FINAL MY1 MONITORING REPORT

MILLSTONE CREEK MITIGATION SITE

Randolph County, North Carolina
Cape Fear River Basin
Cataloging Unit 03030003

DMS Project No. 204
Contract No. 6741
USACE Action ID No. 2018-01788
DWR Project No. 16-1200
DMS Monitoring RFQ No. 16-1447847489 (issued 1/31/2025)

Data Collection: April 2025-November 2025
Submission: January 2026

Prepared for:

NORTH CAROLINA DEPARTMENT OF ENVIRONMENTAL QUALITY
DIVISION OF MITIGATION SERVICES
1652 MAIL SERVICE CENTER
RALEIGH, NORTH CAROLINA 27699-1652

Mitigation Services
ENVIRONMENTAL QUALITY

Millstone Creek Year 1, 2025 Monitoring Summary

General Notes
- No encroachment was identified in MY1 (2025).
- No evidence of nuisance animal activity (i.e., heavy deer browsing, beaver activity, etc.) was observed.

Streams
- All streams within the Site are stable and functioning as designed. Site streams continue to maintain an ordinary high-water mark, and no cross-sections have bank height ratios greater than 1.2.
- NT R1 and UTA R1 each maintained flow for well over 30 consecutive days during MY1 (2025) with 203 and 187 days, respectively. Refer to Appendix A for the visual stream morphology stability assessment (Tables 4A-G) and stream photographs, Appendix C for stream geomorphology data, and Appendix D for stream flow data. No stream areas of concern were identified during MY1 (2025).
- Two bankfull events were documented during MY1 (2025) (Table 11, Appendix D).

Vegetation
- Measurement of the 15 vegetation plots (11 permanent plots and 4 temporary transects) resulted in an average of 162 approved stems/acre. Only one of the 11 permanent plots and none of the 4 temporary transects met the MY3 interim success criteria of 320 stems per acre. Transects 3 and 4 would have met density success criteria with 8 and 9 stems, respectively; however, they failed to meet diversity requirements, and therefore each stem beyond 50% species composition was not included in the stem density calculation. Plots 2 and 11 were each two stems shy of meeting MY3 interim success criteria.
- Areas of low stem density and invasives species were mapped during MY1 (2025). Approximately 1.50 acres are considered to be low stem density areas, and 0.70 acres of invasive species were catalogued (Table 5, Appendix A).

Wetlands
- Both groundwater gauges met success criteria during MY1 (2025) with hydroperiods of 87.3% and 9.8%. (Appendix D).

Year 1 (2025) Groundwater Hydrology Data

Gauge	8% Hydroperiod Success Criteria Achieved - Max Consecutive Days During Growing Season* (Percentage)						
	Year 1 (2025)	Year 2 (2026)	Year 3 (2027)	Year 4 (2028)	Year 5 (2029)	Year 6 (2030)	Year 7 (2031)
1	Yes – 214 Days (87.3%)						
2	Yes – 24 Days (9.8%)						

*Growing season from 3/16 to 11/15

Site Monitoring Activity and Reporting History

Project Milestones	Stream Monitoring Complete	Vegetation Monitoring Complete	Wetland Monitoring	Data Analysis Complete	Completion or Delivery
Construction Earthwork*	--	--	--	--	October 2021 & February 2024
Planting*	--	--	--	--	December 2021 & February 2024
As-Built Documentation*	April 2022 & April 2024	April 2022 & April 2024	--	June 2022 & October 2024	October 2024
Year 1 Monitoring	April 16, 2025	July 31, 2025	March-Nov 2025	December 2025	December 2025

*Site grading, planting, and as-built documentation were conducted in two phases. A Final as-built document was submitted in October 2024, after both phases of the site were constructed.

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Mitigation Services
ENVIRONMENTAL QUALITY

Prepared by:

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919-215-1693 (phone)

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1 PROJECT SUMMARY

North Carolina State University (NCSU) developed and implemented the Millstone Creek Stream and Wetland Mitigation Site (Site) for the North Carolina Division of Mitigation Services (NCDMS). The site is located on two parcels along unnamed tributaries to Millstone Creek in the Piedmont ecoregion of North Carolina. Located in the Cape Fear River Basin, cataloging unit 03030003, the Site is not located within a LWP or TRA. The downstream drainage area of the Site is 8.3 square miles and contains primarily agricultural and wooded land.

1.1 Project Background, Components, and Structure

Located approximately 3 miles southwest of the town of Ramsuer off Highway 22 in Randolph County, the Site encompasses 18.8 acres. Mitigation work included restoration and enhancement I of 3,576 linear feet of perennial stream channels and hydrologic enhancement to an existing 1.323-acre jurisdictional wetland. The Site is expected to provide 3,151.907 Stream Mitigation Units (SMUs) and 0.662 Riparian Wetland Mitigation Units (WMUs) by closeout, with an additional 31.620 SMUs available pending validation of proposed water quality improvements. Water quality sampling is being handled by NCSU through a contract with NCDMS. Site mitigation quantities and credits are summarized in Table 1.

Before construction, land use at the Site was characterized by pastures that were heavily impacted by cattle grazing and the application of swine waste from a confined hog operation. Site work was completed in two phases in order to accommodate a paired watershed study to evaluate the effectiveness of Regenerative Stormwater Conveyance for removing nutrients and sediment in both storm flow and baseflow. Site design was completed in July 2020. Phase I construction was completed in September 2021, and planting was completed in December 2021. Phase II construction and planting were completed in February 2024. Completed project activities, reporting history, completion dates, and project contacts are summarized in Tables 14-15 (Appendix E).

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Table 1. Millstone Creek (Ken Cox) Mitigation Site (ID-204) Project Mitigation Quantities and Credits

Project Segment	Project Phase	Original Mitigation Plan Ft/Ac	As-Built Ft/Ac	Original Mitigation Category	Original Restoratio Level	Original Mitigation Ratio (X:1)	Baseline Credits	WQ Monitoring 4%*	Functional Uplift 2%**	Comments
Stream										
NT R1	1	326	326	Warm	R	1.00000	326.000	13.040	6.520	Design = traditional restoration & RSC media
NT R2	1	103	103	Warm	R	1.00000	103.000	4.120	2.060	Design = traditional restoration & RSC media
Ut A R1	2	523	516	Warm	R	1.00000	516.000	20.640	10.320	WQ station & macrobenthic monitoring yrs 3,5,7
UT A R2	2	100	101	Warm	R	1.00000	101.000	4.040	2.020	WQ station & macrobenthic monitoring yrs 3,5,7
UT B	1	529	523	Warm	R	1.00000	523.000	20.920	10.460	WQ station & macrobenthic monitoring yrs 3,5,7
MC R1	1	1462	1462	Warm	E	1.50000	974.667	0.000	0.000	Macrobenthic monitoring yrs 3,5,7
MC R2	1	533	537	Warm	R	1.00000	537.000	0.000	0.000	Macrobenthic monitoring yrs 3,5,7
						Total:	**3,080.667**	**62.760**	**31.380**	
						Total Stream Credits	**3,143.427**		**3,174.807**	3,151.907 fixed credits; 3,183.527 if 20% total N reduction is achieved
Wetland										
Wetland I	1	1.323	NA	R	E	2.00000	0.662			hydrological improvements
						Total:	**0.662**			

* WQ monitoring data collected

** Dependent upon water quality functional uplift metric achieved

Project Credits

Restoration Level		Stream (Min./Max) Warm	Cool	Cold	Riparian Wetland	Non-Rip Wetland	Coastal Marsh
Restoration		2,168.760 2,200.140					
Re-establishment							
Rehabilitation							
Enhancement					0.662		
Enhancement I		974.667					
Enhancement II							
Creation							
Preservation							
Totals	**min.**	**3,143.427**			**0.662**		
	max.	**3,174.807**			**0.662**		

Table 2: Summary: Goals, Performance and Results

Goal	Treatment	Likely Functional Uplift	Performance Criteria	Measurement	Cumulative Monitoring Results
Enhance processing of nutrients from onsite sources.	Construct stream and wetland systems designed to process nitrogen and phosphorus.	Reduction in sediment and nutrient inputs and treatment. Improved water quality and aquatic habitat.	- Saturation or inundation within the upper 12 inches of the soil surface for, at a minimum, 8% of the growing season during average climatic conditions. - 20% decrease in total N concentrations on NT and UT A (only required for additional 2% SMUs)	- Two groundwater gauges installed in wetland to document enhanced wetland hydrology. - Supplemental water quality monitoring of discharge and TN concentrations downstream of NT R2 and UTA R2.	Both groundwater gauges exceeded the 8% hydroperiod performance standard in MY1.
Improve stream channel stability.	Grade streambanks, Construct stream channels with appropriate bankfull channel dimensions, planform geometry and profile such that channel maintenance and adjustments are representative of other natural systems.	Decrease sediment inputs from channel and bank erosion. Efficiently transport sediment loads and stream flow.	Stable channels with BHR less than 1.2.	Monitoring of 10 cross-sections & visual assessment.	MY1 cross-section measurements indicate no significant deviations from Site design.
Improve instream habitat.	Install habitat features and structures, add LWD, increase bedform diversity, improve in-stream water quality.	Increase in available habitat for macroinvertebrates and fish leading to an increase in biodiversity.	There is no required performance standard for this metric.	Visual assessment and macroinvertebrate surveys conducted via Supplemental Monitoring.	Reported in MY3, MY5 & MY7.
Restore native riparian vegetation.	Plant native tree, understory and grass species in riparian zones, streambank and wetland areas.	Reduce sediment inputs from bank erosion. Increase nutrient processing, uptake and storage within the floodplain. Create riparian habitats. Add a source of LWD and organic material to stream.	- In planted open areas, the survival rate of 320 stems per acre at MY3, 260 planted stems per acre at MY5, and 210 stems per acre at MY7. - Trees in each plot must average 7 feet in height by MY5 and 10 feet by MY7.	11 permanent and 4 mobile 100-square meter vegetation plots placed on 2% of the planted area of the Site and monitored annually.	11 permanent veg plots have been installed and surveyed. 4 mobile veg transects were also surveyed.
Permanently protect site resources from local disturbance including livestock	A conservation easement has been secured and recorded for the Site. A livestock exclusion fence and watering system has been installed with NC DMS funding.	Protection of the Site from encroachment into the conservation easement and direct impact to streams. Supports all functions including Hydrology (reach-scale), Hydraulic, Geomorphology, Physicochemical, and Biology.	Prevent easement encroachment.	Visually inspect the perimeter of the Site to ensure no easement encroachment is occurring.	No easement encroachments.

Table 3. Project Attribute Table

<table>
<tr><th colspan="5">PROJECT INFORMATION</th></tr>
<tr><td>Project Name</td><td>Millstone Creek Mitigation Site</td><td>County</td><td colspan="2">Randolph County</td></tr>
<tr><td>Project Area (acres)</td><td>18.8</td><td>Project Coordinates</td><td colspan="2">N35°41'48.06" W79°37'26.24"</td></tr>
<tr><th colspan="5">PROJECT WATERSHED SUMMARY INFORMATION</th></tr>
<tr><td>Physiographic Province</td><td>Piedmont</td><td>River Basin</td><td colspan="2">Cape Fear</td></tr>
<tr><td>USGS HUC 8-digit</td><td>3030003</td><td>USGS HUC 14-digit</td><td colspan="2">3040101070010</td></tr>
<tr><td>DWR Sub-basin</td><td>3/6/2009</td><td>Land Use Classification</td><td colspan="2">48% pasture, 35% forested, 5% shrub, 7% grassland, 4% developed</td></tr>
<tr><td>Project Drainage Area (sq. mi)</td><td>8.3</td><td>Percentage of Impervious Area</td><td colspan="2"><1%</td></tr>
<tr><th colspan="5">RESTORATION TRIBUTARY SUMMARY INFORMATION</th></tr>
<tr><th>Parameters</th><th>Millstone</th><th>NT</th><th>UTA</th><th>UTB</th></tr>
<tr><td>Pre-project length (feet)</td><td>1,995</td><td>429</td><td>623</td><td>529</td></tr>
<tr><td>Post-project (feet)</td><td>1,999</td><td>429</td><td>617</td><td>523</td></tr>
<tr><td>Valley confinement</td><td>Unconfined</td><td>Confined</td><td>Confined</td><td>Confined</td></tr>
<tr><td>Drainage area (acres)</td><td>5312</td><td>25</td><td>26</td><td>56</td></tr>
<tr><td>Perennial, Intermittent, Ephemeral</td><td>Perennial</td><td>Perennial</td><td>Perennial</td><td>Perennial</td></tr>
<tr><td>DWR Water Quality Classification</td><td colspan="4">C</td></tr>
<tr><td>Dominant Stream Classification (existing)</td><td>E5 / C5</td><td>G5 / F5</td><td>F5</td><td>G5 / E5</td></tr>
<tr><td>Dominant Stream Classification (proposed)</td><td>C5</td><td>B5</td><td>B5</td><td>E5</td></tr>
<tr><td>Dominant Evolutionary class (Simon) if applicable</td><td>Stage IV</td><td>Stage III</td><td>Stage III</td><td></td></tr>
<tr><th colspan="5">REGULATORY CONSIDERATIONS</th></tr>
<tr><th>Parameters</th><th>Applicable?</th><th>Resolved?</th><th colspan="2">Supporting Documentation</th></tr>
<tr><td>Water of the United States - Section 404</td><td>Yes</td><td>Yes</td><td colspan="2" rowspan="2">USACE Nationwide Permit No. 27 and DWQ 401 Water Quality Certification No. 16-1200</td></tr>
<tr><td>Water of the United States - Section 401</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Endangered Species Act</td><td>Yes</td><td>Yes</td><td colspan="2" rowspan="2">Categorical Exclusion in Mitigation Plan (NCSU, 2020)</td></tr>
<tr><td>Historic Preservation Act</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Coastal Zone Management Act (CZMA or CAMA)</td><td>N/A</td><td>N/A</td><td colspan="2">N/A</td></tr>
<tr><td>Essential Fisheries Habitat</td><td>N/A</td><td>N/A</td><td colspan="2">N/A</td></tr>
</table>

1.2 Success Criteria

Monitoring and success criteria for stream restoration should relate to project goals and objectives identified in the Site mitigation plan. From a mitigation perspective, several of the goals and objectives are assumed to be functionally elevated by restoration activities without direct measurement. Other goals and objectives will be considered successful upon achieving success criteria. The following table summarizes Site success criteria.

Table A. Success Criteria

Streams
• Bank height ratios shall not exceed 1.2 and entrenchment ratios shall be at least 1.4 for restored B channels and 2.2 for restored E/C channels to be considered stable. • Visual assessments and photo documentation should indicate that streams are remaining stable and do not exhibit a trend toward systematic instability. • Four bankfull flow events must be documented within the seven-year monitoring period. The four bankfull events must occur in separate years. • Water quality treatment success criteria will be a statistically significant decrease in Total Nitrogen (TN) concentrations in stormflow and base flow samples when compared to the pre-mitigation monitoring data. Success will yield an additional 2% (at risk) of SMUs for NT R1, NT R2, UTA R1, and UTA R2. There will be no loss of credits for failure to meet this performance standard. • Intermittent streams will demonstrate at least 30-days consecutive flow.
Wetland Hydrology
• Annual saturation or inundation within the upper 12 inches of the soil surface for, at a minimum, 8 percent of the growing season* during average climatic conditions.
Vegetation
• Within planted portions of the site, a minimum of 320 stems per acre must be present at year 3; a minimum of 260 stems per acre must be present at year 5; and a minimum of 210 stems per acre must be present at year 7. • Trees must average 7 feet in height at year 5 and 10 feet in height at year 7 in each plot.

* The growing season was not defined in the Site mitigation plan, however, based on the latest 30-year WETS data, it will be defined as March 16 to November 15 (NOAA RRCs 2025).

2 METHODS

Monitoring will be conducted in accordance with 2016 North Carolina Interagency Review Team (NCIRT) Guidelines. Monitoring will be conducted by Axiom Environmental, Inc based on the schedule in Table B. A monitoring summary is outlined in Table C. Annual monitoring reports will be submitted to NCDMS no later than December 1 of each monitoring year.

Table B. Monitoring Schedule

Resource	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Streams	X	X	X		X		X
Wetlands	X	X	X	X	X	X	X
Vegetation	X	X	X		X		X
Macroinvertebrates			X		X		X
Visual Assessment	X	X	X	X	X	X	X
Report Submittal	X	X	X	X	X	X	X

Table C. Monitoring Summary

Stream Parameters				
Parameter	**Method**	**Schedule/Frequency**	**Number/Extent**	**Data Collected/Reported**
Stream Profile	Full longitudinal survey	As-built (unless otherwise required)	All restored stream channels	Graphic and tabular data.
Stream Dimension	Cross-sections	Years 1, 2, 3, 5, and 7	Total of 10 cross-sections on restored channels	Graphic and tabular data.
Channel Stability	Visual Assessments	Yearly	All restored stream channels	Areas of concern will be depicted on a plan view figure with a written assessment and photographs
	Additional Cross-sections	Yearly	Only if instability is documented during monitoring	Graphic and tabular data.
Stream Hydrology	Continuous monitoring of surface water gauges	Continuous recording through the monitoring period	4 surface water gauges; 1 each on MC2, UTB, NTR1, and UTAR1	Surface water data for each monitoring period
Bankfull Events	Continuous monitoring of surface water gauges	Continuous recording through the monitoring period		Surface water data for each monitoring period
	Visual/Physical Evidence	Continuous through the monitoring period	All restored stream channels	Visual evidence, photo documentation, and/or rain data.
Wetland Parameters				
Parameter	**Method**	**Schedule/Frequency**	**Number/Extent**	**Data Collected/Reported**
Wetland Enhancement (Hydrologic)	Groundwater gauges	Years 1- 7 throughout the year with the growing season defined as March 16-November 15* downloaded quarterly	2 gauges spread throughout enhanced wetlands	Groundwater and rain data for each monitoring period
Vegetation Parameters				
Parameter	**Method**	**Schedule/Frequency**	**Number/Extent**	**Data Collected/Reported**
Vegetation Establishment and Vigor	Permanent vegetation plots 0.0247 acre (100 square meters) in size; *CVS-EEP Protocol for Recording Vegetation*, *Version 4.2* (Lee et al. 2008)	As-built, Years 1, 2, 3, 5, and 7	11 plots spread across the Site	Species, height, planted vs. volunteer, stems/acre
	Annual random vegetation plots, 0.0247 acre (100 square meters) in size	As-built, Years 1, 2, 3, 5, and 7	4 random transects spread across the Site	Species and height

* The growing season was not defined in the Site mitigation plan, however, based on the latest 30-year WETS data, it will be defined as March 16 to November 15 (NOAA RRCs 2025).

3 MONITORING YEAR 1 – DATA ASSESSMENT

Annual monitoring and site visits were conducted between April and November 2025 to assess the condition of the project. Stream, wetland, and vegetation criteria for the Site follow the approved success criteria presented in the Mitigation Plan and summarized in Section 1.2; monitoring methods are detailed in Section 2.

3.1 Stream Assessment

Morphological surveys for MY1 were conducted on April 16, 2025. All streams within the Site are stable and functioning as designed. Site streams continue to maintain an ordinary high-water mark, and no cross-sections have bank height ratios greater than 1.2. Additionally, NT R1 and UTA R1 each maintained flow for well over 30 consecutive days during MY1 (2025) with 203 and 187 days, respectively. Refer to Appendix A for the visual stream morphology stability assessment (Tables 4A-G) and stream photographs, Appendix C for stream geomorphology data, and Appendix D for stream flow data. No stream areas of concern were identified during MY1 (2025).

Two bankfull events were documented during MY1 (2025) (Table 11, Appendix D).

3.2 Hydrology Assessment

Both groundwater gauges met success criteria during MY1 (2025) with hydroperiods of 87.3% and 9.8%, respectively. (Appendix D).

3.3 Vegetative Assessment

The MY1 (2025) vegetative survey was completed on July 31, 2025. Measurement of the 15 vegetation plots (11 permanent and 4 temporary transects) resulted in an average of 162 approved stems/acre. Only one of the 11 permanent plots and none of the 4 temporary transects met the MY3 interim success criteria of 320 stems per acre. Transects 3 and 4 would have met density success criteria with 8 and 9 stems, respectively; however, they failed to meet diversity requirements, and therefore each stem beyond 50% species composition was not included in the stem density calculation. Plots 2 and 11 were each two stems shy of meeting MY3 interim success criteria. Vegetation plot data are summarized in Tables 7 and 8 (Appendix B).

Areas of clearly low stem density and dense invasives species were mapped during MY1 (2025). 1.45 acres were observed to be low stem density areas, and 0.19 acres of invasive species (dense Chinese privet and multiflora rose) were catalogued (Figure 1 and Table 5, Appendix A).

3.4 Monitoring Year 1 Summary

Overall, the Site looks good, is performing as intended, and is on track to meet stream and wetland success criteria. Wetland hydrologic improvement is evident, and all streams within the Site are stable and are meeting project goals. Planted vegetation has experienced significant mortality since the original plantings in 2021 and 2024 and is not on track to meet the MY3 interim requirement of 320 planted stems per acre. An adaptive management plan will be proposed to be implemented during MY2 (2026).

4 REFERENCES

Lee, M.T., R.K. Peet, S.D. Roberts, and T.R. Wentworth. 2008. CVS-EEP Protocol for Recording Vegetation. Version 4.2. North Carolina Department of Environment and Natural Resources, Ecosystem Enhancement Program. Raleigh, North Carolina.

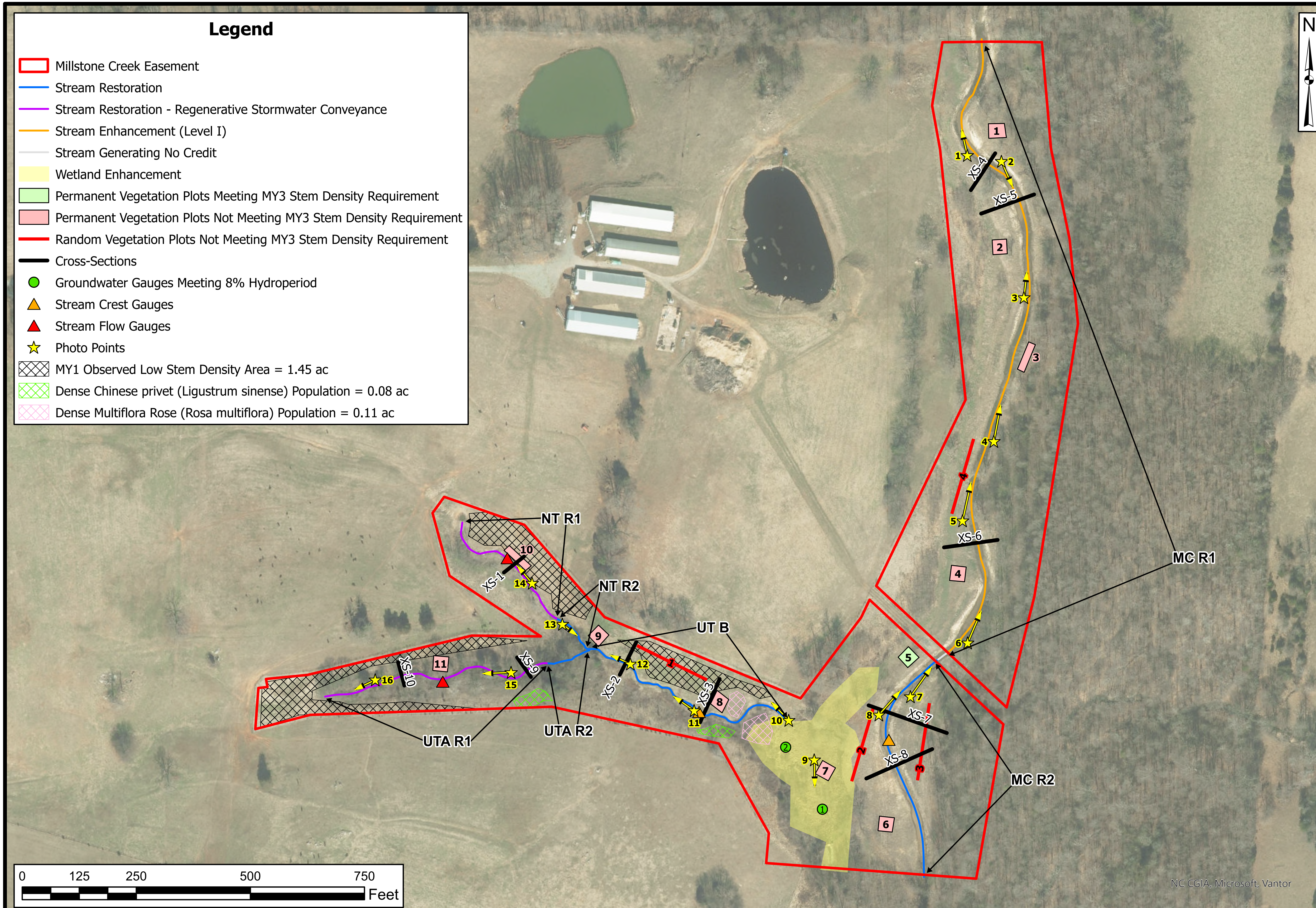
National Oceanic and Atmospheric Administration (NOAA) Regional Climate Centers (RCCs). 2025. Agricultural Applied Climate Information System (AgACIS). Climate Analysis for Wetlands

North Carolina Division of Mitigation Services (NCDMS). 2014. Stream and Wetland Mitigation Monitoring Guidelines. North Carolina Department of Environmental Quality, Raleigh, North Carolina.

North Carolina Interagency Review Team (NCIRT). 2016. Wilmington District Stream and Wetland Compensatory Mitigation Update. October 24, 2016.

North Carolina State University. 2025. North Carolina State Climate Office. Products: Station Scout. KSCR Siler City Municipal Airport. https://products.climate.ncsu.edu/cardinal/scout/?station=KSCR.

Appendix A: Visual Assessment Data



Axiom Environmental, Inc.

Prepared for:

Mitigation Services
ENVIRONMENTAL QUALITY

Project:

MILLSTONE CREEK MITIGATION SITE

Randolph County, NC

Title:

CURRENT CONDITIONS PLAN VIEW

Drawn by: KRJ

Date: DEC 2025

Scale: 1:2,400

Project No.: 25-010

FIGURE

1

Table 4A. Visual Stream Morphology Stability Assessment Table
North Tributary Reach 1

Major Channel Category		Metric	Number Stable, Performing as Intended	Total Number in As-built	Amount of Unstable Footage	% Stable, Performing as Intended
					Assessed Stream Length	326
					Assessed Bank Length	652
Bank	**Surface Scour/Bare Bank**	Bank lacking vegetative cover resulting from poor growth and/or surface scour			0	100%
	Toe Erosion	Bank toe eroding to the extent that bank failure appears likely. Does NOT include undercuts that are modest, appear sustainable and are providing habitat.			0	100%
	Bank Failure	Fluvial and geotechnical - rotational, slumping, calving, or collapse			0	100%
					0	100%
Structure	**Grade Control**	Grade control structures exhibiting maintenance of grade across the sill.	14	14		100%
	Bank Protection	Bank erosion within the structures extent of influence does not exceed 15%.	14	14		100%

Table 4B. Visual Stream Morphology Stability Assessment Table
North Tributary Reach 2

Major Channel Category		Metric	Number Stable, Performing as Intended	Total Number in As-built	Amount of Unstable Footage	% Stable, Performing as Intended
					Assessed Stream Length	103
					Assessed Bank Length	206
Bank	**Surface Scour/Bare Bank**	Bank lacking vegetative cover resulting from poor growth and/or surface scour			0	100%
	Toe Erosion	Bank toe eroding to the extent that bank failure appears likely. Does NOT include undercuts that are modest, appear sustainable and are providing habitat.			0	100%
	Bank Failure	Fluvial and geotechnical - rotational, slumping, calving, or collapse			0	100%
					0	100%
Structure	**Grade Control**	Grade control structures exhibiting maintenance of grade across the sill.	4	4		100%
	Bank Protection	Bank erosion within the structures extent of influence does not exceed 15%.	4	4		100%

Table 4C. Visual Stream Morphology Stability Assessment Table
Un-Named Tributary B

Major Channel Category		Metric	Number Stable, Performing as Intended	Total Number in As-built	Amount of Unstable Footage	% Stable, Performing as Intended
					Assessed Stream Length	529
					Assessed Bank Length	1058
Bank	**Surface Scour/Bare Bank**	Bank lacking vegetative cover resulting from poor growth and/or surface scour			0	100%
	Toe Erosion	Bank toe eroding to the extent that bank failure appears likely. Does NOT include undercuts that are modest, appear sustainable and are providing habitat.			0	100%
	Bank Failure	Fluvial and geotechnical - rotational, slumping, calving, or collapse			0	100%
					0	100%
Structure	**Grade Control**	Grade control structures exhibiting maintenance of grade across the sill.	16	16		100%
	Bank Protection	Bank erosion within the structures extent of influence does not exceed 15%.	16	16		100%

Table 4D. Visual Stream Morphology Stability Assessment Table
Millstone Creek Reach 1

Major Channel Category		Metric	Number Stable, Performing as Intended	Total Number in As-built	Amount of Unstable Footage	% Stable, Performing as Intended
					Assessed Stream Length	1462
					Assessed Bank Length	2924
Bank	**Surface Scour/Bare Bank**	Bank lacking vegetative cover resulting from poor growth and/or surface scour			0	100%
	Toe Erosion	Bank toe eroding to the extent that bank failure appears likely. Does NOT include undercuts that are modest, appear sustainable and are providing habitat.			0	100.0%
	Bank Failure	Fluvial and geotechnical - rotational, slumping, calving, or collapse			0	100%
					0	100.0%
Structure	**Grade Control**	Grade control structures exhibiting maintenance of grade across the sill.	32	32		100%
	Bank Protection	Bank erosion within the structures extent of influence does not exceed 15%.	32	32		100%

Table 4E. Visual Stream Morphology Stability Assessment Table
Millstone Creek Reach 2

Major Channel Category		Metric	Number Stable, Performing as Intended	Total Number in As-built	Amount of Unstable Footage	% Stable, Performing as Intended
					Assessed Stream Length	533
					Assessed Bank Length	1066
Bank	**Surface Scour/Bare Bank**	Bank lacking vegetative cover resulting from poor growth and/or surface scour			0	100%
	Toe Erosion	Bank toe eroding to the extent that bank failure appears likely. Does NOT include undercuts that are modest, appear sustainable and are providing habitat.			0	100%
	Bank Failure	Fluvial and geotechnical - rotational, slumping, calving, or collapse			0	100%
					0	100%
Structure	**Grade Control**	Grade control structures exhibiting maintenance of grade across the sill.	10	10		100%
	Bank Protection	Bank erosion within the structures extent of influence does not exceed 15%.	10	10		100%

Table 4F. Visual Stream Morphology Stability Assessment Table
Un-Named Tributary A - Reach 1

Major Channel Category		Metric	Number Stable, Performing as Intended	Total Number in As-built	Amount of Unstable Footage	% Stable, Performing as Intended
					Assessed Stream Length	516
					Assessed Bank Length	1032
Bank	**Surface Scour/Bare Bank**	Bank lacking vegetative cover resulting from poor growth and/or surface scour			0	100%
	Toe Erosion	Bank toe eroding to the extent that bank failure appears likely. Does NOT include undercuts that are modest, appear sustainable and are providing habitat.			0	100%
	Bank Failure	Fluvial and geotechnical - rotational, slumping, calving, or collapse			0	100%
					0	100%
Structure	**Grade Control**	Grade control structures exhibiting maintenance of grade across the sill.	24	24		100%
	Bank Protection	Bank erosion within the structures extent of influence does not exceed 15%.	24	24		100%

