source. Locations of measured bank erosion are prioritized in the following section.

To achieve the wastewater treatment plant effluent nutrient reductions at Site 50 via nutrient optimization, a 29% reduction in nitrogen (7,279 lbs./year) and a 63% reduction in phosphorus (6,753 lbs./year) in the effluent would be necessary. Currently the effluent averages 2 mg/L of P and 4.5 mg/L of N. A nationwide study (US EPA 2023) of 1,000 wastewater treatment plants using both conventional and advanced treatment technologies found that effluent concentrations of < 8 mg/L total nitrogen and <1 mg/L total phosphorus are obtainable. Further, operators in Kentucky facilities (US EPA 2020) were able to achieve total nitrogen concentrations of 4 mg/L and total phosphorus of 0.67 mg/L. Treatment types and influent characteristics can vary between systems, but these Kentucky specific effluent concentrations were utilized as a target for the Versailles System. Achieving these concentrations would represent an 11% reduction in nitrogen and a 67% reduction in phosphorus output from the current levels. Thus, the proposed phosphorus reductions are deemed achievable, particularly because additional reductions may be achieved via biological controls in combination with poly aluminum chloride treatment as recently demonstrated by Lexington's West Hickman Wastewater Treatment Plant. However, nitrogen reductions to 3.2 mg/L is deemed outside of the limits of technology. Therefore, nitrogen loading reductions of 4,511 lbs./year were unallocated. This load is the equivalent of the direct sewage output of 500 households or the feces of over 5800 dogs. Therefore, achieving the nitrogen benchmark at Site 50 is currently deemed technologically unfeasible.

8 Stream habitat and bank erosion prioritization

According to Table 5, the macroinvertebrate populations at several sites were impacted including "poor" conditions in urban Versailles (Sites 50-51) and "fair" conditions at the mouth of the watershed (Site 44). Habitat was indicated to be impacted at all sites except Sites 44 and 47 with poor riparian zones being the greatest contributor. To prioritize improvement of stream habitat and bank erosion, statistics were calculated according to parcel boundaries for the riparian zone and bank erosion.

A total of 215 parcels have streams with riparian impacts in the Glenns Creek Watershed. The Riparian Impact Index was calculated for each of these parcels with the results shown in Figure 33. Eighteen parcels with over a mile of highly impacted riparian bank were identified for prioritized outreach for tree planting or no mow zones. These properties represent 38 of the 83 miles of impacted stream banks (46%) in the watershed, and thus the greatest opportunities for large scale success with landowner buy-in.

A total of 125 properties, 14 of which were field measured, contained lengths of stream on which bank erosion was predicted to occur. The Erosion Rating was calculated based on the percentage of erosion occurring on each property, with the results shown in Figure 34. Fifteen properties with over a quarter mile of erosion were identified as priorities for erosion repair or armoring. These properties represent 6.5 of the 14.2 miles (46%) of the erosion occurring in the watershed, and thus the greatest opportunities for improvement with landowner buy-in.

Figure 33 –Priorities for riparian habitat by property

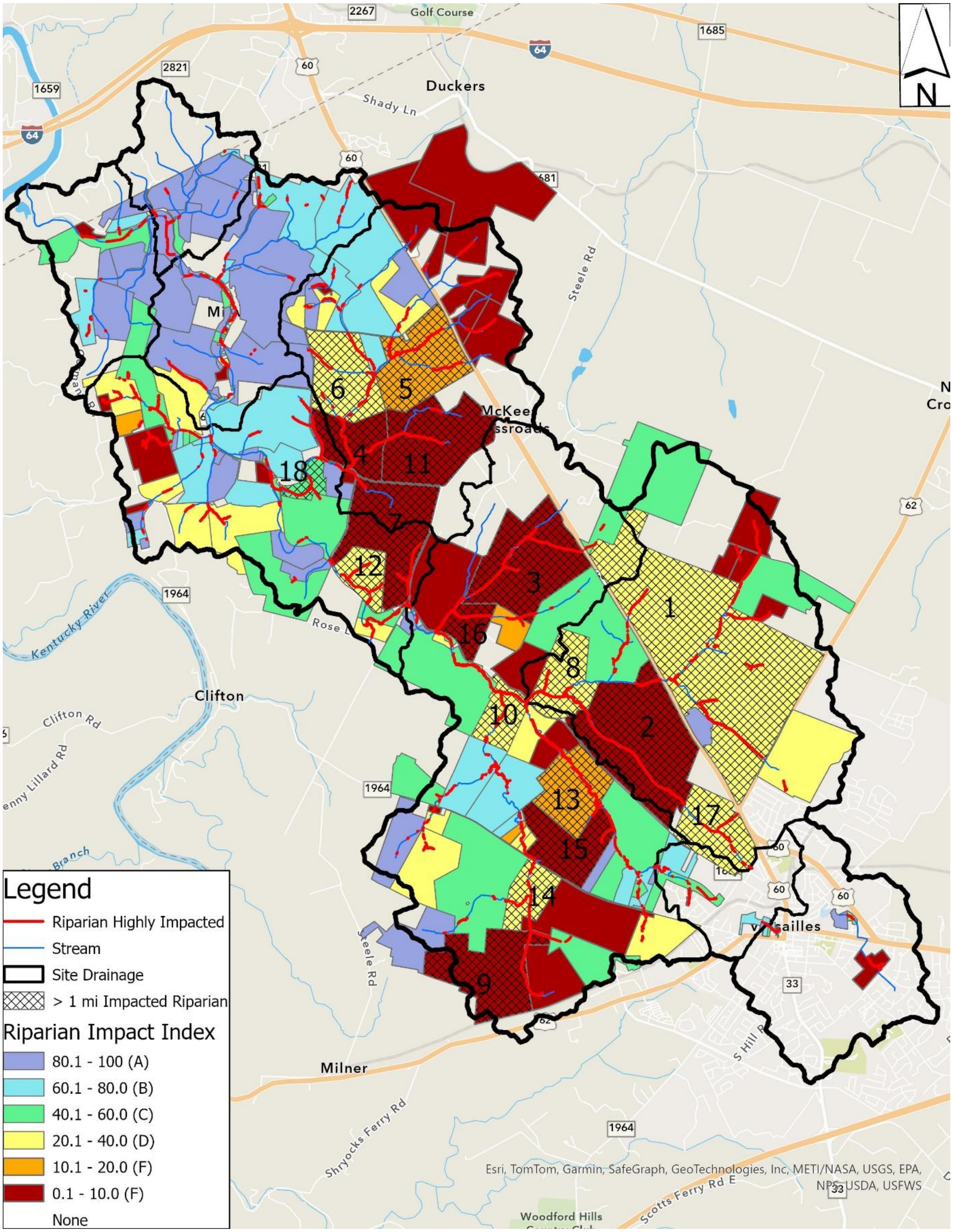
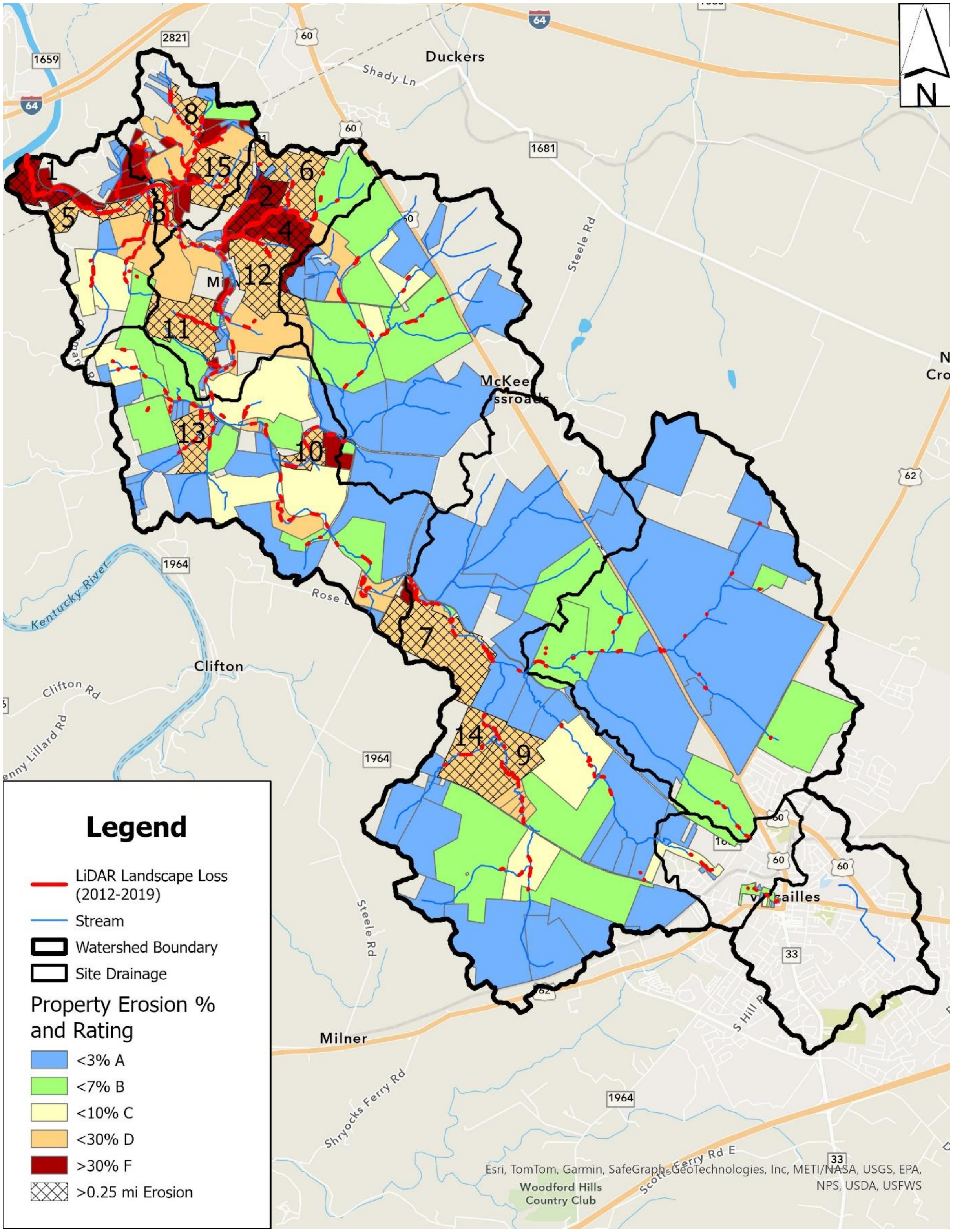


Figure 34 –Priorities for stream bank erosion by property



9 Best management practices and pollutant load reduction

To achieve the load reductions detailed in this report, best management practices must be applied by willing property owners in the watershed. A complete implementation plan will be detailed outside of this report. However, we will note here that focus groups were utilized to receive feedback from stakeholders in the Glenns Creek Watershed about their prioritization of practices. The prioritized list of practices is detailed in the Glenns Creek Focus Group Analysis Report (Evans et al 2024). These practices were selected by the stakeholders from the *Kentucky Triple Bottom Line Analysis of Conservation Practices* (Evans et al. 2024), which provides general ranges for bacterial and nutrient reduction efficiencies. However, in the development of the Triple Bottom Line Analysis, specific load reduction rates were generated for use in load reduction calculations. These values are included in **Appendix C** of this report along with the stakeholder prioritized rating for the Glenns Creek Watershed.

10 References

American Rivers. (2022). "Free Rivers: The State of Dam Removal in the United States." https://www.americanrivers.org/wp-content/uploads/2023/02/DamList2021_Report_02172022_FINAL3.pdf

American Society of Civil Engineers. (2014). Pathogens in Urban Stormwater Systems. Urban Water Resources Research Council, Pathogens in Wet Weather Flows Technical Committee, Environmental and Water Resources Institute, American Society of Engineers.

American Veterinary Medical Association. (2024). "2024 AVMA Pet Ownership and Demographic Sourcebook." https://www.avma.org/resources-tools/reports-statistics/us-pet-ownership-statistics

Audubon Christmas Bird Count. (2021). 2021 Results for Frankfort (KYFR), Center jct. us 127 & sr 1900. "https://netapp.audubon.org/CBCObservation/Historical/ResultsByCount.aspx

Blum, A. G., Ferraro, P. J., Archfield, S. A., & Ryberg, K. R. (2020). Causal effect of impervious cover on annual flood magnitude for the United States. Geophysical Research Letters, 47, e2019GL086480. https://doi.org/10.1029/2019GL086480

Cowan, N., Brownlie, W., Tomlinson, S., Carnell, E., Drewer, J., Dragosits, U., … Spears, B. M. (2024). A global assessment of nitrogen and phosphorus generated in the waste streams of domesticated cats and dogs. *Sustainable Environment*, *10*(1). https://doi.org/10.1080/27658511.2024.2415181

D'Amato, Victor. (2016). "Nutrient Attenuation in Chesapeake Bay Watershed Onsite Wastewater Treatment Systems – Final Report." Chesapeake Bay Onsite Wastewater Nutrient Attenuation Expert Review Panel. Report to US EPA. https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/draft_final_report_nutrient_attenuation_in_onsite_systems_8-31-16.pdf

Evans, Barry, Anthony Aufdenkampe, Mike Hickman, Reid Chistianson. 2023. Model My Watershed BMP Spreadsheet Tool v1.0.1 updated 2023-08-15. Available at https://github.com/WikiWatershed/MMW-BMP-spreadsheet-tool

Evans, Steven J., Lee Moser, Malissa McAlister, James Shelley. (2024). Glenns Creek Focus Group Analysis Report. Technical report submitted to Kentucky Division of Water. October 2024.

Evans, Steven J., Lee Moser, James Shelley, Malissa McAlister. (2024). Kentucky Triple Bottom Line Analysis of Conservation Practices. October 2024. https://kwri.uky.edu/tbl

Foreman-Worsley R, Finka LR, Ward SJ, Farnworth MJ. Indoors or Outdoors? An International Exploration of Owner Demographics and Decision Making Associated with Lifestyle of Pet Cats. Animals (Basel). 2021 Jan 20;11(2):253. doi: 10.3390/ani11020253. PMID: 33498511; PMCID: PMC7909512.

Ford, William I., Admin Husic, Alex Fogle, Joseph Taraba. (2019). “Long-term assessment of nutrient flow pathway dynamics and in-stream fate in a temperate karst agroecosystem watershed.” Hydrological Processes. 33(11), 1610-1628. https://doi.org/10.1002/hyp.13427

Halich, Greg. (2020). “Sacred Cows and Stocking Rates.” University of Kentucky Department of Agricultural Economics web article. July 28, 2020. https://agecon.ca.uky.edu/sacred-cows-and-stocking-rates

Higgins, Steve, Stephanie Mehlhope, Lee Moser, and Sarah Wightman. (2024). “Appropriate All Weather Surfaces for Livestock.” University of Kentucky Cooperative Extension Service bulletin. Revised April 2024. https://publications.ca.uky.edu/files/AEN115.pdf

Lee, Brad. (2012). HENV-502: Septic System Failure and Environmental Impacts. University of Kentucky Cooperative Extension Service Fact Sheet. https://publications.ca.uky.edu/henv-502

Lusk MG, Toor GS, Inglett PW. Organic nitrogen in residential stormwater runoff: Implications for stormwater management in urban watersheds. Sci Total Environ. 2020 Mar 10;707:135962. doi: 10.1016/j.scitotenv.2019.135962. Epub 2019 Dec 7. PMID: 31863977.

Manitoba Agriculture. (2008). “The Basics and Benefits of Bale Grazing.” Fact sheet developed by Manitoba Agriculture Food and Rural Initiatives, Agriculture and Agri-Food, and Manitoba Forage Council. February 2008. https://www.gov.mb.ca/agriculture/livestock/beef/pubs/baa05s04j.pdf

McGill, Timothy, "Assessing Machine Learning Utility in Predicting Hydrologic and Nitrate Dynamics in Karst Agroecosystems" (2022). Theses and Dissertations--Biosystems and Agricultural Engineering. 90. https://uknowledge.uky.edu/bae_etds/90

McGrath, Josh and Edwin Ritchey. (2023). AGR-1: Lime and Fertilizer Recommendations, 2020-2021.” University of Kentucky Cooperative Extension Publication, Lexington, KY. https://publications.ca.uky.edu/agr-1.

Raabe, Steve. (Summer 2022). “Lexington-Fayette Urban County Government Stormwater Survey Report of Findings.” Report submitted to Lexington-Fayette Urban County Government. OpinionWorks LLC, Annapolis, Maryland.

Radcliff, Cory, William I. Ford, Saeid Nazari, Christopher Shepard. 2021. Impact of water source dynamics on dissolved reactive phosphorus loadings in heterogenous karst agroecosystems with phosphatic limestones. Hydrological Processes. 2021;35:e14422. https://doi.org/10.1002/hyp.14422

Schwab, G.J. and M.W. Piersawl. (2010). Soil Sampling and Nutrient Management in Horse Pastures. University of Kentucky Cooperative Extension Service. AGR-200. https://forages.ca.uky.edu/files/agr200.pdf

Smith, S. C. F., Meiners, S. J., Hastings, R. P., Thomas, T., and Colombo, R. E. (2017). Low-Head Dam Impacts on Habitat and the Functional Composition of Fish Communities. *River Res. Applic.*, 33: 680–689. doi: 10.1002/rra.3128.

Stroud Water Research Center. (2024). Model My Watershed Technical Documentation. https://wikiwatershed.org/knowledge-base/water-quantity-and-quality-models/#7-2-watershed-multi-year-model

Teutsch, Chris D., Krista L. Lea, R.J. Coleman, and S. Ray Smith. (n.d.) Improving Kentucky Horse Pastures. University of Kentucky Cooperative Extension Service. https://forages.ca.uky.edu/files/improving_ky_horse_pastures.pdf

USDA. (2005). “Composting Dog Waste.” Fairbanks Soil and Water Conservation District. Fairbanks, AK. https://www.nrcs.usda.gov/sites/default/files/2022-10/Composting-Dog-Waste-Booklet-Alaska.pdf

USDA. (2017). “Woodford County, Kentucky 2017 Census of Agriculture County Profile. https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/County_Profiles/Kentucky/cp21239.pdf

USDA NRCS. (2008). Part 651 Agricultural Waste Management Field Handbook. Chapter 4: Agricultural Waste Characteristics https://dnn9n7kh1.blob.core.windows.net/portals/0/Professional%20Licensure/E-Reference%20Book/Natural%20Resources%20&%20Ecology/agr_waste_mgmt_2-26.pdf?sr=b&si=DNNFileManagerPolicy&sig=Hrf9TncgEr7z0ok9UjXIesl3BJdetuuHHVNRePmakCU%3D

US EPA. (2001). “Bacterial Indicator Tool.” Office of Water. EPA-823-B-01-003. https://www.epa.gov/sites/default/files/2015-07/bit.zip

US EPA. (2002). Onsite Wastewater Treatment Systems Manual. US. EPA Office of Research and Development Office of Water. EPA/625/R-00/008. https://www.epa.gov/sites/default/files/2015-06/documents/2004_07_07_septics_septic_2002_osdm_all.pdf

US EPA (2020). “Kentucky Operators Take the Lead in Reducing Nutrients.” EPA 820-F-20-003. https://www.epa.gov/sites/default/files/2020-10/documents/ky01_national-nutrient-study_820f20003_june-2020.pdf

US EPA. (2023). National Study of Nutrient Removal and Secondary Technologies. Webpage last updated on October 5, 2023. https://www.epa.gov/eg/national-study-nutrient-removal-and-secondary-technologies#accomplished

Virginia Cooperative Extension. (2024). “Improper Mowing of Lawns Can Impact Water Quality.” https://ext.vt.edu/lawn-garden/turfandgardentips/tips/ImproperMowing.html

Yetman, Kenneth T. (2001). “Stream Corridor Assessment Survey: Survey Protocols.” Maryland Department of Natural Resources, Watershed Restoration Division. https://dnr.maryland.gov/streams/Publications/SCAProtocols.pdf

Appendices

Appendix A: Summary of prior published water quality studies in Glenns Creek Watershed

Appendix B: Camden Creek nutrient sampling report

Appendix C: Glenns Creek stakeholder prioritized list of conservation practices with pollutant reduction efficiencies

Appendix A:
Summary of prior published water quality studies in Glenns Creek Watershed
Steven Evans, November 2024

The Glenns Creek Watershed has been the focus of numerous water quality investigations conducted by faculty and staff at the University of Kentucky dating back to at least the late nineties. This summary is intended to review and highlight relevant aspects of this literature pertaining to watershed management and planning.

The C. Oran Little Agricultural Research Center (ARC) is a nearly 1,500-acre farm purchased in 1991 and located in the headwaters of the Glenns Creek Watershed within the drainage of Camden Creek (Figure 1). The farm is home to beef, swine, equine, and sheep research units and is also utilized for row crop production. Because the land is underlain by phosphatic Ordovician limestone and is characterized by broad, shallow sinkholes with multiple springs, it is a natural research site for the water quality of karst agroecosystems. The ARC is also located within minutes of the city of Versailles and several springs which drain the majority of the urban area (Figure 2). The comparison between urban karst and agricultural karst has invited several comparative research studies.

Figure 1: C. Oran Little Farm boundary in relation to spring and stream sampling sites

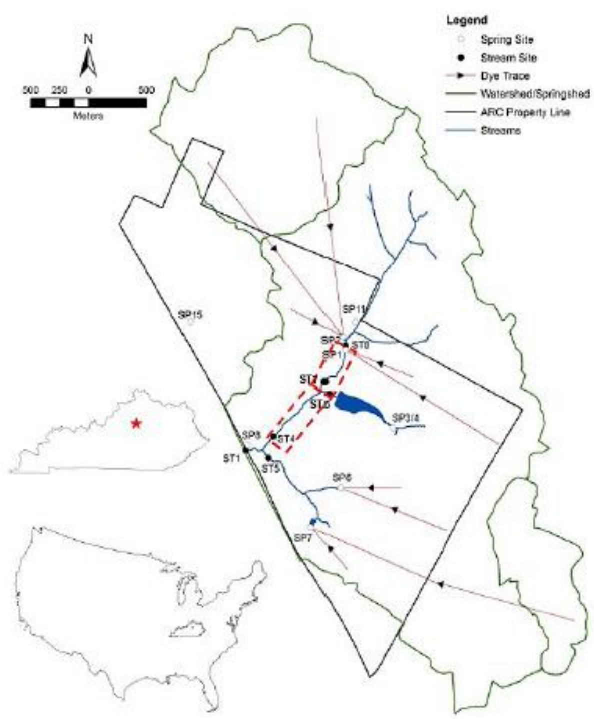
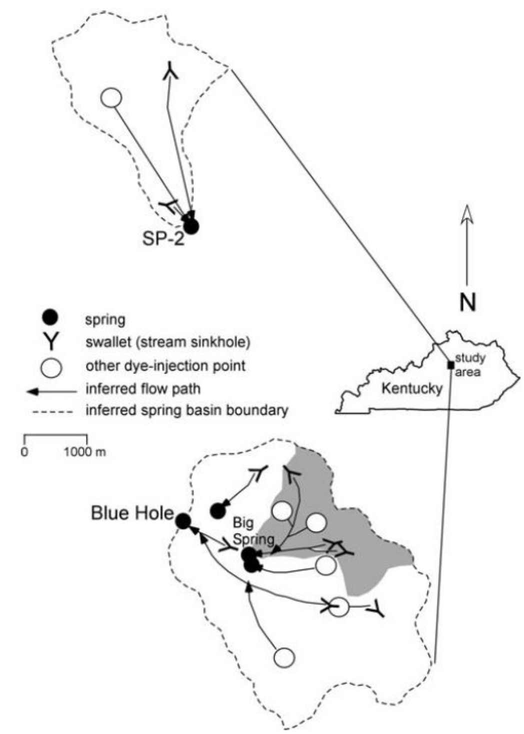


Figure 2: Comparison between the study areas of the agricultural groundwater basin (SP-2) and urban groundwater basin (Blue Hole and Big Spring)

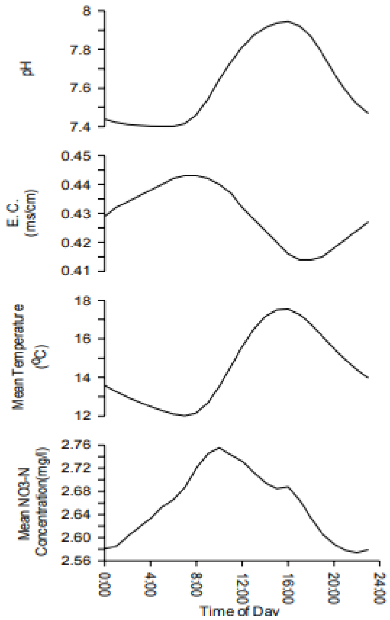


For the purposes of this summary, we will trace the relevant research in order of publication.

Comparison of Sampling Strategies

In 2003, Fogle, Taraba and Dinger published a paper (2003) which examined error estimates in pollutant mass loading studies utilizing two different sampling methods and error due to diurnal fluctuations. The researchers utilized a network of eleven weirs installed on site beginning in 1994 along with ISCO samplers, grab sampling, and YSI multi-parameter water quality sondes with conductivity pH, temperature, dissolved oxygen, turbidity, and nitrate sensors. The study then compared grab sampling with instantaneous flow sampling, grab sampling with continuous flow measurement, and continuous monitoring data. They found monthly grab sampling with continuous flow monitoring to produce the best results while being economical. Result indicated that the best time to sample was when the diurnal cycle (Figure 3) was nearest the daily mean, around midnight and 1300 hours for conductivity and 0500 hours for nitrate.

Figure 3: Mean parameter values at each hour (Fogle et al. 2003)



Cattle Grazing and BMPs

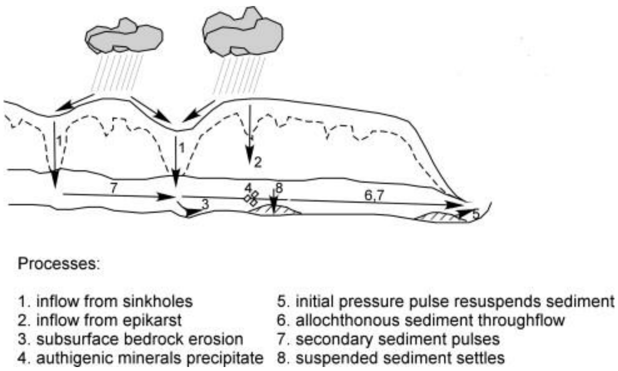
Dr. Agouridis and others (2004) summarized the findings of two years of monitoring exploring the relative impact of cattle production practices on water quality based on three treatments: a control, BMPs with open stream access, and BMPs with livestock stream exclusion. Only minimal benefits were observed from the BMPs due to the upstream soils, geology, and bedrock stream morphology.

Characterizing Fecal Inputs and Sediment at Urban and Agricultural Springs

From 2009 - 2011, a series of papers were published by an interdisciplinary group of University of Kentucky faculty and students based on monitoring conducted from 2002 to 2005.

The ratio between atypical colonies and typical colonies of total coliform were evaluated as an indicator of "hot spots" of fecal contamination in a laboratory experiment joined with field monitoring of the karst urban springs of Versailles (Ward et al. 2009). The study implicates "accidental sewage spills associated with construction" in the vicinity of the spring as contributing to the fecal source from Versailles. Another study (Reed et al. 2011) compared the agricultural spring at ARC to the urban Blue Hole spring just upstream of the Versailles wastewater treatment plant. It was inferred that the Blue Hole was "probably impacted by leakage from sanitary sewers" while the agricultural spring (SP-2) was not impacted by human fecal sources.

Figure 4: Schematic model of sediment transport in karst aquifers (from Reed et al. 2010)



An analysis of the sediment from the rural (SP-2) and urban (Blue Hole) spring sites found that the sediment at both sites was largely quartz, calcite and organic matter of silt to coarse sand size with sediment at the Blue Hole smaller than the rural spring.

Specific conductance was found to drop in response to precipitation driven flow increases while turbidity was found to spike in pulses as sediment was remobilized and flushed through the karst system (Figure 4).

The findings suggest that sediment storage within the karst basins may include time scales of decades to centuries.

Long-term Assessment of Nutrient Flow Dynamics

In 2019, Ford et al. summarized the results of nutrient monitoring conducted from 1996 to 2007 on the ARC. Their goal was “to quantify the hydrologic and in-stream aquatic vegetation controls on nutrient dynamics” of Camden Creek and the spring inputs.

As a result of the study, multiple linear regression analysis was utilized to predict the nutrient concentration (C_{pre}) of the springs and the stream based on the flow (Q) and the day of the year (Day) (Table 1). Figure 5 shows the results of this modeling as compared to measured results.