Table 4G. Visual Stream Morphology Stability Assessment Table
Un-Named Tributary A - Reach 2

Major Channel Category		Metric	Number Stable, Performing as Intended	Total Number in As-built	Amount of Unstable Footage	% Stable, Performing as Intended
					Assessed Stream Length	101
					Assessed Bank Length	202
Bank	**Surface Scour/Bare Bank**	Bank lacking vegetative cover resulting from poor growth and/or surface scour			0	100%
	Toe Erosion	Bank toe eroding to the extent that bank failure appears likely. Does NOT include undercuts that are modest, appear sustainable and are providing habitat.			0	100%
	Bank Failure	Fluvial and geotechnical - rotational, slumping, calving, or collapse			0	100%
					0	100%
Structure	**Grade Control**	Grade control structures exhibiting maintenance of grade across the sill.	5	5		100%
	Bank Protection	Bank erosion within the structures extent of influence does not exceed 15%.	5	5		100%

Table 5. Visual Vegetation Assessment Table

Planted acreage **16.5**

Vegetation Category	Definitions	Mapping Threshold	Combined Acreage	% of Planted Acreage
Bare Areas	Very limited cover of both woody and herbaceous material.	0.10 acres	0.00	0.0%
Low Stem Density Areas	Woody stem densities clearly below target levels based on current MY stem count criteria.	0.10acres	1.45	8.8%
Total			1.45	8.8%
Areas of Poor Growth Rates	Planted areas where average height is not meeting current MY Performance Standard.	0.10 acres	0.00	0.0%
Cumulative Total			1.45	8.8%

Easement Acreage **18.8**

Vegetation Category	Definitions	Mapping Threshold	Combined Acreage	% of Easement Acreage
Invasive Areas of Concern	Several dense populations of Chinese privet (Ligustrum sinense) and multiflora roase (Rosa multiflora) observed during MY1.	0.10 acres	0.19	1.0%
Easement Encroachment Areas	Encroachment may be point, line, or polygon. Encroachment to be mapped consists of any violation of restrictions specified in the conservation easement. Common encroachments are mowing, cattle access, vehicular access. Encroachment has no threshold value as will need to be addressed regardless of impact area.	none	# Encroachments noted	

Millstone Creek
MY1 (2025) Vegetation Monitoring Photographs

Plot 1

Plot 2

Plot 3

Plot 4

Plot 5

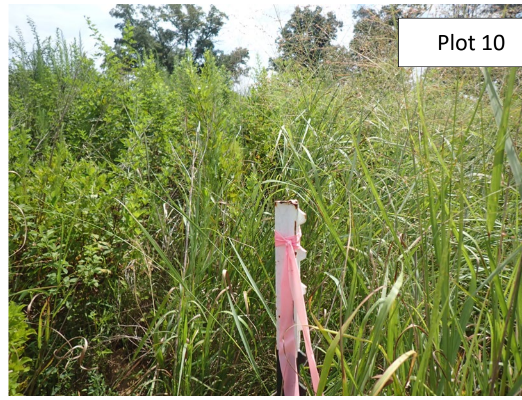
Plot 6

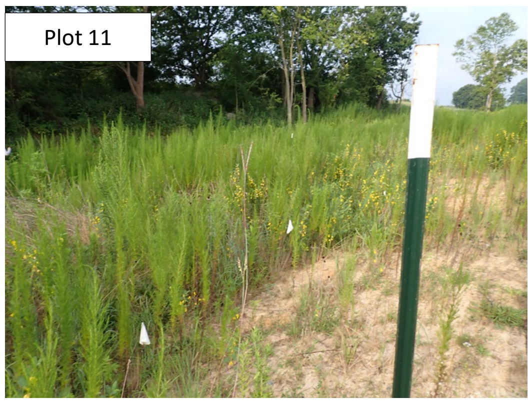
Plot 7

Plot 8

Millstone Creek
MY1 (2025) Vegetation Monitoring Photographs


Plot 9


Plot 10


Plot 11


Transect 1


Transect 2


Transect 3


Transect 4

Millstone Creek
MY-01 (2025) Photo Log

Photo 1: CCPV Permanent Photo Point 1
Millstone Creek upstream (photo taken 7/30/25)

Photo 2: CCPV Permanent Photo Point 2
Millstone Creek upstream (photo taken 7/30/25)

Millstone Creek
MY-01 (2025) Photo Log

Photo 3: CCPV Permanent Photo Point 3
Millstone Creek upstream (photo taken 7/30/25)

Photo 4: CCPV Permanent Photo Point 4
Millstone Creek (photo taken 7/30/25)

Millstone Creek
MY-01 (2025) Photo Log

Photo 5: CCPV Permanent Photo Point 5
Millstone Creek (photo taken 7/30/25)

Photo 6: CCPV Permanent Photo Point 6
Millstone Creek (photo taken 7/30/25)

Millstone Creek
MY-01 (2025) Photo Log

Millstone Creek
MY-01 (2025) Photo Log


Photo 9: CCPV Permanent Photo Point 9
Wetland Enhancement Area (photo taken 7/30/25)


Photo 10: CCPV Permanent Photo Point 10
UTB Facing Upstream (photo taken 7/30/25)

Millstone Creek
MY-01 (2025) Photo Log

Millstone Creek
MY-01 (2025) Photo Log

Photo 13: CCPV Permanent Photo Point 13
NT R2 Facing Downstream (photo taken 7/30/25)

Photo 14: CCPV Permanent Photo Point 14
NT R1 Facing Upstream (photo taken 7/30/25)

Millstone Creek
MY-01 (2025) Photo Log

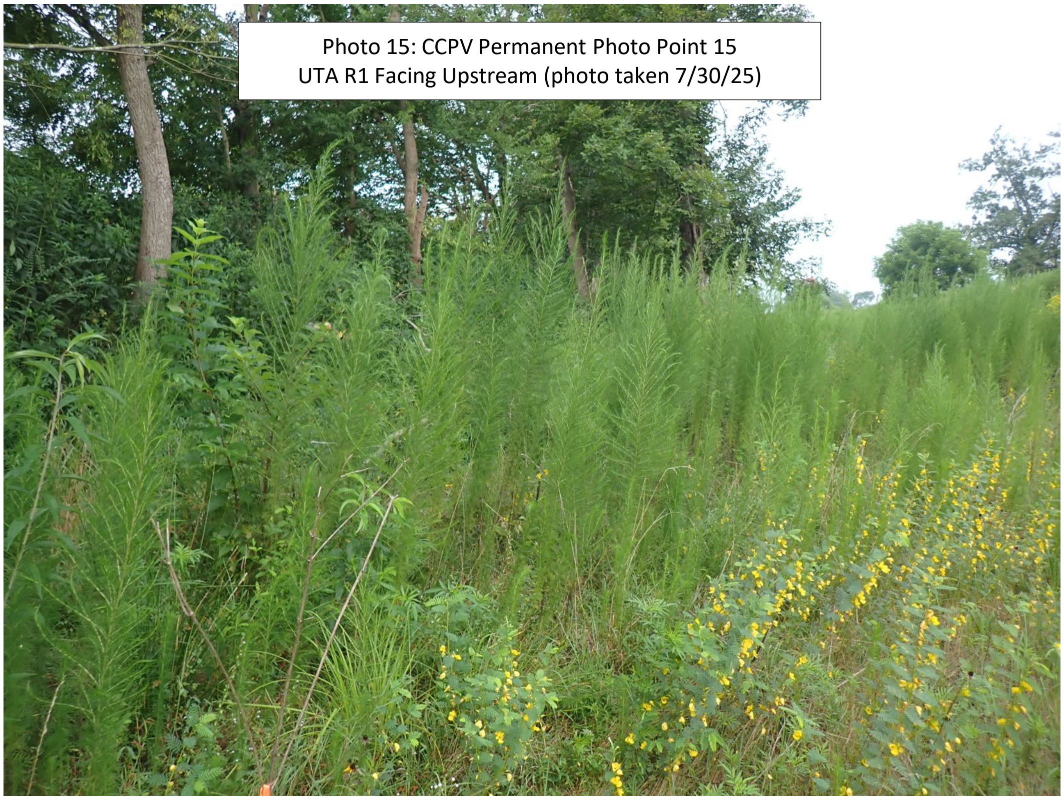


Photo 15: CCPV Permanent Photo Point 15
UTA R1 Facing Upstream (photo taken 7/30/25)

Photo 16: CCPV Permanent Photo Point 16
UTA R1 Facing Upstream (photo taken 7/30/25)

Appendix B: Vegetation Data

Table 6A. Planted Woody Vegetation
Table 6B. Permanent Seed Mix
Table 7. Vegetation Plot Counts and Densities
Table 8. Vegetation Plot Data Table from Vegetation Data Entry Tool

Table 6A. Planted Woody Vegetation
Millstone Creek Mitigation Site

Vegetation Area	Streambank		Floodplain		Upland Hardwood Forest		Supplemental Planting Zone		TOTAL
Area (acres)	**2.3**		**4.9**		**6.6**		**2.7**		**16.5**
Density	**2,800**		**680**		**680**		**200**		**--**
Species	**# planted***	**% of total**	**# planted**	**% of total**	**# planted**	**% of total**			**# planted**
*Silky dogwood (*Cornus amomum)*	1644	25%							1644
*Silky willow (*Salix sericea*)	1644	25%							1644
*Elderberry (*Sambucus canadensis*)	1644	25%							1644
Yellowroot (*Xanthorhiza simplicissima*)	658	10%							658
**Buttonbush (*Cephalanthus occidentalis*)	986	15%	170	5%					1156
Tag alder (*Alnus serrulata*)			170	5%					170
River birch (*Betula nigra*)			476	14%					476
Ironwood (*Carpinus caroliniana*)			340	10%					340
Water oak (*Quercus nigra*)			170	5%					170
Inkberry (*Ilex grabra*)			340	10%					340
Tulip poplar (*Liriodendron tulipifera*)			340	10%					340
Sycamore (*Platanus occidentalis*)			340	10%					340
Black gum (*Nyssa sylvatica*)			170	5%					170
Swamp chestnut oak (*Quercus michauxii*)			204	6%					204
Possumhaw (*Viburnum nudum*)			204	6%					204
Willow oak (*Quercus phellos*)			238	7%	225	5%	27	5%	490
Black walnut (*Juglans nigra*)			238	7%	314	7%			552
White oak (*Quercus alba*)					675	15%	81	15%	756
Black cherry (*Prunus serotina*)					450	10%	54	10%	504
Redbud (*Cercis canadensis*)					293	6%	54	10%	347
Persimmon (*Diospyros virginiana*)					293	6%	54	10%	347
Overcup oak (*Quercus lyrata*)					450	10%	54	10%	504
Sassafras (*Sassafras albidum*)					225	5%	27	5%	252
Red oak (*Quercus rubra*)					675	15%	81	15%	756
Chestnut oak (*Quercus prinus*)					450	10%	54	10%	504
American beech (*Fagus grandifolia*)					450	10%	54	10%	504
TOTAL	**6,576**	**100%**	**3,400**	**100%**	**4,500**	**100%**	**540**	**100%**	**15,013**

* Provided as live stakes
** Provided as lives stakes on streambanks and bareroot in floodplain zone

Table 6B. Permanent Seed Mix
Millstone Creek Mitigation Site

Wetland Seed Mix – 20 lbs /acre		
Species	**Common Name**	**Percent**
Bidens aristosa	Showy tickseed sunflower	7
Carex vulpinoidea	Fox sedge	12
Dichanthelium clandestinum	Deertongue	8
Elymus virginicus	Virginia wildrye	20
Juncus effusus	Soft rush	4
Panicum dichotomiflorum	Smooth panicgrass	14
Panicum rigidulum	Redtop panicgrass	8
Panicum virgatum	Switchgrass	23
Polygonum pennsylvanicum	Pennsylvania smartweed	2
Sparganium americanum	Eastern bur reed	2
		100
Streambank and Floodplain Seed Mix – 20 lbs /acre		
Agrostis perennans	Autumn bentgrass	15
Andropogon gerardii	Big bluestem	10
Coreopsis lanceolata	Lanceleaf coreopsis	10
Elymus virginicus	Virginia wildrye	20
Juncus effusus	Soft rush	5
Panicum virgatum	Switchgrass	15
Rudbeckia hirta	Black eyed Susan	10
Schizachyrium scoparium	Little bluestem	5
Sorghastrum nutans	Indian grass	5
Tripsacum dactyloides	Eastern gammagrass	5
		100
Upland Hardwood Forest Seed Mix – 20 lbs /acre		
Achillea millefolium	Common yarrow	10
Agrostis perennans	Autumn bentgrass	6
Asclepias tuberosa	Butterfly weed	1
Bidens aristosa	Showy tickseed sunflower	11
Chamaecrista fascisulata	Partridge pea	10
Coreopsis lanceolata	Lanceleaf coreopsis	10
Echinacea purpurea	Purple coneflower	4
Elymus virginicus	Virginia wildrye	6
Gaillardia pulchella	Indian blanket	8
Helianthus angustifolius	Swamp sunflower	2
Helianthus maximiliani	Maximilian's sunflower	2
Monarda puntata	Spotted beebalm	2
Rudbeckia hirta	Black eyed Susan	6
Schizachyrium scoparium	Little bluestem	4
Sorghastrum nutans	Indian grass	6
Symphyotrichum pilosum	Heath aster	1
Tridens flavus	Purpletop	4
Tripsacum dactyloides	Eastern gammagrass	6
Verbena hastata	Blue vervain	1
		100

Table 7. Planted Vegetation Totals
Millstone Creek Mitigation Site

Plot #	Planted Stems/Acre	Stem Density Success Criteria Met?	Species Count ≥4?	Dominant Species Composition ≤50%?
1	202	No	Yes	Yes
2	243	No	No	Yes
3	0	No	No	No
4	81	No	No	Yes
5	324	Yes	Yes	Yes
6	202	No	No	Yes
7	81	No	No	Yes
8	121	No	No	No
9	81	No	No	Yes
10	121	No	No	Yes
11	243	No	Yes	Yes
R-1	81	No	No	No
R-2	162	No	No	No
R-3	202	No	No	No
R-4	283	No	No	No
Average Planted Stems/Acre	**162**	**No**		

Table 8. Vegetation Plot Data Table from Vegetation Data Entry Tool

Planted Acreage	16.5
Date of Initial Plant	2021-12-28
Date(s) of Supplemental Plant(s)	2024-02-01
Date(s) Mowing	NA
Date of Current Survey	2025-07-31
Plot size (ACRES)	0.0247

	Scientific Name	Common Name	Tree/ Shrub	Indicator Status	Veg Plot 1 F		Veg Plot 2 F		Veg Plot 3 F		Veg Plot 4 F		Veg Plot 5 F		Veg Plot 6 F		Veg Plot 7 F	
					Planted	Total	Planted	Total	Planted	Total	Planted	Total	Planted	Total	Planted	Total	Planted	Total
Species Included in Approved Mitigation Plan	Alnus serrulata	hazel alder	Tree	OBL														
	Betula nigra	river birch	Tree	FACW							1	1	2	2				
	Diospyros virginiana	common persimmon	Tree	FAC														
	Fraxinus pennsylvanica	green ash	Tree	FACW			3	3							2	2	1	1
	Liriodendron tulipifera	tuliptree	Tree	FACU	1	1							1	1				
	Nyssa aquatica	water tupelo	Tree	OBL														
	Nyssa sylvatica	blackgum	Tree	FAC	1	1											1	1
	Platanus occidentalis	American sycamore	Tree	FACW	2	2							4	4	2	2		
	Quercus michauxii	swamp chestnut oak	Tree	FACW											1	1		
	Quercus nigra	water oak	Tree	FAC									1	1				
	Quercus pagoda	cherrybark oak	Tree	FACW														
	Quercus phellos	willow oak	Tree	FAC			1	1			1	1						
	Quercus sp.																	
	Viburnum nudum	possumhaw	Shrub	OBL	1	1	2	2										
Sum	Performance Standard				5	5	6	6	0	0	2	2	8	8	5	5	2	2
Mitigation Plan Performance Standard	Current Year Stem Count					5		6		0		2		8		5		2
	Stems/Acre					202		243		0		81		324		202		81
	Species Count					4		3		0		2		4		3		2
	Dominant Species Composition (%)					40		50		0		50		50		40		50
	Average Plot Height (ft.)					7		6		0		5		7		3		3
	% Invasives					0		0		0		0		0		0		0
Post Mitigation Plan Performance Standard	Current Year Stem Count					5		6		0		2		8		5		2
	Stems/Acre					202		243		0		81		324		202		81
	Species Count					4		3		0		2		4		3		2
	Dominant Species Composition (%)					40		50		0		50		50		40		50
	Average Plot Height (ft.)					7		6		0		5		7		3		3
	% Invasives					0		0		0		0		0		0		0

1). Bolded species are proposed for the current monitoring year, italicized species are not approved, and a regular font indicates that the species has been approved.

2). The "Species Included in Approved Mitigation Plan" section contains only those species that were included in the original approved mitigation plan. The "Post Mitigation Plan Species" section includes species that are being proposed through a mitigation plan addendum for the current monitoring year (bolded) , species that have been approved in prior monitoring years through a mitigation plan addendum (regular font), and species that are not approved (italicized).

3). The "Mitigation Plan Performance Standard" section is derived only from stems included in the original mitigation plan, whereas the "Post Mitigation Plan Performance Standard" includes data from mitigation plan approved, post mitigation plan approved, and proposed stems.

Table 8. Vegetation Plot Data Table from Vegetation Data Entry Tool (continued)

Planted Acreage	16.5
Date of Initial Plant	2021-12-28
Date(s) of Supplemental Plant(s)	2024-02-01
Date(s) Mowing	NA
Date of Current Survey	2025-07-31
Plot size (ACRES)	0.0247

	Scientific Name	Common Name	Tree/ Shrub	Indicator Status	Veg Plot 8 F		Veg Plot 9 F		Veg Plot 10 F		Veg Plot 11 F		Veg Plot 1 R	Veg Plot 2 R	Veg Plot 3 R	Veg Plot 4 R
					Planted	Total	Planted	Total	Planted	Total	Planted	Total	Total	Total	Total	Total
Species Included in Approved Mitigation Plan	Alnus serrulata	hazel alder	Tree	OBL			1	1								
	Betula nigra	river birch	Tree	FACW	1	1	1	1						2	1	
	Diospyros virginiana	common persimmon	Tree	FAC							1	1				
	Fraxinus pennsylvanica	green ash	Tree	FACW												
	Liriodendron tulipifera	tuliptree	Tree	FACU												3
	Nyssa aquatica	water tupelo	Tree	OBL							1	1				
	Nyssa sylvatica	blackgum	Tree	FAC												
	Platanus occidentalis	American sycamore	Tree	FACW	3	3							4	3	7	6
	Quercus michauxii	swamp chestnut oak	Tree	FACW					1	1						
	Quercus nigra	water oak	Tree	FAC					1	1	1	1				
	Quercus pagoda	cherrybark oak	Tree	FACW					1	1						
	Quercus phellos	willow oak	Tree	FAC							2	2				
	Quercus sp.										1	1				
	Viburnum nudum	possumhaw	Shrub	OBL												
Sum	Performance Standard				4	4	2	2	3	3	6	6	4	5	8	9
Mitigation Plan Performance Standard	Current Year Stem Count					4		2		3		6	4	5	8	9
	Stems/Acre					121		81		121		243	81	162	202	283
	Species Count					2		2		3		5	1	2	2	2
	Dominant Species Composition (%)					75		50		33		33	100	60	88	67
	Average Plot Height (ft.)					5		5		3		1	3	6	8	12
	% Invasives					0		0		0		0	0	0	0	0
Post Mitigation Plan Performance Standard	Current Year Stem Count					4		2		3		6	4	5	8	9
	Stems/Acre					121		81		121		243	81	162	202	283
	Species Count					2		2		3		5	1	2	2	2
	Dominant Species Composition (%)					75		50		33		33	100	60	88	67
	Average Plot Height (ft.)					5		5		3		1	3	6	8	12
	% Invasives					0		0		0		0	0	0	0	0

1). Bolded species are proposed for the current monitoring year, italicized species are not approved, and a regular font indicates that the species has been approved.
2). The "Species Included in Approved Mitigation Plan" section contains only those species that were included in the original approved mitigation plan. The "Post Mitigation Plan Species" section includes species that are being proposed through a mitigation plan addendum for the current monitoring year (bolded) , species that have been approved in prior monitoring years through a mitigation plan addendum (regular font), and species that are not approved (italicized).
3). The "Mitigation Plan Performance Standard" section is derived only from stems included in the original mitigation plan, whereas the "Post Mitigation Plan Performance Standard" includes data from mitigation plan approved, post mitigation plan approved, and proposed stems.

Appendix C: Stream Geomorphology Data

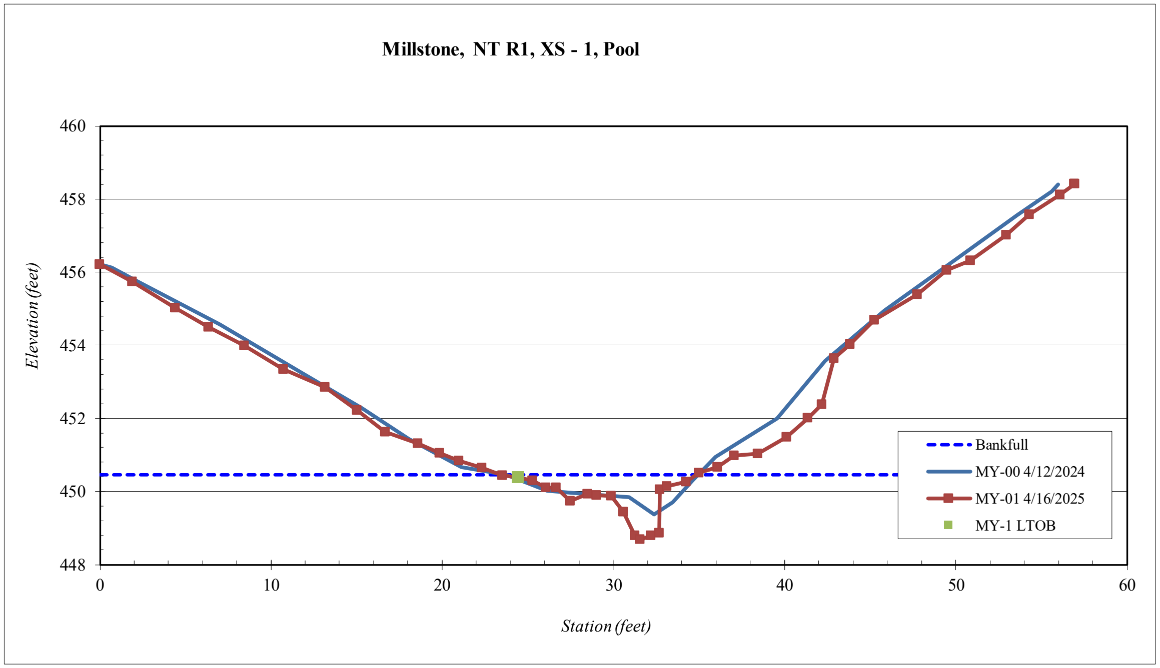
Cross-Sections with Annual Overlays
Table 9A-G. Baseline Stream Data Summary Tables
Table 10. Cross-Section Morphology Monitoring Summary

Site	Millstone Creek
Watershed:	Cape Fear River Basin, 03030003
XS ID	NT R1, XS - 1, Pool
Feature	Pool
Date:	4/16/2025
Field Crew:	Perkinson, Heider-Metour

Station	Elevation
0.00	456.31
1.89	455.83
4.41	455.13
6.36	454.60
8.45	454.09
10.71	453.44
13.17	452.95
15.02	452.32
16.66	451.72
18.60	451.42
19.86	451.14
20.98	450.94
22.34	450.74
23.51	450.54
24.43	450.49
25.27	450.40
26.06	450.20
26.67	450.21
27.47	449.83
28.49	450.04
29.01	449.99
29.86	449.98
30.58	449.54
31.25	448.90
31.55	448.78
32.20	448.89
32.67	448.96
32.73	450.14
33.12	450.23
34.26	450.36
34.98	450.61
36.09	450.77
37.05	451.08
38.44	451.14
40.12	451.58
41.34	452.10
42.17	452.47
42.88	453.73
43.82	454.13
45.23	454.79
47.75	455.48
49.46	456.16
50.84	456.42
52.95	457.12
54.31	457.67
56.09	458.21
56.92	458.51
56.94	458.51

SUMMARY DATA	
Bankfull Elevation:	450.5
Bank Hieght Ratio:	0.96
Thalweg Elevation:	448.8
LTOB Elevation:	450.4
LTOB Max Depth:	1.6
LTOB Cross Sectional Area:	5.2

Stream Type	B 5

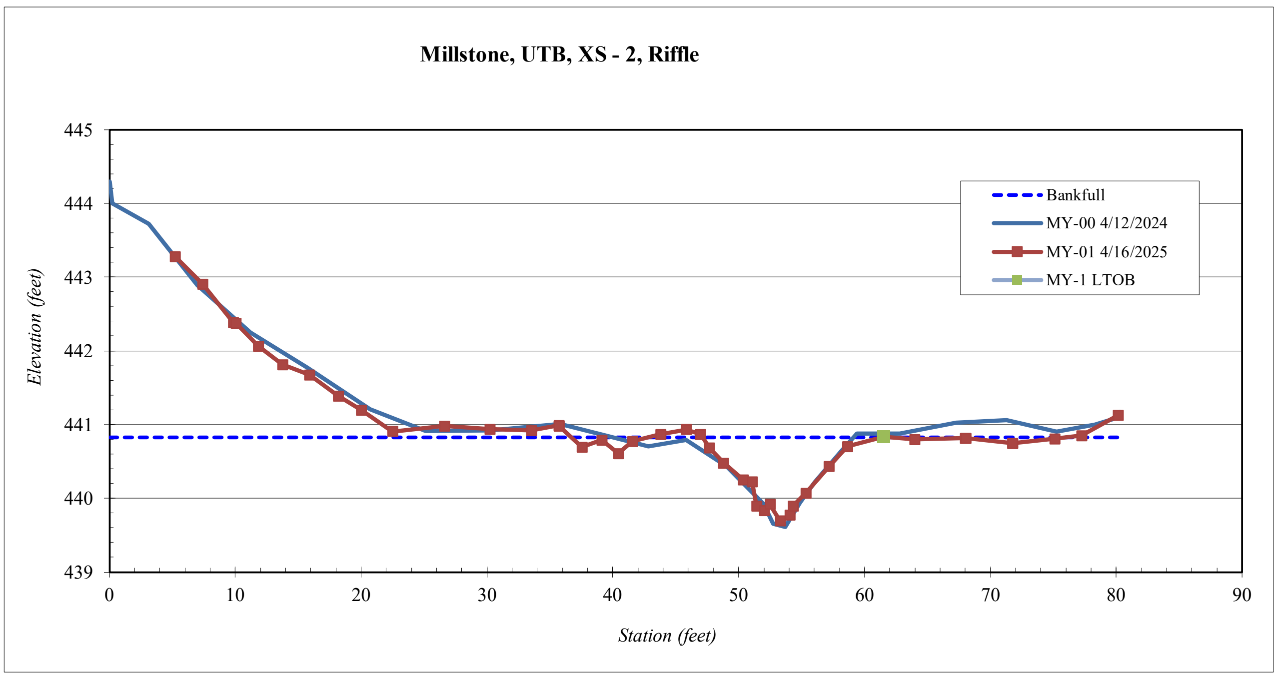


Site	Millstone Creek
Watershed:	Cape Fear River Basin, 03030003
XS ID	UTB, XS - 2, Riffle
Feature	Riffle
Date:	4/16/2025
Field Crew:	Perkinson, Heider-Metour

Station	Elevation
5.20	443.28
7.41	442.91
9.84	442.39
10.03	442.38
11.83	442.07
13.74	441.82
15.86	441.68
18.16	441.39
20.01	441.20
22.47	440.91
26.61	440.98
30.22	440.94
33.54	440.92
35.70	440.99
35.70	440.98
37.55	440.69
39.10	440.79
40.44	440.61
41.58	440.77
43.78	440.87
45.83	440.93
46.97	440.87
47.64	440.69
48.80	440.48
50.36	440.25
51.04	440.22
51.43	439.89
52.04	439.83
52.50	439.92
53.29	439.70
54.07	439.78
54.31	439.89
55.33	440.07
57.17	440.43
58.64	440.71
61.54	440.83
63.97	440.80
67.97	440.82
68.04	440.81
71.75	440.74
71.78	440.75
75.11	440.80
77.23	440.85
80.16	441.13

SUMMARY DATA	
Bankfull Elevation:	440.8
Bank Hieght Ratio:	1.01
Thalweg Elevation:	439.7
LTOB Elevation:	440.8
LTOB Max Depth:	1.1
LTOB Cross Sectional Area:	7.2

Stream Type	E 5

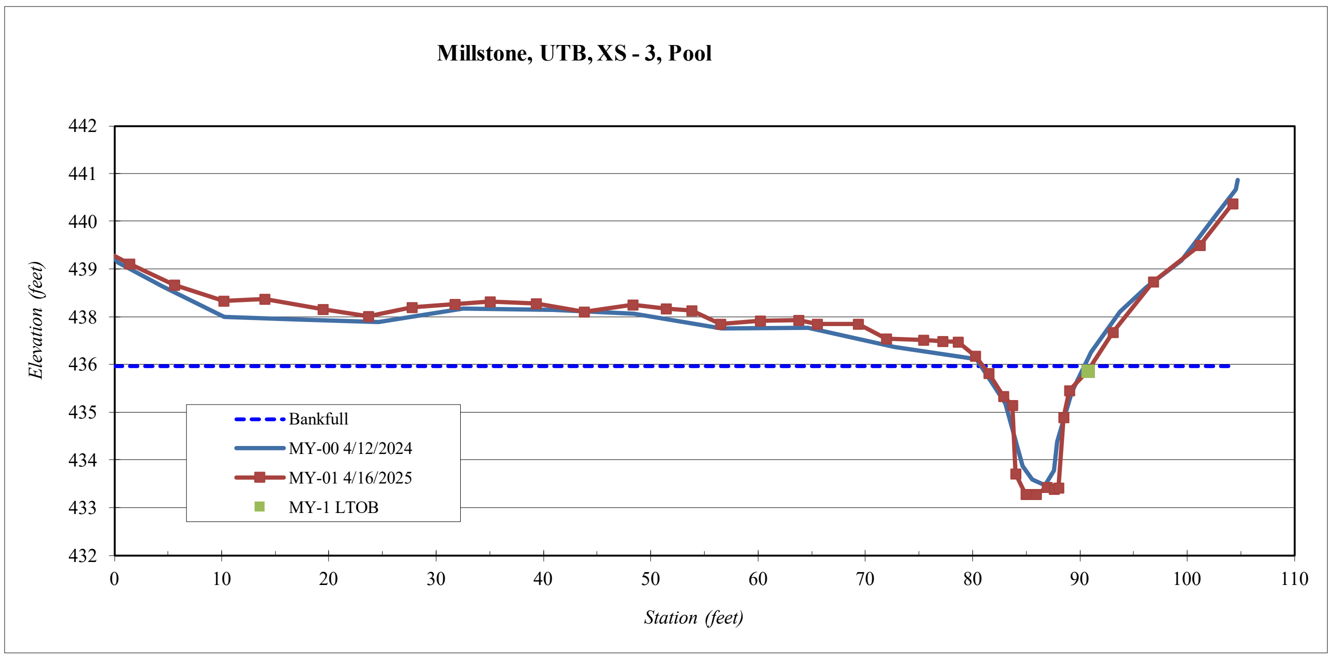


Site	Millstone Creek
Watershed:	Cape Fear River Basin, 03030003
XS ID	UTB, XS - 3, Pool
Feature	Pool
Date:	4/16/2025
Field Crew:	Perkinson, Heider-Metour