The analysis revealed two different flow pathways: slow flow and quick / intermediate flow. The time that it would take to completely drain the reservoir assuming no additional recharge or recession slope changes was calculated for each groundwater reservoir as well as the percentage of the nutrient load. The slow flow reservoir, consisting of low permeability matrix pores and small fissures, was calculated to drain in 14 days. This type of flow was found to comprise 75% of stream flow, 70% of phosphorus (DRP) load, and 80% of nitrate load. The quick / intermediate flow reservoir drain time was calculate as 4 days as surface runoff moves to sinkholes and perched aquifers through epikarst fractures and conduits. This represents 25% of the flow, 30% of phosphorus load, and 20% of nitrate load.

Table 1: Results of multiple linear regression analysis on ARC farm. Values in parenthesis are standard error. (Ford et al. 2019)

$$C_{pre}{}^{i,j} = \beta_0{}^{i,j} + \beta_1{}^{i,j}{*}Q + \beta_2{}^{i,j}{*}\ln(Q) + \beta_3{}^{i,j}{*}Day + \beta_4{}^{i,j}{*}\left(Day^2\right)$$

Spring	**DRP**	**NO_3^-**
β_0	0.21 (0.02)****	5.3 (0.60)****
β_1 (Q)	0.14 (0.03)****	1.7 (0.87)[a]*
β_2 (ln(Q))	$-9.1{*}10^{-3}$ ($5.5{*}10^{-3}$)	−0.22 (0.15)
β_3 (*Day*)	$1.8{*}10^{-4}$ ($2.3{*}10^{-4}$)	−0.01 ($6.4{*}10^{-3}$)**
β_4 (*Day*^{2})	$-3.9{*}10^{-7}$ ($5.9{*}10^{-7}$)	$3.9{*}10^{-5}$ ($1.6{*}10^{-5}$)**
Stream	**DRP**	**NO_3^-**
β_0	0.24 (0.01)****	7.3 (0.29)****
β_1 (Q)	0.07 (0.02)***	−2.26 (0.45)****
β_2 (ln(Q))	0.02 ($3.4{*}10^{-3}$)****	0.77 (0.07)****
β_3 (*Day*)	$-1.1{*}10^{-4}$ ($1.4{*}10^{-4}$)	−0.02 ($2.9{*}10^{-3}$)****
β_4 (*Day*^{2})	$3.1{*}10^{-7}$ ($3.6{*}10^{-7}$)	$5.7{*}10^{-5}$ ($7.5{*}10^{-6}$)****

Note. For predictive modelling purposes, parameters with p values <0.10 and overall models with p-values of <0.10 were included.

[a]Not included in final regression model because coefficient was found to be insignificant ($p > 0.1$) when simplifying the model structure.

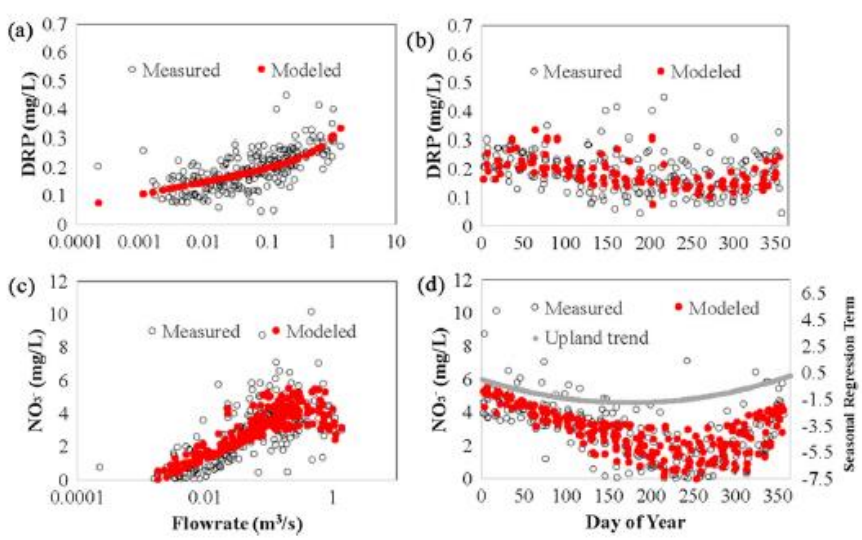
*$p < 0.1$.

**$p < 0.05$.

***$p < 0.01$.

****$p < 0.001$.

Figure 5: Comparison of measured vs. predicted nutrient concentrations based on regression modeling for Camden Creek dissolved reactive phosphorus (DRP) and nitrate(NO_3^-) (Ford et al. 2019)



Because the slow flow pathway is the predominant contributor to watershed loads, management practices addressing surface runoff (such as in Agouridis et al. 2004) would have a lesser impact on in-stream loading while physical and biochemical processes in the soil are more important controls on nitrate loading. Furthermore, it was noted that the soils and conduit sediments had limited capacity to retain phosphorus leached from surface soils.

Figure 6: Duckweed mats on Camden Creek (Bunnell et al. 2020)

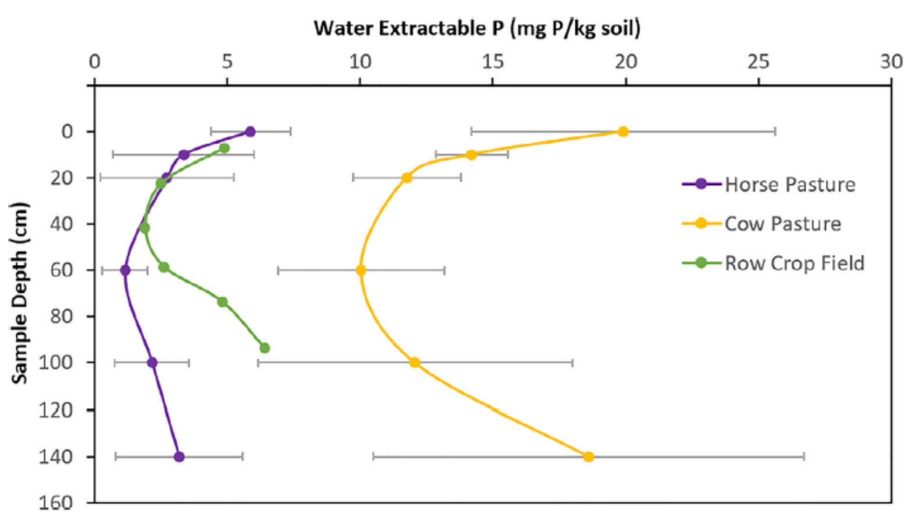
Camden Creek Duckweed Denitrification

Ford et al. (2019) implied that floating mats of aquatic vegetation (i.e. duckweed) was playing a major role in denitrification on the ARC. Bunnell et al. (2020) measured and modeled effect of duckweed on the streams of Camden Creek. They found that denitrification by duckweed "accounted for an average of 46 percent of total N removal in the studied stream reach which was higher than rates reported is wastewater ponds ranging from 10-40% of total N removal." They noted that at some seasons of the year denitrification reached close to 100%. They cite the use of duckweed in wastewater treatment system for the potential for harvesting to improve nutrient uptake and using it as a feed supplement.

Camden Creek Phosphorus

As a flow up to the long-term assessment of nutrient dynamics at Camden Creek, Radcliff et al. (2021) investigated soil profiles in three different upland fields: horse pasture, cow pasture, and row crops. As shown in Figure 7, the results showed higher levels at the soil surface (0–20 cm) which decreased with uptake in the root zone (20–100 cm) before again increasing below the root zone (greater than 100 cm) where it leaches into longer-term storage in the subsoil surface along with natural geologic contributions. The cow pasture showed the highest overall concentrations with similar levels for rowcrop and horse fields. The study states "these results partially reflect findings from chronically fertilized agroecosystems, which have demonstrated vertical stratification of P with high WEP levels in near surface soils, that is exacerbated by no-till or conservation tillage practices."

Figure 7: Water extractable phosphorus in soil profiles from three upland field sites



In light of the soil dynamics factoring into instream phosphorus concentrations, four potential best management practices were recommended. First, they cautiously recommend implementing vegetative buffers around sinkholes to help reduce surface phosphorus inputs. Second, they recommend the exclusion of livestock from vulnerable sinkhole fields. Third, they noted the opportunity for uptake of phosphorus at the spring-surface water interfaces by aquatic vegetation (i.e. duckweed). And lastly, they recognize the opportunity for constructed wetlands to act as a phosphorus sink.

Camden Creek Nitrate

In 2022, McGill published a machine learning model of nitrate dynamics on Camden Creek. He found that, as with phosphorus, the soil profile was stratified in regards to nitrate and increased soil moisture corresponded to higher instream concentrations. "When the shallower depths of the soil profile (10 and 20-cm depths) had increasing soil moisture contents without a response in deeper soil layers, some increase in nitrate concentration were observed, although responses were often relatively small. Conversely, as deeper layers of the soil profile (e.g., 50-cm) had increasing soil moisture content, larger shifts were observed in nitrate concentrations."

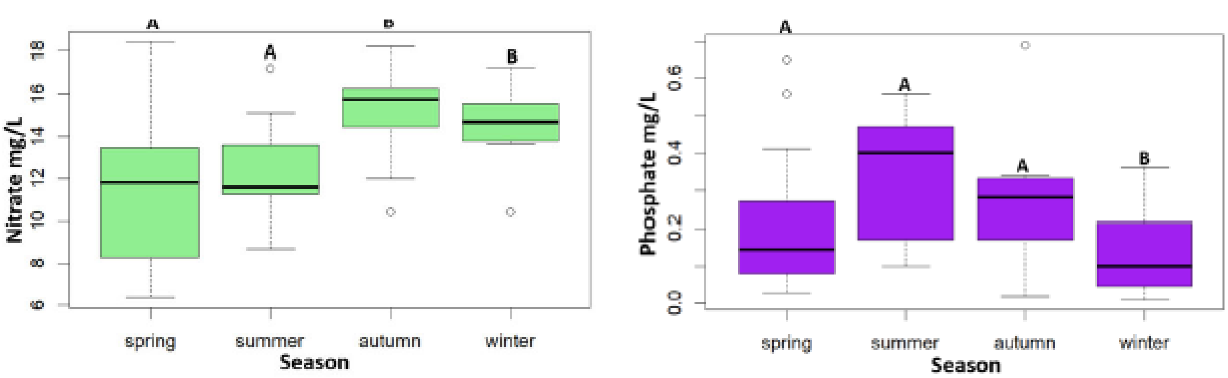
They also found that the lower regions of the soil profile are becoming disconnected and acting as a reservoir of nitrate: "As a rule of thumb, the effective root depth accounts for about 70% of the moisture extracted by the root. This indicates most of the vegetation growing at the LRC is extracting much of the required water and nutrients from the regions of the soil profile shallower than 50-cm during the main growth season. This results in the 50-cm and deeper regions of the soil becoming disconnected, leading to a buildup of nitrate and other nutrients during the warmer summer months. Following the growth season and the deeper regions of the soil matrix become connected to the macropores and karst pathways, a flushing of nitrate occurs from these karst agroecosystems, resulting in elevated nitrate exports throughout the wetter, winter months."

McGill catalogued all fertilization amounts and fields to which they were applied conducted over a multi-year period and evaluated the contributions to stream concentrations. The study found fertilization had little direct impact to the stream but that fertilization contributions by legacy storage: "Our findings suggest fertilization in agricultural practices had limited impact on nitrate concentrations which likely reflect the low application rates of both inorganic and organic fertilizers within the study watershed, although legacy N contributions are likely important. These legacy contributions have been reported to persist for several decades, with nearly 30% of total applied organic N still residing in soil organic matter or leaking into the hydrosphere over a 30-year period."

Camden Creek *E.coli* and Fluorescence

Dapkus (2022), sought to use tryptophan-like fluorescence as an indicator of non-point source pollution in the Inner Bluegrass. His findings did not support the viability of this model. His monitoring, conducted in 2021 and 2022, was consistent with prior studies (Figure 8).

Figure 8: Boxplots of seasonal nutrient concentrations at ARC (Dapkus 2022)



Works Cited:

Agouridis, C. T., Edwards, D. R., Workman, S. R., Bicudo, J. R., Taraba, J. L., Vanzant, E. S., & Gates, R. S. (2004). Effects of cattle grazing and BMPs on stream water quality. In *2004 ASAE Annual Meeting* (p. 1). American Society of Agricultural and Biological Engineers. http://dx.doi.org/10.13031/2013.17667

Bunnell, N. L., Ford, W. I., Fogle, A. W., & Taraba, J. (2020). Reach-Scale Model of Aquatic Vegetation Quantifies N Fate in a Bedrock-Controlled Karst Agroecosystem Stream. *Water*, *12*(9), 2458. https://doi.org/10.3390/w12092458

Bunnell, N. L. (2020). *Quantifying nitrogen fate in karst agroecosystem streams of central Kentucky: development and application of numerical modeling and insight from high-resolution sensors*. Master's thesis: University of Kentucky https://doi.org/10.13023/etd.2020.339

Dapkus, Ryan. (2022). "Tryptophan-Like Fluorescence and Non-Point Source Pollution in Karst Basins, Inner Bluegrass Region, Kentucky" Theses and Dissertations--Earth and Environmental Sciences. 96. https://uknowledge.uky.edu/ees_etds/96

Fogle, A. W., Taraba, J. L., & Dinger, J. S. (2003). Effect of Stream Diurnal Variations on Mass Loads in a Small Agricultural Karst Watershed. https://web.archive.org/web/20060107182939id_/http://rocco.bae.uky.edu:80/uk-arc/downloads/Papers/papers/TMDL.pdf

Fogle, A. W., Taraba, J. L., & Dinger, J. S. (2003). Mass load estimation errors utilizing grab sampling strategies in a karst watershed. *JAWRA Journal of the American Water Resources Association*, *39*(6), 1361-1372. https://doi.org/10.1111/j.1752-1688.2003.tb04423.x

McGill, Timothy, "Assessing Machine Learning Utility in Predicting Hydrologic and Nitrate Dynamics in Karst Agroecosystems" (2022). Theses and Dissertations--Biosystems and Agricultural Engineering. 90. https://uknowledge.uky.edu/bae_etds/90

Radcliff, Cory, William I. Ford, Saeid Nazari, Christopher Shepard. 2021. Impact of water source dynamics on dissolved reactive phosphorus loadings in heterogenous karst agroecosystems with phosphatic limestones. Hydrological Processes. 2021;35:e14422. https://doi.org/10.1002/hyp.14422

Reed, T. M., Fryar, A. E., Brion, G. M., & Ward, J. W. (2011). Differences in pathogen indicators between proximal urban and rural karst springs, Central Kentucky, USA. *Environmental Earth Sciences*, 64(1), 47-55. https://doi.org/10.1007/s12665-010-0816-8

Reed, T.M., McFarland, J.T., Fryar, A.E., Fogle, A.W., Taraba, J.L. (2010). Sediment discharges during storm flow from proximal urban and rural karst springs, central Kentucky, USA. Journal of Hydrology, 383, 280–290. https://doi.org/10.1016/j.jhydrol.2009.12.043

Ford, William I., Admin Husic, Alex Fogle, Joseph Taraba. (2019). "Long-term assessment of nutrient flow pathway dynamics and in-stream fate in a temperate karst agroecosystem watershed." Hydrological Processes. 33(11), 1610-1628. https://doi.org/10.1002/hyp.13427

Ward, J.W., *Reed, T.M., Fryar, A.E., and Brion, G.M., 2009, Using the AC/TC ratio to identify fecal inputs in a karst groundwater basin: Environmental & Engineering Geoscience, v. 15, no. 2, p. 57–65, http://dx.doi.org/10.2113/gseegeosci.15.2.57

Camden Creek Nutrient Evaluation Report

December 2023

J. Adam Shelley[1], Steve Evans[1], Lee Moser[2]

[1]Kentucky Water Research Institute, University of Kentucky; 2 Martin-Gatton College of Agriculture, Food and Environment Cooperative Extension Service

Executive Summary

This research builds upon the efforts of identifying the causes of erosion and the sources of high nutrient concentrations in the Glenns Creek watershed. This understanding is crucial for the effective implementation of Best Management Practices (BMPs) aimed at reducing sediment and nutrient loads within the watershed. Camden Creek, a tributary of Glenns Creek, was identified as a potential source of nutrients; therefore, additional investigations are required to precisely identify the activities contributing to these nutrient inputs for more targeted BMP implementation. From 11/6/2023 – 11/8/2023, KWRI and UKY Extension collected 17 Orthophosphate (PO_4) and 42 Nitrate (NO_3) samples from various points along the longitudinal profile of Camden Creek to provide a comprehensive understanding of the spatial distribution and variability of Orthophosphate (PO_4) and Nitrate (NO_3) concentrations and their relationship with karst terrain and agricultural practices.

Principal Findings:

- Nutrient concentrations varied significantly along Camden Creek, with PO_4 concentrations ranging from 0.07 mg/L to 1.63 mg/L and NO_3 levels varying from 0.31 mg/L to 5.76 mg/L.
- Hot spots for high nutrient concentrations were identified near karst springs, indicating a strong influence of karst hydrology on nutrient contribution. A strong negative correlation was observed between the distance from springs and nitrate concentrations, suggesting a decrease in nutrient levels as the distance from karst springs increased.
- The study highlighted the complexity of nutrient dynamics in a karst-dominated agricultural landscape, pointing to both offsite and onsite sources.
- Sixteen erosion sites were identified during the survey. Almost all the occurrences are related to infrastructure (weirs) that has been installed in the stream.

The findings of the study underscore the need for targeted management strategies in the Glenns Creek watershed. The significant influence of karst inputs on nutrient levels highlights the necessity of integrating karst hydrology into watershed management plans. Furthermore, the contribution of agricultural practices to nutrient concentrations necessitates the implementation of effective Best Management Practices (BMPs) to mitigate the nutrient input into Glenns Creek. These should be tailored to address both the unique characteristics of karst environment and the specific agricultural practices prevalent in the area. The degree of karst influence was determined by a series of visualization, analysis, and statistical techniques, which are detailed below. Additionally, details regarding the karst hydrologic inventory and an overview of hydrogeologic controls have been included to provide an understanding of the dynamic system underlying the University of Kentucky's Research Farm.

Study Area

In the Inner Bluegrass region, groundwater movement occurs through channels in the epikarst, and shallow conduits known as interbasin aquifers and through deeper conduits that penetrate clay-rich layers in the Lexington Limestone. These deeper conduits are referred to as main-stem conduits. The interbasin aquifers are responsible for supplying water to shallow springs and streams that disappear underground, whereas the intrabasin aquifers contribute their flow to the tributaries that flow into the Kentucky River, which serves as the primary base level control for the region's hydrological system (Thrailkill et al., 1982). Camden Creek is an extensively studied fluviokarstic system that flows through the University of Kentucky's C. Oran Little Research Farm, whose area is characterized by rolling hills and a definitive sinkhole plain. The underlying karst terrain was formed in the Middle to Upper Ordovician carbonate rocks of the High Bridge Group Lexington Limestone and the Clays Ferry Formation (KGS, 1985).

Seven major perennial springs and numerous seeps have been documented along Camden Creek and its tributaries. For the purposes of this research, only five of the seven springs will be discussed. The rising bluehole spring, WSP-2 (Figure 1), forms the headwaters of Camden Creek. Sources of recharge for WSP-2 have been identified through dye traces as an unnamed sink and swallet approximately 1.5 km north of WSP-2 (Currens et al., 2002). The recharge area of WSP-2 has been delineated at 2.56 km^2, and the land use within the catchment is predominantly agricultural. Approximately 120 meters downstream, another spring, WSP-1, resurges beneath a limestone shelf from a conduit. The recharge area for WSP-1 is ostensibly localized within the farm boundary, but further tracing is needed for confirmation.

Another notable spring on the property is WSP-7, a fourth-magnitude spring that discharges from Pin Oak Cave and flows into a tributary of Camden Creek (KGS, 1985). The groundwater basin feeding the Pin Oak Spring (WSP-7) has been delineated to 2.98 km^2. The land use for this basin is mixed between residential and agricultural. Additionally, it is necessary to mention that a small seep on an adjacent stream branch contributes some flow to this tributary. However, the source of the seep originates from a different and much smaller groundwater basin whose land use is agriculture. Lastly, the Spring seep, WSP 3/4 is located near the outlet of the largest pond but does not have any tracing data for sourcing.

Methodology

The study, conducted from November 6 to 8, 2023, involved a collaborative effort between the Kentucky Water Resources Institute (KWRI) and the University of Kentucky (UKY) Extension. The primary focus was to document severe erosion sites but the acquisition of a new probe allowed for in-situ sampling and analysis of nutrient concentrations, specifically Orthophosphate (PO_4) and Nitrate (NO_3), in Camden Creek's longitudinal profile. Due to budgetary constraints, PO_4 was sampled at selected sites only. The methodology encompassed site selection, data collection, and comprehensive spatial and statistical analyses. In total, 17 PO_4 and 42 Nitrate NO_3 samples were collected from various points along the longitudinal profile of Camden Creek. PO4 was not collected at every site due to funding constraints.

Sampling Strategy

Site Selection and Planning: Using ArcGIS Pro, sampling sites were strategically chosen and randomly assigned at 100-meter intervals along the creek's centerline. This approach ensured comprehensive coverage of the creek's varying landscapes and features.

Karst Hydrologic Inventory (KHI): Prior to sampling, a detailed KHI was undertaken to identify and incorporate karst features into the sampling plan. Additional sampling points were included at major springs, with some adjustments made due to site accessibility and conditions.

Data Collection

Nutrient Sampling: A HACH SL1000 portable water quality analyzer, equipped with an Intellical™ ISENO3181 Standard Nitrate Ion-Selective-Electrode (ISE) and Orthophosphate Chemkey® Reagents, was used to measure nutrient concentrations.

Indicator Parameter Measurement: Alongside nutrient sampling, indicator parameters such as pH, Specific Conductivity (SpC), and water temperature were recorded at nitrate sample sites using a multi-parameter handheld meter. Regrettably, dissolved oxygen measurements could not be taken due to technical issues with the probe membrane.

Field Documentation: All field data documentation was streamlined using ArcGIS Field Maps on an iOS device, ensuring efficient post-processing and data integrity.

Spatial and Statistical Analysis

Visualization and Spatial Analysis: The initial analysis involved visualizing sample results graphically, followed by spatial analyses to understand the distribution of nitrate concentrations across the creek.

Moran's I Analysis: Performed to assess spatial autocorrelation and determine if high nitrate concentrations were spatially clustered.

Empirical Bayesian Kriging Interpolation: Utilized to rapidly identify areas of high nitrate concentration. The resulting model was optimized through cross-validation and semi-variogram analysis techniques.

Getis-Ord Gi* Analysis: Conducted to pinpoint areas of statistically significant nutrient concentration.

Proximity Analysis and Kruskal-Wallis ANOVA: Used to aggregate data into groups near the springs, and Kruskal-Wallis ANOVA, with Conover's pairwise tests, determined statistical differences in nutrient concentrations among these groups. Sampling locations downstream from the springs that fell into a 152.4 m (500 ft) buffer and had geochemical values reflective of the spring discharge were selected. In total, five groups were selected: WSP-1, WSP-2, WSP-3/4, WSP-7/UNSP-1, and WSP-8.

Non-Parametric Correlation Analysis: Employed to evaluate the relationship between the distance from springs and nitrate concentrations.

Results

The comprehensive analysis of nutrient concentrations in Camden Creek yielded insightful findings. The primary focus was on the spatial distribution and statistical significance of Orthophosphate (PO_4) and Nitrate (NO_3) concentrations, particularly in relation to karst features and agricultural practices in the area.

Nutrient Concentration Findings

Orthophosphate and Nitrate Levels: PO_4 concentrations ranged from 0.07 mg/L to 1.63 mg/L, with a mean of 0.78 mg/L and a median of 0.80 mg/L. The standard deviation was 0.35 mg/L. NO_3 levels varied from 0.31 mg/L to 5.76 mg/L, with an average concentration of 3.017 mg/L and a median of 3.35 mg/L. The standard deviation for nitrate was 1.83 mg/L.

Indicator Parameters

pH, Conductivity, and Temperature: pH values spanned from 6.74 to 8.16, with a mean of 7.576 and a median of 7.65. Conductivity measurements ranged between 349 µS/cm and 665 µS/cm, with a mean of 489.33 µS/cm. Water temperature varied from 6.88°C to 17.63°C, with a mean temperature of 12.35°C.

Parameter	Minimum	Maximum	Mean	Median	Standard Deviation
Orthophosphate (mg/L)	0.07	1.63	0.78	0.8	0.35
Nitrate (mg/L)	0.31	5.76	3.01	3.35	1.83
pH (S.U.)	6.74	8.16	7.57	7.65	0.39
SpC (µS/cm)	349.0	665.0	489.33	514.0	71.18
Temperature (°C)	6.88	17.63	12.35	12.71	2.78

Spatial and Statistical Analysis

Hot and Cold Spot Identification: The Getis-Ord Gi* analysis revealed statistically significant hot spots for nitrate concentrations clustered around the springs, particularly near WSP-7 and WSP-3/4. Proximity analysis was employed to accurately aggregate data into groups reflecting spring discharge influence. In addition, the Getis-Ord Gi* analysis also revealed a band of statistically significant cold spots for nitrate concentrations that were clustered along the main channel of Camden Creek, downstream of any spring influence.

Kruskal-Wallis ANOVA: Since all the springs identified originate from different groundwater sources, it was necessary to determine the significance of concentrations observed at WSP-7/UNSP-1 and WSP-3/4. The Kruskal-Wallis ANOVA analysis, supplemented with post-hoc Conover's pairwise tests, identified statistically significant differences in nutrient concentrations among the spring groups. Notably, concentrations from WSP-7/UNSP-1 were distinct from other springs.

Correlation Analysis: A strong negative correlation (-0.68) was observed between the distance from the springs and nitrate concentrations, indicating that nutrient levels decreased as the distance from the springs increased. This pattern was consistent downstream of the spring influence zones.