Station	Elevation
-1.00	439.11
1.41	438.79
5.57	438.30
5.62	438.29
10.17	437.91
13.99	437.96
19.42	437.72
23.65	437.54
27.75	437.76
31.74	437.84
35.01	437.89
39.29	437.85
43.80	437.66
48.32	437.83
51.44	437.74
53.78	437.69
56.49	437.38
60.17	437.45
63.74	437.47
65.52	437.37
69.30	437.37
71.96	437.02
75.41	437.00
77.21	436.96
78.63	436.95
80.25	436.62
81.51	436.20
82.89	435.66
83.70	435.45
84.01	433.82
84.98	433.34
85.93	433.34
86.94	433.51
87.55	433.45
87.99	433.49
88.48	435.15
89.00	435.79
90.71	436.27
93.05	437.18
96.82	438.37
101.17	439.24
104.21	440.22

SUMMARY DATA	
Bankfull Elevation:	436.4
Bank Hieght Ratio:	0.96
Thalweg Elevation:	433.3
LTOB Elevation:	436.3
LTOB Max Depth:	2.9
LTOB Cross Sectional Area:	14.5

Stream Type	E 5

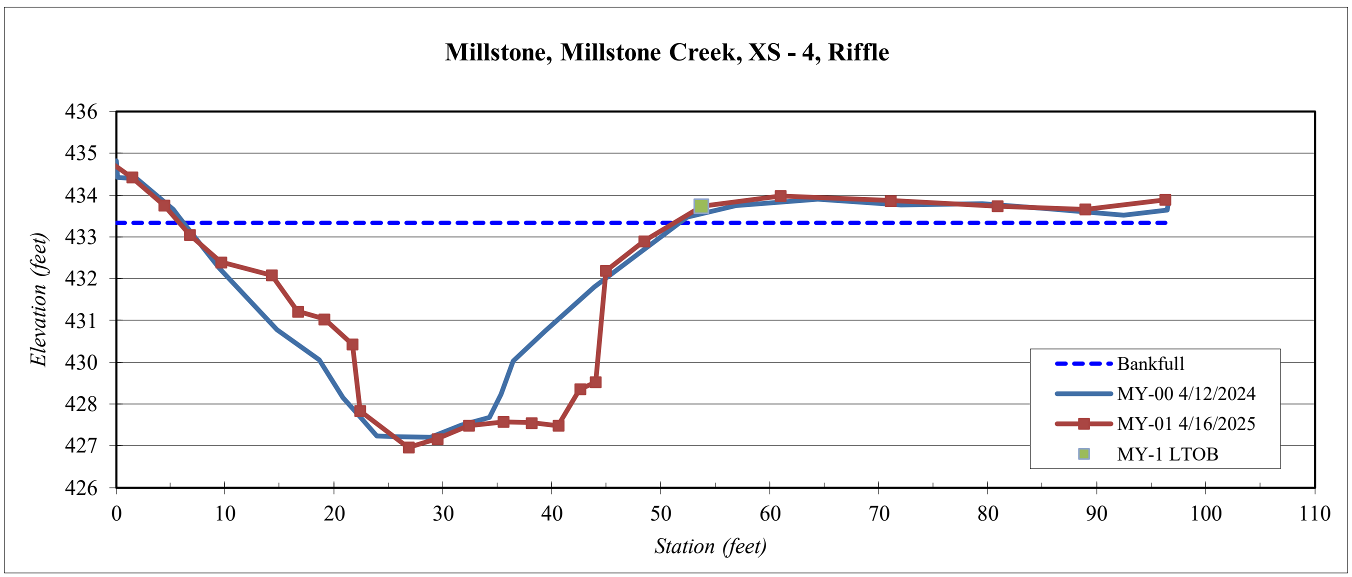


Site	Millstone Creek
Watershed:	Cape Fear River Basin, 03030003
XS ID	Millstone Creek, XS - 4, Riffle
Feature	Riffle
Date:	4/16/2025
Field Crew:	Perkinson, Heider-Metour

Station	Elevation
-0.80	435.11
1.48	434.63
4.45	433.87
6.81	433.07
9.63	432.33
14.31	431.98
16.68	431.01
19.14	430.80
21.73	430.11
22.41	428.31
26.86	427.33
29.52	427.56
32.38	427.92
35.56	428.02
38.13	427.99
40.61	427.91
42.58	428.90
44.03	429.09
44.97	432.10
48.50	432.91
53.79	433.84
60.99	434.13
71.10	434.00
80.90	433.85
88.95	433.77
96.30	434.02

SUMMARY DATA	
Bankfull Elevation:	433.4
Bank Hieght Ratio:	1.07
Thalweg Elevation:	427.3
LTOB Elevation:	433.8
LTOB Max Depth:	6.5
LTOB Cross Sectional Area:	174.2

Stream Type	C 5

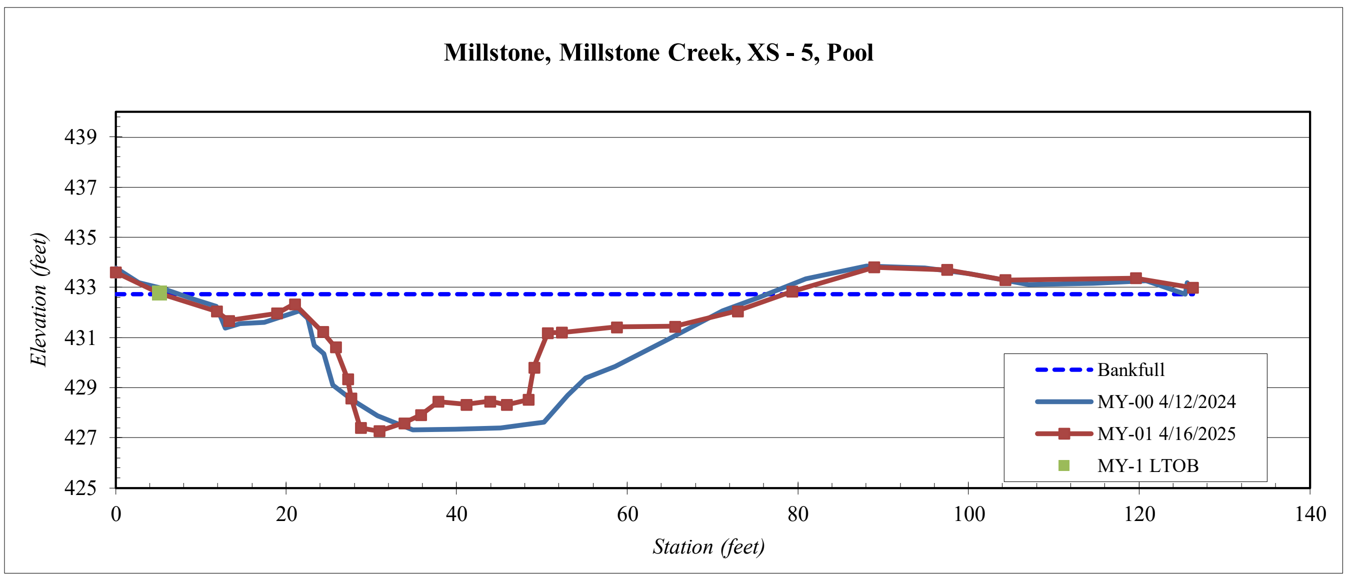


Site	Millstone Creek
Watershed:	Cape Fear River Basin, 03030003
XS ID	Millstone Creek, XS - 5, Pool
Feature	Pool
Date:	4/16/2025
Field Crew:	Perkinson, Heider-Metour

Station	Elevation
0.00	433.59
5.26	432.75
11.88	432.04
13.25	431.67
18.95	431.96
20.99	432.34
24.28	431.22
25.79	430.62
27.24	429.35
27.65	428.57
28.72	427.40
30.89	427.28
33.82	427.58
35.77	427.91
37.85	428.45
41.10	428.33
43.92	428.46
45.85	428.32
48.40	428.52
49.07	429.81
50.69	431.19
52.27	431.19
58.78	431.42
65.61	431.45
72.94	432.05
79.32	432.83
88.95	433.82
97.50	433.70
104.31	433.29
119.60	433.37
126.30	432.99

SUMMARY DATA	
Bankfull Elevation:	432.7
Bank Hieght Ratio:	1.00
Thalweg Elevation:	427.3
LTOB Elevation:	432.8
LTOB Max Depth:	5.5
LTOB Cross Sectional Area:	155.7

Stream Type	C 5

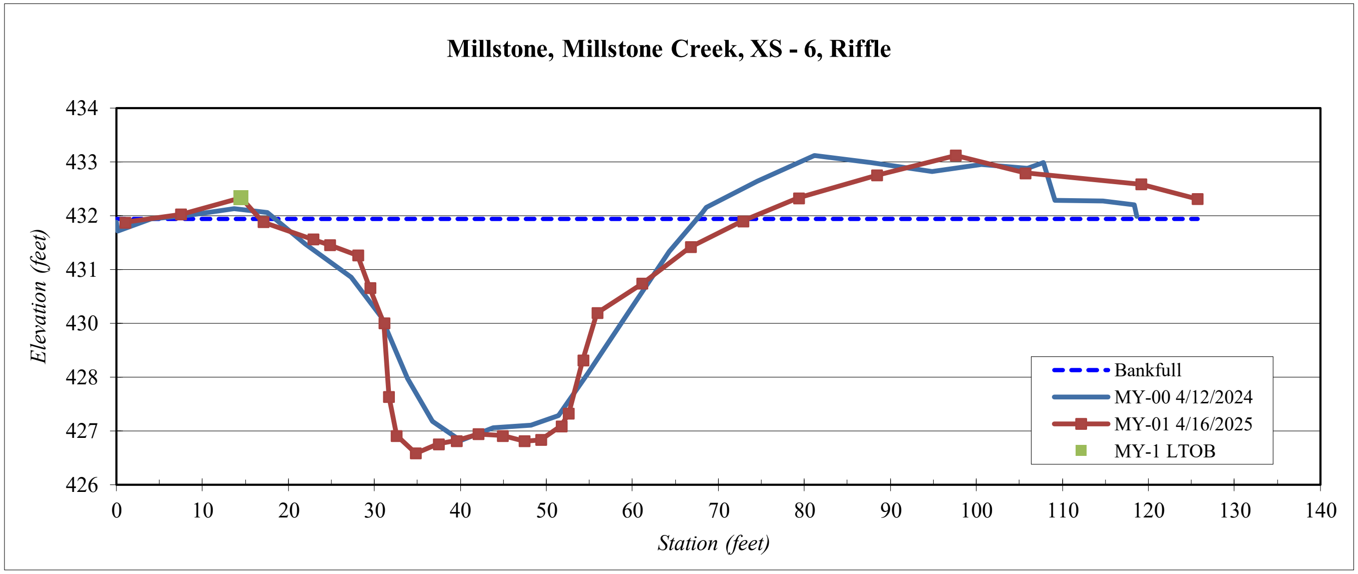


Site	Millstone Creek
Watershed:	Cape Fear River Basin, 03030003
XS ID	Millstone Creek, XS - 6, Riffle
Feature	Riffle
Date:	4/16/2025
Field Crew:	Perkinson, Heider-Metour

Station	Elevation
1.00	431.75
7.52	431.92
14.50	432.26
17.08	431.76
22.86	431.39
24.83	431.27
28.07	431.05
29.48	430.37
31.11	429.63
31.69	428.09
32.59	427.27
34.82	426.90
37.46	427.09
39.52	427.15
42.10	427.30
44.88	427.27
47.47	427.15
49.36	427.18
51.74	427.47
52.59	427.73
54.27	428.85
55.91	429.84
61.14	430.46
66.77	431.23
72.85	431.78
79.34	432.26
88.42	432.74
97.59	433.17
105.65	432.79
119.18	432.55
125.71	432.24

SUMMARY DATA	
Bankfull Elevation:	431.8
Bank Hieght Ratio:	0.99
Thalweg Elevation:	426.9
LTOB Elevation:	431.8
LTOB Max Depth:	4.9
LTOB Cross Sectional Area:	129.6

Stream Type	C 5

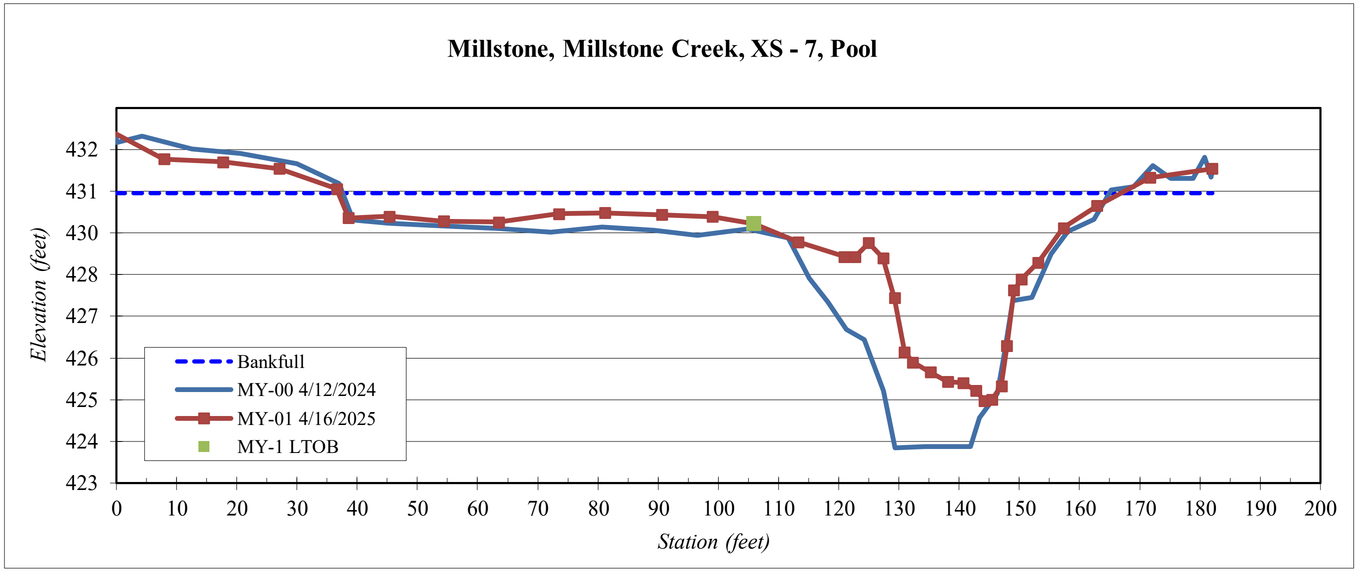


Site	Millstone Creek
Watershed:	Cape Fear River Basin, 03030003
XS ID	Millstone Creek, XS - 7, Pool
Feature	Pool
Date:	4/16/2025
Field Crew:	Perkinson, Heider-Metour

Station	Elevation
-1.00	432.39
7.93	431.62
17.68	431.55
27.08	431.37
36.62	430.82
38.58	430.03
45.35	430.08
54.34	429.94
63.54	429.92
73.55	430.15
81.15	430.17
90.64	430.12
99.05	430.07
105.99	429.87
113.23	429.39
120.95	428.98
122.68	428.98
124.95	429.36
127.34	428.95
129.28	427.86
130.94	426.40
132.32	426.12
135.25	425.85
138.14	425.59
140.65	425.56
142.84	425.34
144.21	425.07
145.48	425.11
147.00	425.48
147.92	426.56
149.10	428.07
150.37	428.38
153.11	428.83
157.34	429.77
162.89	430.36
171.65	431.13
182.05	431.37

SUMMARY DATA	
Bankfull Elevation:	430.7
Bank Hieght Ratio:	0.85
Thalweg Elevation:	425.1
LTOB Elevation:	429.9
LTOB Max Depth:	4.8
LTOB Cross Sectional Area:	102.0

Stream Type	C 5

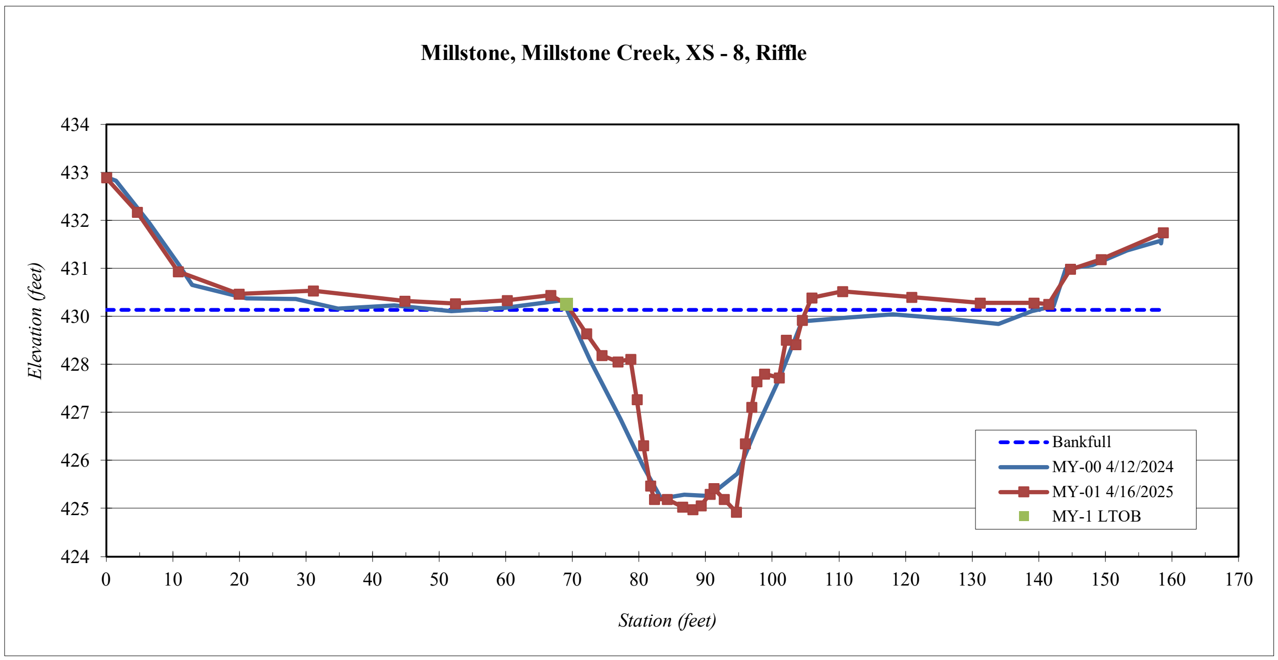


Site	Millstone Creek
Watershed:	Cape Fear River Basin, 03030003
XS ID	Millstone, XS - 8, Riffle
Feature	Riffle
Date:	4/16/2025
Field Crew:	Perkinson, Heider-Metour

Station	Elevation
0.00	432.89
4.63	432.09
10.83	430.68
19.97	430.15
31.07	430.23
44.85	429.98
52.41	429.93
60.20	430.00
66.69	430.12
69.08	429.91
72.06	429.22
74.45	428.71
76.84	428.55
78.70	428.62
79.65	427.66
80.65	426.58
81.68	425.63
82.28	425.32
84.18	425.32
86.51	425.14
88.01	425.08
89.28	425.17
90.64	425.44
91.18	425.57
92.75	425.32
94.57	425.02
95.97	426.63
96.90	427.49
97.64	428.09
98.76	428.27
100.99	428.19
102.05	429.07
103.49	428.97
104.48	429.54
105.90	430.06
110.55	430.22
120.95	430.08
131.19	429.94
139.28	429.94
141.47	429.91
144.73	430.73
149.34	430.96
158.69	431.59

SUMMARY DATA	
Bankfull Elevation:	429.8
Bank Hieght Ratio:	1.03
Thalweg Elevation:	425.1
LTOB Elevation:	429.9
LTOB Max Depth:	4.8
LTOB Cross Sectional Area:	94.4

Stream Type	C 5

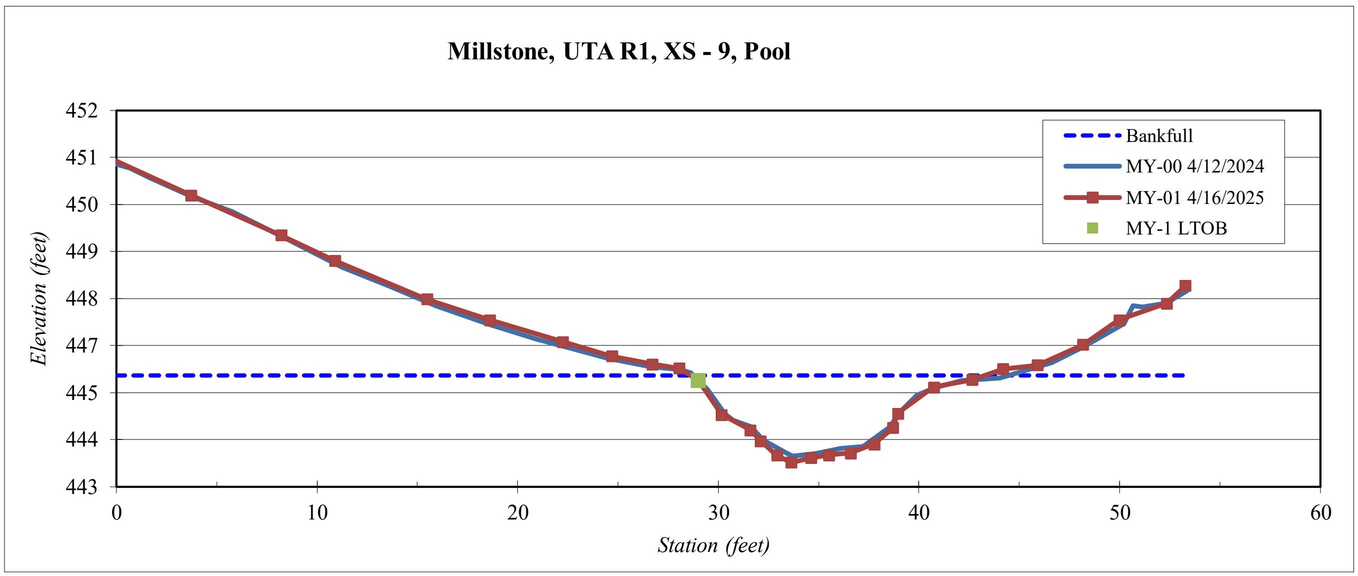


Site	Millstone Creek
Watershed:	Cape Fear River Basin, 03030003
XS ID	UTA R1, XS - 9, Pool
Feature	Pool
Date:	4/16/2025
Field Crew:	Perkinson, Heider-Metour

Station	Elevation
-0.30	451.10
3.72	450.20
8.20	449.24
10.90	448.63
15.48	447.70
18.60	447.20
22.23	446.68
24.68	446.33
26.69	446.14
28.05	446.04
29.02	445.74
30.15	444.92
31.60	444.56
32.11	444.30
32.91	443.95
33.62	443.78
34.62	443.88
35.51	443.95
36.58	444.00
37.77	444.21
38.70	444.61
38.95	444.95
40.73	445.59
42.64	445.76
44.18	446.03
45.91	446.12
48.17	446.61
49.97	447.21
52.34	447.61
53.27	448.03

SUMMARY DATA	
Bankfull Elevation:	445.9
Bank Hieght Ratio:	0.93
Thalweg Elevation:	443.8
LTOB Elevation:	445.7
LTOB Max Depth:	2.0
LTOB Cross Sectional Area:	15.0

Stream Type	B 5



Site	Millstone Creek
Watershed:	Cape Fear River Basin, 03030003
XS ID	UTA R1, XS - 10, Riffle
Feature	Riffle
Date:	4/16/2025
Field Crew:	Perkinson, Heider-Metour

Station	Elevation
-0.20	464.75
2.26	464.42
5.38	464.01
7.88	463.87
10.21	463.47
12.65	463.05
14.88	462.54
17.24	462.21
19.52	462.10
22.01	461.90
24.13	461.61
25.22	461.36
26.48	461.16
27.15	461.33
28.56	461.05
29.59	460.93
31.04	461.01
32.09	460.92
33.23	460.84
34.76	460.98
35.91	461.20
36.15	461.54
37.17	461.43
38.51	461.43
40.50	461.36
42.98	461.91
45.89	462.82
47.06	463.21
48.84	464.09
51.32	464.69
51.96	465.03

SUMMARY DATA	
Bankfull Elevation:	461.4
Bank Hieght Ratio:	0.95
Thalweg Elevation:	460.8
LTOB Elevation:	461.4
LTOB Max Depth:	0.5
LTOB Cross Sectional Area:	3.4

Stream Type	B 5

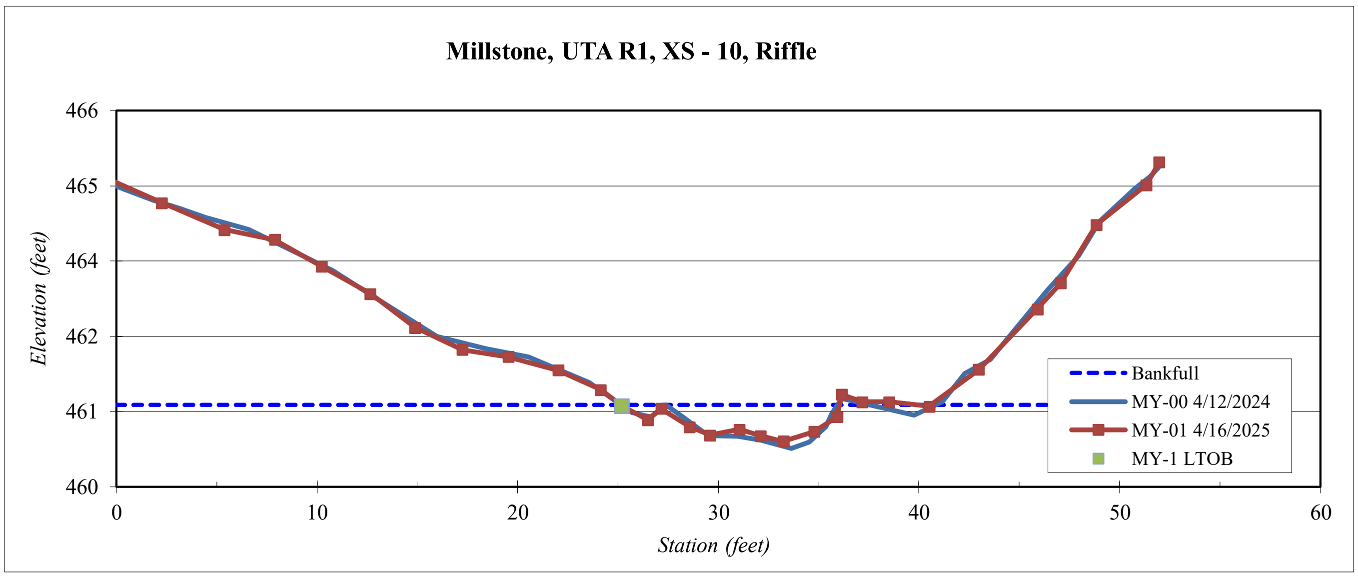


Table 9A. Baseline Stream Data Summary
Millstone Creek - North Tributary Reach 1 (NTR1)

Parameter	Pre-Existing Condition (applicable)					Design		Monitoring Baseline (MY0)		
Riffle Only	Min	Mean	Med	Max	n	Min	Max	Min	Max	n
Bankfull Width (ft)	5.8	5.85	5.85	5.9	2	8		8.2		1
Floodprone Width (ft)	8.3	8.5	8.5	8.7	2	14.3		16.5		1
Bankfull Mean Depth (ft)	0.4	0.5	0.5	0.6	2	0.4		0.41		1
Bankfull Max Depth (ft)	0.6	0.75	0.75	0.9	2	0.5		0.65		1
Bankfull Cross Sectional Area (ft^2)	2.3	3	3	3.7	2	3.5		3.4		1
Width/Depth Ratio	9.4	11.95	11.95	14.5	2	18.3		19.8		1
Entrenchment Ratio	1.4	1.45	1.45	1.5	2	1.8		2.0		1
Bank Height Ratio	**3**	**3.1**	**3.1**	**3.2**	**2**	**1**		**1**		**1**
Max part size (mm) mobilized at bankfull	48-108					93-172		86-164		
Rosgen Classification	G5/F5					B5		B5		
Bankfull Discharge (cfs)	9.7					15.4		14.3		
Sinuosity (ft)	1.03					1.1		1.1		
Water Surface Slope (Channel) (ft/ft)	0.023					0.048		0.047		
Other										

Table 9B. Baseline Stream Data Summary
Millstone Creek - North Tributary Reach 2 (NTR2)

Parameter	Pre-Existing Condition (applicable)					Design		Monitoring Baseline (MY0)		
Riffle Only	Min	Mean	Med	Max	n	Min	Max	Min	Max	n
Bankfull Width (ft)		4.9			1	4.9		9.7		1
Floodprone Width (ft)		9.8			1	8.3		21		1
Bankfull Mean Depth (ft)		0.5			1	0.5		0.5		1
Bankfull Max Depth (ft)		0.6			1	0.6		1.7		1
Bankfull Cross Sectional Area (ft^2)		2.3			1	2.3		4.6		1
Width/Depth Ratio		10.2			1	10.2		20.5		1
Entrenchment Ratio		2.0			1	1.7		2.2		1
Bank Height Ratio		1			1	1		1		**1**
Max part size (mm) mobilized at bankfull	70-141					70-141		60-127		
Rosgen Classification	B5					B5		B5		
Bankfull Discharge (cfs)	8.8					8.8		14.0		
Sinuosity (ft)	1.05					1.05		1.05		
Water Surface Slope (Channel) (ft/ft)	0.037					0.037		0.029		
Other										

Table 9C. Baseline Stream Data Summary
Millstone Creek - UTB

Parameter	Pre-Existing Condition (applicaple)					Design		Monitoring Baseline (MY0)		
Riffle Only	Min	Mean	Med	Max	n	Min	Max	Min	Max	n
Bankfull Width (ft)	4.4	4.8	4.4	5.6	3	10	15	13.1		1
Floodprone Width (ft)	6.2	34.7	10.1	88.0	3	65.0		65.0		1
Bankfull Mean Depth (ft)	0.5	0.6	0.7	0.7	3	0.7	0.9	0.5		1
Bankfull Max Depth (ft)	0.9	0.9	0.9	0.9	3	0.9	1.5	1.2		1
Bankfull Cross Sectional Area (ft^2)	2.1	2.9	3.0	3.7	3	7.0	13.0	7.1		1
Width/Depth Ratio	6.6	8.1	8.4	9.3	3	14.3	21.4	24.3		1
Entrenchment Ratio	1.4	7.7	1.8	20.0	3	6.5	4.3	4.9		1
Bank Height Ratio	**1.0**	1.7	1.7	**2.3**	3	1		1.0		**1**
Max part size (mm) mobilized at bankfull	33-82					52-114		29-76		
Rosgen Classification	G5/E5					C5		C5		
Bankfull Discharge (cfs)	8.1					26.0		19.6		
Sinuosity (ft)	1.08					1.08		1.12		
Water Surface Slope (Channel) (ft/ft)	0.0144					0.014		0.014		
Other										

Table 9D. Baseline Stream Data Summary
Millstone Creek - Millstone Creek Reach 1 (MCR1)

Parameter	Pre-Existing Condition (applicaple)					Design		Monitoring Baseline (MY0)		
Riffle Only	Min	Mean	Med	Max	n	Min	Max	Min	Max	n
Bankfull Width (ft)	28.9	37.8	37.8	46.6	3	28.9	46.6	67.53	46.627	2
Floodprone Width (ft)	216.8	273.8	273.8	330.9	3	216.8	330.9	65	65	2
Bankfull Mean Depth (ft)	2.6	2.7	2.7	2.7	3	2.6	3.3	2.0	3.3	2
Bankfull Max Depth (ft)	3.3	3.7	3.7	4.1	3	3.4	4.8	4.8	5.9	2
Bankfull Cross Sectional Area (ft^2)	75.3	99.5	99.5	123.6	3	75.3	123.6	135.95	153.9	2
Width/Depth Ratio	11.1	14.4	14.4	17.6	3	11.1	17.6	33.5	14.1	2
Entrenchment Ratio	7.1	7.3	7.3	7.5	3	7.1	7.5	1.0	1.4	2
Bank Height Ratio	**1.0**	1.1	1.1	**1.1**	3	1.0	1.1	1	1	**2**
Max part size (mm) mobilized at bankfull	167-260					67-85		19-57		
Rosgen Classification	G5/E5					C5		C5		
Bankfull Discharge (cfs)	9.7					243-295		363.4		
Sinuosity (ft)	1.08					1.06		1.12		
Water Surface Slope (Channel) (ft/ft)	0.0144					0.002		0.0022		
Other										

Table 9E. Baseline Stream Data Summary
Millstone Creek - Millstone Creek Reach 2 (MCR2)

Parameter	Pre-Existing Condition (applicaple)					Design		Monitoring Baseline (MY0)		
Riffle Only	Min	Mean	Med	Max	n	Min	Max	Min	Max	n
Bankfull Width (ft)		30.9			1	36.0		34.5		1
Floodprone Width (ft)	219.4	225.6	225.6	231.8	1	216.8	330.9	225.0		1
Bankfull Mean Depth (ft)		3.4			1	2.6		2.7		1
Bankfull Max Depth (ft)		4.3			1	3.6		4.2		1
Bankfull Cross Sectional Area (ft^2)		105.8			1	85.0		94.3		1
Width/Depth Ratio		9.0			1	13.8		12.7		1
Entrenchment Ratio	7.1	7.3	7.3	7.5	1	6.0	9.2	6.5		1
Bank Height Ratio		1.2			1	1.0	1.0	1.0		**1**
Max part size (mm) mobilized at bankfull	27-73					24-72		21-60		
Rosgen Classification	E5					C5		C5		
Bankfull Discharge (cfs)	358.4					305.0		270.3		
Sinuosity (ft)	1.13					1.09		1.08		
Water Surface Slope (Channel) (ft/ft)	0.0021					0.002		0.0019		
Other										

Table 9F. Baseline Stream Data Summary
Millstone Creek - UTA Reach 1 (UTA1)

Parameter	Pre-Existing Condition (applicaple)					Design		Monitoring Baseline (MY0)		
Riffle Only	Min	Mean	Med	Max	n	Min	Max	Min	Max	n
Bankfull Width (ft)	7.2	10.133	11.3	11.9	3	8		8.8		1
Floodprone Width (ft)	13.56	16.47	17.85	18	3	20		23		1
Bankfull Mean Depth (ft)	0.3	0.6	0.7	0.8	3	0.4		0.4		1
Bankfull Max Depth (ft)	1.2	1.2	1.2	1.2	3	0.5		0.7		1
Bankfull Cross Sectional Area (ft^2)	2	6.6333	8	9.9	3	3.3		3.6		1
Width/Depth Ratio	14.3	18.7	15.8	26	3	18.3		21.0		1
Entrenchment Ratio	1.2	1.7	1.5	2.5	3	2.5		2.6		1
Bank Height Ratio					3	1		1		**1**
Max part size (mm) mobilized at bankfull	117-203					96-176		96-176		
Rosgen Classification	F5					C5		C5		
Bankfull Discharge (cfs)	34.7					20.0		1.0		
Sinuosity (ft)	1.04					1.04		1.04		
Water Surface Slope (Channel) (ft/ft)	0.0405					0.052		0.052		
Other										

Table 9G. Baseline Stream Data Summary
Millstone Creek - UTA Reach 2 (UTA2)

Parameter	Pre-Existing Condition (applicaple)					Design		Monitoring Baseline (MY0)		
Riffle Only	Min	Mean	Med	Max	n	Min	Max	Min	Max	n
Bankfull Width (ft)		14.5			1	8		11.4		1
Floodprone Width (ft)		15.95			1	20		24		1
Bankfull Mean Depth (ft)		1			1	1		0.6		1
Bankfull Max Depth (ft)		1.3			1	1.3		1.0		1
Bankfull Cross Sectional Area (ft^2)		14.6			1	8		6.6		1
Width/Depth Ratio		14.3			1	8		19.9		1
Entrenchment Ratio		1.1			1	2.5		2.1		1
Bank Height Ratio		1			1			1		**1**
Max part size (mm) mobilized at bankfull	118-204					148-239		58-123		
Rosgen Classification	F5					E5		B5		
Bankfull Discharge (cfs)	82.1					38.0		24.2		
Sinuosity (ft)	1.02					1.02		1.02		
Water Surface Slope (Channel) (ft/ft)	0.027					0.022		0.023		
Other										

Table 10. Cross Section Morphology Monitoring Summary

Millstone Creek / DMS: 204

Cross Section 1 (Pool - NTR1)	MY0	MY1	MY2	MY3	MY5	MY7	MY+
Bankfull Elevation (ft) - Based on AB-Bankfull[1] Area	450.45	450.46					
Bank Height Ratio_Based on AB Bankfull[1] Area	1.00	0.96					
Thalweg Elevation	449.37	448.78					
LTOB[2] Elevation	450.45	450.40					
LTOB[2] Max Depth (ft)	1.08	1.62					
LTOB[2] Cross Sectional Area (ft^2)	5.76	5.20					

Cross Section 2 (Riffle - UTB)	MY0	MY1	MY2	MY3	MY5	MY7	MY+
Bankfull Elevation (ft) - Based on AB-Bankfull[1] Area	440.79	440.82					
Bank Height Ratio_Based on AB Bankfull[1] Area	1.00	1.01					
Thalweg Elevation	439.61	439.70					
LTOB[2] Elevation	440.79	440.83					
LTOB[2] Max Depth (ft)	1.18	1.14					
LTOB[2] Cross Sectional Area (ft^2)	7.10	7.20					

Cross Section 3 (Pool - UTB)	MY0	MY1	MY2	MY3	MY5	MY7	MY+
Bankfull Elevation (ft) - Based on AB-Bankfull[1] Area	436.53	436.38					
Bank Height Ratio_Based on AB Bankfull[1] Area	1.00	0.96					
Thalweg Elevation	433.56	433.34					
LTOB[2] Elevation	436.53	436.27					
LTOB[2] Max Depth (ft)	2.97	2.93					
LTOB[2] Cross Sectional Area (ft^2)	15.57	14.55					

Cross Section 4 (Riffle - MC R1)	MY0	MY1	MY2	MY3	MY5	MY7	MY+
Bankfull Elevation (ft) - Based on AB-Bankfull[1] Area	433.56	433.41					
Bank Height Ratio_Based on AB Bankfull[1] Area	1.00	1.07					
Thalweg Elevation	427.61	427.33					
LTOB[2] Elevation	433.56	433.84					
LTOB[2] Max Depth (ft)	5.95	6.51					
LTOB[2] Cross Sectional Area (ft^2)	153.88	174.22					

Cross Section 5 (Pool - MC R1)	MY0	MY1	MY2	MY3	MY5	MY7	MY+
Bankfull Elevation (ft) - Based on AB-Bankfull[1] Area	432.07	432.73					
Bank Height Ratio_Based on AB Bankfull[1] Area	1.00	1.00					
Thalweg Elevation	427.32	427.28					
LTOB[2] Elevation	432.07	432.75					
LTOB[2] Max Depth (ft)	4.75	5.48					
LTOB[2] Cross Sectional Area (ft^2)	154.17	155.74					

Cross Section 6 (Riffle - MC R1)	MY0	MY1	MY2	MY3	MY5	MY7	MY+
Bankfull Elevation (ft) - Based on AB-Bankfull[1] Area	431.96	431.82					
Bank Height Ratio_Based on AB Bankfull[1] Area	1.00	0.99					
Thalweg Elevation	427.43	426.90					
LTOB[2] Elevation	431.96	431.76					
LTOB[2] Max Depth (ft)	4.53	4.86					
LTOB[2] Cross Sectional Area (ft^2)	133.02	129.58					

Cross Section 7 (Pool - MC R2)	MY0	MY1	MY2	MY3	MY5	MY7	MY+
Bankfull Elevation (ft) - Based on AB-Bankfull[1] Area	429.49	430.71					
Bank Height Ratio_Based on AB Bankfull[1] Area	1.00	0.85					
Thalweg Elevation	423.83	425.07					
LTOB[2] Elevation	429.49	429.87					
LTOB[2] Max Depth (ft)	5.66	4.79					
LTOB[2] Cross Sectional Area (ft^2)	146.27	102.03					

Cross Section 8 (Riffle - MC R2)	MY0	MY1	MY2	MY3	MY5	MY7	MY+
Bankfull Elevation (ft) - Based on AB-Bankfull[1] Area	429.51	429.78					
Bank Height Ratio_Based on AB Bankfull[1] Area	1.00	1.03					
Thalweg Elevation	425.42	425.08					
LTOB[2] Elevation	429.51	429.91					
LTOB[2] Max Depth (ft)	4.09	4.83					
LTOB[2] Cross Sectional Area (ft^2)	89.89	94.43					

Cross Section 9 (Pool - UTA R1)	MY0	MY1	MY2	MY3	MY5	MY7	MY+
Bankfull Elevation (ft) - Based on AB-Bankfull[1] Area	445.74	445.87					
Bank Height Ratio_Based on AB Bankfull[1] Area	1.00	0.93					
Thalweg Elevation	443.94	443.78					
LTOB[2] Elevation	445.74	445.74					
LTOB[2] Max Depth (ft)	1.80	1.96					
LTOB[2] Cross Sectional Area (ft^2)	13.92	14.98					

Cross Section 10 (Riffle - UTA R1)	MY0	MY1	MY2	MY3	MY5	MY7	MY+
Bankfull Elevation (ft) - Based on AB-Bankfull[1] Area	461.38	461.38					
Bank Height Ratio_Based on AB Bankfull[1] Area	1.00	0.95					
Thalweg Elevation	460.73	460.84					
LTOB[2] Elevation	461.38	461.36					
LTOB[2] Max Depth (ft)	0.65	0.52					
LTOB[2] Cross Sectional Area (ft^2)	3.63	3.38					

The above morphology parameters reflect the 2018 guidance that arose from the mitigation technical workgroup consisting of DMS, the IRT and industry mitigation providers/practitioners. The outcome resulted in the focus on three primary morphological parameters of interest for the purposes of tracking channel change moving forward. They are the bank height ratio using a constant As-built bankfull area and the cross sectional area and max depth based on each years low top of bank. These are calculated as follows:

1 - **Bank Height Ratio (BHR)** takes the As-built bankful area as the basis for adjusting each subsequent years bankfull elevation. For example if the As-built bankfull area was 10 ft2, then the MY1 bankfull elevation would be adjusted until the calculated bankfull area within the MY1 cross section survey = 10 ft2. The BHR would then be calculated with the difference between the low top of bank (LTOB) elevation for MY1 and the thalweg elevation for MY1 in the numerator with the difference between the MY1 bankfull elevation and the MY1 thalweg elevation in the denominator. This same process is then carried out in each successive year.

2 - **LTOB Area and Max depth -** These are based on the LTOB elevation for each years survey (The same elevation used for the LTOB in the BHR calculation). Area below the LTOB elevation will be used and tracked for each year as above. The difference between the LTOB elevation and the thalweg elevation (same as in the BHR calculation) will be recroded and tracked above as LTOB max depth.

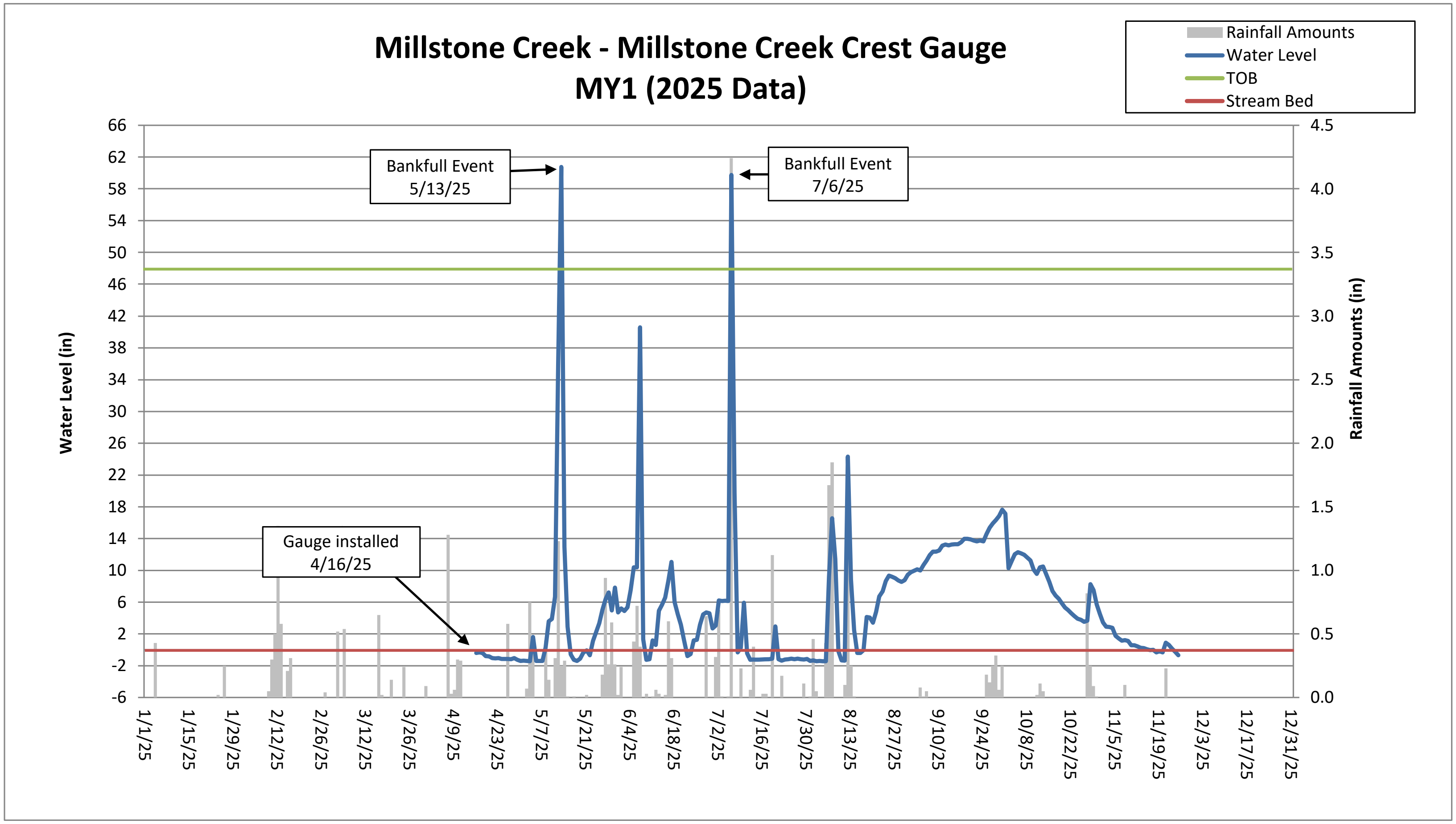
Note: The smaller the channel the closer the survey measurements are to their limit of reliable detection, therefore inter-annual variation in morphological measurement (as a percentage) is by default magnified as channel size decereases. Some of the variability above is the result of this factor and some is due to the large amount of depositional sediments observed.

Appendix D: Hydrologic Data

Table 11. Verification of Bankfull Events

Date of Data Collection	Date of Occurrence	Method	Reach(es)	Monitoring Year	Photo (if available)
July 31, 2025	May 13, 2025	The crest gauge on Millstone Creek and flow gauges on UTA and NTR1 documented a bankfull event after 1.79 inches of rain was recorded between May 11 and 13, 2025 at a nearby rain gauge*.	Millstone Cr, UTA, NTR1	MY1	--
July 31, 2025	July 6, 2025	Crest gauges on Millstone Creek and UTB and flow gauges on UTA and NTR1 documented a bankfull event after 4.24 inches of rain was recorded on July 6, 2025 at a nearby rain gauge*.	Millstone Cr, UTB, UTA, NTR1	MY1	--

*KSCR Siler City Municipal Airport



Millstone Creek - Millstone Creek Crest Gauge
MY1 (2025 Data)
Rainfall Amounts
Water Level
TOB
Stream Bed
Bankfull Event 5/13/25
Bankfull Event 7/6/25
Gauge installed 4/16/25
Water Level (in)
Rainfall Amounts (in)
66
62
58
54
50
46
42
38
34
30
26
22
18
14
10
6
2
-2
-6
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1/1/25
1/15/25
1/29/25
2/12/25
2/26/25
3/12/25
3/26/25
4/9/25
4/23/25
5/7/25
5/21/25
6/4/25
6/18/25
7/2/25
7/16/25
7/30/25
8/13/25
8/27/25
9/10/25
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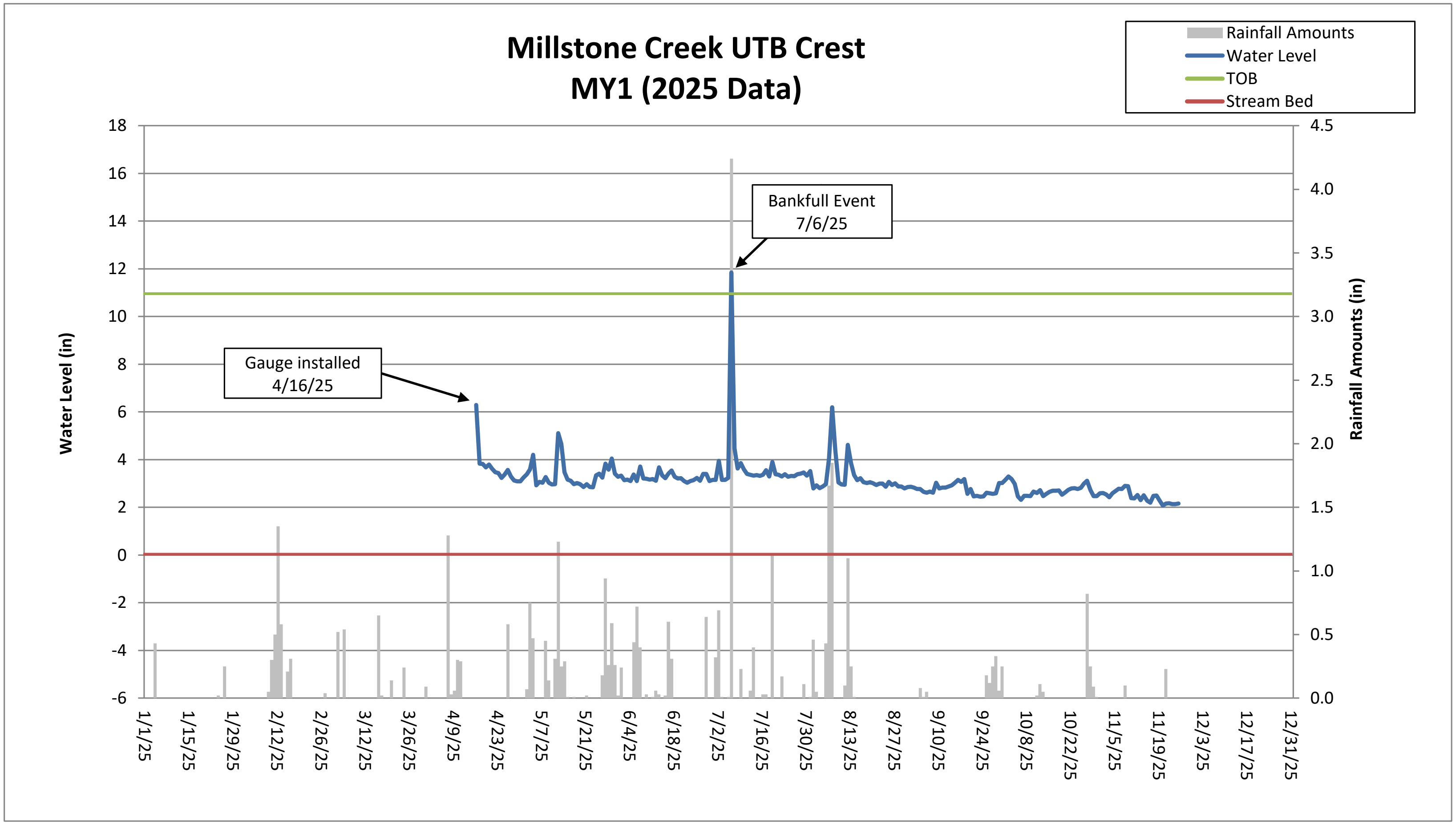
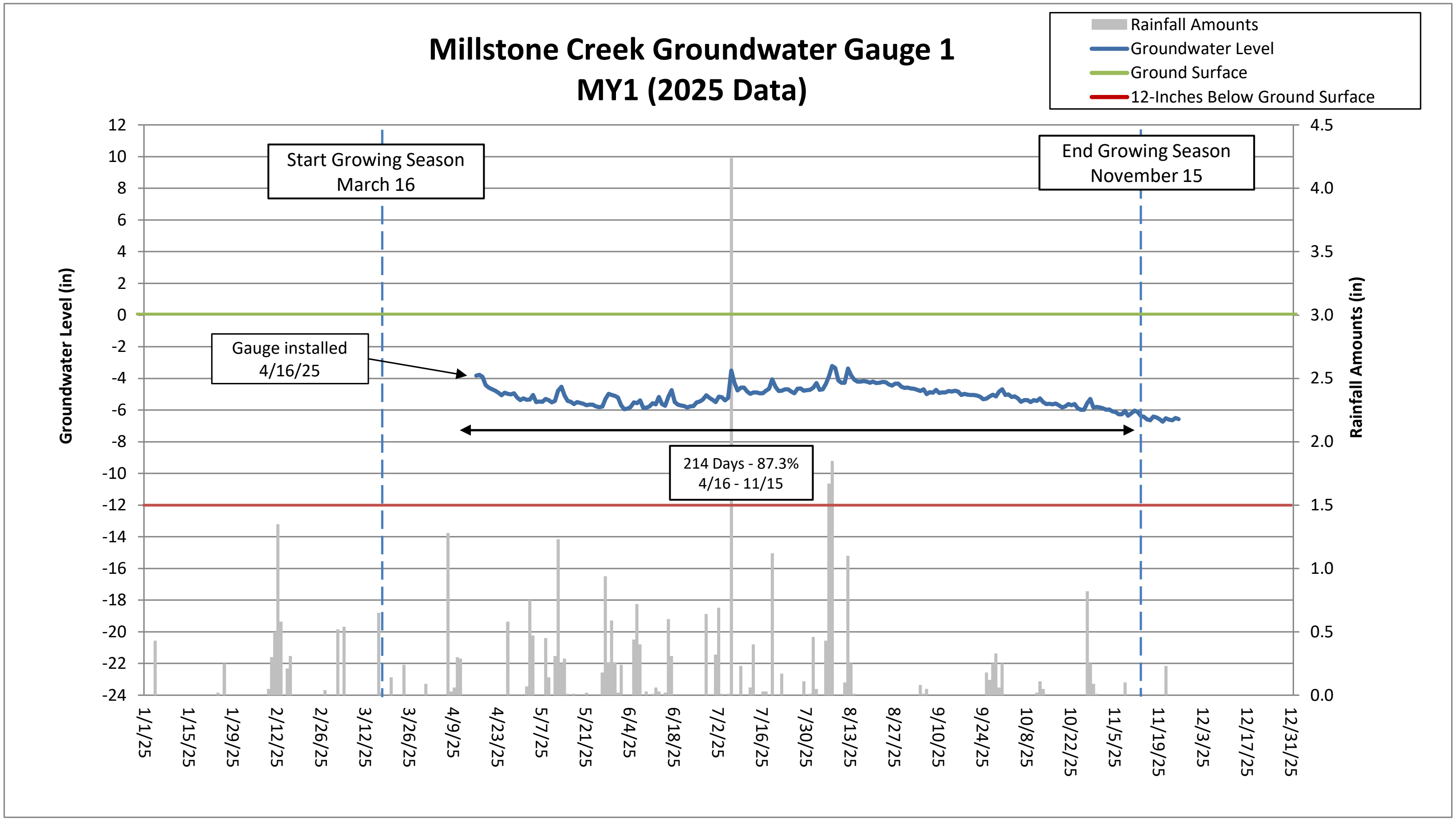
11/5/25
11/19/25
12/3/25
12/17/25
12/31/25



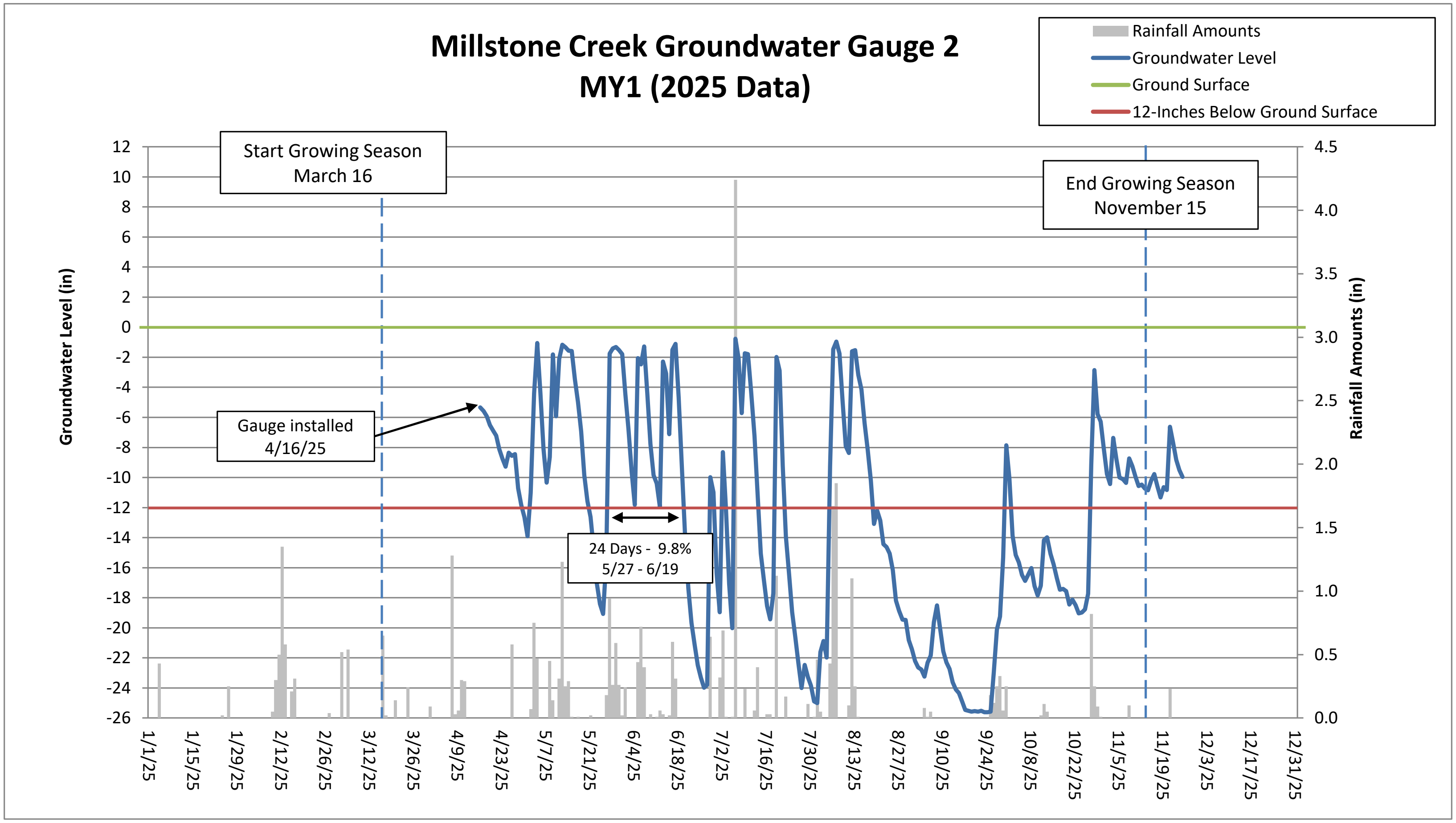
Millstone Creek UTB Crest
MY1 (2025 Data)
Rainfall Amounts
Water Level
TOB
Stream Bed
Water Level (in)
Rainfall Amounts (in)
Gauge installed
4/16/25
Bankfull Event
7/6/25
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1/1/25
1/15/25
1/29/25
2/12/25
2/26/25
3/12/25
3/26/25
4/9/25
4/23/25
5/7/25
5/21/25
6/4/25
6/18/25
7/2/25
7/16/25
7/30/25
8/13/25
8/27/25
9/10/25
9/24/25
10/8/25
10/22/25
11/5/25
11/19/25
12/3/25
12/17/25
12/31/25

Table 12. Groundwater Hydrology Data
Summary of Monitoring Period/Hydrology Success Criteria by Year

Gauge	8% Hydroperiod Success Criteria Achieved – Max Consecutive Days During Growing Season (Percentage)						
	Year 1 (2025)	Year 2 (2026)	Year 3 (2027)	Year 4 (2028)	Year 5 (2029)	Year 6 (2030)	Year 7 (2031)
1	Yes – 214 Days (87.3%)						
2	Yes – 24 Days (9.8%)						



Millstone Creek Groundwater Gauge 1
MY1 (2025 Data)
Rainfall Amounts
Groundwater Level
Ground Surface
12-Inches Below Ground Surface
Start Growing Season
March 16
End Growing Season
November 15
Gauge installed
4/16/25
214 Days - 87.3%
4/16 - 11/15
Groundwater Level (in)
Rainfall Amounts (in)
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1/1/25
1/15/25
1/29/25
2/12/25
2/26/25
3/12/25
3/26/25
4/9/25
4/23/25
5/7/25
5/21/25
6/4/25
6/18/25
7/2/25
7/16/25
7/30/25
8/13/25
8/27/25
9/10/25
9/24/25
10/8/25
10/22/25
11/5/25
11/19/25
12/3/25
12/17/25
12/31/25