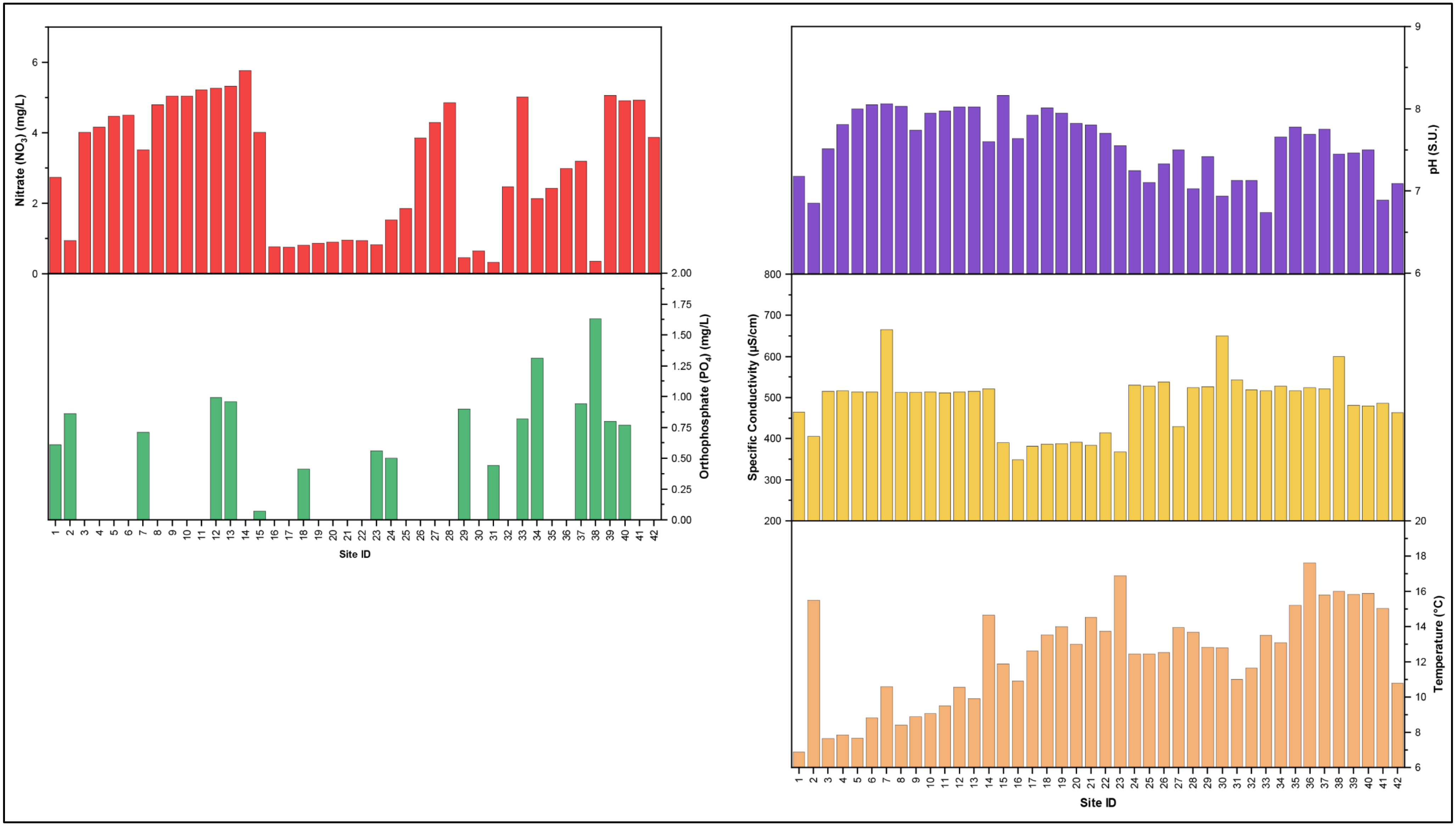


Figure 1: Camden Creek Sample Site Results

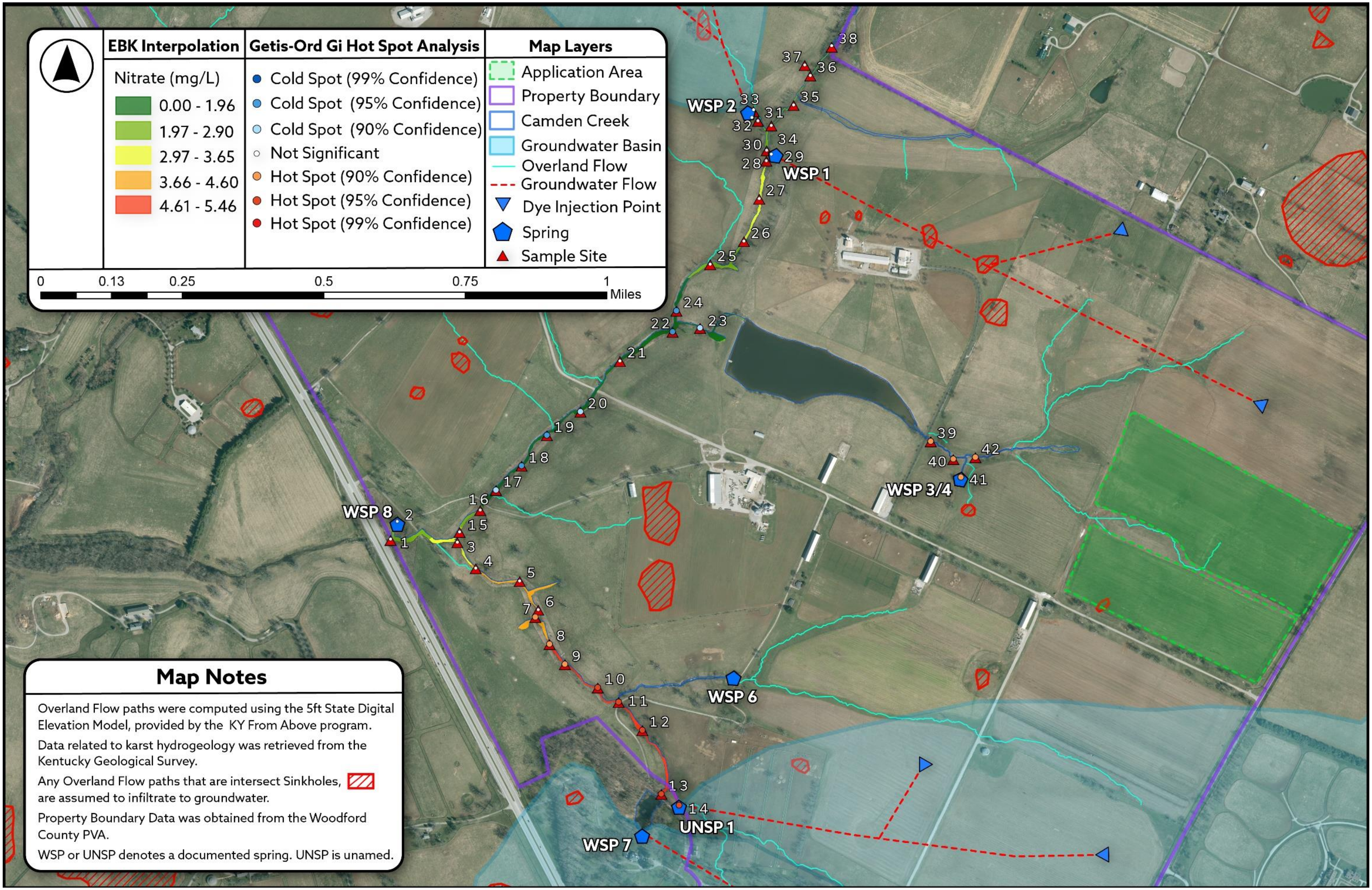


Figure 2: Camden Creek Study Area/Analysis Map

Conclusions

The results indicate a significant influence of karst inputs on nutrient levels in Camden Creek. The highest concentrations of NO_3 and PO_4 were consistently found near karst springs, suggesting a link between karst hydrology and nutrient contribution. Notably, the measurements at and near WSP 7 and WSP 3/4 were identified as statistically significant hot spots. The presence of statistically significant cold spots for nitrate concentrations along the main channel of Camden Creek, downstream of spring influences, implies that the high density of duckweed (Lemma Minor) and other vegetation attenuates the nutrient concentrations downstream of the springs. Based on the detailed Karst Hydrologic Inventory (KHI) and analyses, it is likely that the increased nutrient concentrations within Camden Creek are attributable to offsite sources. Furthermore, the findings suggest that while offsite sources significantly contribute to nutrient concentrations in Camden Creek due to the density of sinkholes and karst inputs, onsite agricultural practices, particularly manure application, cannot be overlooked as a contributing factor. It is worth noting that overland flow not intercepted by the karst system does flow directly into the creek from the manure application areas (WSP 3/4). Moreover, this is the case for many of the fields on the property. This emphasizes the complexity of nutrient dynamics in karst-dominated agricultural landscapes and underscores the importance of integrated watershed management approaches. These results offer a detailed understanding of the spatial variability of nutrient concentrations in Camden Creek, highlighting the need for targeted management strategies that consider both karst hydrology and land use practices.

References

Currens, J.C., Paylor, R.L., and Ray, J.A., 2002. Mapped karst ground-water basins in the Lexington 30 × 60 minute quadrangle. Kentucky Geological Survey, Series 11, Map and Chart Series 10, 1 sheet.

Kentucky Geological Survey, 1985. Caves and Karst of Kentucky. SPECIAL PUBLICATION 12, Series XI.

Thrailkill, J., 1989. Shallow conduit-flow carbonate aquifers: conceptual models and parameter evaluation. In: Moore, J.E., Zaporozec, A.A., Csallany, S.C., and Varney, T.C. (Eds.), Recent advances in ground-water hydrology. American Institute of Hydrology, Minneapolis, MN, pp. 153-159.

Appendix A:
Summary of prior published water quality studies in Glenns Creek Watershed
Steven Evans, November 2024

The Glenns Creek Watershed has been the focus of numerous water quality investigations conducted by faculty and staff at the University of Kentucky dating back to at least the late nineties. This summary is intended to review and highlight relevant aspects of this literature pertaining to watershed management and planning.

The C. Oran Little Agricultural Research Center (ARC) is a nearly 1,500-acre farm purchased in 1991 and located in the headwaters of the Glenns Creek Watershed within the drainage of Camden Creek (Figure 1). The farm is home to beef, swine, equine, and sheep research units and is also utilized for row crop production. Because the land is underlain by phosphatic Ordovician limestone and is characterized by broad, shallow sinkholes with multiple springs, it is a natural research site for the water quality of karst agroecosystems. The ARC is also located within minutes of the city of Versailles and several springs which drain the majority of the urban area (Figure 2). The comparison between urban karst and agricultural karst has invited several comparative research studies.

Figure 1: C. Oran Little Farm boundary in relation to spring and stream sampling sites

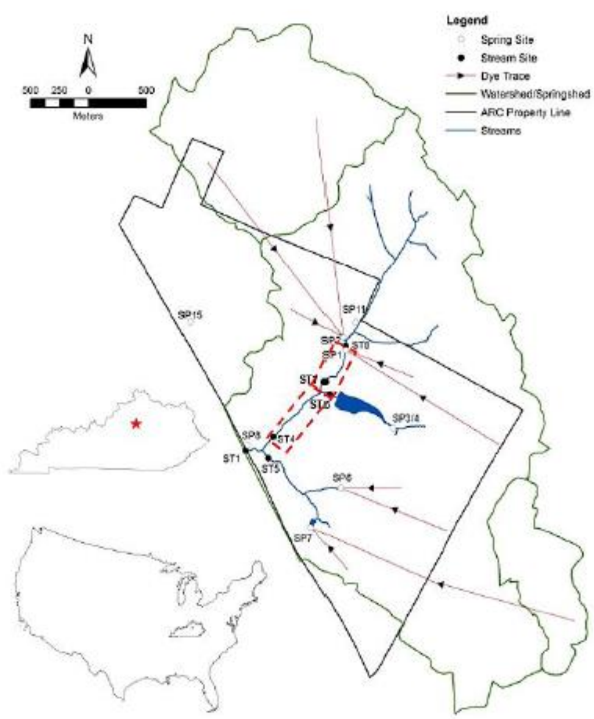
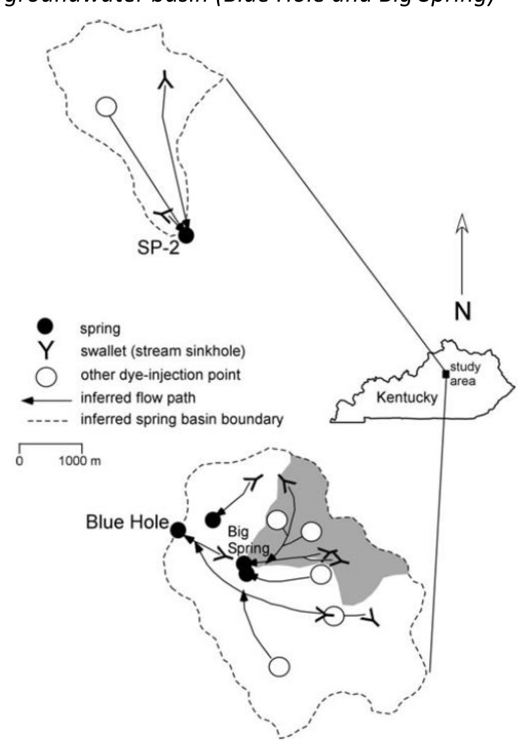


Figure 2: Comparison between the study areas of the agricultural groundwater basin (SP-2) and urban groundwater basin (Blue Hole and Big Spring)

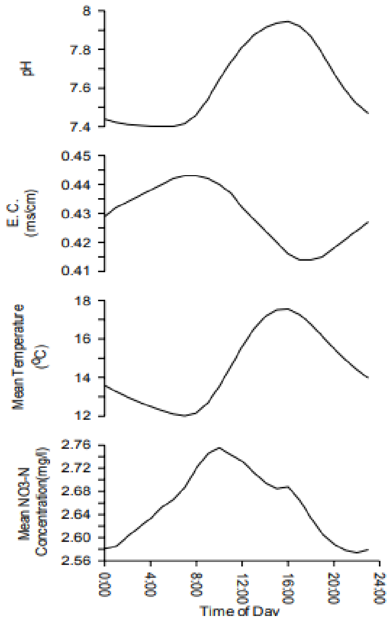


For the purposes of this summary, we will trace the relevant research in order of publication.

Comparison of Sampling Strategies

In 2003, Fogle, Taraba and Dinger published a paper (2003) which examined error estimates in pollutant mass loading studies utilizing two different sampling methods and error due to diurnal fluctuations. The researchers utilized a network of eleven weirs installed on site beginning in 1994 along with ISCO samplers, grab sampling, and YSI multi-parameter water quality sondes with conductivity pH, temperature, dissolved oxygen, turbidity, and nitrate sensors. The study then compared grab sampling with instantaneous flow sampling, grab sampling with continuous flow measurement, and continuous monitoring data. They found monthly grab sampling with continuous flow monitoring to produce the best results while being economical. Result indicated that the best time to sample was when the diurnal cycle (Figure 3) was nearest the daily mean, around midnight and 1300 hours for conductivity and 0500 hours for nitrate.

Figure 3: Mean parameter values at each hour (Fogle et al. 2003)



Cattle Grazing and BMPs

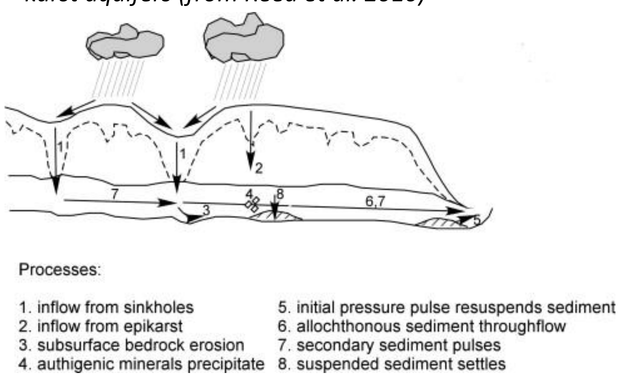
Dr. Agouridis and others (2004) summarized the findings of two years of monitoring exploring the relative impact of cattle production practices on water quality based on three treatments: a control, BMPs with open stream access, and BMPs with livestock stream exclusion. Only minimal benefits were observed from the BMPs due to the upstream soils, geology, and bedrock stream morphology.

Characterizing Fecal Inputs and Sediment at Urban and Agricultural Springs

From 2009 - 2011, a series of papers were published by an interdisciplinary group of University of Kentucky faculty and students based on monitoring conducted from 2002 to 2005.

The ratio between atypical colonies and typical colonies of total coliform were evaluated as an indicator of “hot spots” of fecal contamination in a laboratory experiment joined with field monitoring of the karst urban springs of Versailles (Ward et al. 2009). The study implicates “accidental sewage spills associated with construction” in the vicinity of the spring as contributing to the fecal source from Versailles. Another study (Reed et al. 2011) compared the agricultural spring at ARC to the urban Blue Hole spring just upstream of the Versailles wastewater treatment plant. It was inferred that the Blue Hole was “probably impacted by leakage from sanitary sewers” while the agricultural spring (SP-2) was not impacted by human fecal sources.