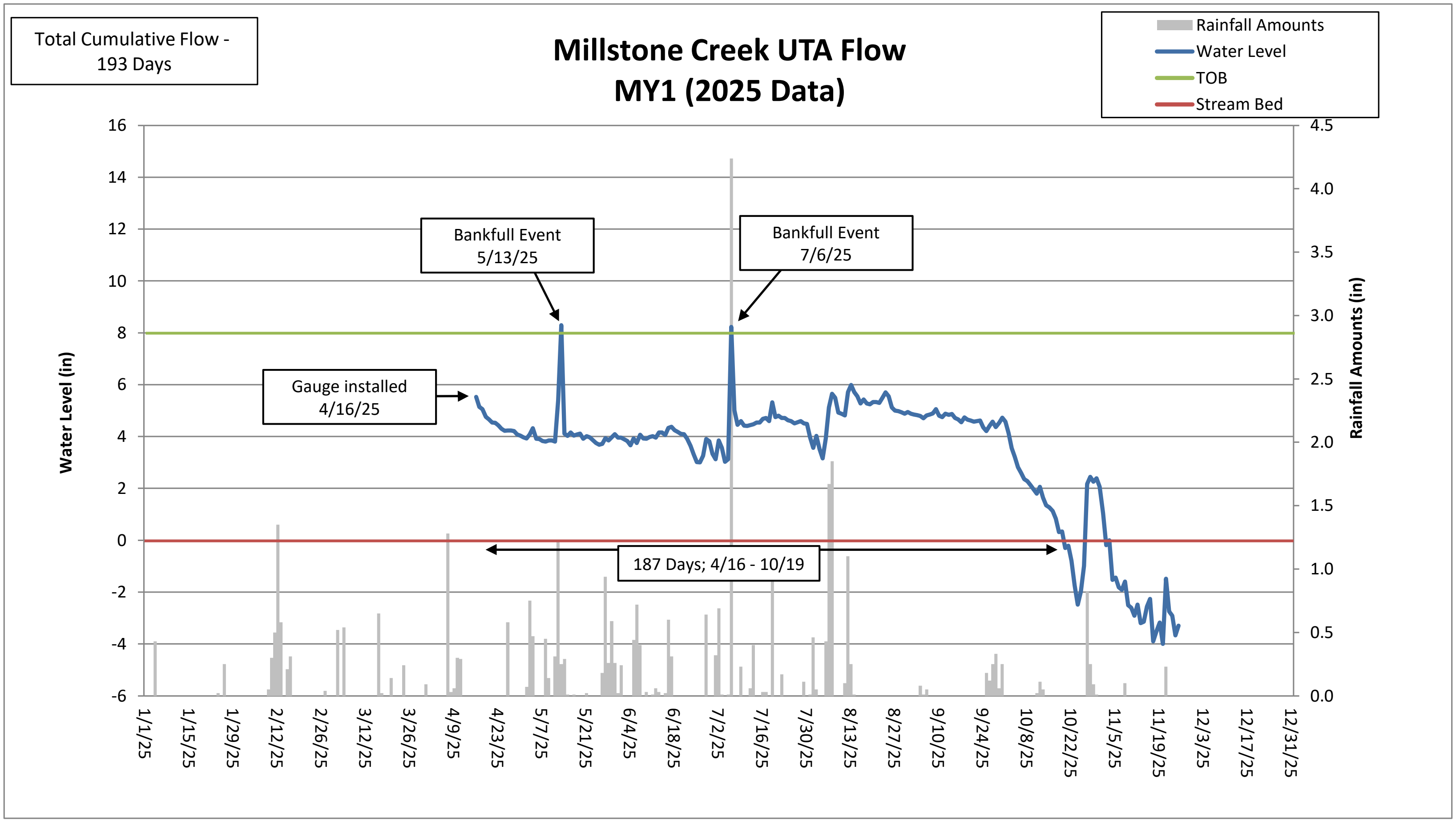
Millstone Creek Groundwater Gauge 2
MY1 (2025 Data)
Rainfall Amounts
Groundwater Level
Ground Surface
12-Inches Below Ground Surface
Start Growing Season
March 16
End Growing Season
November 15
Gauge installed
4/16/25
24 Days - 9.8%
5/27 - 6/19
Groundwater Level (in)
Rainfall Amounts (in)
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1/1/25
1/15/25
1/29/25
2/12/25
2/26/25
3/12/25
3/26/25
4/9/25
4/23/25
5/7/25
5/21/25
6/4/25
6/18/25
7/2/25
7/16/25
7/30/25
8/13/25
8/27/25
9/10/25
9/24/25
10/8/25
10/22/25
11/5/25
11/19/25
12/3/25
12/17/25
12/31/25

Table 13A. UTA Channel Evidence

UTA Channel Evidence	Year 1 (2025)
Max consecutive days channel flow	187
Total cumulative days channel flow	193
Presence of litter and debris (wracking)	Yes
Leaf litter disturbed or washed away	Yes
Matted, bent, or absence of vegetation (herbaceous or otherwise)	Yes
Sediment deposition and/or scour indicating sediment transport	Yes
Water staining due to continual presence of water	Yes
Formation of channel bed and banks	Yes
Sediment sorting within the primary path of flow	Yes
Sediment shelving or a natural line impressed on the banks	Yes
Change in plant community (absence or destruction of terrestrial vegetation and/or transition to species adapted for flow or inundation for a long duration, including hydrophytes)	Yes
Development of channel pattern (meander bends and/or channel braiding) at natural topographic breaks, woody debris piles, or plant root systems	Yes
Exposure of woody plant roots within the primary path of flow	No
Other:	

Table 13B. NTR1 Channel Evidence

NTR1 Channel Evidence	Year 1 (2025)
Max consecutive days channel flow	203
Total cumulative days channel flow	207
Presence of litter and debris (wracking)	Yes
Leaf litter disturbed or washed away	Yes
Matted, bent, or absence of vegetation (herbaceous or otherwise)	Yes
Sediment deposition and/or scour indicating sediment transport	Yes
Water staining due to continual presence of water	Yes
Formation of channel bed and banks	Yes
Sediment sorting within the primary path of flow	Yes
Sediment shelving or a natural line impressed on the banks	Yes
Change in plant community (absence or destruction of terrestrial vegetation and/or transition to species adapted for flow or inundation for a long duration, including hydrophytes)	Yes
Development of channel pattern (meander bends and/or channel braiding) at natural topographic breaks, woody debris piles, or plant root systems	Yes
Exposure of woody plant roots within the primary path of flow	No
Other:	


Total Cumulative Flow - 193 Days
Millstone Creek UTA Flow
MY1 (2025 Data)
Rainfall Amounts
Water Level
TOB
Stream Bed
Bankfull Event 5/13/25
Bankfull Event 7/6/25
Gauge installed 4/16/25
187 Days; 4/16 - 10/19
Water Level (in)
Rainfall Amounts (in)
16
14
12
10
8
6
4
2
0
-2
-4
-6
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1/1/25
1/15/25
1/29/25
2/12/25
2/26/25
3/12/25
3/26/25
4/9/25
4/23/25
5/7/25
5/21/25
6/4/25
6/18/25
7/2/25
7/16/25
7/30/25
8/13/25
8/27/25
9/10/25
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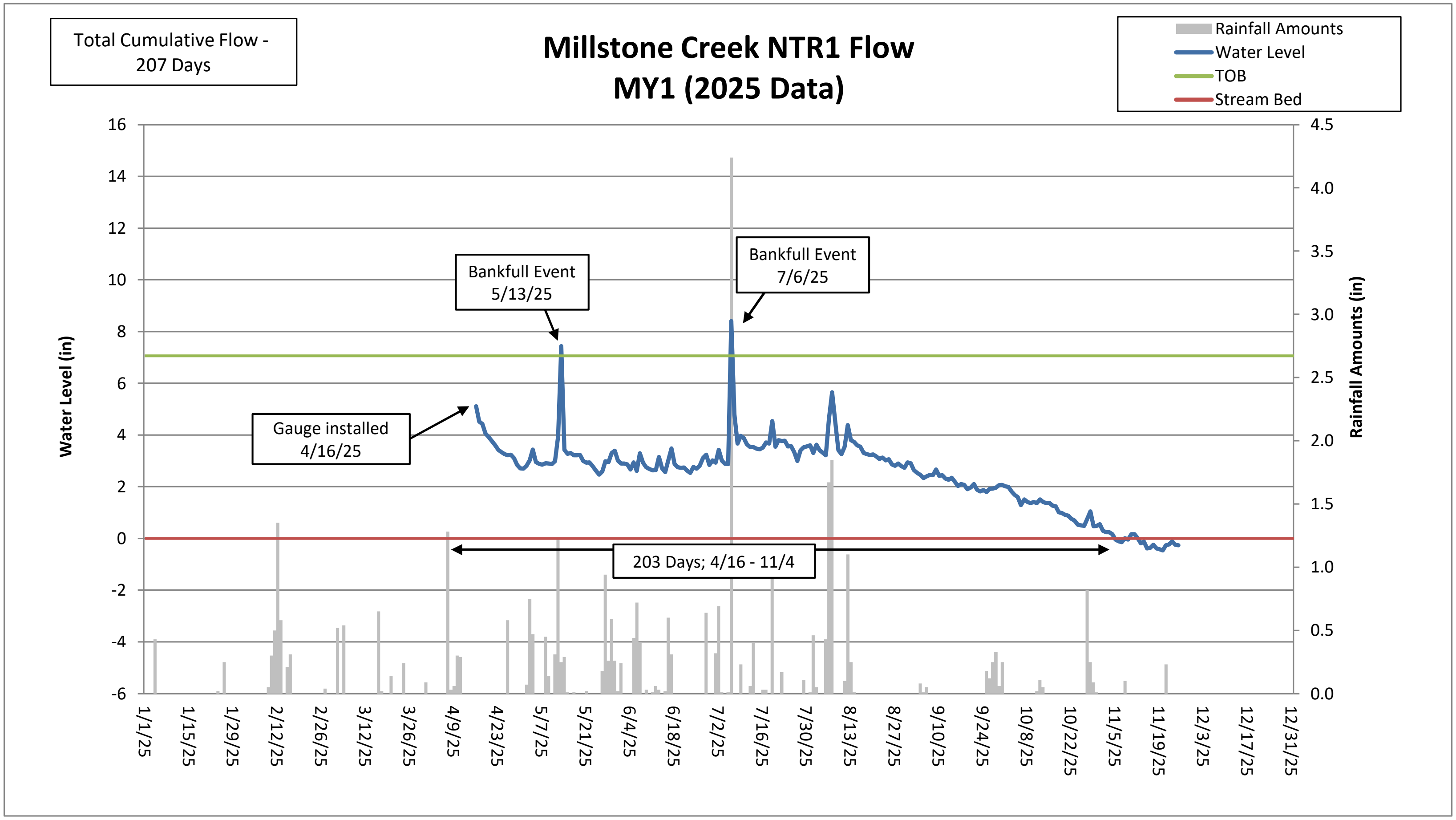
11/5/25
11/19/25
12/3/25
12/17/25
12/31/25



Total Cumulative Flow - 207 Days
Millstone Creek NTR1 Flow
MY1 (2025 Data)
Rainfall Amounts
Water Level
TOB
Stream Bed
Bankfull Event 5/13/25
Bankfull Event 7/6/25
Gauge installed 4/16/25
203 Days; 4/16 - 11/4
Water Level (in)
Rainfall Amounts (in)
16
14
12
10
8
6
4
2
0
-2
-4
-6
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1/1/25
1/15/25
1/29/25
2/12/25
2/26/25
3/12/25
3/26/25
4/9/25
4/23/25
5/7/25
5/21/25
6/4/25
6/18/25
7/2/25
7/16/25
7/30/25
8/13/25
8/27/25
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12/3/25
12/17/25
12/31/25

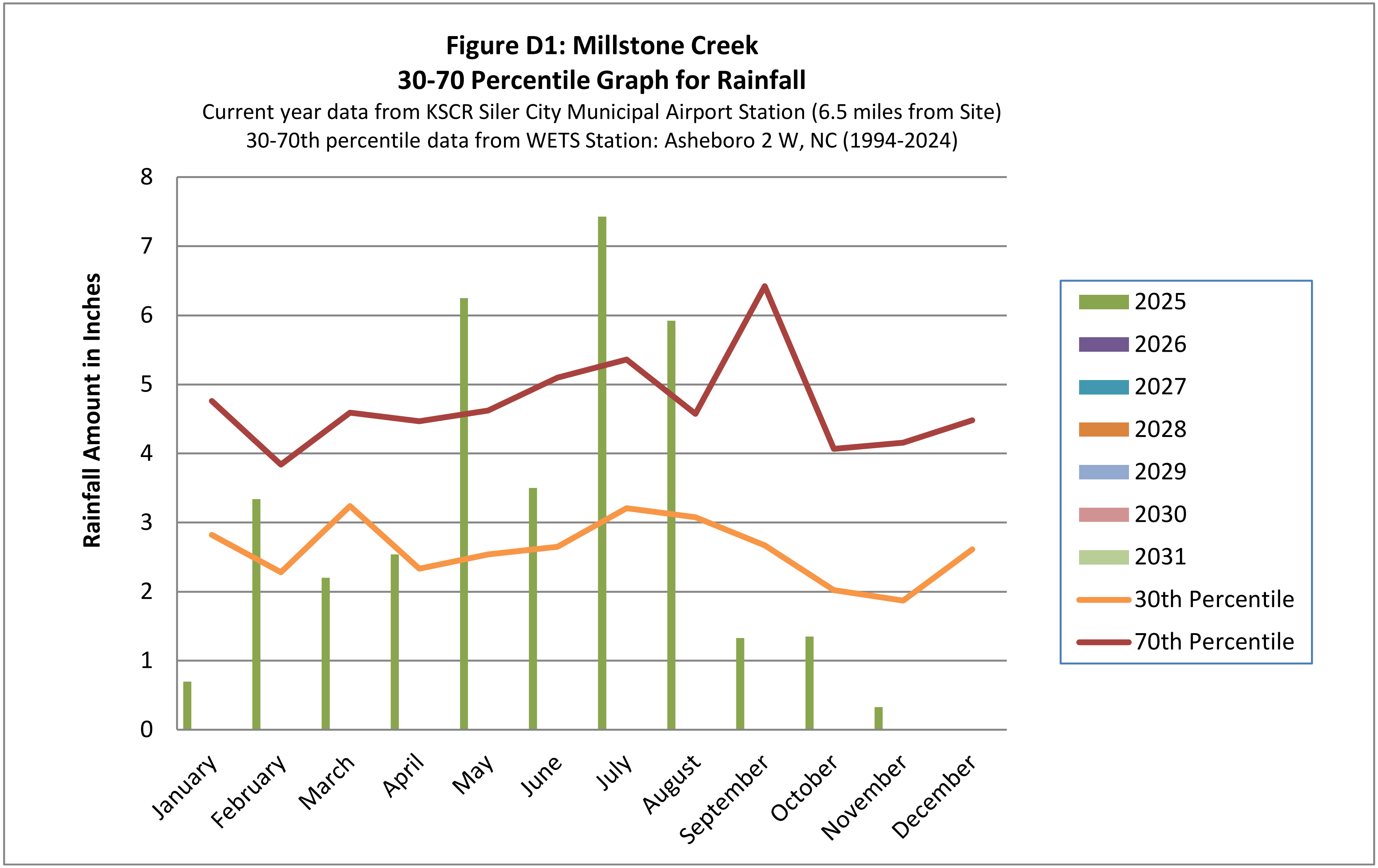


Figure D1: Millstone Creek
30-70 Percentile Graph for Rainfall
Current year data from KSCR Siler City Municipal Airport Station (6.5 miles from Site)
30-70th percentile data from WETS Station: Asheboro 2 W, NC (1994-2024)
Rainfall Amount in Inches
0
1
2
3
4
5
6
7
8
January
February
March
April
May
June
July
August
September
October
November
December
2025
2026
2027
2028
2029
2030
2031
30th Percentile
70th Percentile

Appendix E: Project Timeline and Contact Info

Table 14. Project Timeline

Table 15. Project Contacts

Table 14. Project Timeline

Activity or Deliverable		Data Collection Complete	Task Completion or Deliverable Submission
Project Instituted		NA	May 22, 2006
Mitigation Plan Approved		May 1, 2020	July 16, 2020
Construction (Grading) Completed Phase I		September, 2021	October, 2021
Construction (Grading) Completed Phase II		December, 2023	February, 2024
Planting Completed Phase I		December 1, 2021	December 28, 2021
Planting Completed Phase II		February, 2024	March, 2024
As-built Survey Completed Phase I		September, 2021	January, 2022
As-built Survey Completed Phase II		February, 2024	June, 2024
MY-0 Baseline Report	Stream Survey	April, 2022/April 2024	April, 2022/ October 2024
	Vegetation Survey		
MY1 Monitoring	Stream Survey	April 16, 2025	December, 2025
	Vegetation Survey	July 31, 2025	
MY2 Monitoring	Stream Survey		
	Vegetation Survey		
MY3 Monitoring	Stream Survey		
	Vegetation Survey		
MY4 Monitoring	NA	NA	
MY5 Monitoring	Stream Survey		
	Vegetation Survey		
MY6 Monitoring	NA	NA	
MY7 Monitoring	Stream Survey		
	Vegetation Survey		

Table 15. Project Contacts

Millstone Creek/204	
Provider	NC Division of Mitigation Services
Mitigation Provider POC	Melonie Allen, NC Division of Mitigation Services
Designer	Barbara A. Doll & Jonathan Page, Biological & Agricultural Engineering Dept., NC State University, Box 7625, Raleigh NC 27695
Primary project design POC	Barbara A. Doll, 919-515-5287
Construction Contractor	Backwater Environmental, PO Box 1107, 515 S. Kennedy St., Eden, NC 27289
Post-Construction Monitoring Contractor	Axiom Environmental, 218 Snow Ave., Raleigh, NC 27603
Primary Monitoring POC	Phillip Perkinson, 252-908-1545

DMS Appendix D

Millstone Creek (DMS ID 204) Baseline Report Monitoring Plan and Credit Strategy Memo

This memo is intended to provide clarification for the Millstone Creek credit strategy presented in the Millstone Creek Mitigation Site Final Mitigation Plan prepared by NCSU dated May 7, 2020 as well as the site monitoring plan for Monitoring Years 1 through 7. The Millstone Creek site is a pre-instrument mitigation project. The project consists of stream restoration, stream enhancement, and riparian wetland enhancement. Please find attached Table 1.1 Millstone Creek Site Mitigation Credit Summary excerpted from the final mitigation Plan; and Table 1. 0 Millstone Creek (Ken Cox) Mitigation Site (ID-204) Project Mitigation Quantities and Credits attached. Table 1.0 duplicates Table 1.1 data but is presented in the current DMS approved format. DMS is proposing to use the current version of the table in the Baseline Monitoring Report and subsequent reports. Project Maps (Figure 1.0 Pre-Project Supplemental Monitoring Map, Figure 2.0 Post Project Supplemental Monitoring Map, and Figure 3.0 Millstone Creek Monitoring Map -Years 1-7) have also been enclosed. The project is comprised of the following components:

<u>Stream Reaches</u>

- North Tributary Reach 1 (NT R1)
- North Tributary Reach 2 (NT R2)
- Unnamed Tributary A Reach 1 (UTA R1)
- Unnamed Tributary A Reach 2 (UTA R2)
- Unnamed Tributary B (UT B)
- Millstone Creek Reach 1 (MC R1)
- Millstone Creek R2 (MC R2)

<u>Wetland Units</u>

- Wetland 1

Project Background

Project site land use is pasture is actively grazed by beef cattle. There are two on-site hog houses and a waste lagoon; swine waste is land applied to the pastures adjacent to project reaches NT and UT A. On-site water quality data collection was initiated in June of 2014 to establish a site baseline, pre-project, water quality profile. The pre-project water quality profile indicated elevated levels of nutrient loading (Millstone Mitigation Plan – Appendix A). The two tributaries subject to adjacent swine waste application (NT and UTA) having similar drainage areas, channel morphology, and land use were ideal candidates for a paired watershed study to investigate the efficacy of the use Regenerative Stormwater Conveyance (RSC) in a rural landscape. RSC was employed to physically stabilize both channels through industry accepted design practices, while concurrently ameliorating elevated nutrient inputs through incorporation of a carbon and sand media in the channel bed. Employing this design option required additional post construction supplemental monitoring to measure nutrient removal efficacies. The irregular credit strategy submitted in the Millstone Mitigation Plan is predicated on:

- RSC expanding the functional uplift' footprint' beyond the RSC design reaches
- Extensive pre and post project monitoring, analysis of data, and publication of findings
- Targeted approach to address site stressor in concert with specified minimum efficacy to be validated via direct measurement

The paired watershed study also necessitated a phased approach to project construction. Project phases include pre-project, Phase I, and Phase II construction. Please find below detailed information on construction and associated monitoring phases, a summary of the supplemental monitoring protocols and site work completed, along with justification for the proposed irregular credit strategy.

I. Project Phases

Pre-Project Phase

The pre-project phase is defined by the initial water quality data collection phase which began June 2014 and concluded in 2019. DMS funded cattle exclusion fencing and watering stations were installed during the pre-project phase in 2015. This allowed an initial pre and post fencing " Effects of Livestock Exclusion on Pollution Export From a North Carolina Beef Cow Pasture" (Line, Doll, 2023) study to quantify the effects of livestock exclusion on pollution export. Pre-project phase data established the baseline nutrient loading profile for the site. Pre-project monitoring findings were included in the Millstone Mitigation Plan.

Phase I Construction & Monitoring

Phase I of project construction consisted of all work on MC1, MC2, NT1, NT2, UTB. Phase I construction began in April of 2021 and was completed in January 2022. Upon completion of phase I work, the site was re-instrumented with water quality monitoring stations and data collection resumed. Post phase I data collection was conducted between March 2022 – November 2023 (18 months). Post Phase I data allowed direct measurements and comparison of water quality metrics between a tributary subjected to RSC design (NT RI) and a control tributary (UTA R1). This comparison was used to determine if RSC should be used in construction of UTA R1 in phase II.

Phase II Construction & Monitoring

Phase II of project construction consisted of all work on UTA. Phase II construction began in November 2023 and was completed in February 2024. Upon completion of phase II construction, the project was re-instrumented with water quality monitoring stations and data collection resumed in March 2024. It is anticipated that NCSU Phase II water quality data will be completed in March 2025. This will result in 12 months of post construction data collection.

Table A. Summary of Millstone Creek Supplemental Water Quality Data Collection:

Water Quality Monitoring Phase	Dates	Cumulative Months
Pre-project	8/2014 - 2019	60 months (5 yrs.)
Phase I	3/2022 – 11/ 2023	18 months (1.5 yrs.)
Phase II	2/2024 – 3/2025	13 months (1.1 yrs.)

II. Pre- Project Supplemental Monitoring

Pre – Project Water Quality Monitoring Station

Pre-construction water quality stations were installed on NT R2, UTA R2 and Millstone Creek in 8/2014. These stations measured stage, discharge, velocity and allowed a stage discharge rating table to be developed to enable flow propositional automated sampling. Flow proportional sampling was conducted on baseflow, and stormflow and the analyte analyzed for TKN, NH3-N, NOX-N, TP, TSS. Grab samples were also collected to validate automated sampling and every four weeks for fecal coliform and dissolved phosphorus (DP). In-situ probes were installed on the tributaries to measure turbidity, conductivity, and water temperature. Pre-construction monitoring concluded in 2019.

Groundwater gauges

Groundwater gauges with sensors were installed on NT and UTA in 2014 to measure steam recharge, temperature, and conductivity. The gauges were sampled regularly on a monthly basis November – May and on an ad-hoc basis when wells contained water. The wells were sampled for TKN, NOX-N, NH3-N, and TP, selected samples also analyzed for DP and TOC. Pre-construction monitoring concluded in 2019.

Macrobenthic Sampling

Pre-construction surveys were conducted on all tributaries (NT R2, UTA R2, UTB) in 11/2014, 4/2015, 11/2015 and 6/2016. Surveys were conducted on Millstone Creek in 11/2015 and 6/2016.

III. Post Construction (Phase I &II) Standard Monitoring :

The complexity of the Millstone Creek project phasing and supplemental monitoring introduced ambiguity in the post construction (phase I and II) site monitoring plan. The Mitigation Plan proposed supplemental monitoring in years 1,2,3 that was intended to capture what was defined as ' pre-project phases I and II" above which would be defined in a standard monitoring schedule as occurring prior to and during MY 1. The MY 1,2,3 indicated in Table 10.3 Millstone Creek supplemental Monitoring Components was intended to convey that monitoring would occur post phase I construction for 1.5 years and additionally during post phase II construction for 1.5 years for a total of 3 monitoring years. There were also discrepancies between Figure 10.1 Millstone Creek Site Monitoring Plan and Table 10.2 Millstone Creek Mitigation Monitoring Components in the mitigation plan. To address this ambiguity DMS is proposed the following standard monitoring be approved for the site:

Table B. Millstone Monitoring Components: MY 1 -7

Monitoring Station Type	Number of Stations	Location of Stations	Monitoring Schedule
Cross Sections	10*	See figure x	MY 1,2,3,5,7
Vegetation Plots	11 fixed**, 4 mobile	See figure x	MY 1,2,3,5,7
Wetland Groundwater Gauges	2***	Wetland 1	MY 1,2,3,4,5,6,7
Surface Water: Flow Gauges	2****	NT R1, UTA R1	MY 1,2,3,4,5,6,7
Surface Water: Bankfull Gauges*****	2	UT B, MC R2	MY 1,2,3,4,5,6,7
Substrate Reach Wide WP Pebble Count	2 reaches******	MC R1,MC R2	MY 1,3,7
Photo Points	16	See figure X	MY 1,2,3,4,5,6,7
C.E Boundary Inspection	NA	Entire boundary	MY 1,2,3,4,5,6,7

***Cross sections**

Total revised from Mitigation Plan 11 in Table 10.2 to reflect the number presented in Figure 10.1; removal of cross section proposed for NT R1 riffle.

**** Vegetation Plots**

Total proposed 11, revised from Mitigation Plan Table 10,2 to include requested wetland plot

***** Wetland Groundwater Gauges**

Total of 2, no change proposed, clarification of map and table

****** Surface water: Flow Gauges**

Total of 2 proposed, in upper third of NT R1 and UTA R1 respectively

******* Surface water: Bankfull Gauges**

Total of 2 proposed, 1 on mid reach of UTB and one on MC R2

******** Reach wide wetted perimeter pebble counts –** reduced to exclude NT, UTA and UT B and limited frequency to three years.

Post construction Supplemental Monitoring

Clarification of Supplemental Monitoring proposed to occur post construction (phases I and II). Monitoring year 1 will occur in 2025.

Monitoring Station Type	Number of Stations	Location of Stations	Monitoring Schedule
Water Quality – Automated sampler	3	NT R2, UTA R2, Wetland 1 outflow	MY 1 or until 20% reduction in total N
Riparian GW wells	3	NT R1, UTA R1	MY 1
In-channel GW wells	2	NT R1	MY1
Macroinvertebrate Sampling Points	5	NT R2, UTA R2, UT B, MC R1, MC R2	MY 3,5,7

IV. Mitigation Site Work Summary

NT R1 and UTA R1 (326 l.f. and 523 l.f.)
Project Credits for NT R1 and UTA R1 are presented in Table 1. Attached. DMS has proposed restoration with the standard 1:1 mitigation ration applied for both reaches. The design for NR R1 and UTA R1 is a modified step-pool system. The design implemented consisted of filling the channel to raise the bed, grading the entire length of both banks on both reaches, installation of constructed riffle/boulder step structures on average every 22 feet. The modifications include adjustment to the riffle and pool design and grading plans to increase volumes to accommodate 80/20 sand and mulch media. The media was placed under riffles and pools to facilitate nutrient amelioration. These reaches were also subjected to cattle exclusion fencing, invasive species treatment to include fescue, and planting. Minor adjustments to the design were made to accommodate on-site conditions; grading adjustment on upper reach of NT 1 R 1 and alignment shift on UTA R1 to accommodate bedrock.

NT R2 and UTA R2 (103 l.f. and 100 l.f.)
Project credits for NT R2 and UTA R 2 are also proposed as restoration at 1:1 credit ratio. The design implemented on these reaches consisted of grading both banks for the length of the channels, installation of constructed riffles with grade control structures, log steps, every 25 linear feet. These reaches were also subjected to cattle exclusion fencing, invasive species treatment to include fescue, and planting.

Ut B (529 l.f)
The design implemented on Ut B consisted for grading the length of both banks on both channels, installation of log sills every 35 feet in concert with constructed riffles in appropriate locations and stabilization at end of reach at Wetland 1. These reaches were also subjected to cattle exclusion fencing, invasive species treatment to include fescue, and planting. The channel was re-aligned on the downstream 120 linear feet by 5 – 8 feet during construction and 20 linear feet of grading was eliminated at the top of the reach.

Millstone Creek Reaches 1 and 2
Project credits for reaches Millstone Creek reach 1 and 2 (MC R1 and MC R2) were derived by using standard credit ratios based on traditional stream enhancement and restoration work, respectively.

V. Millstone Creek Quantities and Credits: Credit Ratio Adjustments

Millstone tributary reaches NT R1 and UTA R1 are proposed as restoration with a credit ratio of 1:1. The design and mitigation work completed on these reaches meet the industry accepted definition of restoration as these systems were designed as step-pool systems.

The request for a 1:1 credit ratio for the downstream reaches (NT R2, UTA R2 and UTB) is predicated on the direct address of elevated nutrient inputs to the system through modified channel design and construction. The ancillary design component of the widened pools, additional grading to ensure adequate volume for, and the installation of, the wood/mulch media were intended to promote increased functional return for the whole of the Millstone Creek tributary system (NT R1, NT R2, UTA R1, UTA R2, UT B). These modified structures were installed on 849 linear feet of channel (NT R1, UTA R1) which met industry accepted stream restoration standards without employment of RSC. The remaining tributaries (NT R2, UTA R2, UT B) represent 732 linear feet combined, which meet or exceed, the accepted practices to support Enhancement I stream work typically credited at 1.5:1. The request to increase the credit ratio on 732 linear feet from 1.5: 1 to 1:1 is based on modifications to channel design and construction techniques that increase the functional uplift relative to standard EI stream mitigation practices on these reaches.

VI. Millstone Creek Supplemental Monitoring: Credit Quantity Adjustments

Credit Increases: Supplemental Monitoring

Credit increases of 4% were proposed on credit generated on reaches NT R 1, NT R2, UTA R1, UTA R2 and UT B based on supplemental monitoring. The request for increased credit for supplemental monitoring is based on the extensive monitoring schedule, complexity of the protocol, as well as subsequent data analysis and publication of findings. The Millstone Creek monitoring efforts exceeded typical post project monitoring .

Credit Increases: Nitrogen Reduction Metric

A 2% credit increase has been proposed on NT R1, NT R2, UTA R1, UTA R2 and UT B based on meeting a 20% reduction in total N as compared to baseline pre-construction data. The monitoring to validate the reduction will be completed by NCSU and is estimated to be end in March 2025. DMS proposes that this be awarded upon meeting the reduction metric with no further sampling or analysis required. If the standard is not met in 2025, monitoring must continue until the standard is met, or DMS may discontinue the monitoring and forfeit the 2% credit adjustment based on this metric.