Figure 4: Schematic model of sediment transport in karst aquifers (from Reed et al. 2010)



An analysis of the sediment from the rural (SP-2) and urban (Blue Hole) spring sites found that the sediment at both sites was largely quartz, calcite and organic matter of silt to coarse sand size with sediment at the Blue Hole smaller than the rural spring.

Specific conductance was found to drop in response to precipitation driven flow increases while turbidity was found to spike in pulses as sediment was remobilized and flushed through the karst system (Figure 4).

The findings suggest that sediment storage within the karst basins may include time scales of decades to centuries.

Long-term Assessment of Nutrient Flow Dynamics

In 2019, Ford et al. summarized the results of nutrient monitoring conducted from 1996 to 2007 on the ARC. Their goal was "to quantify the hydrologic and in-stream aquatic vegetation controls on nutrient dynamics" of Camden Creek and the spring inputs.

As a result of the study, multiple linear regression analysis was utilized to predict the nutrient concentration (C_{pre}) of the springs and the stream based on the flow (Q) and the day of the year (Day) (Table 1). Figure 5 shows the results of this modeling as compared to measured results.

Table 1: Results of multiple linear regression analysis on ARC farm. Values in parenthesis are standard error. (Ford et al. 2019)

$$C_{pre}{}^{i,j} = \beta_0{}^{i,j} + \beta_1{}^{i,j} * Q + \beta_2{}^{i,j} * \ln(Q) + \beta_3{}^{i,j} * Day + \beta_4{}^{i,j} * \left(Day^2\right)$$

Spring	DRP	NO_3^-
β_0	0.21 (0.02)****	5.3 (0.60)****
β_1 (Q)	0.14 (0.03)****	1.7 (0.87)[a]*
β_2 (ln(Q))	$-9.1*10^{-3}$ ($5.5*10^{-3}$)	−0.22 (0.15)
β_3 (*Day*)	$1.8*10^{-4}$ ($2.3*10^{-4}$)	−0.01 ($6.4*10^{-3}$)**
β_4 (*Day*^{2})	$-3.9*10^{-7}$ ($5.9*10^{-7}$)	$3.9*10^{-5}$ ($1.6*10^{-5}$)**
Stream	**DRP**	**NO_3^-**
β_0	0.24 (0.01)****	7.3 (0.29)****
β_1 (Q)	0.07 (0.02)***	−2.26 (0.45)****
β_2 (ln(Q))	0.02 ($3.4*10^{-3}$)****	0.77 (0.07)****
β_3 (*Day*)	$-1.1*10^{-4}$ ($1.4*10^{-4}$)	−0.02 ($2.9*10^{-3}$)****
β_4 (*Day*^{2})	$3.1*10^{-7}$ ($3.6*10^{-7}$)	$5.7*10^{-5}$ ($7.5*10^{-6}$)****

Note. For predictive modelling purposes, parameters with p values <0.10 and overall models with p-values of <0.10 were included.

[a]Not included in final regression model because coefficient was found to be insignificant ($p > 0.1$) when simplifying the model structure.

*$p < 0.1$.

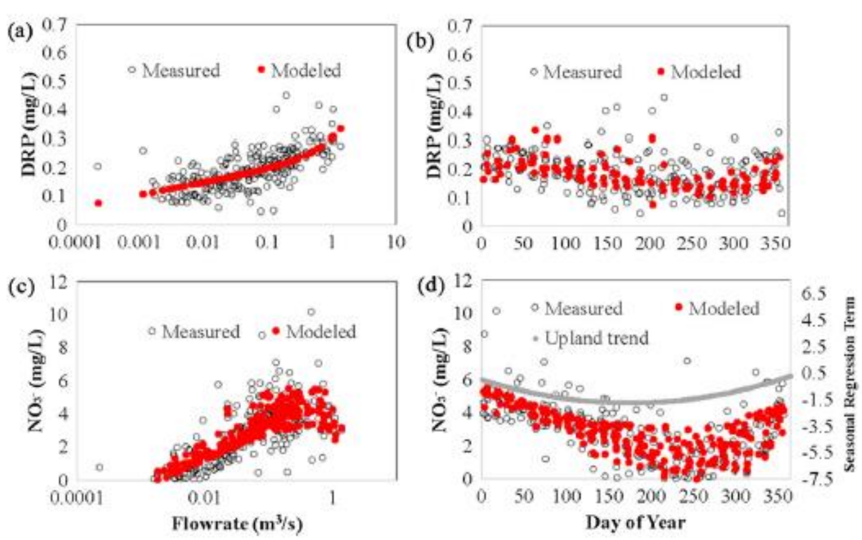
**$p < 0.05$.

***$p < 0.01$.

****$p < 0.001$.

The analysis revealed two different flow pathways: slow flow and quick / intermediate flow. The time that it would take to completely drain the reservoir assuming no additional recharge or recession slope changes was calculated for each groundwater reservoir as well as the percentage of the nutrient load. The slow flow reservoir, consisting of low permeability matrix pores and small fissures, was calculated to drain in 14 days. This type of flow was found to comprise 75% of stream flow, 70% of phosphorus (DRP) load, and 80% of nitrate load. The quick / intermediate flow reservoir drain time was calculate as 4 days as surface runoff moves to sinkholes and perched aquifers through epikarst fractures and conduits. This represents 25% of the flow, 30% of phosphorus load, and 20% of nitrate load.

Figure 5: Comparison of measured vs. predicted nutrient concentrations based on regression modeling for Camden Creek dissolved reactive phosphorus (DRP) and nitrate(NO_3^-) (Ford et al. 2019)



Because the slow flow pathway is the predominant contributor to watershed loads, management practices addressing surface runoff (such as in Agouridis et al. 2004) would have a lesser impact on in-stream loading while physical and biochemical processes in the soil are more important controls on nitrate loading. Furthermore, it was noted that the soils and conduit sediments had limited capacity to retain phosphorus leached from surface soils.

Figure 6: Duckweed mats on Camden Creek (Bunnell et al. 2020)

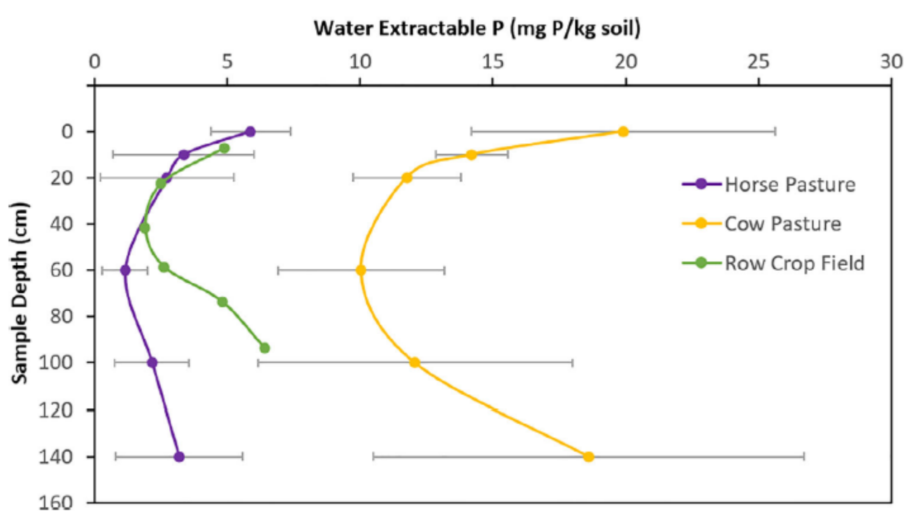
Camden Creek Duckweed Denitrification

Ford et al. (2019) implied that floating mats of aquatic vegetation (i.e. duckweed) was playing a major role in denitrification on the ARC. Bunnell et al. (2020) measured and modeled effect of duckweed on the streams of Camden Creek. They found that denitrification by duckweed "accounted for an average of 46 percent of total N removal in the studied stream reach which was higher than rates reported is wastewater ponds ranging from 10-40% of total N removal." They noted that at some seasons of the year denitrification reached close to 100%. They cite the use of duckweed in wastewater treatment system for the potential for harvesting to improve nutrient uptake and using it as a feed supplement.

Camden Creek Phosphorus

As a flow up to the long-term assessment of nutrient dynamics at Camden Creek, Radcliff et al. (2021) investigated soil profiles in three different upland fields: horse pasture, cow pasture, and row crops. As shown in Figure 7, the results showed higher levels at the soil surface (0–20 cm) which decreased with uptake in the root zone (20–100 cm) before again increasing below the root zone (greater than 100 cm) where it leaches into longer-term storage in the subsoil surface along with natural geologic contributions. The cow pasture showed the highest overall concentrations with similar levels for rowcrop and horse fields. The study states "these results partially reflect findings from chronically fertilized agroecosystems, which have demonstrated vertical stratification of P with high WEP levels in near surface soils, that is exacerbated by no-till or conservation tillage practices."

Figure 7: Water extractable phosphorus in soil profiles from three upland field sites



In light of the soil dynamics factoring into instream phosphorus concentrations, four potential best management practices were recommended. First, they cautiously recommend implementing vegetative buffers around sinkholes to help reduce surface phosphorus inputs. Second, they recommend the exclusion of livestock from vulnerable sinkhole fields. Third, they noted the opportunity for uptake of phosphorus at the spring-surface water interfaces by aquatic vegetation (i.e. duckweed). And lastly, they recognize the opportunity for constructed wetlands to act as a phosphorus sink.

Camden Creek Nitrate

In 2022, McGill published a machine learning model of nitrate dynamics on Camden Creek. He found that, as with phosphorus, the soil profile was stratified in regards to nitrate and increased soil moisture corresponded to higher instream concentrations. "When the shallower depths of the soil profile (10 and 20-cm depths) had increasing soil moisture contents without a response in deeper soil layers, some increase in nitrate concentration were observed, although responses were often relatively small. Conversely, as deeper layers of the soil profile (e.g., 50-cm) had increasing soil moisture content, larger shifts were observed in nitrate concentrations."

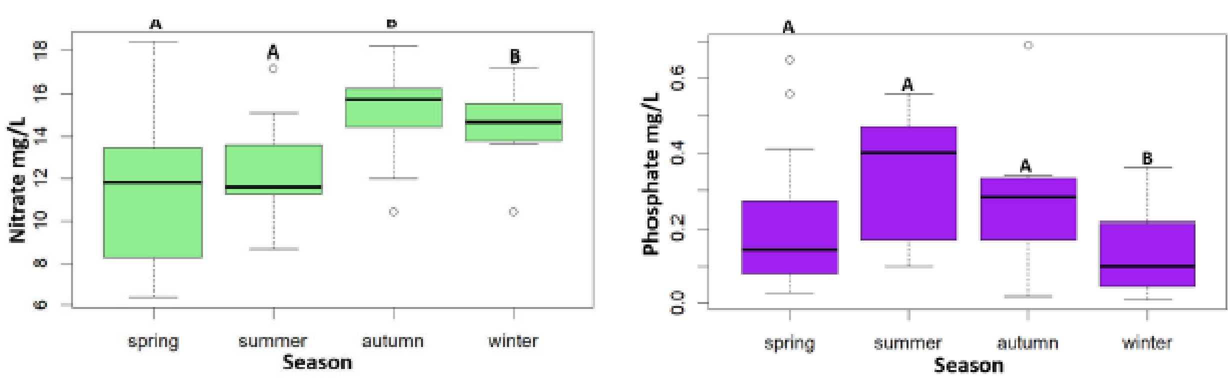
They also found that the lower regions of the soil profile are becoming disconnected and acting as a reservoir of nitrate: "As a rule of thumb, the effective root depth accounts for about 70% of the moisture extracted by the root. This indicates most of the vegetation growing at the LRC is extracting much of the required water and nutrients from the regions of the soil profile shallower than 50-cm during the main growth season. This results in the 50-cm and deeper regions of the soil becoming disconnected, leading to a buildup of nitrate and other nutrients during the warmer summer months. Following the growth season and the deeper regions of the soil matrix become connected to the macropores and karst pathways, a flushing of nitrate occurs from these karst agroecosystems, resulting in elevated nitrate exports throughout the wetter, winter months."

McGill catalogued all fertilization amounts and fields to which they were applied conducted over a multi-year period and evaluated the contributions to stream concentrations. The study found fertilization had little direct impact to the stream but that fertilization contributions by legacy storage: "Our findings suggest fertilization in agricultural practices had limited impact on nitrate concentrations which likely reflect the low application rates of both inorganic and organic fertilizers within the study watershed, although legacy N contributions are likely important. These legacy contributions have been reported to persist for several decades, with nearly 30% of total applied organic N still residing in soil organic matter or leaking into the hydrosphere over a 30-year period."

Camden Creek *E.coli* and Fluorescence

Dapkus (2022), sought to use tryptophan-like fluorescence as an indicator of non-point source pollution in the Inner Bluegrass. His findings did not support the viability of this model. His monitoring, conducted in 2021 and 2022, was consistent with prior studies (Figure 8).

Figure 8: Boxplots of seasonal nutrient concentrations at ARC (Dapkus 2022)



Works Cited:

Agouridis, C. T., Edwards, D. R., Workman, S. R., Bicudo, J. R., Taraba, J. L., Vanzant, E. S., & Gates, R. S. (2004). Effects of cattle grazing and BMPs on stream water quality. In *2004 ASAE Annual Meeting* (p. 1). American Society of Agricultural and Biological Engineers. http://dx.doi.org/10.13031/2013.17667

Bunnell, N. L., Ford, W. I., Fogle, A. W., & Taraba, J. (2020). Reach-Scale Model of Aquatic Vegetation Quantifies N Fate in a Bedrock-Controlled Karst Agroecosystem Stream. *Water*, *12*(9), 2458. https://doi.org/10.3390/w12092458

Bunnell, N. L. (2020). *Quantifying nitrogen fate in karst agroecosystem streams of central Kentucky: development and application of numerical modeling and insight from high-resolution sensors*. Master's thesis: University of Kentucky https://doi.org/10.13023/etd.2020.339

Dapkus, Ryan. (2022). "Tryptophan-Like Fluorescence and Non-Point Source Pollution in Karst Basins, Inner Bluegrass Region, Kentucky" Theses and Dissertations--Earth and Environmental Sciences. 96. https://uknowledge.uky.edu/ees_etds/96

Fogle, A. W., Taraba, J. L., & Dinger, J. S. (2003). Effect of Stream Diurnal Variations on Mass Loads in a Small Agricultural Karst Watershed. https://web.archive.org/web/20060107182939id_/http://rocco.bae.uky.edu:80/uk-arc/downloads/Papers/papers/TMDL.pdf

Fogle, A. W., Taraba, J. L., & Dinger, J. S. (2003). Mass load estimation errors utilizing grab sampling strategies in a karst watershed. *JAWRA Journal of the American Water Resources Association*, *39*(6), 1361-1372. https://doi.org/10.1111/j.1752-1688.2003.tb04423.x

McGill, Timothy, "Assessing Machine Learning Utility in Predicting Hydrologic and Nitrate Dynamics in Karst Agroecosystems" (2022). Theses and Dissertations--Biosystems and Agricultural Engineering. 90. https://uknowledge.uky.edu/bae_etds/90

Radcliff, Cory, William I. Ford, Saeid Nazari, Christopher Shepard. 2021. Impact of water source dynamics on dissolved reactive phosphorus loadings in heterogenous karst agroecosystems with phosphatic limestones. Hydrological Processes. 2021;35:e14422. https://doi.org/10.1002/hyp.14422

Reed, T. M., Fryar, A. E., Brion, G. M., & Ward, J. W. (2011). Differences in pathogen indicators between proximal urban and rural karst springs, Central Kentucky, USA. *Environmental Earth Sciences*, 64(1), 47-55. https://doi.org/10.1007/s12665-010-0816-8

Reed, T.M., McFarland, J.T., Fryar, A.E., Fogle, A.W., Taraba, J.L. (2010). Sediment discharges during storm flow from proximal urban and rural karst springs, central Kentucky, USA. Journal of Hydrology, 383, 280–290. https://doi.org/10.1016/j.jhydrol.2009.12.043

Ford, William I., Admin Husic, Alex Fogle, Joseph Taraba. (2019). "Long-term assessment of nutrient flow pathway dynamics and in-stream fate in a temperate karst agroecosystem watershed." Hydrological Processes. 33(11), 1610-1628. https://doi.org/10.1002/hyp.13427

Ward, J.W., *Reed, T.M., Fryar, A.E., and Brion, G.M., 2009, Using the AC/TC ratio to identify fecal inputs in a karst groundwater basin: Environmental & Engineering Geoscience, v. 15, no. 2, p. 57–65, http://dx.doi.org/10.2113/gseegeosci.15.2.57

Camden Creek Nutrient Evaluation Report

December 2023

J. Adam Shelley[1], Steve Evans[1], Lee Moser[2]

[1]Kentucky Water Research Institute, University of Kentucky; 2 Martin-Gatton College of Agriculture, Food and Environment Cooperative Extension Service

Executive Summary

This research builds upon the efforts of identifying the causes of erosion and the sources of high nutrient concentrations in the Glenns Creek watershed. This understanding is crucial for the effective implementation of Best Management Practices (BMPs) aimed at reducing sediment and nutrient loads within the watershed. Camden Creek, a tributary of Glenns Creek, was identified as a potential source of nutrients; therefore, additional investigations are required to precisely identify the activities contributing to these nutrient inputs for more targeted BMP implementation. From 11/6/2023 – 11/8/2023, KWRI and UKY Extension collected 17 Orthophosphate (PO_4) and 42 Nitrate (NO_3) samples from various points along the longitudinal profile of Camden Creek to provide a comprehensive understanding of the spatial distribution and variability of Orthophosphate (PO_4) and Nitrate (NO_3) concentrations and their relationship with karst terrain and agricultural practices.

Principal Findings:

- Nutrient concentrations varied significantly along Camden Creek, with PO_4 concentrations ranging from 0.07 mg/L to 1.63 mg/L and NO_3 levels varying from 0.31 mg/L to 5.76 mg/L.
- Hot spots for high nutrient concentrations were identified near karst springs, indicating a strong influence of karst hydrology on nutrient contribution. A strong negative correlation was observed between the distance from springs and nitrate concentrations, suggesting a decrease in nutrient levels as the distance from karst springs increased.
- The study highlighted the complexity of nutrient dynamics in a karst-dominated agricultural landscape, pointing to both offsite and onsite sources.
- Sixteen erosion sites were identified during the survey. Almost all the occurrences are related to infrastructure (weirs) that has been installed in the stream.

The findings of the study underscore the need for targeted management strategies in the Glenns Creek watershed. The significant influence of karst inputs on nutrient levels highlights the necessity of integrating karst hydrology into watershed management plans. Furthermore, the contribution of agricultural practices to nutrient concentrations necessitates the implementation of effective Best Management Practices (BMPs) to mitigate the nutrient input into Glenns Creek. These should be tailored to address both the unique characteristics of karst environment and the specific agricultural practices prevalent in the area. The degree of karst influence was determined by a series of visualization, analysis, and statistical techniques, which are detailed below. Additionally, details regarding the karst hydrologic inventory and an overview of hydrogeologic controls have been included to provide an understanding of the dynamic system underlying the University of Kentucky's Research Farm.

Study Area

In the Inner Bluegrass region, groundwater movement occurs through channels in the epikarst, and shallow conduits known as interbasin aquifers and through deeper conduits that penetrate clay-rich layers in the Lexington Limestone. These deeper conduits are referred to as main-stem conduits. The interbasin aquifers are responsible for supplying water to shallow springs and streams that disappear underground, whereas the intrabasin aquifers contribute their flow to the tributaries that flow into the Kentucky River, which serves as the primary base level control for the region's hydrological system (Thrailkill et al., 1982). Camden Creek is an extensively studied fluviokarstic system that flows through the University of Kentucky's C. Oran Little Research Farm, whose area is characterized by rolling hills and a definitive sinkhole plain. The underlying karst terrain was formed in the Middle to Upper Ordovician carbonate rocks of the High Bridge Group Lexington Limestone and the Clays Ferry Formation (KGS, 1985).

Seven major perennial springs and numerous seeps have been documented along Camden Creek and its tributaries. For the purposes of this research, only five of the seven springs will be discussed. The rising bluehole spring, WSP-2 (Figure 1), forms the headwaters of Camden Creek. Sources of recharge for WSP-2 have been identified through dye traces as an unnamed sink and swallet approximately 1.5 km north of WSP-2 (Currens et al., 2002). The recharge area of WSP-2 has been delineated at 2.56 km^2, and the land use within the catchment is predominantly agricultural. Approximately 120 meters downstream, another spring, WSP-1, resurges beneath a limestone shelf from a conduit. The recharge area for WSP-1 is ostensibly localized within the farm boundary, but further tracing is needed for confirmation.

Another notable spring on the property is WSP-7, a fourth-magnitude spring that discharges from Pin Oak Cave and flows into a tributary of Camden Creek (KGS, 1985). The groundwater basin feeding the Pin Oak Spring (WSP-7) has been delineated to 2.98 km^2. The land use for this basin is mixed between residential and agricultural. Additionally, it is necessary to mention that a small seep on an adjacent stream branch contributes some flow to this tributary. However, the source of the seep originates from a different and much smaller groundwater basin whose land use is agriculture. Lastly, the Spring seep, WSP 3/4 is located near the outlet of the largest pond but does not have any tracing data for sourcing.

Methodology

The study, conducted from November 6 to 8, 2023, involved a collaborative effort between the Kentucky Water Resources Institute (KWRI) and the University of Kentucky (UKY) Extension. The primary focus was to document severe erosion sites but the acquisition of a new probe allowed for in-situ sampling and analysis of nutrient concentrations, specifically Orthophosphate (PO_4) and Nitrate (NO_3), in Camden Creek's longitudinal profile. Due to budgetary constraints, PO_4 was sampled at selected sites only. The methodology encompassed site selection, data collection, and comprehensive spatial and statistical analyses. In total, 17 PO_4 and 42 Nitrate NO_3 samples were collected from various points along the longitudinal profile of Camden Creek. PO4 was not collected at every site due to funding constraints.

Sampling Strategy

Site Selection and Planning: Using ArcGIS Pro, sampling sites were strategically chosen and randomly assigned at 100-meter intervals along the creek's centerline. This approach ensured comprehensive coverage of the creek's varying landscapes and features.

Karst Hydrologic Inventory (KHI): Prior to sampling, a detailed KHI was undertaken to identify and incorporate karst features into the sampling plan. Additional sampling points were included at major springs, with some adjustments made due to site accessibility and conditions.

Data Collection

Nutrient Sampling: A HACH SL1000 portable water quality analyzer, equipped with an Intellical™ ISENO3181 Standard Nitrate Ion-Selective-Electrode (ISE) and Orthophosphate Chemkey® Reagents, was used to measure nutrient concentrations.

Indicator Parameter Measurement: Alongside nutrient sampling, indicator parameters such as pH, Specific Conductivity (SpC), and water temperature were recorded at nitrate sample sites using a multi-parameter handheld meter. Regrettably, dissolved oxygen measurements could not be taken due to technical issues with the probe membrane.

Field Documentation: All field data documentation was streamlined using ArcGIS Field Maps on an iOS device, ensuring efficient post-processing and data integrity.

Spatial and Statistical Analysis

Visualization and Spatial Analysis: The initial analysis involved visualizing sample results graphically, followed by spatial analyses to understand the distribution of nitrate concentrations across the creek.

Moran's I Analysis: Performed to assess spatial autocorrelation and determine if high nitrate concentrations were spatially clustered.

Empirical Bayesian Kriging Interpolation: Utilized to rapidly identify areas of high nitrate concentration. The resulting model was optimized through cross-validation and semi-variogram analysis techniques.

Getis-Ord Gi* Analysis: Conducted to pinpoint areas of statistically significant nutrient concentration.

Proximity Analysis and Kruskal-Wallis ANOVA: Used to aggregate data into groups near the springs, and Kruskal-Wallis ANOVA, with Conover's pairwise tests, determined statistical differences in nutrient concentrations among these groups. Sampling locations downstream from the springs that fell into a 152.4 m (500 ft) buffer and had geochemical values reflective of the spring discharge were selected. In total, five groups were selected: WSP-1, WSP-2, WSP-3/4, WSP-7/UNSP-1, and WSP-8.

Non-Parametric Correlation Analysis: Employed to evaluate the relationship between the distance from springs and nitrate concentrations.

Results

The comprehensive analysis of nutrient concentrations in Camden Creek yielded insightful findings. The primary focus was on the spatial distribution and statistical significance of Orthophosphate (PO_4) and Nitrate (NO_3) concentrations, particularly in relation to karst features and agricultural practices in the area.

Nutrient Concentration Findings

Orthophosphate and Nitrate Levels: PO_4 concentrations ranged from 0.07 mg/L to 1.63 mg/L, with a mean of 0.78 mg/L and a median of 0.80 mg/L. The standard deviation was 0.35 mg/L. NO_3 levels varied from 0.31 mg/L to 5.76 mg/L, with an average concentration of 3.017 mg/L and a median of 3.35 mg/L. The standard deviation for nitrate was 1.83 mg/L.

Indicator Parameters

pH, Conductivity, and Temperature: pH values spanned from 6.74 to 8.16, with a mean of 7.576 and a median of 7.65. Conductivity measurements ranged between 349 µS/cm and 665 µS/cm, with a mean of 489.33 µS/cm. Water temperature varied from 6.88°C to 17.63°C, with a mean temperature of 12.35°C.

Parameter	Minimum	Maximum	Mean	Median	Standard Deviation
Orthophosphate (mg/L)	0.07	1.63	0.78	0.8	0.35
Nitrate (mg/L)	0.31	5.76	3.01	3.35	1.83
pH (S.U.)	6.74	8.16	7.57	7.65	0.39
SpC (µS/cm)	349.0	665.0	489.33	514.0	71.18
Temperature (°C)	6.88	17.63	12.35	12.71	2.78

Spatial and Statistical Analysis

Hot and Cold Spot Identification: The Getis-Ord Gi* analysis revealed statistically significant hot spots for nitrate concentrations clustered around the springs, particularly near WSP-7 and WSP-3/4. Proximity analysis was employed to accurately aggregate data into groups reflecting spring discharge influence. In addition, the Getis-Ord Gi* analysis also revealed a band of statistically significant cold spots for nitrate concentrations that were clustered along the main channel of Camden Creek, downstream of any spring influence.

Kruskal-Wallis ANOVA: Since all the springs identified originate from different groundwater sources, it was necessary to determine the significance of concentrations observed at WSP-7/UNSP-1 and WSP-3/4. The Kruskal-Wallis ANOVA analysis, supplemented with post-hoc Conover's pairwise tests, identified statistically significant differences in nutrient concentrations among the spring groups. Notably, concentrations from WSP-7/UNSP-1 were distinct from other springs.

Correlation Analysis: A strong negative correlation (-0.68) was observed between the distance from the springs and nitrate concentrations, indicating that nutrient levels decreased as the distance from the springs increased. This pattern was consistent downstream of the spring influence zones.