Table 1. Millstone Creek (Ken Cox) Mitigation Site (ID-204) Project Mitigation Quantities and Credits										
		Original								
		Mitigation		Original	Original	Original		WQ	Functional	
	Proje	Plan	As-Built	Mitigation	Restoratio	Mitigation	Baseline	Monitorin	Uplift	
Project Segment	Phas e	Ft/Ac	Ft/Ac	Category	Level	Ratio (X:1)	Credits	4%*	2%**	Comments
Stream										
NT R1	1	326	326	Warm	R	1.00000	326.000	13.040	6.520	Design = traditional restoration & RSC media
NT R2	1	103	103	Warm	R	1.00000	103.000	4.120	2.060	Design = traditional restoration & RSC media
Ut A R1	2	523	516	Warm	R	1.00000	523.000	20.920	10.460	WQ station & macrobenthic monitoring yrs 3,5,7
UT A R2	2	100	101	Warm	R	1.00000	100.000	4.000	2.000	WQ station & macrobenthic monitoring yrs 3,5,7
UT B	1	529	523	Warm	R	1.00000	529.000	21.160	10.580	W.Q. station & macrobenthic monitoring yrs 3,5,7
MC R1	1	1462	1462	Warm	E	1.50000	974.667	0.000	0.000	Macrobenthic monitoring yrs 3,5,7
MC R2	1	533	537	Warm	R	1.00000	533.000	0.000	0.000	Macrobenthic monitoring yrs 3,5,7
						Total:	**3,088.667**	**63.240**	**31.620**	
Stream Credits							**3,151.907**		**3,183.527**	3,151.907 fixed credits; 3,183.527 if 20% Total N reduction is achieved
Wetland										
Wetland I	1	1.323	NA	R	E	2.00000	0.662			hydrological improvements
						Total:	**0.662**			

* WQ monitoring data collected

** Dependent upon water quality functional uplift metric achie

Project Credits

Restoration Level		Stream (Min./Max) Warm	Cool	Cold	Riparian Wetland	Non-Rip Wetland	Coastal Marsh
Restoration		2177.907 2,208.860					
Re-establishment							
Rehabilitation							
Enhancement					0.662		
Enhancement I		974.667					
Enhancement II							
Creation							
Preservation							
Totals	**min.**	**3,151.907**			**0.662**		
	max.	**3,183.527**			**0.662**		

Total Stream Credit

Total Wetland Credit **0.66**

Wetland Mitigation Category		Restoration Level	
CM	Coastal Marsh	HQP	High Quality Preservation
R	Riparian	P	Preservation
NR	Non-Riparian	E	Wetland Enhancement - Veg and Hydro
		EII	Stream Enhancement II
		EI	Stream Enhancement I
		C	Wetland Creation

Table 1a. Millstone Creek (Ken Cox) Mitigation Site (ID-204) Project Mitigation Quantities and Credits

Project Segment	Project Phase	Original Mitigation Plan Ft/Ac	As-Built Ft/Ac	Original Mitigation Category	Original Restoration Level	Original Mitigation Ratio (X:1)	Baseline Credits	WQ Monitoring 4%*	Functional Uplift 2%**	Comments
Stream										
NT R1	1	326	326	Warm	R	1.00000	326.000	13.040	6.520	Design = traditional restoration & RSC media
NT R2	1	103	103	Warm	R	1.00000	103.000	4.120	2.060	Design = traditional restoration & RSC media
Ut A R1	2	523	516	Warm	R	1.00000	516.000	20.640	10.320	WQ station & macrobenthic monitoring yrs 3,5,7
UT A R2	2	100	101	Warm	R	1.00000	101.000	4.040	2.020	WQ station & macrobenthic monitoring yrs 3,5,7
UT B	1	529	523	Warm	R	1.00000	523.000	20.92	10.460	W.Q. station & macrobenthic monitoring yrs 3,5,7
MC R1	1	1462	1462	Warm	E	1.50000	974.667	0.000	0.000	Macrobenthic monitoring yrs 3,5,7
MC R2	1	533	537	Warm	R	1.00000	537.000	0.000	0.000	Macrobenthic monitoring yrs 3,5,7
						Total:	**3,080.667**	**62.76**	**31.380**	
Stream Credits							**3,143.427**		**3,174.807**	3,143.427 fixed credits; 3,174.807 if 20% Total N reduction is achieved
Wetland										
Wetland I	1	1.323	NA	R	E	2.00000	0.662			hydrological improvements
						Total:	**0.662**			

* WQ monitoring data collected

** Dependent upon water quality functional uplift metric achievement

Restoration Level		Stream (Min./Max) Warm	Cool	Cold	Riparian Wetland	Non-Rip Wetland	Coastal Marsh
Restoration		2,168.760 2,200.140					
Re-establishment							
Rehabilitation							
Enhancement					0.662		
Enhancement I		974.667					
Enhancement II							
Creation							
Preservation							
Totals	**min.**	**3,143.427**			**0.662**		
	max.	**3,174.807**			**0.662**		

Wetland Mitigation Category		**Restoration Level**	
CM	Coastal Marsh	HQP	High Quality Preservation
R	Riparian	P	Preservation
NR	Non-Riparian	E	Wetland Enhancement - Veg and Hydro
		EII	Stream Enhancement II
		EI	Stream Enhancement I
		C	Wetland Creation

Table 1: Project Quantities and Credits

Project Segment	Phase	Mitigation Plan Footage	As-Built Footage	Mitigation Category	Restoration Level	Mitigation Ratio (X:1)	Credits	WQ Monitoring (4%)	WQ Reduction Std. Achieved (2%)*	Comments
NT R1	I	326	326	Warm	R	1:1	326.00	13.04	6.52	Step-pool system with Regenerative Stormwater Conveyance
NT R2	I	103	103	Warm	R	1:1	103.00	4.12	2.06	Bank grading, in-stream structures, WQ treatment on NT R1
UTA R1	II	523	516	Warm	R	1:1	523.00	20.92	10.46	Step-pool system with Regenerative Stormwater Conveyance
UTA R2	II	100	101	Warm	R	1:1	100.00	4.00	2.00	Bank grading, in-stream structures, invasive removal
UTB	I	529	523	Warm	R	1:1	529.00	21.16	10.58	Bank grading, in-stream structures, WQ treatment on NT R1
MC R1	I	1462	1462	Warm	E1	1.5:1	974.67	0.00	0.00	Bank grading, in-stream structures, bank treatments, planting
MC R2	I	533	537	Warm	R	1:1	533.00	0.00	0.00	Priority 2 approach. Appropriate bankfull channel dimensions, minor floodplain grading, in-stream structures, bank treatments, planting
Totals		3576	3568				3088.67	63.24	31.62**	
Wetland 1		E	N/A		Enhancement	1.323 AC	2:1		0.662	Hydrological enhancement through filling ditch; no planting per IRT guidance

*The 2% Reduction is not available until data collection is complete and analyzed.

**Note the water quality credit differs from the 26.22 reported in the mitigation plan due to a math error.

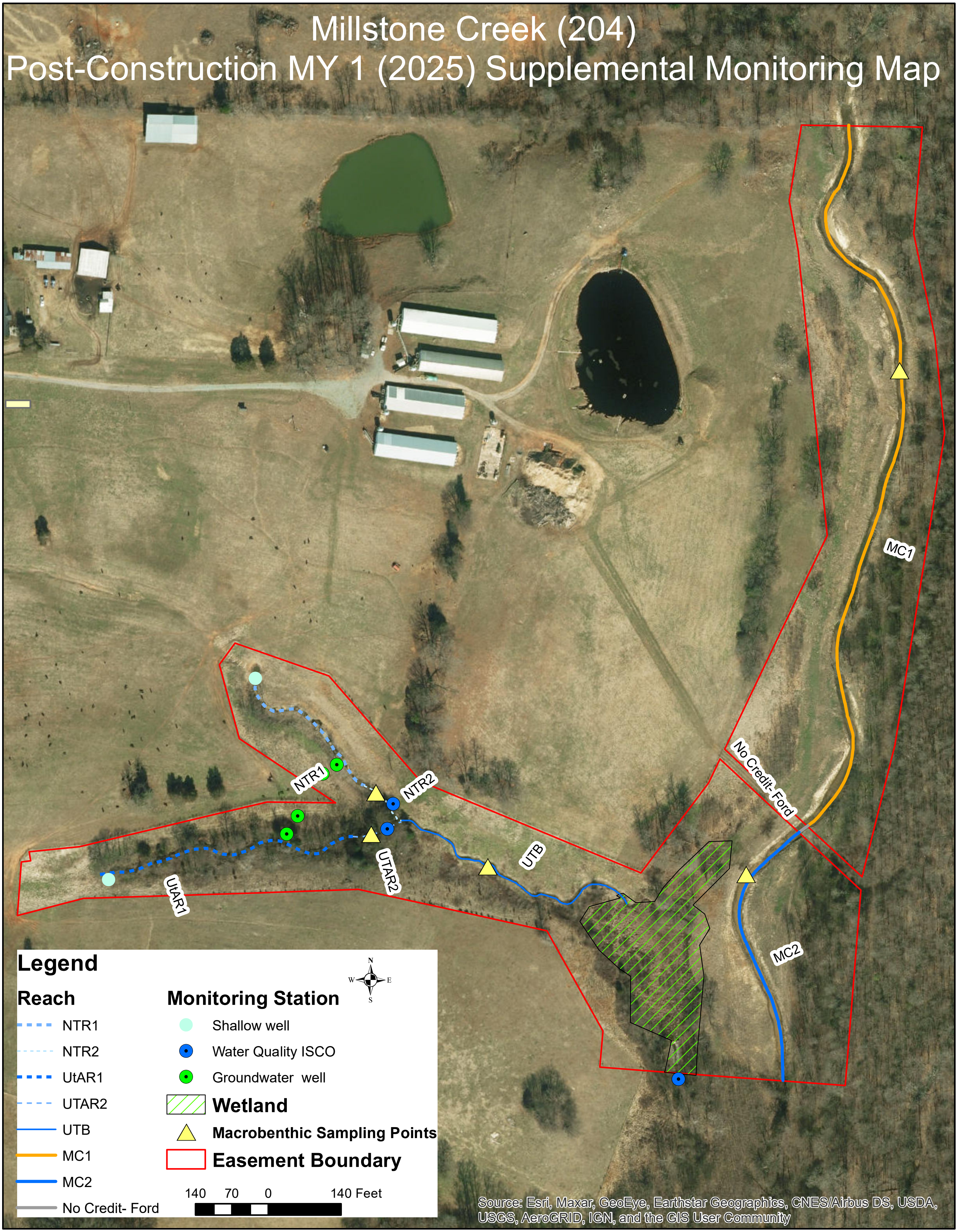

Millstone Creek (204)
Post-Construction MY 1 (2025) Supplemental Monitoring Map
MC1
MC2
No Credit- Ford
NTR1
NTR2
UTB
UTAR2
UtAR1
Legend
Reach
NTR1
NTR2
UtAR1
UTAR2
UTB
MC1
MC2
No Credit- Ford
Monitoring Station
Shallow well
Water Quality ISCO
Groundwater well
Wetland
Macrobenthic Sampling Points
Easement Boundary
140 70 0 140 Feet
N
S
E
W
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 2.0 Millstone Creek (204)
Post-Project Supplemental Monitoring Map-MY 1 (2025)

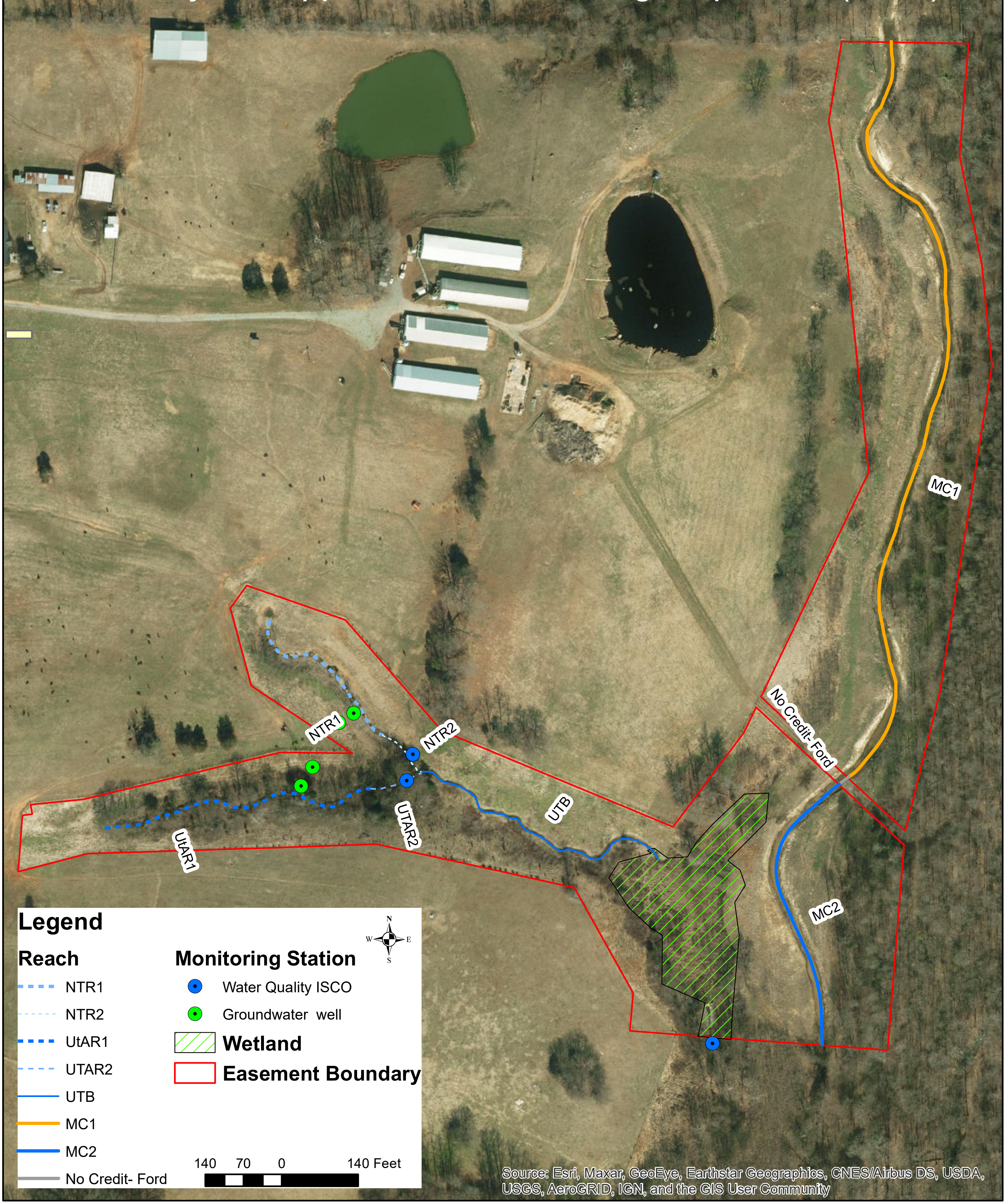
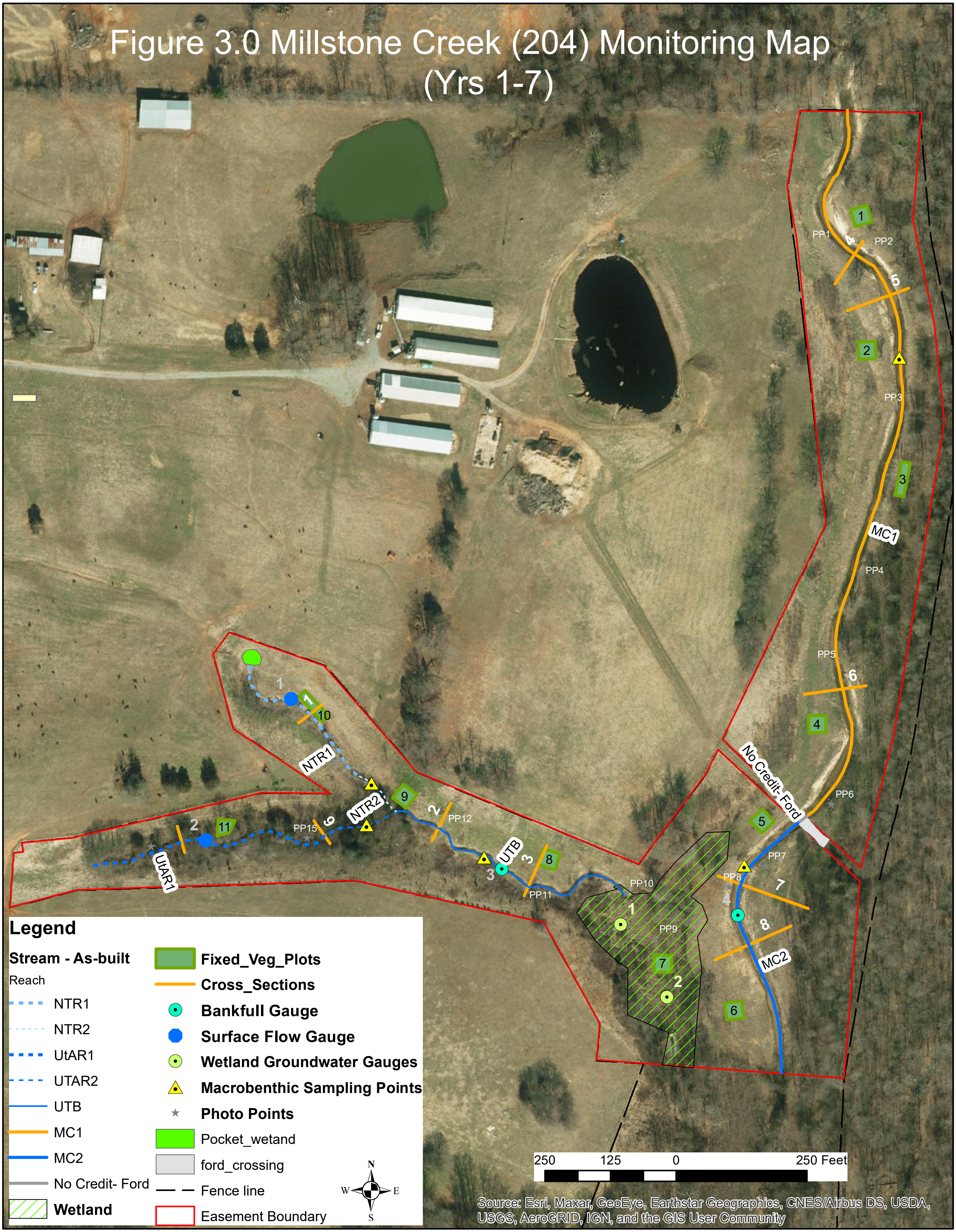


Figure 3.0 Millstone Creek (204) Monitoring Map (Yrs 1-7)



Millstone Creek Restoration Final Monitoring Report

Randolph County, North Carolina

NC DEQ CONTRACT #6017

Prepared for:

NC Department of Environment Quality Division of Mitigation Services
1652 Mail Service Center Raleigh, NC 27699-1652

August 5, 2025

Prepared by:

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Contents

BACKGROUND

The NC Division of Mitigation Services completed two phases of restoration on Millstone Creek including two unnamed streams/tributaries located on a private family farm in Randolph County. The restoration work was for the purpose of accruing compensatory mitigation credit. The design, mitigation plan documents and construction oversight of both phases were completed by NC Sea Grant and NC State University's Biological and Agricultural Engineering Department (NCSU BAE). In addition, starting in August 2014, NCSU BAE was contracted to conduct research to evaluate changes in water quality and biology at the site. This report includes summaries of all the water quality monitoring data and analyses for the site.

Site Characteristics

The Millstone Mitigation Site was located in Randolph County, approximately 3 miles southeast of the Town of Ramseur off Highway 22 in the Slate Belt region of central North Carolina. The site encompassed two small perennial streams, referred to as the NT and UTA streams/tributaries, that originated in a beef cow pasture and flowed east-southeast before joining to form an unnamed tributary (UTB) to Millstone Creek. The unnamed tributary was several hundred feet long before ending as an existing jurisdictional wetland that drained into Millstone Creek (MC). Beef cow pasture was the predominant land use for both the NT and UTA watersheds with the only difference being a small area of driveway and barns in the NT watershed and a small section of two-lane state road in the UTA watershed. Therefore, the land use for both stream watersheds was the same and because they were part of the same large pasture, the management was the same. The topography of the pasture was gently rolling with slopes ranging from 2 to 12%. Soils were predominantly of the Cecil sandy loam and Mecklenburg loam series underlain by red clay and saprolite. These soils tend to be deep and well-drained with a typical depth to bedrock of more than 4.9 ft and depth to high water table of 5.9 ft.

Between 90 and 100 beef cows plus their calves grazed about half to two-thirds of the year on the entire pasture, including most of the non-growing season. This equates to a stocking rate of nominally 0.4 to 0.5 cow/ac/yr depending on the amount of time the herd spends on the pasture during the growing season. The calves were moved to another pasture after weaning, so they only partially contributed to the stocking rate. The vegetation on the pasture was mostly bermudagrass and fescue. Swine waste supernatant from a lagoon servicing about 3,000 hogs per year was applied to the pasture. Swine lagoon liquid was applied to the pasture using a big gun sprinkler system, while lagoon slurry was applied occasionally via an agitate, pump, haul, and spread system. The application of swine waste using the same equipment and procedures was repeated each year of the project, except for possibly the first half of 2022 when the hog finishing operation was temporarily suspended. Estimated average application rates of nitrogen and phosphorus were 10.2 lb N/ac and 1.96 lb P/ac.

The NT stream drains an area of 23 acres to its confluence with UTA, which drains an area of 25 acres to the confluence. The channels for both streams were generally 6-10 feet wide with a much narrower baseflow channel on each. Both stream channels were severely incised in places with streambanks ranging from 4-13 feet high. The highest banks were near the upstream end of each channel where a large headcut had formed sometime prior to the start of the project. Occasionally parts of the streambanks sloughed onto the bed of the channel creating high episodic sediment loads in the streams.

The confluence of NT and UTA formed a 2nd order perennial stream referred to as reach B of the unnamed tributary (UTB) to Millstone Creek. The UTB stream was impacted by channelization and impounding in the distant past, livestock trampling, and intensive cattle grazing of riparian vegetation. Prior to this project's restoration effort, the stream channel was moderately incised through its upstream and middle reaches with banks ranging from 3-5 ft high. The lower reach of UTB was relatively flat as it widened into a jurisdictional wetland on the floodplain of Millstone Creek. However, the wetland had been degraded by damming, ditching, cattle access, grazing and deposition of eroded sediment delivered from UTB, so it was not functioning as a wetland.

Prior to this project, Millstone Creek was a 4th order sand bed system with a large watershed (DA = 8.3 mi^2), low sinuosity and low channel water surface slope (0.0021 ft./ft.). The creek valley was flat and moderately confined to unconfined within the easement boundaries. The hillside sloped steeply down from terraces on the east and west sides of the valley. The creek transported a heavy sediment load from upstream of the project boundaries that was accumulating across the streambed and negatively affecting aquatic habitat. The banks were impacted by cattle access and removal of native riparian vegetation, which caused mild to severe bank erosion and lateral migration of several meander bends.

Restoration and Enhancement Work

In October and November of 2015 prior to the restoration work, livestock exclusion fencing (LEF) was installed around an 18.8-acre conservation easement that included the entire mitigation project area. The fencing excluded cattle from the riparian corridor nominally 50-100 ft from the banks of all the stream reaches (Line and Doll, 2023). An alternate livestock watering system outside of the fenced area was installed shortly after the fence. Vegetation in the excluded riparian corridor grew rapidly during the spring and summer of 2016, such that the riparian corridors (Figure 1) including stream channels (Figure 2) that were not shaded by trees stabilized quickly. Because there were more trees along the UTA stream, vegetation in and on the banks of that stream channel took more time than the NT stream to become established.

Figure 1. Typical riparian corridor before (left) and after (right) livestock exclusion fencing.

Figure 2. Typical section of North stream before (left) and after (right) exclusion fencing.

Construction for Phase I of the restoration effort was completed in September of 2021 with planting of vegetation completed in December. Phase I included the restoration and enhancement of Millstone Creek (MC), the installation of a media-based regenerative stormwater conveyance (RSC) system (Figure 3) and enhancement along the NT Stream, restoration of the Unnamed Tributary Reach B (UTB) and hydrologic enhancement of an existing jurisdictional wetland (Table 1). The RSC (Figure 3) consisted of an open surface channel with a series of riffle and step pools constructed over a carbon-rich, porous media bed. The riffle/pool geometry was designed to retain water in shallow pools and dissipate energy as water flowed downstream in rock-lined steps and riffles. Similar to other media-based BMPs, the media had a high hydraulic conductivity to promote infiltration and movement of water in the bed, where filtration, sorption, and enhanced biotransformations were expected to occur. Further, the media contained 15%–20% by volume of shredded wood chip mulch to serve as a carbon source for microbial biotransformation of inorganic (NOx) nitrogen to nitrogen gas (N_2). Native vegetation was planted in and along the channel to increase both water quality and hydrologic benefits through uptake of nutrients and evapotranspiration. An existing wetland near the downstream end of UTB was enhanced prior to the RSC1 period (Figure 4, right). A log structure was installed at the outlet of the wetland to stabilize the transition zone between the wetland and the off-site ditch. Natural volunteer vegetation proliferated during the project, most of which did not appear to be traditional wetland vegetation.

Figure 3. Section of NT stream RSC during construction (left) and after completion (right)

Figure 4. A section of the RSC on UTA (left) and the wetland on UTB (right).

Stream structures including log riffles, log j-hooks, and brush toe protection were installed in Millstone Creek to improve stream bed habitat (MC R1 and MC R2). Streambanks were sloped and planted to reduce erosion. For MC R2, the creek was realigned to have more meanders and the banks excavated so that water from the channel could access the floodplain more frequently. An old spoil pile near the northern boundary of the wetland was excavated and the material was used to fill the existing ditch in the wetland. This modification was intended to expand the wetland area and increase hydraulic retention times in order to enhance nutrient treatment and uptake

Phase II construction included the construction of an RSC and enhancement work along reach A of the Unnamed Tributary (UTA). It finished in January of 2024 with the planting being completed immediately following the construction. This RSC was constructed using the same design principles as the RSC on the NT stream (Figure 4, left). However, for UTA the elevation of the stream channel was not raised and there was considerably less soil material spread across the upland areas of the riparian corridor.

A summary of the restoration and enhancement actions is provided in Table 1 and a map indicating the stream reaches and the 18.8-acre conservation easement for the site are provided in Figure 5. Monitoring and field-collected data were used to develop and guide the mitigation effort so that the restoration was designed to optimize functional uplift with respect to existing conditions, specific landscape processes, in-stream fluvial processes and onsite constraints. This report includes the water quality monitoring data for all phases of the project. An existing condition monitoring report including monitoring data to that point in time was provided to NC DMS in February of 2018. Post-restoration water quality monitoring and flow data are compared to the pre-restoration and the post-fencing data that were presented in the 2018 report.

Table 1. Summary of Mitigation Restoration and Enhancement Actions.

Segment	Phase	Length /Area	Description of Restoration/Enhancement Actions
NT R1	I	326 ft	Step-pool system with Regenerative Stormwater Conveyance
NT R2	I	103 ft	Bank grading, in-stream structures
UTB	I	523 ft	Bank grading, in-stream structures
MC R1	I	1462 ft	Bank grading, in-stream structures, bank treatments, planting
MC R2	I	537 ft	Priority 2 stream restoration. Appropriate bankfull channel dimensions, minor floodplain grading, in-stream structures, bank treatments, planting
Wetland	I	1.323 acres	Hydrological enhancement through filling ditch; no planting per IRT guidance
UTA R1	II	516 ft	Step-pool system with Regenerative Stormwater Conveyance
UTA R2	II	101 ft	Bank grading, in-stream structures, invasive plant removal

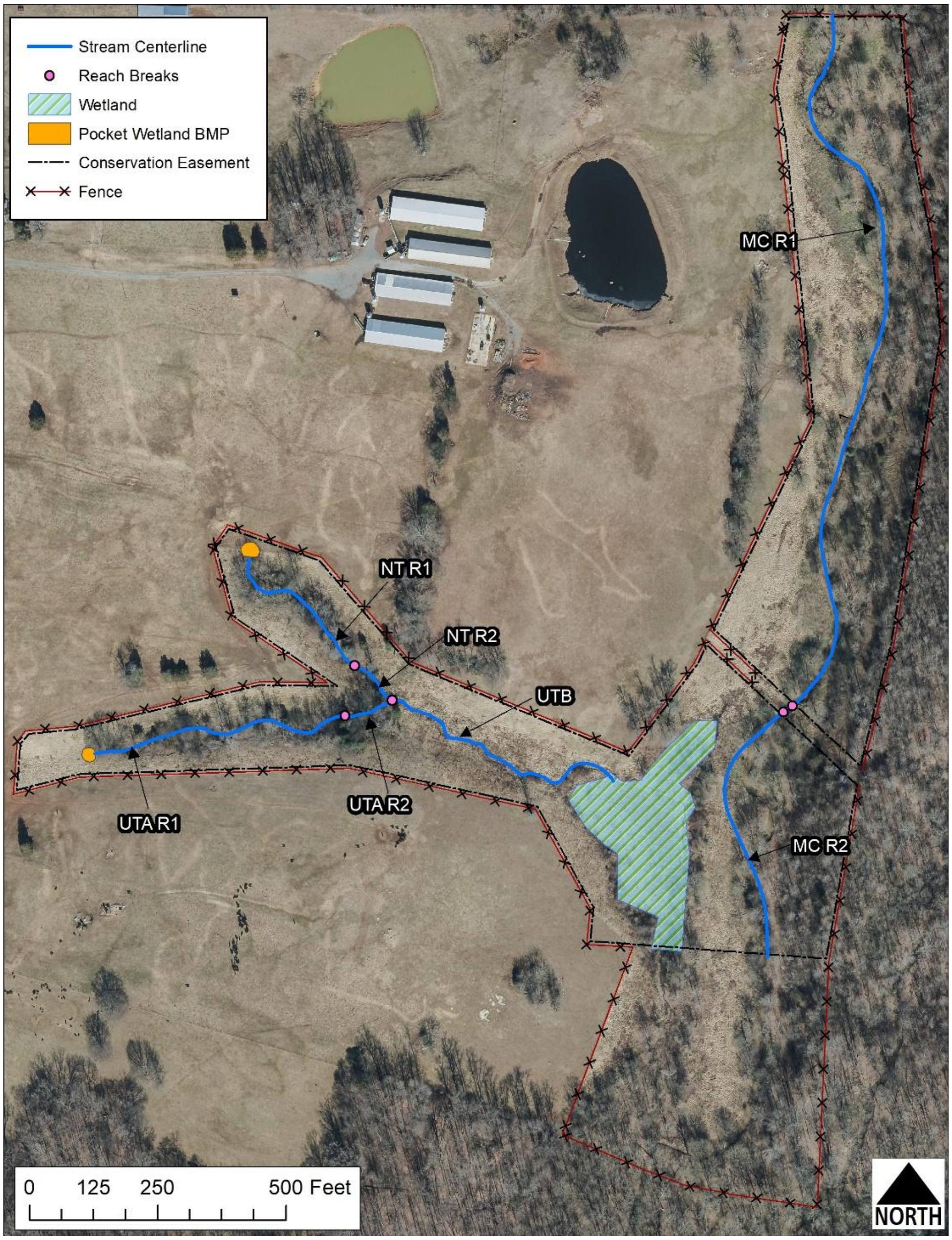


Figure 5. Map of Millstone Creek Mitigation Project Reaches.

Monitoring Goals, Objectives and Approach

The overall goal of the monitoring effort was to document the effectiveness of the restoration measures at improving the water quality of streams/tributaries that drain to Millstone Creek. For the RSCs, the water quality monitoring was also conducted to determine if a 20% reduction in the total nitrogen (TN) concentrations in the NT and UTA stream discharge was achieved as was the goal stated in the Millstone Creek Site Final Mitigation Plan. Specific objectives included documenting/evaluating:

1. The water quality improvement associated with livestock exclusion fencing (LEF)

2. The reduction in total nitrogen concentrations associated with the RSCs on the NT and UTA streams.
3. The effectiveness of regenerative stormwater conveyance (RSC) for reducing nutrient and sediment loads from agricultural sources.
4. The flow dynamics of water transport through media-based RSC treatment systems.
5. The water temperatures for Millstone Creek before and after LEF and restoration to provide a baseline to compare to temperatures after riparian vegetation becomes established.
6. The changes in water temperature associated with implementing an RSC on the NT stream.

Four periods of monitoring were conducted including pre-restoration (Pre), post-livestock exclusion fencing (Fence), Post phase I RSC construction on the NT stream (RSC1) and post phase II construction of the RSC on the UTA stream (RSC2). The time periods and monitoring activities conducted during each period are outlined in Table 2. In addition, the locations of the monitoring stations are shown in Figure 6 and a monitoring timeline including periods of no monitoring is shown in Figure 7.

Table 2: Summary of Monitoring Periods, Sites, and Activities.