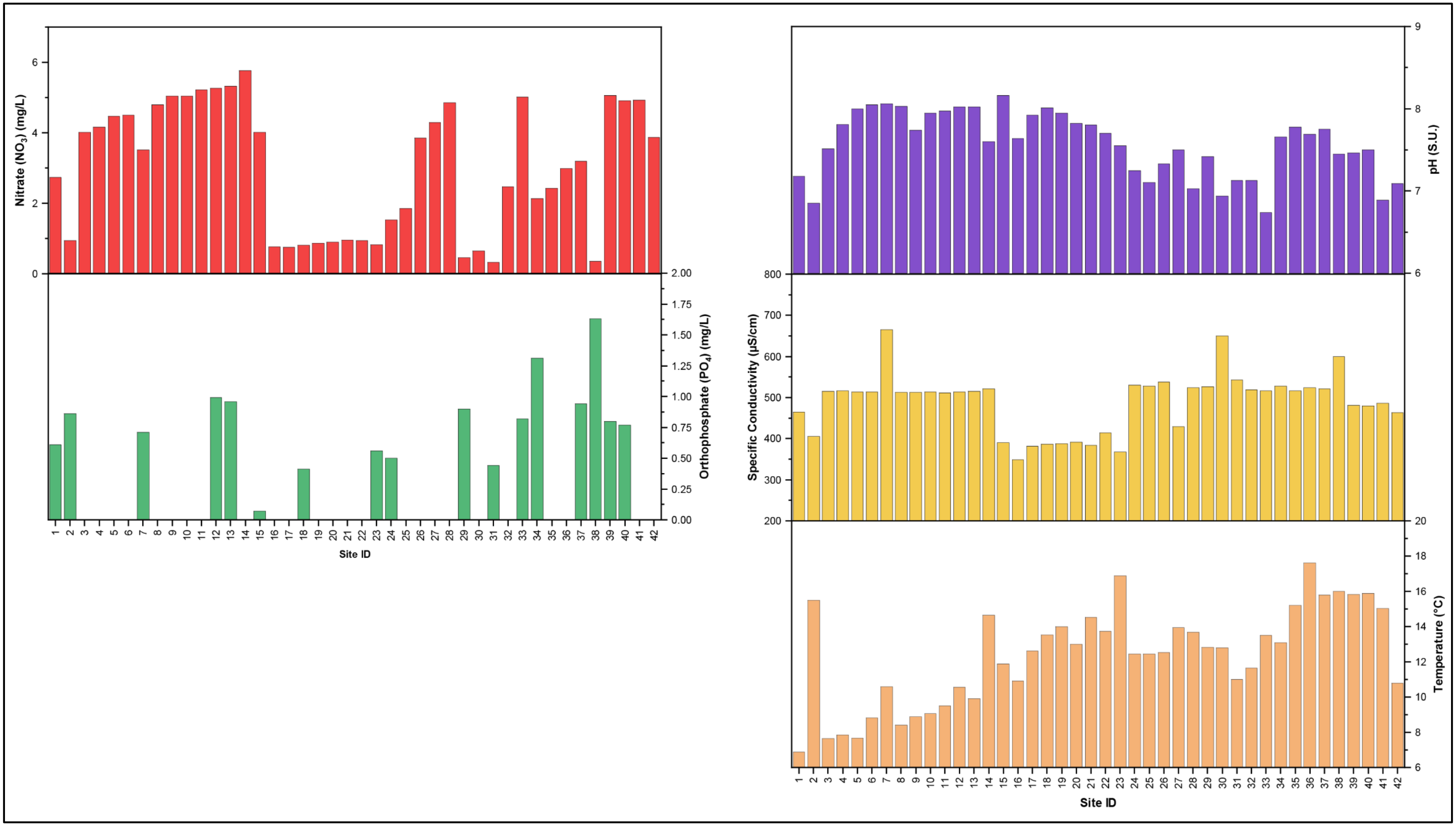


Figure 1: Camden Creek Sample Site Results

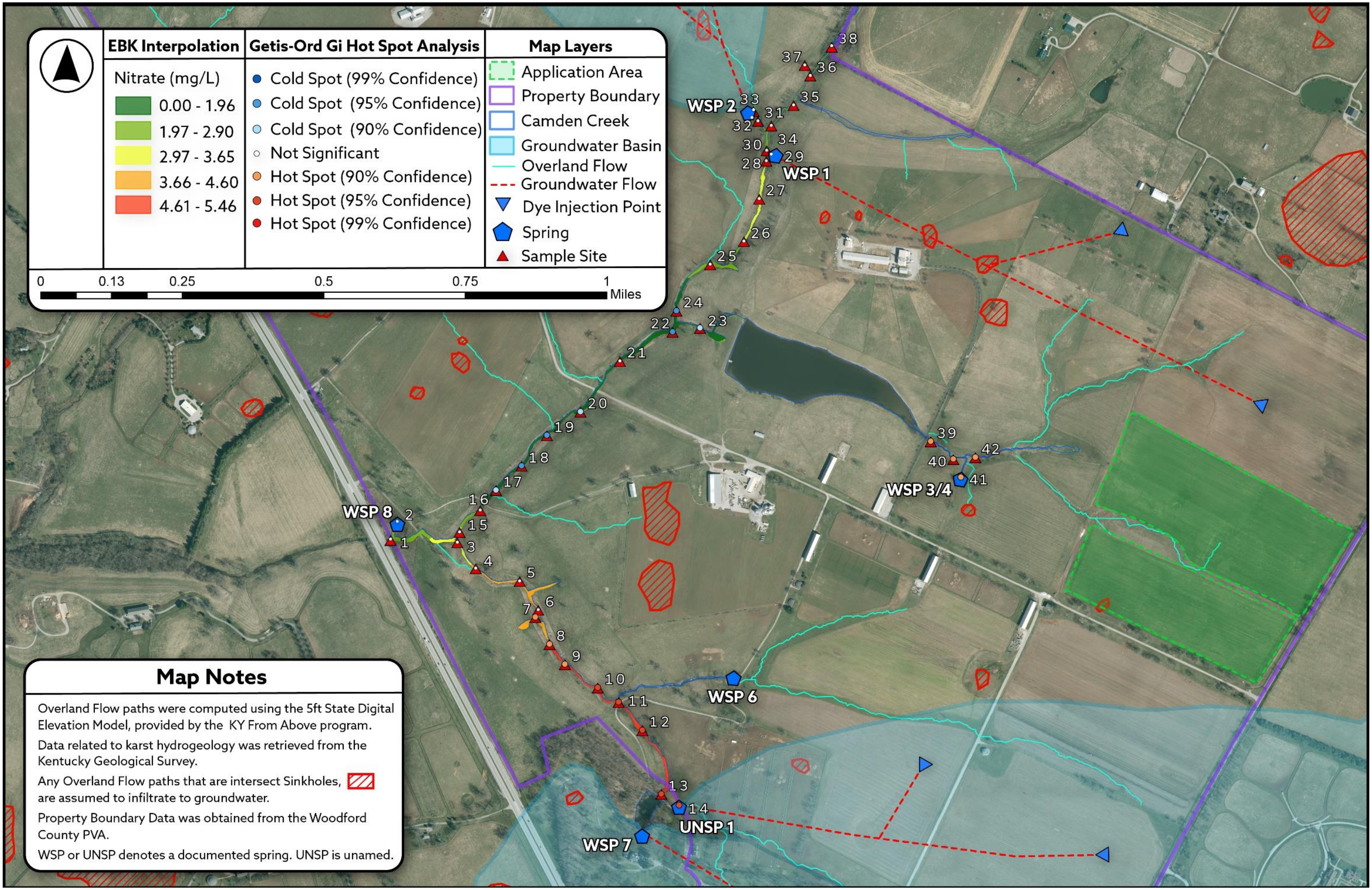


Figure 2: Camden Creek Study Area/Analysis Map

Conclusions

The results indicate a significant influence of karst inputs on nutrient levels in Camden Creek. The highest concentrations of NO_3 and PO_4 were consistently found near karst springs, suggesting a link between karst hydrology and nutrient contribution. Notably, the measurements at and near WSP 7 and WSP 3/4 were identified as statistically significant hot spots. The presence of statistically significant cold spots for nitrate concentrations along the main channel of Camden Creek, downstream of spring influences, implies that the high density of duckweed (Lemma Minor) and other vegetation attenuates the nutrient concentrations downstream of the springs. Based on the detailed Karst Hydrologic Inventory (KHI) and analyses, it is likely that the increased nutrient concentrations within Camden Creek are attributable to offsite sources. Furthermore, the findings suggest that while offsite sources significantly contribute to nutrient concentrations in Camden Creek due to the density of sinkholes and karst inputs, onsite agricultural practices, particularly manure application, cannot be overlooked as a contributing factor. It is worth noting that overland flow not intercepted by the karst system does flow directly into the creek from the manure application areas (WSP 3/4). Moreover, this is the case for many of the fields on the property. This emphasizes the complexity of nutrient dynamics in karst-dominated agricultural landscapes and underscores the importance of integrated watershed management approaches. These results offer a detailed understanding of the spatial variability of nutrient concentrations in Camden Creek, highlighting the need for targeted management strategies that consider both karst hydrology and land use practices.

References

Currens, J.C., Paylor, R.L., and Ray, J.A., 2002. Mapped karst ground-water basins in the Lexington 30 × 60 minute quadrangle. Kentucky Geological Survey, Series 11, Map and Chart Series 10, 1 sheet.

Kentucky Geological Survey, 1985. Caves and Karst of Kentucky. SPECIAL PUBLICATION 12, Series XI.

Thrailkill, J., 1989. Shallow conduit-flow carbonate aquifers: conceptual models and parameter evaluation. In: Moore, J.E., Zaporozec, A.A., Csallany, S.C., and Varney, T.C. (Eds.), Recent advances in ground-water hydrology. American Institute of Hydrology, Minneapolis, MN, pp. 153-159.

Appendix C: Glenns Creek stakeholder prioritized list of conservation practices with pollutant reduction efficiencies

Agricultural BMPs:

Practice Code	Conservation Practice	Community Prioritization (1 low to 4 high)	% Reduction			
			E. coli	N	P	Sed
R-1	Land Retirement	3.44	0	18*	0	377*
R-1	Conversion to Hay or Pasture	3.44	0	17*	0	489*
R-2	Crop Nutrient Management	3.55	0	8	10	0
R-3	Conservation Tillage and Crop Residue Use	3.82	0	8	41	49
R-3	Cover Crop	3.82	0	23	3	4
R-4	Contour Farming	3.40	0	28	40	34
R-4	Terrace	3.40	0	25	31	40
R-5	Phosphorus Removal Systems	2.09	0	0	50	60
R-5	Saturated Buffers	2.09	0	20	0	0
R-5	Denitrifying Ditch Bioreactors	2.09	0	20	0	0
R-6	Irrigation Water Capture Reuse	1.50	0	25	4	40
R-6	Drainage Water Level Control Structures	1.50	0	35	55	70
R-6	Blind Inlet Drainage Control	1.50	0	33	0	0
R-7	Precision Intensive Rotational/Prescribed Grazing	3.91	69	10	24	30
R-7	Dairy Precision Feeding and Forage Management	3.91	0	24	25	0
R-7	Horse Pasture Management	3.91	0	0	20	40
R-8	Livestock Shade Structures	3.40	85	0	0	0
R-9	Livestock Exclusion Fencing	3.91	42	20	30	62
R-9	Off Stream Watering Without Fencing	3.91	85	5	8	10
R-9	Streambank Stabilization and Fencing	3.91	0	15	22	58
R-9	Streambank Protection w/o Fencing	3.91	0	75	75	75
R-9	Limited / Gated Stream Crossing	3.91	46	0	0	0
R-10	Barnyard / Feedlot Stormwater Runoff Control	3.64	96	45	70	40
R-10	Loafing Lot / Heavy Use Area Management	3.64	96	20	20	40
R-10	Feedlot Solids Separation Basin	3.64	0	35	56	0
R-11	Animal Waste Management System	2.55	0	80	90	0
R-11	Animal Waste Storage Facility	2.55	0	65	60	0
R-12	Manure Injection	3.22	0	10	24	0
R-12	Manure Treatment (Thermochemical)	3.22	0	60	0	0
R-12	Manure Treatment (Composting)	3.22	0	22	0	0
R-12	Manure Incorporation	3.22	0	8	17	0
R-13	Poultry Litter Storage and Management	2.70	0	14	14	0
R-14	Soil Conservation and Water Quality Plans	3.91	0	6	10	17
R-15	Wetland	3.63	0	25	28	18
R-16	Septic Tank Pumping	3.91	0	5	0	0

* Avg lbs./acre

Agricultural BMPs (continued):

Practice Code	Conservation Practice	Community Prioritization (1 low to 4 high)	% Reduction			
			E. coli	N	P	Sed
R-16	Advanced Septic Denitrification	3.91	0	63	0	0
R-16	Advanced Septic Effluent	3.91	0	44	0	0
R-16	Advanced Septic Secondary Treatment	3.91	0	40	0	0

Streamside BMPs:

Practice Code	Conservation Practice	Community Prioritization (1 low to 4 high)	% Reduction			
			E. coli	N	P	Sed
S-1	Two-Stage Ditch	2.68	0	12	28	31
S-2	Riparian Buffer: Forested 32 - 65 Feet	3.88	0	46	66	87
S-2	Riparian Buffer: Grass 32 - 65 Feet	3.88	0	46	77	90
S-2	Riparian Buffer: Grass/Woody 32 - 65 Feet	3.88	0	65	83	91
S-2	Riparian Buffer: Grass 16 - 32 Feet	3.88	0	43	38	51
S-3	Bank Restoration	2.43	0	0	0	248 lbs./ft/year
S-3	Bank Armoring	2.43	0	0	0	248 lbs./ft/year
S-4	Stream channel structures	2.97	0	0	0	248 lbs./ft/year
S-4	Low-head dam removal	2.97	0	0	0	0
S-5	Vegetated Filter Strip	3.37	79	0	85	52
S-5	Grassed swales	3.37	0	28	23	60

Urban BMPs:

Practice Code	Conservation Practice	Community Prioritization (1 low to 4 high)	% Reduction			
			E. coli	N	P	Sed
U-1	Urban Nutrient Management Plan	2.67	0	13	7	0
U-2	Conservation Landscaping Practices	3.17	0	39	25	0
U-2	Bioretention/raingardens - A/B soils	3.17	43	75	80	85
U-2	Bioretention/raingardens - C/D soils	3.17	43	25	45	55
U-3	Rainwater Harvesting (Cisterns and Rain Barrels)	2.67	0	0	0	55
U-4	Tree Planting	3.83	0	85	91	82
U-5	Green Roofs	1.67	0	0	0	0
U-6	Permeable Pavement w/ Veg. - A/B soils, no underdrain	2.17	0	48	50	70
U-6	Permeable Pavement w/ Veg. - A/B soils, underdrain	2.17	0	78	80	85
U-6	Permeable Pavement w/ Veg. - C/D soils, underdrain	2.17	0	15	20	55
U-7	Tree Box / Tree Trench	3.00	0	52	65	85
U-8	High-Rate Media Filtration	2.00	0	47	33	59
U-8	Sand and Organic Filters	2.00	0	16	45	84
U-8	High-Rate Biofiltration	2.00	0	0	49	88
U-9	Catch Basin Inserts	3.17	0	0	40	36
U-9	Hydrodynamic Separation Devices	3.17	0	0	23	39
U-9	Oil/Grit Separators and Baffle Boxes	3.17	0	0	64	57
U-10	Underground Detention	2.50	83	30	60	82
U-11	Infiltration Basin	2.50	0	83	85	95
U-11	Infiltration Trench	2.50	0	55	60	75
U-12	Stormwater Wetland	3.40	86	0	28	61
U-12	Settling basin	3.40	0		52	82
U-12	Wet Pond	3.40	83	26	51	76
U-12	Wetland Channel	3.40	0	18	0	0
U-13	Dry Detention Ponds	2.60	44	0	26	66
U-14	Dry Well	1.60	0	0	0	0
U-15	Alum Injection	1.00	0	60	90	95
U-16	Street Sweeping	2.75	0	2	6	12
U-17	Wastewater Treatment Plant Nutrient Optimization	3.75	0	50	36	0
U-17	Sanitary Sewer Overflow Abatement	3.75	500,000 cfu/100mLs	9.5 mg/L	1.9 mg/L	370 mg/L
U-17	Sanitary sewer replacement or rehab	3.75	1,500,000 cfu/100mLs	33 mg/L	5.8 mg/L	370 mg/L