Monitoring Period	Time Period	Duration (months)	Reach	Monitoring Effort
Pre-Restoration (Pre)	8/5/14-12/2/15	16	NT & UTA	• Rainfall & Discharge • Nutrients & Sediment in Baseflow and Stormflow • Groundwater Levels • Nutrients in Groundwater • Surface & Groundwater Temperature • Benthic Macroinvertebrates*
			Mill	• Discharge* • Nutrients & Sediment in Discharge* • Surface Water Temperature • Benthic Macroinvertebrates*
			UTB	• Benthic Macroinvertebrates*
Post Livestock Exclusion Fencing (Fence)	1/1/16 - 10/26/17	22	NT & UTA	• Rainfall & Discharge • Nutrients & Sediment in Baseflow and Stormflow • Groundwater Levels • Surface & Groundwater Temperature • Nutrients in Groundwater • Benthic Macroinvertebrates*
			Mill	• Discharge*
				• Nutrients & Sediment in Discharge
				• Surface Water Temperature
Post Phase I Construction (RSC1)	7/13/21 to 8/15/23	25	NT	• Rainfall & Discharge • Nutrients & Sediment in Baseflow and Stormflow

				• Surface & Ground Water Levels • Nutrients in Groundwater • Surface & Groundwater Temperature • Flow Dynamics (Fiber Optic)
			UTA	• Discharge • Nutrients & Sediment in Baseflow and Stormflow • Groundwater Levels • Nutrients in Groundwater • Surface & Groundwater Temperature
			UTB	• Surface Water Temperature • Water Surface Elevation
			WET	• Discharge • Nutrients & Sediment in Baseflow & Stormflow
			Mill	• Surface water elevation & Temperature
Post Phase II Construction (RSC2)	3/26/24-3/4/25	11	NT	• Discharge • Nutrients & Sediment in Baseflow and Stormflow • Surface & Ground Water Levels • Nutrients in Groundwater • Surface & Groundwater Temperature • Flow Dynamics (Fiber Optic)
			UTA	• Discharge • Nutrients & Sediment in Baseflow and Stormflow • Surface & Ground Water Levels • Nutrients in Groundwater • Surface & Groundwater Temperature
			UTB	• Surface Water Temperature • Water Surface Elevation
			Mill	• Surface Water Elevation & Temperature
			WET	• Discharge • Nutrients & Sediment in Baseflow & Stormflow

*Results included in 2018 Pre-Restoration Monitoring Report

Figure 6. Map of monitoring sites.

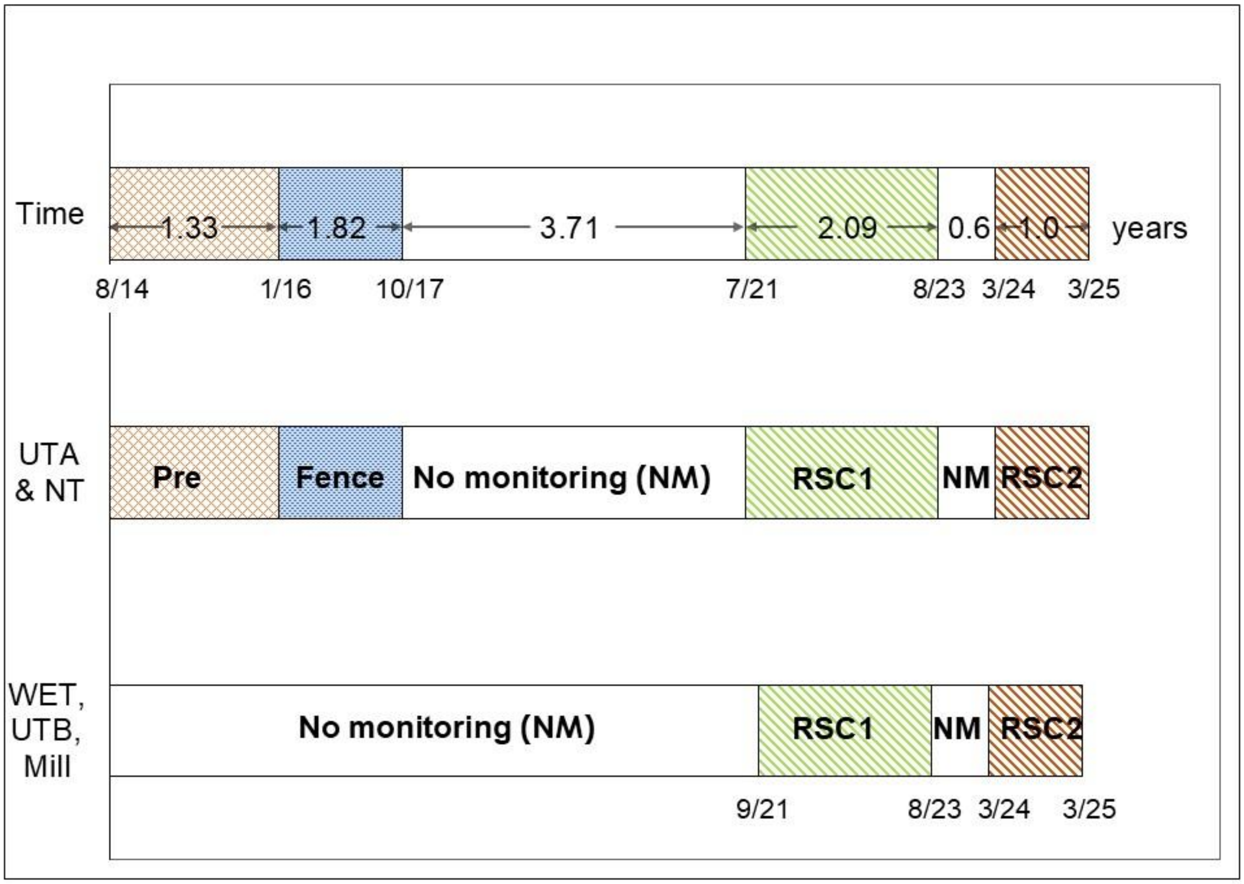


Figure 7. Water quality monitoring timeline.

Experimental Design

Nutrient and sediment loading in surface water are driven by factors that affect source, mobilization, and delivery (Granger et al., 2010). Sources of sediment and nutrients occur naturally, but are often increased by many kinds of human activity such as agricultural production. Mobilization occurs when sediment and nutrients become detached from their source through processes such as erosion, desorption, or mineralization. Delivery is the connectivity of the source to the stream by surface or subsurface pathways. The LEF implemented in this project focused primarily on mitigating the delivery of nutrients and sediment to the stream via surface runoff, whereas the RSC focused on mitigating nitrogen during transport in the stream.

The experimental or monitoring design for surface water employed a before/after approach for the LEF and a paired watershed approach for the RSC. The before/after approach for the LEF was used because there was no control watershed/stream available during the Pre and Fence monitoring periods as the LEF was implemented on both streams. The statistical power of this approach was enhanced by using data from two adjacent streams monitored simultaneously. For the RSC, the site was ideally suited for the statistically powerful paired watershed approach as there were two adjacent (paired) streams with similar hydrologic and geomorphic characteristics originating from the same pasture and only one RSC was constructed at a time (Figure 8). The approach entailed monitoring rainfall on and discharge from both streams for at least one year and then implementing mitigation/treatment practices on one stream (treatment stream/watershed), while the other stream/watershed (control) remained unchanged. In this way, water quality data from the control watershed are used in statistical analyses to account for natural and/or climatic changes over time thereby isolating the change in water quality resulting from the treatment practice, which in this project was the RSC on the NT stream.

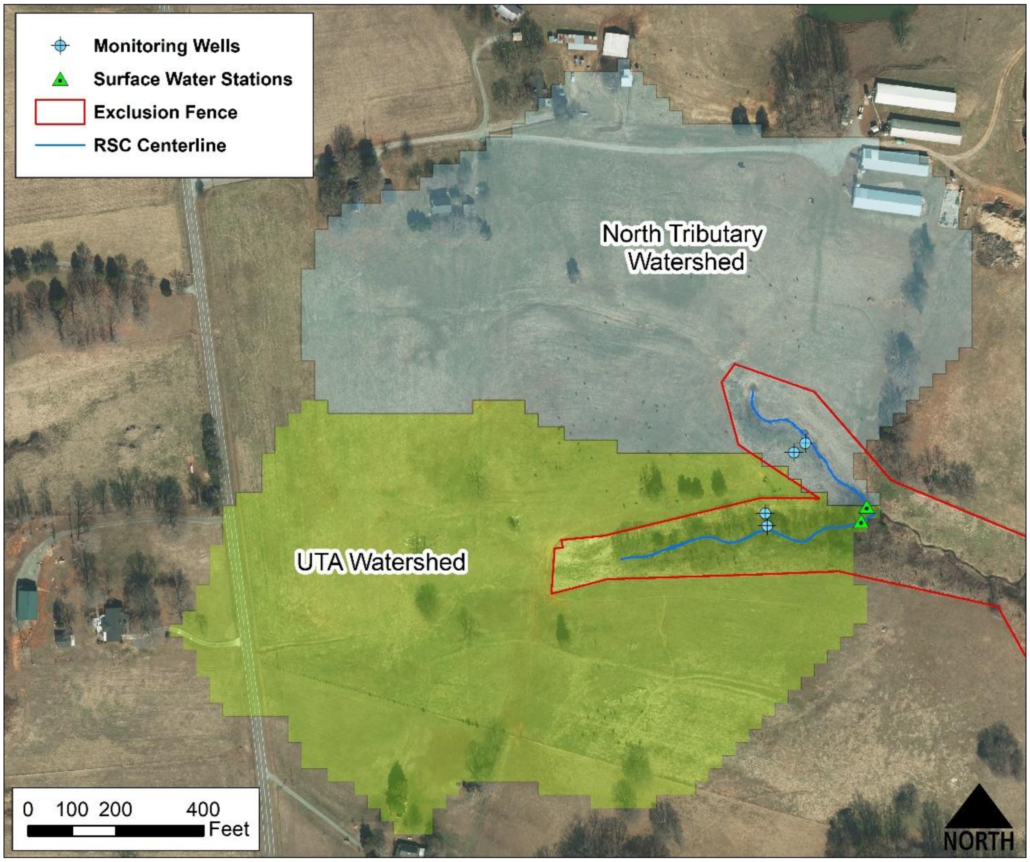


Figure 8. Map of NT and UTA watersheds with monitoring stations and wells shown.

To address the challenges of quantifying subsurface water flux in the NT RSC system, this study used Fiber-Optic (FO) Distributed Temperature Sensing (DTS) technology to obtain measurements of subsurface water flux flowing through the RSC media. FO DTS was applied because its high spatial resolution, which can provide detailed insight into subsurface flow dynamics including the partitioning of the surface and subsurface flows during precipitation events.

METHODS

Surface water monitoring

Surface water monitoring stations were installed along the UTA and NT streams in August 2014 (Figure 6). A station on Millstone Creek, Mill-dn, just downstream of the project was installed in November 2015 (outside the bounds of Figure 6) and another station was installed at the outlet of the wetland (referred to as WET hereafter) on the UTB stream reach on 9/29/21. While all four stations had a stream staff gage, and an automated sampler, the UTA, NT or

North, and WET stations also had a trapezoidal flume installed to facilitate measurement of the range of discharges/flows expected (Figure 9). The trapezoidal flume was chosen as a discharge monitoring device because it provided a stable cross-section that could pass the vegetative and other debris that was expected from the pasture and wooded stream banks in addition to facilitating discharge measurements at low and medium to high discharges. At each station, an automated sampler was installed with an integrated flowmeter that measured water depth/stage continuously. The stream stations (UTA, NT) and the wetland station (WET) also employed a Doppler-based velocity measuring sensor/probe for several months to monitor water depth and velocity continuously from which discharge was computed for a range of stages. In addition, manual measurements of discharge were conducted using a graduated bucket and stopwatch (for low discharge) and a stream pygmy meter (for high discharge) to validate the measurements made by the automated Doppler-based sensors. All the discharge and associated depth/stage measurements were used to develop and update a stage-discharge relationship for each monitoring station. This relationship was entered into the sampler and used to estimate discharge from continuous measurements of stage. For each station/flume, the stage-discharge relationship was updated as new measurements were made, but for the most part the relationship stayed relatively consistent during each phase of the project as long as the flume was maintained. Maintenance involved constant cleaning of the flume to maintain the same roughness, which also meant covering the flume to prevent algae from growing on the flume surface (which changed the roughness also). Also, plugging leaks to prevent bypass flow was accomplished on several occasions.

Figure 9. Trapezoidal flume for NT monitoring station.

For the wetland, the added challenge of backwater from Millstone Creek interrupting monitoring during high discharge events was encountered. In addition, for medium to large events (depending on the runoff/discharge rate) discharge from upstream bypassed (deduced from observations after several large events) the wetland and flowed across the floodplain directly into Millstone Creek thereby bypassing the WET monitoring station. This made the monitoring and computing of total load/export leaving the wetland problematic. Therefore, the evaluation of wetland effectiveness at removing pollutants focused on nonstorm discharge and pollutant loading. This is appropriate as the wetland had little storage capacity so its effectiveness at reducing pollutants in storm discharge was likely negligible.

At the Millstone Creek station (Mill-dn), at least 15 manual stream discharge measurements using a pygmy stream current meter were made to develop a stage-discharge relationship for low to medium (<120 cfs) discharges. For higher discharges, a stationary automated Doppler-based sensor (Sontek SL) mounted on the bank of the stream was used to measure velocity across the stream. These measurements were combined with stream cross-section survey data to compute discharge. These data combined with the manual discharge measurements were used to develop a stage-discharge rating table for the station. It should be noted that the streambed was sandy, which resulted in an unstable cross section. This added considerable uncertainty to the discharge monitoring even though several manual discharge measurements were made to update the stage-discharge relationship.

For all four monitoring stations, the samplers were programmed to collect duplicate flow-proportional samples of stream discharge. One of the duplicates was placed in an odd-numbered sampler bottle that had H_2SO_4 added to reduce the pH<2, while the other duplicate was added to an empty even-numbered bottle. For the tributary stations, samples were divided into non-storm (bottles 1-4) and storm groups (bottles 5-24). Nonstorm samples were collected during periods of no to minimal rainfall (~baseflow in general less than 10-15 gpm), whereas storm samples were collected during significant storm events. Significant storm events were delineated as those for which the stage increased 0.02-0.03 ft above the nonstorm stage. The stage at which storm samples were collected was updated in the sampler's program every two-weeks during visits to the station. The nonstorm samples will be referred to as baseflow samples herein even though they might not all have been collected during baseflow. For the Millstone Creek monitoring station (Mill-dn), the sampler was programmed to sample baseflow and stormflow combined, because, the delineation between baseflow and stormflow was more variable and not as well-defined for this larger stream.

Samples from the machines were retrieved every two weeks and composite samples were made from the odd numbered bottles for analysis of total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), nitrate+nitrite nitrogen (NOx-N), and total phosphorus (TP) and the even-numbered bottles for analysis of total suspended solids (TSS). The term ammonia refers to two nitrogen species which are in equilibrium in water, the un-ionized ammonia (NH_3-N) and the ionized ammonium ion (NH4+). In this project, the analysis for ammonia measured total ammonia (NH_3-N plus NH4+) content, but for simplicity it will be referred to in this report as NH_3-N. The composite samples were made from an equal volume aliquot drawn from each sampler bottle and placed in the corresponding laboratory container. The extended period (up to ~2 weeks) the samples remained at ambient temperatures prior to retrieval was not in accordance with standard methods (Eaton et al., 1995); however, past monitoring has shown that surface water samples stored at pH<2 is adequate to preserve samples in similar circumstances (Line et al., 2016).

For storms with missed samples due to equipment failure, too little discharge, or low battery power, the average concentration of samples collected during the same treatment period with a high or low peak discharge was used to compute the load. High peak discharge was defined as generally greater than about 150-160 gpm as discharge greater than this was likely to originate from the pasture upslope of the fenced riparian corridor and facilitate efficient transport of pollutants to the monitoring stations. Hence, if the peak discharge for the storm was greater than 150-160 gpm, the mean concentration for the high group of storms was used as the estimate and if lower, then the mean for the low peak discharge storms was used. For missed nonstorm/baseflow samples, the average of samples collected during the entire treatment period were used as estimates in load calculations, because pollutant concentrations in baseflow were much less variable.

In addition to automated sampler samples, from August 2016 to May 2023 (from July 2021 to May 2023 collected weekly under separate grant) grab samples were collected weekly or monthly from UTA and NT and analyzed for fecal coliform (FC) and dissolved phosphorus (DP). The DP samples were filtered immediately after collection and both DP and FC samples were delivered on ice to the laboratory within 2 hours of collection. Further, during April-June of 2016, 2022, 2023, and 2024 in-situ probes were installed at the UTA and NT stations to measure conductivity and temperature of the water. Separate in-situ temperature sensors were installed at the NT and UTA stations to measure water temperature continuously throughout the entire project.

Baseflow and stormflow loads were computed for the UTA, NT, and WET stations from discharge and sample analysis data and summed to yield total load for each 2-week period between visits. For the Mill-dn station a combined load was computed for each period by multiplying the concentrations for the 2-week flow-proportional composite sample by the accumulated discharge. These loads were then summed for each monitoring period to yield a total load for the period. The total was then divided by the drainage area and duration to compute an annualized export or loading rate.

Inflow load to the wetland was not monitored but was estimated by summing the 2-week load from NT and UTA and adding an estimated load for the area (8.0 acres) downstream of the stream monitoring stations and upstream of the wetland (Figure 6). The load for the 8.0 acres was estimated by computing the average load per acre for UTA and NT and then multiplying it by 8.0 acres. This estimate assumes that since all stream reaches have similar upland pastures and riparian buffers, the influx of pollutants to the streams should also be similar. Further, the unmonitored 8.0 acres comprised only 14% of the inflow watershed so it should have little influence on the uncertainty of inflow loads.

Water samples were analyzed by the NCSU Center for Applied Aquatic Ecology (CAAE) lab during the Pre and Fence periods and Cameron Testing Services (Cameron) of Sanford, NC during the RSC1 and RSC2 periods. The change in labs for the RSC1 period was needed due to the CAAE discontinuing fecal coliform analysis. Both labs were NC State Certified, so quality assurance/quality control (QA/QC) data for the labs are not included herein, but are available from the NC DEQ Laboratory Certification Branch. Field or sampling QA/QC data are shown in Table C1 in the Appendix C. Results for three blanks submitted to the CAAE document concentrations less than the reportable limit (RL) for TKN, NOx-N, and TP indicating no contamination related to washing, sampling, handling, or lab analysis; however, concentrations greater than the RL occurred for NH_3-N, although the last two were very close to the RL. The RL for NH_3-N (0.018 mg/L) was quite low for surface water samples; in fact none of the surface water samples and only three of the groundwater samples reached this low a concentration. Results for blanks sent to the Cameron lab were mixed with the 12/14/21 sample having both TKN and NOx-N concentrations well above the RL. However, the last two blanks were less than or nearly at the RL thereby indicating that the 12/14/21 blank was likely an outlier and not an indication of systemic problems.

Because it was not a commercial laboratory, standards for NOx-N and TP were purchased from Fisher Scientific and a blind sample prepared and sent to the CAAE lab for analysis. Lab results showed excellent agreement with the standard concentration. A duplicate sample was prepared to assess the repeatability of the combination of sample preparation and lab analysis (Table C1). Results for TKN and NH_3-N were excellent (<10%) while those for NOx-N and TP were still acceptable (~20%). Overall, the QA/QC results show acceptable levels of quality/uncertainty.

Atmospheric monitoring

A tipping bucket raingage was installed near the NT station in August 2014 to measure rainfall continuously. A manual raingage was installed along the edge of the pasture to provide a backup and for comparing to the tipping bucket raingage data. Both gages were installed away from overhanging or other obstructions. A second tipping bucket raingage was installed at the WET station in April 2024 to provide an additional back-up for continuous rainfall measurements. For the few periods when no on-site measurement was successfully made, hourly rainfall data for the Siler City airport from the NC State Climate Office website was used.

A HOBO temperature and pressure sensor was installed at the UTA monitoring station shelter during the Pre, Fence, and RSC1 periods and was moved to the NT station shelter during the RSC2 period. The sensor was located in a place that was shaded from the sun to prevent direct solar radiation from affecting the temperature measurements.

Groundwater monitoring

Groundwater monitoring for this project focused on inorganic or nitrate-nitrogen concentrations. Nitrate, the dominant form of nitrogen in these streams, is a highly soluble and mobile anion which does not easily adsorb to soil particles, which makes it more of a potential contaminate of groundwater (Jury and Nielsen, 1989). In watersheds with nitrate contaminated groundwater, surface water-groundwater exchange delivers nitrate to streams, especially during wetter years when the mobilization of nitrate from soil porewater and shallow groundwater is enhanced (Webber et al, 2023). These factors make the monitoring of ground water essential in determining the effectiveness of the RSC as it is designed to treat near-surface ground water.

At the start of the project, two groundwater monitoring well pairs were installed along the UTA and NT stream channels (Figure 6). For each pair, one well was located on the stream bank and the other on the upland area on a line approximately perpendicular to the stream channel. For the UTA upland well (UTG2), boreholes were dug at three separate locations until one of acceptable depth was obtained. The final location (less than 15 m upslope of the streambank well) and depth (only ~2.2 m, 7.2 ft) were not optimal, but considered the best available given the compaction and resistance of the soil and parent material. The relatively shallow depth of this well yielded results that are biased toward periods of relatively high water table as there will be no samples during periods of lower table. In addition, there were many missing water table elevation values for UTG2, because it was dry during many visits (likely due to how shallow it was). The other well (UTG1) on UTA was located on the streambank directly downslope from UTG2 and in line with the expected movement of groundwater. Similarly, two wells were installed on the NT tributary (NGR1 on the streambank and NGR2 ~ 50ft upslope from the streambank); however, both wells were of desired depth (at least 2 ft below the water table). Each well was dug with a 3 in diameter bucket auger after which a 2 in PVC well casing was inserted in the borehole. The bottom 2-3 ft of the casing was perforated and covered with sock. Clean sand was poured into the borehole to fill it within about 8 in of the ground surface. Bentonite well seal was then poured into the borehole to the top.

During construction of the RSCs, wells UTG1, UTG2, and NGR1 were destroyed. These wells were reinstalled in about the same locations after the RSC on each stream was completed. Again several boreholes on each of the UTA stream wells were needed until an acceptable depth was obtained. Because the streambank well (UTG1) was not as deep as desired, results may be skewed toward periods of higher groundwater table as no samples were obtained when the water table was low. After installation, the top of each well casing, which was used as a reference during water surface measurements, was surveyed to determine its elevation. Each well was instrumented with a HOBO sensor suspended from the well cap via fishing line. The sensor measured and recorded the groundwater level and temperature continuously.

Samples of groundwater were collected (when there was water in the well) at least six times per year. During each sampling visit the distance from the top of the well casing to the water level was measured using a tape measure with a water sensor on the end. This distance along with the elevation of the top of the casing was then used as reference level/elevation for the HOBO water level measurements. A bailer that was dedicated to the well was used to remove standing water from the well. The well was then left to refill for at least two hours after which, the bailer was gently lowered into the well to fill and then retrieved to fill lab bottles for analysis. Samples were analyzed for TKN, NOx-N, NH_3-N, and TP and selected samples were analyzed for DP and total organic carbon (TOC). Samples analyzed for DP were filtered immediately after collection. All samples were delivered to the laboratory within 3 hours of collection.

Temperature monitoring

Water temperature was monitored continuously via HOBO sensors at the two stream monitoring stations (NT and UTA), the four groundwater monitoring wells (NGR1, NGR2, UTG1, and UTG2), and the five stream gages (NST1, NST2, UTST, UTB, and Mill) shown in Figure 6. Sensors in the ground water well and the five stream gages were installed as described below in the WSE monitoring section. Air temperature and pressure were also monitored continuously at either the UTA (during the Pre, Fence, and RSC1 periods) or NT (RSC2 period) station. When portions of the air temperature and pressure data were lost due to sensor malfunction, data transfer device malfunction, and suspension of monitoring, data from the nearby State Climate Office (SCO) Siler City station were used.

Water Surface Elevation (WSE) monitoring

Two shallow (< 3ft) wells/gages were installed in October 2021 on the NT stream in the channel after the RSC was constructed to monitor surface discharge in the stream. One well was located in the upper third (NST1) and the other in the lower third (NST2) of the RSC's channel length (Figure 6). Two additional similar wells were installed along the UTB (UTB) and Millstone Creek (Mill) stream reaches in October 2021. Further, after completion of the RSC on UTA another well (UTST) was installed in the UTA stream channel in June 2024. The wells consisted of a 2-inch diameter PVC pipe, attached to a stable post, installed vertically with one end below the water surface and the other extending well above the normal water surface elevation. A HOBO water depth and temperature sensor was suspended via fishing line from the cap inside the pipe to an elevation well below the normal WSE. The top of the pipe was surveyed to determine its elevation, which was then used as a reference for water surface elevation (WSE) calculations. The WSEs were then compared to the stream channel elevation to determine if surface discharge was present. This comparison was subject to considerable uncertainty at the NST1, NST2, and UTST gages as the stream channel was variable and the baseflow water depth was very shallow.

The gages were visited regularly to download data and measure the distance from the top of the pipe down to the water surface to provide a check for WSEs measured by the HOBO sensor. The controlling streambed feature immediately downstream of the gage was also surveyed to determine its elevation, which was then used to compare to the WSE to determine whether there was surface discharge. For the two NT gages the controlling streambed feature was the sandy streambed and small rocks that had been added. This was somewhat problematic as the sand was shifting. In addition, excavation to install fiber optic cables changed the streambed near the gages, which likely, at least temporarily, changed the elevation of the downstream control section. For the UTA stream gage, the downstream control section was a gap between boulders in the rock step structure which the surface water flowed. For both the NT and UTA stream gages, automated measurement of surface discharge was problematic due to the very shallow depth of surface flow; therefore, even small changes in the stream bed or uncertainty in WSE measurements can change the results. Given these factors, any WSE within 0.1 feet of the controlling streambed elevation was considered surface flow as this distance is within the margin of error for the survey and monitoring equipment used.

In-situ Conductivity monitoring

Calibrated Sondes were installed at the UTA and NT stream monitoring stations during the spring (usually May-June) of the Pre, Fence, RSC1, and RSC2 periods. The Sondes were mounted to a post such that the conductivity sensor was suspended in stream water near the monitoring station. Continuous data, collected on 5-10 minute intervals, from the Sondes were transferred via cable to the automated samplers and downloaded with the other sampler data.

Pollutant Load Calculations and Statistical analyses

To compute surface water loads, concentrations of analytes in the 2-week composite flow-proportional samples for baseflow and stormflow were multiplied by the corresponding baseflow or storm discharge volume for the 2-week period. If more than 1 storm occurred during the period the one 2-week composite stormflow concentration was used with the discharge for each storm to compute the loads. If the storm produced too little stormflow to trigger sample collection, the average concentration for small storms (defined as discharge less than about 10,000 gallons and peak discharge less than about 100-150 gpm) was used. The baseflow and stormflow loads were summed to obtain the total load for each 2-week period. These surface water 2-week loads were then used in the statistical analyses after undergoing log-transformation. The log-transformation was necessary to reduce the skew in the load data. For the LEF, because there was no control watershed or stream, before-after statistical analysis using analysis of variance (ANOVA) was employed to determine if the pre-LEF loads (Pre period) were significantly different (at the 0.05 level) than the post-LEF (Fence period) loads for each stream. Effectiveness was quantified as simply the reduction in the export rates, which would mirror the loads as the export rate is simply all the loads summed and divided by a constant (i.e. drainage area and time).

For the RSC on the NT stream, the analysis of covariance (ANCOVA) was employed with data from the UTA stream during the Fence and RSC1 periods used as the control (paired watershed design). This assumes that the effectiveness of the Fence remained constant during the two periods, which was reasonable since both watershed were treated/managed the same. For the

UTA RSC, the loads from the NT RSC1 and RSC2 periods were used as a control because no further treatment after the RSC was implemented. Using the NT as a control during these periods assumed that the effectiveness of the RSC was constant over these time periods, which may not have been the case. When the ANCOVA indicated a significant difference between the Pre- and Post-RSC loads, a least squares means (LS means) test was performed to further assess statistical significance and quantify the amount of difference/change.

For the wetland, 2-week nonstorm loads were used to evaluate its effectiveness. Because the inflow and outflow loads were paired, a paired t-test statistical analysis was used to test for a significant difference between inflow and outflow loads.

Subsurface Flow Dynamics (Fiber Optic)

Subsurface flux was measured at two locations along the NT RSC using a continuous fiber optic (FO) cable. One location was upstream near the start of the RSC, and the other was downstream close to the discharge flume (Figure 10). Each subsurface flux measuring location was equipped with a continuous FO cable section secured to galvanized steel fencing. The FO cable was secured in a serpentine shape to provide flux measurements at 10 different depths with the deepest transect located at a depth of 2.5 ft below the surface. A groundwater well was installed next to each flux monitoring location and the groundwater table was monitored every 30 minutes over the whole duration of the measurements. The additional length of the FO-cable was placed in four calibration baths kept at different temperatures, which are monitored using RBRsolo temperature sensors.

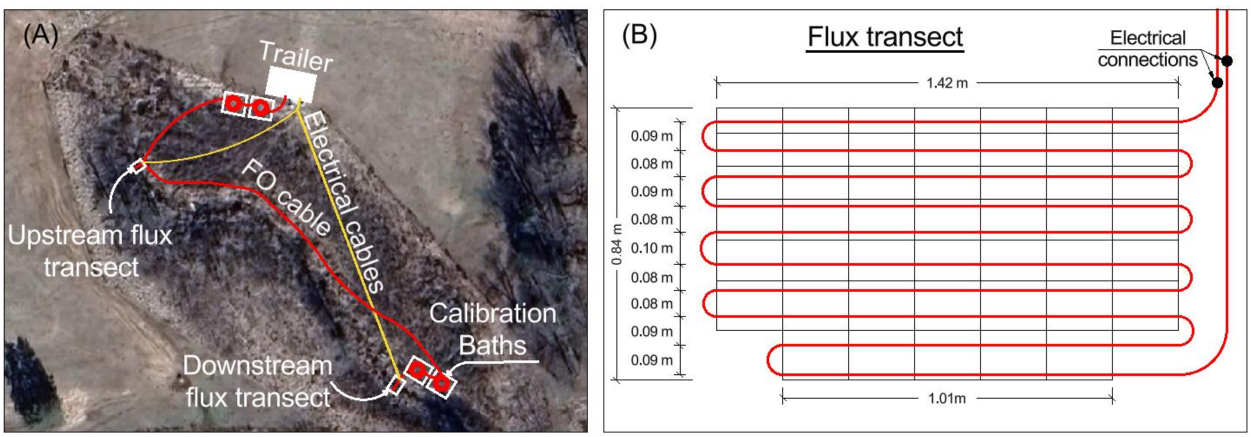


Figure 10. Layout of the DTS installation (A), vertical cross-section of the installed FO cable layout at each flux monitoring location (B).

The end of the FO cables was then connected to a solar-powered Silixa XT-DTS unit (Silixa Ltd, UK) placed inside a nearby trailer. Hourly subsurface water fluxes were monitored over five periods (44 days in total) covering several storms between November 2023 and July 2024. Hourly flux measurements were obtained by applying a 30-minute heat pulse every hour. The temperature increased due to every flux measurement was computed at each location along the FO cable as the mean temperature observed at that location over the last five minutes in the heat pulse after subtracting the effect of the ambient temperature before the heat pulse started. Then, the fluxes were calculated using the calibrated Perzlmaier Model resulting from the FO DTS experiments previously conducted in the BAE laboratory.

The total subsurface flow rate through the upstream and downstream monitoring locations was computed by multiplying the mean measured subsurface flux at that location by the effective area covered by the FO cable shown in Figure 10b. Then, the subsurface flow rates were compared to the surface flow rates monitored at the flume to estimate the partitioning between surface and subsurface flow.

The 2D distribution of the flux passing through both the monitoring locations was also investigated to have a better understanding of the flux distribution through the RSC system at different surface flow conditions. The measurements along the fiber optic cable at each location (Figure 10) were converted to 2D flux measurements using linear interpolation using MATLAB R2024a (Mathworks, Natick, Massachusetts).

RESULTS AND DISCUSSION

The nutrients and sediment monitoring results were divided into livestock exclusion fencing and regenerative stormwater conveyance sections as each of these targeted different nutrients. The water temperature results are presented as a separate section because the monitoring was not designed to document changes in water temperature resulting from all of various restoration efforts (this would require a control stream for each restoration). So, only the RSC on NT was evaluated for its effect on water temperature.

Effectiveness of Livestock Exclusion Fencing (LEF)

The start of the post implementation fencing period (Fence) was somewhat subjective as the construction of the LEF was completed in October 2015, but the fence's gates were left open for much of November and December due to a problem with the watering system; therefore, data collected during December 2015 were not used in the analysis of fence effectiveness. Also, monitoring data for the UTA stream during the RSC1 period was added to the Fence dataset, because the Fence was the only mitigation practice on the UTA during this period. Further, extending the monitoring data through the RSC1 period provided the opportunity to assess the longer-term effectiveness of the LEF.

Surface water concentrations

While surface water concentration data alone can often provide misleading or incomplete characterizations of water quality, it can be used to evaluate trends as a first step in assessing the effects of mitigation measures on water quality. Boxplots of sample concentration data for the UTA and NT streams are shown in Figures 11 through 16. The period shown as 'Pre' in the figures refers to the period prior to the installation of exclusion fencing, while the 'Fence' was after fencing was installed and the 'RSC1' was after the RSC was constructed on the NT stream, so these data (RSC1 for NT) and all of the RSC2 data will be discussed in a later section as they were not used in assessing the LEF effectiveness. From a broad hydrologic perspective, it is evident that concentrations in storm samples for TKN, NH_3-N, TP, and TSS were generally greater than those for baseflow samples and that concentrations during the Pre period were generally greater than during the other periods. Further, concentrations of all five constituents were relatively high during the Pre period thereby highlighting the need for mitigation measure(s).

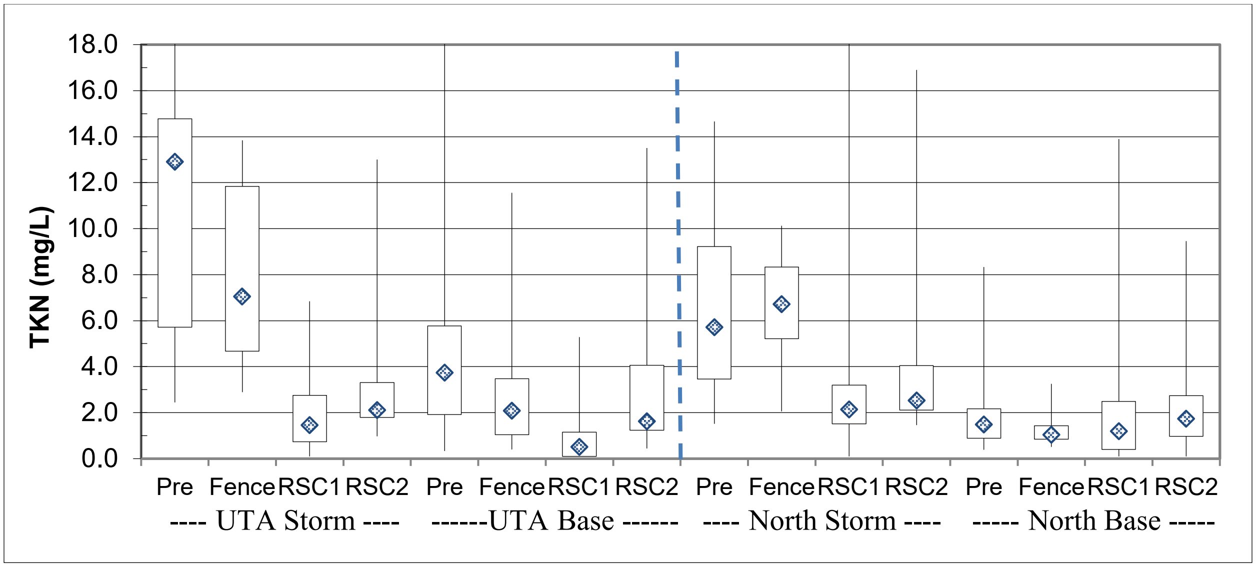


Figure 11. TKN concentration in storm and nonstorm (Base) flow samples from the UTA and NT streams.

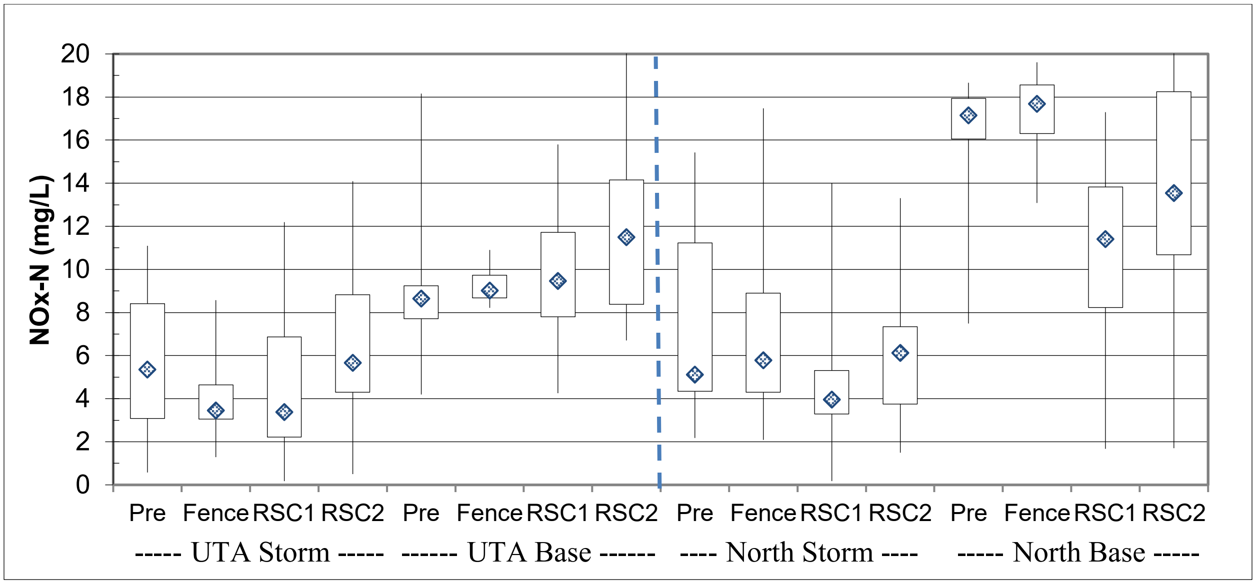


Figure 12. NOx-N concentrations in storm and nonstorm (Base) flow samples from the UTA and NT streams.

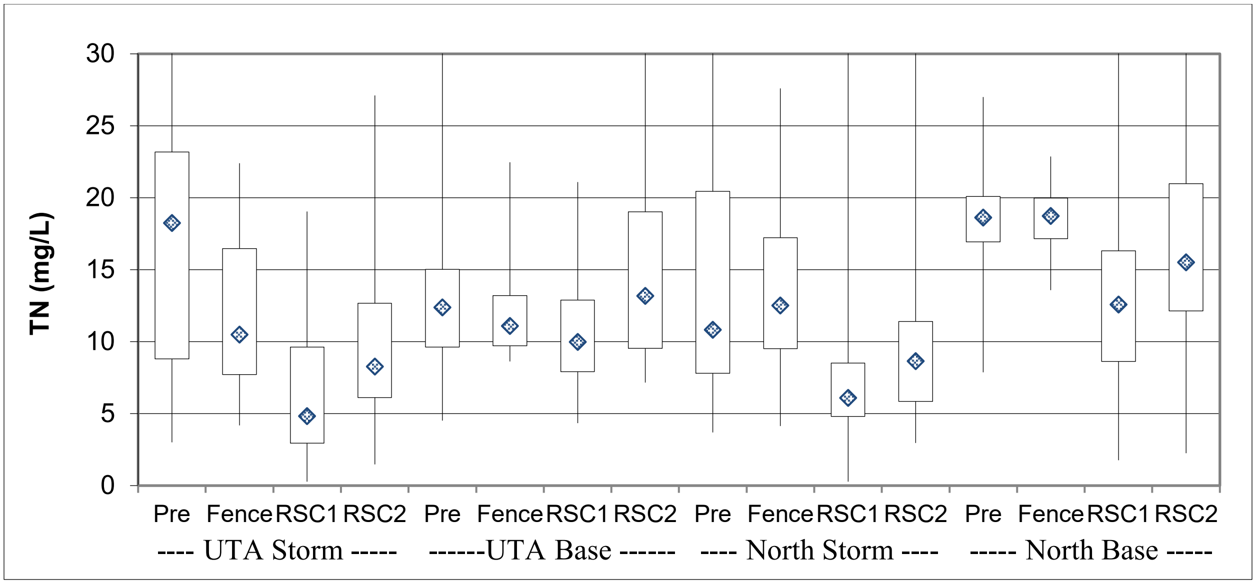


Figure 13. TN concentrations in storm and nonstorm (Base) flow samples from the UTA and NT streams.

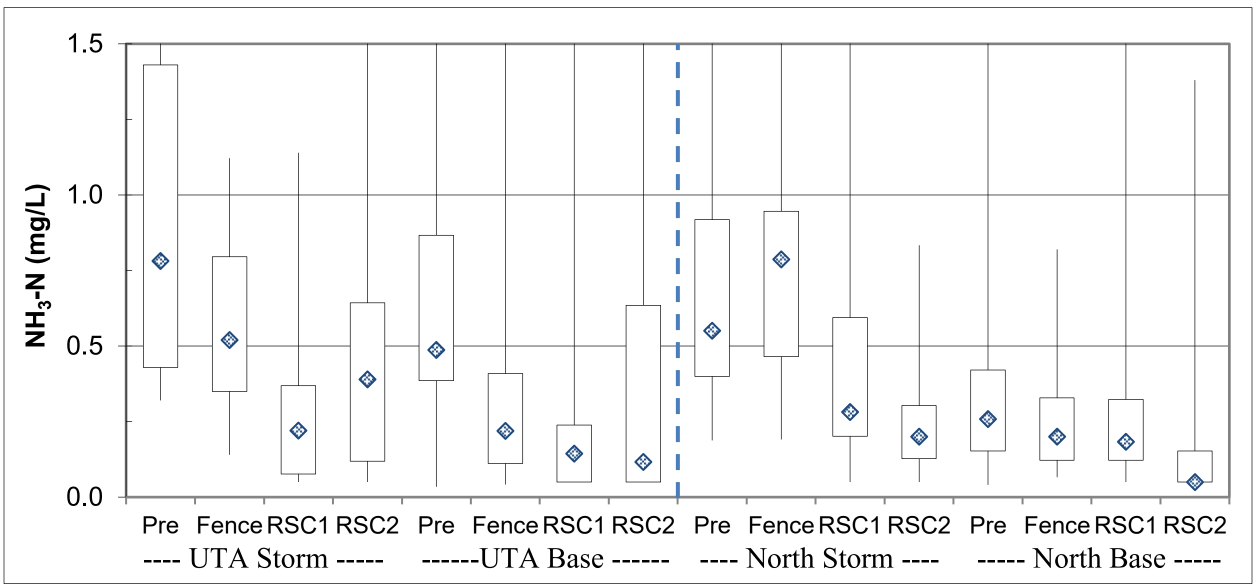


Figure 14. NH_3-N concentrations in storm and nonstorm (Base) flow samples from the UTA and NT streams.

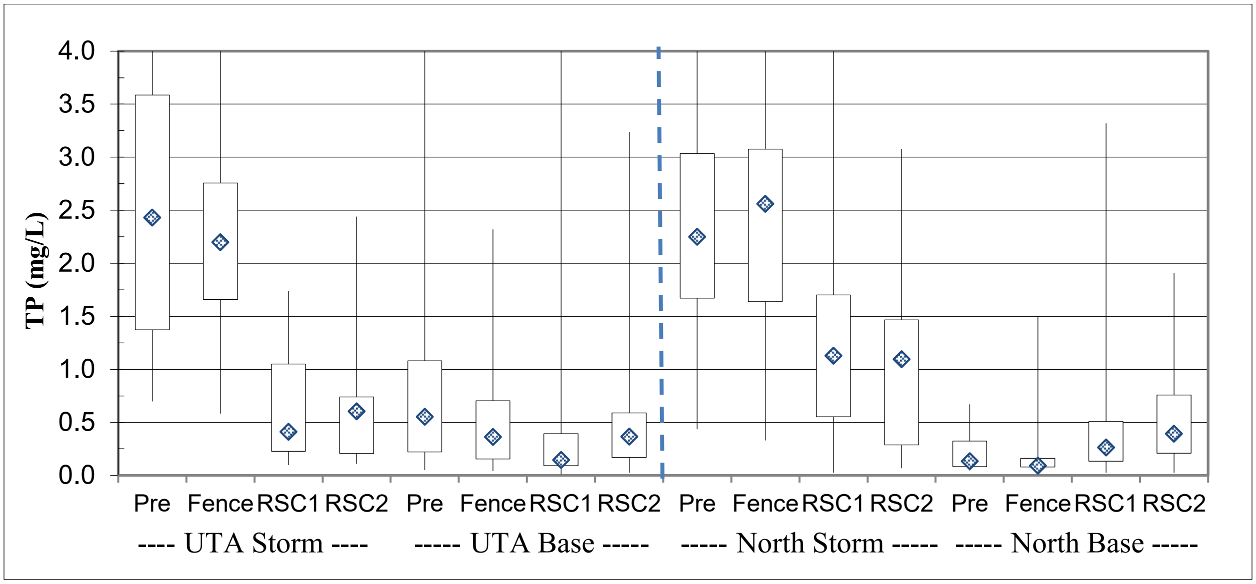


Figure 15. TP concentrations in storm and nonstorm (Base) flow samples from the UTA and NT streams.

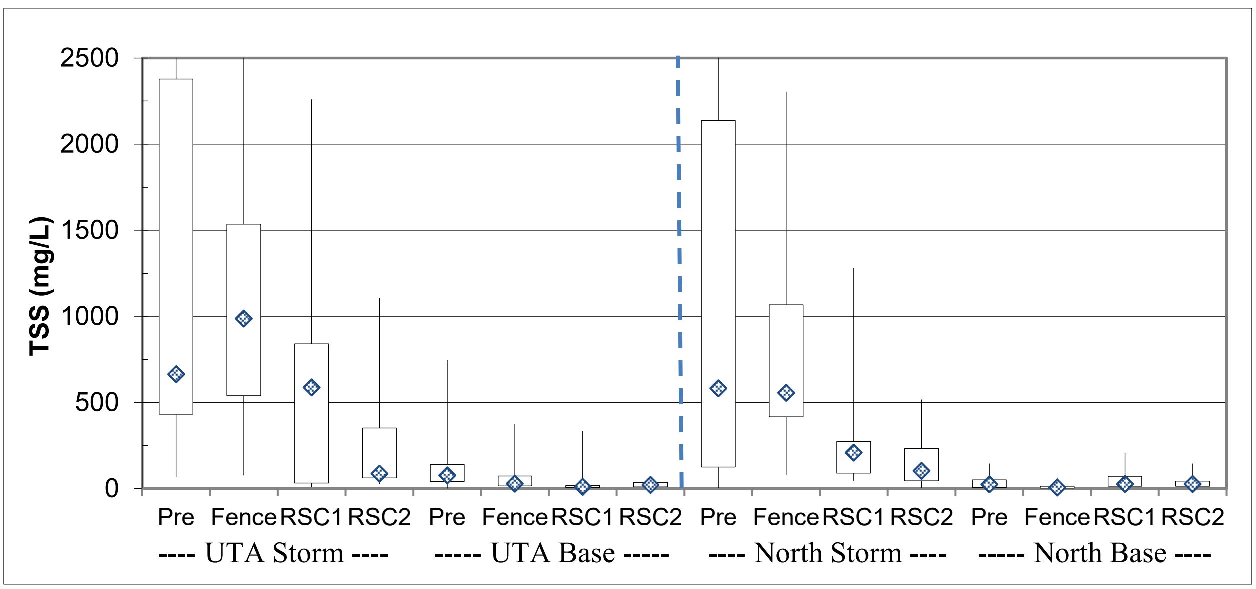


Figure 16. TSS concentrations in storm and nonstorm (Base) flow samples for the UTA and NT streams.

For the UTA stream, both stormflow and nonstorm TKN, TN, NH_3-N, and TP concentrations decreased from the Pre to Fence to RSC1 periods with the RSC1 period having the greatest decrease (Figures 11, 13, 14 and 15). Concentrations continued to decrease from the Fence to RSC1 period, even though no additional restoration measures were implemented, indicating that the effectiveness of the LEF improved over time. This was expected as vegetation in the excluded corridor and stream channel required time to become established with the shaded areas of the stream bank being the last to establish. The relatively large and consistent decreases in concentration for TKN, TN, NH_3-N, and TP provide considerable evidence of a significant treatment effect of the LEF.

Trends in TSS concentrations were not as conclusive, as the medians for storm samples increased from the Pre to Fence period and then decreased during the RSC1 period to about the same as the Pre period, whereas, median TSS concentrations in baseflow decreased consistently from the Pre to Fence to RSC1 (Figure 16). Interquartile ranges for storm concentrations during the Fence and RSC1 periods were less than the Pre period, which could indicate that the LEF was effective at reducing TSS concentrations from large storms or that fewer large storms occurred during the Fence period. This was expected as increased vegetation, particularly deeper rooted varieties, can prevent bank and upland concentrated flow erosion, which often contribute to very high episodic sediment loss. Comparisons of storms is problematic, but a quick look showed that a large (1.65 inches in 2 hours) intense storm during the Pre period (6/27/15) caused an excessive volume of sediment load to reach the monitoring station (Figure 17) and at least two large intense storms during the RSC1 period (on 6/26/23 1.58 inches in 0.7 hours and on 7/8/23 2.06 inches in 1.1 hours) caused no more than normal sediment load, so it appears from these limited observations that the LEF was effective at reducing TSS load. For NOx-N, the LEF had no consistent effect on concentrations. Thus, the concentration data provided some evidence of a treatment effect of the LEF on the water quality of the UTA stream, but it was not definitive.

Figure 17. Picture of UTA stream flume and sediment deposition on 6/30/15.

For the NT stream, median concentrations of TKN, TN, NOx-N, NH_3-N, and TP in stormflow increased slightly from the Pre to Fence periods whereas, all but NOx-N decreased in baseflow flow (Figures 11-15). Interquartile ranges where similar for both periods. For TSS, median concentrations and interquartile ranges in stormflow and baseflow decreased from the Pre to Fence periods indicating the LEF decreased TSS concentrations (Figure 16). The Pre TSS storm concentrations were similar to those for the UTA stream; however, the concentrations during the Fence period were much less indicating that the LEF was more effective at reducing TSS concentrations on the NT stream. Observation of stream channels and banks showed that vegetation grew faster and denser in the NT stream channel (likely due to less shading) compared to the UTA thereby stabilizing the NT channel quicker. This is consistent with the concentration data in that high TSS concentrations associated with streambank and bed erosion were diminished. The consistently high median concentration of NOx-N in the baseflow discharge of the NT stream during the Fence period indicates that another mitigation measure/BMP is needed to treat this source of nitrogen. Thus, while the TSS concentration data suggested a potentially significant effect of the LEF on the NT stream, the nutrient concentration data are inconclusive.

To add perspective, while our lab analysis was not specific for NH_3-N (the principal form of toxic ammonia), it is still informative to compare to toxicity levels. NH_3-N has been reported to be toxic to freshwater organisms at concentrations ranging from 0.53 to 22.8 mg/L with the toxicity generally increasing as pH and temperature increase. The median NH_3-N concentration in UTA baseflow approached the 0.53 mg/L level during the Pre period, but was reduced to much less during the Fence and RSC1 levels further emphasizing the effectiveness of the LEF.

Rainfall and discharge

Rainfall and resulting stream discharge can affect both pollutant concentrations and loads; therefore, evaluating trends in rainfall and discharge is important when assessing the effectiveness of mitigation measures. The medians of 2-week rainfall accumulations for each period decreased slightly from the Pre to the RSC1 periods, while the interquartile ranges were similar with those of the Fence period being slightly wider (Figure 18a). The annualized total rainfall for each period (shown as values near the top of graph) decreased considerably from the Pre to the Fence period and recovered some during the RSC1 period. A t-test conducted on the 2-week rainfall totals suggested that neither the Fence nor the RSC1 period was significantly different (at the 0.05 level) from the Pre period.

Like rainfall, the median of the 2-week total discharges decreased from the Pre to Fence period for both streams and then, for the UTA stream, recovered some during the RSC1 period (Figure 18b). The interquartile range for the Pre period was greater than the Fence and RSC1 (for UTA) periods, which was unexpected as the range for rainfall during the Pre period was less than during the Fence and RSC1 periods. The decrease in discharge variability can be attributed to an increase in vegetation and a likely decrease in soil compaction in the exclusion zone. The total annualized discharge (numbers near the top of the graph) decreased from the Pre to Fence periods for both streams and then recovered some for the RSC1 period on UTA reflecting the trends in rainfall.

From an overall hydrologic perspective, the streams flowed continuously at the monitoring stations during the entire period yielding an unusually high percentage (~70% for both) of the total discharge as non-storm, baseflow. The accumulated volume of baseflow on both tributaries was much greater than the volume of storm discharge, which was unexpected considering the topography of the pasture and the soils; however, the deeply incised stream channels likely contributed as they were deep enough to access groundwater. The low storm discharge may be attributed to the relatively dense grass and the roughness of the ground surface in the pasture. Much of the pasture had numerous 8-10 ft diameter and 1-2 ft deep depressions in it while the area between the access road and the NT stream also had several old terraces built along the contours. The depressions and terraces created a macro-roughness that likely enhanced infiltration, thereby reducing surface runoff.

Boxplots of storm and baseflow discharge are shown in Figure 18c. The boxplots of storm are for individual storm's cumulative discharge whereas those for base are for 2-week total baseflow discharge. For UTA and NT, the medians and interquartile ranges for storm discharge decreased from the Pre to Fence (and RSC1 for UTA) period indicating that the storm size decreased for successive periods. Total 2-week baseflow also decreased from the Pre period. The decrease in discharge could result in decreased pollutant load; therefore, the evaluation of the LEF effectiveness should consider changes in discharge.

Surface water loads

Nonstorm and stormflow discharge and pollutant export for the UTA and NT streams are shown in Table 3. For UTA, baseflow discharge and all 6 pollutant nonstorm export rates decreased from the Pre to the Fence period and then all the nonstorm export rates, except NOx-N, decreased further during the RSC1 period. Baseflow export rates of NOx-N decreased 11% from the Pre to the RSC1 period, which was less than that of discharge (15%) indicating that the LEF likely had no effect on NOx-N export in baseflow. Like baseflow, stormflow discharge and all 6 pollutant export rates in stormflow decreased from the Pre to the Fence and further to the RSC1 period. Hence, while the LEF was effective during its first year, it became even more effective over time as vegetation became more established.

Table 3. Nonstorm and Storm Discharge and Pollutant Export from UTA and NT for Fence.

	Dur. yr	Discharge in/yr	TKN	NOx-N	NH_3-N	TN	TP	TSS
			----------------------		lb/ac-yr		---------------------	
Nonstorm (Baseflow) for UTA								
Pre	1.33	6.15	5.36	12.62	0.85	18.0	1.00	157
Fence	1.81	4.91	2.84	10.39	0.42	13.2	0.57	62
RSC1	2.09	5.20	1.14	11.23	0.40	12.4	0.50	35
Stormflow for UTA								
Pre	1.33	2.59	5.35	2.86	0.52	8.2	1.57	1063
Fence	1.81	1.12	1.64	1.23	0.18	2.9	0.53	262
RSC1	2.09	2.28	0.47	0.42	0.05	0.9	0.07	80
Nonstorm (Baseflow) for NT								
Pre	1.33	6.38	3.14	22.44	0.70	25.6	0.42	61
Fence	1.81	5.80	1.55	22.90	0.32	24.5	0.16	13
Stormflow for NT								
Pre	1.33	2.83	4.26	4.67	0.45	8.9	1.64	551
Fence	1.70	1.26	1.73	2.23	0.18	4.0	0.75	190

Comparing baseflow to stormflow reductions, it is evident that the LEF was more effective at reducing pollutant export from stormflow as the export during RSC1 was from 7 to 24 times less than the Pre period, whereas, it was only 2 to 5 times less in baseflow. This was expected as the proliferation of vegetation associated with the LEF stabilized the land and stream channels in the riparian corridor and filtered pollutants in storm runoff from the pasture.

For the NT stream, an RSC was constructed in the channel prior to the RSC1 period, so only data from the Fence period were used here. Like the UTA stream, baseflow and stormflow discharge and export rates for TKN, NH_3-N, TP, and TSS decreased from the Pre to Fence period, thereby reinforcing the conclusion that LEF was effective at reducing pollutant export in both baseflow and stormflow (Table 3). The LEF was also effective at reducing NOx-N export in stormflow from NT, but not in baseflow. A possible reason for this is that a general decrease in the amount of available nitrogen tends to decrease export of all forms of nitrogen, but the definitive reason is unknown.

Comparing the streams, nonstorm export rates of TKN, NH_3-N, TP, and TSS during both the Pre and Fence periods were greater for the UTA stream compared to the NT stream, while nonstorm export of NOx-N was greater for the NT stream. Export of TSS in baseflow from the UTA stream was much greater than the NT during the Pre period due most likely to the sediment from the storms of 6/25/15 to 6/27/15, which deposited a large volume of sediment in the UTA stream channel from a bank failure(s) in the upper third of the channel (Figure 17). During the Fence period, nonstorm TSS export from the UTA stream was also greater. Observation documented considerably more widespread and denser vegetation on the banks and streambed of the NT stream compared to UTA. The tree canopy on the UTA stream was greater than the NT stream; thus, the shading resulted in vegetation being slower to grow and less dense in the UTA stream channel. The relatively high nonstorm export of NOx-N from the NT stream and the fact that it was much greater than the UTA stream was unexpected as both streams drain the same pasture. Concentrations of NOx-N in groundwater wells near the NT stream (see below) were also high.

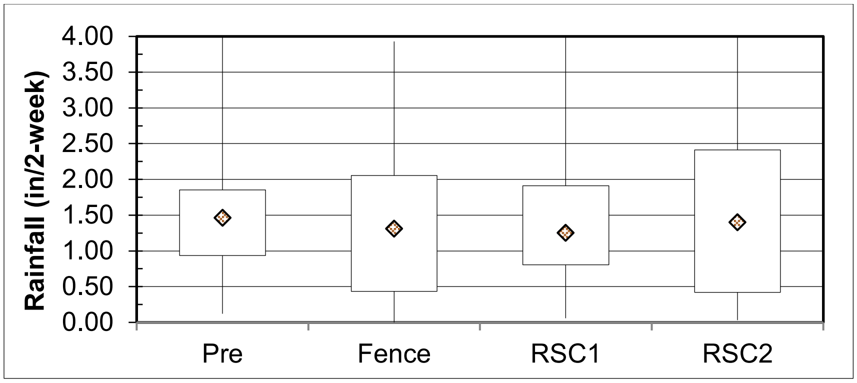
Export rates of TKN, NH_3-N, NOx-N, TN, and TP in stormflow during the Pre period were similar between the streams, whereas TSS export was much greater from the UTA. During the Fence period, stormflow export rates for all pollutants for both streams were similar. Thus, the export rate data show that the water quality of both streams improved with the installation of the LEF, but continued improvement was needed, particularly in nonstorm NOx-N export, which would require additional mitigation practice(s) such as an RSC.

Combined stormflow and baseflow export for the UTA and NT streams and the Millstone Creek station (Mill-dn) are shown in Table 4 along with rainfall and discharge. Annual rainfall totals decreased from the Pre to Fence and RSC1 periods resulting in similar decreases in runoff/discharge for both streams. Boxplots of distributions of 2-week rainfall and total discharge are shown in Figure 18a and b. The median 2-week rainfall total decreased from the Pre to the Fence to the RSC1 period, while the interquartile ranges were similar. Median 2-week total discharge for both streams decreased from the Pre- to Fence periods, but then increased slightly in the RSC1 period. Some of the reduction in total discharge for the Fence and RSC1 periods could be attributed to a treatment effect of the LEF as vegetation inside the excluded corridor proliferated resulting in increased water use via evapotranspiration and possibly greater infiltration (resulting in less runoff), but more than likely, most of the decrease was due to decreased rainfall accumulation and/or size and intensity of storms. Regarding storm size, the frequency of large storms (rainfall>51 mm) was greatest during the Pre period (3.0 per year) followed by the RSC1 (2.9 per year) and the Fence (1.1 per year). However, the difference in 2-week total discharges between the Pre and the combined Fence and RSC1 periods was not statistically significant.

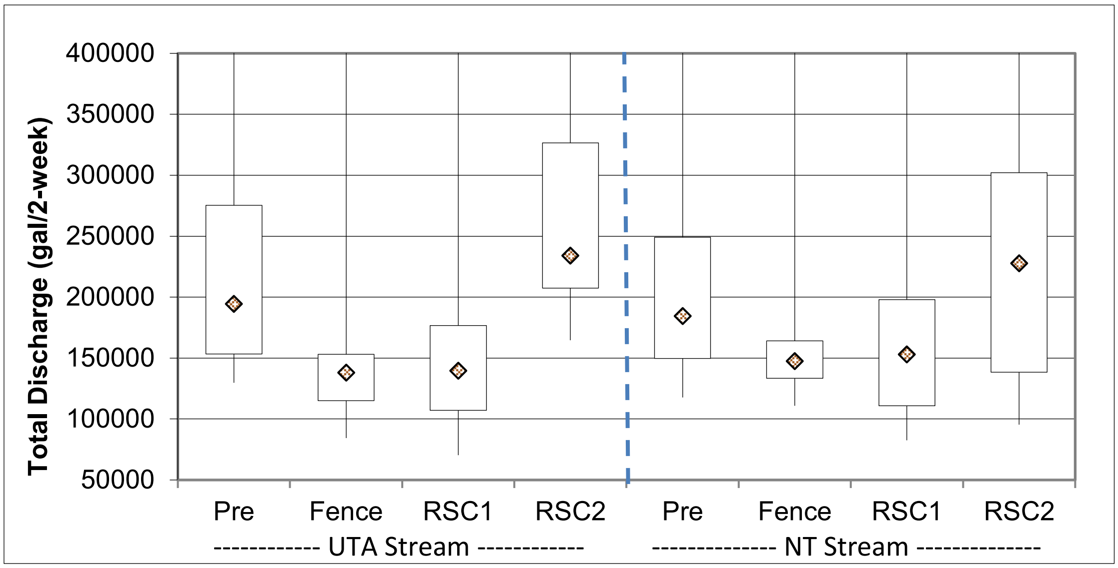
Table 4. Rainfall, Runoff, and Total Load/export for the LEF Evaluation.

	Dur. yr	Rain in/yr	Discharge in/yr	TKN	NOx-N	NH_3-N	TN	TP	TSS
				----------------------		lb/ac-yr		---------------------	
UTA Stream									
Pre	1.33	45.1	8.74	10.71	15.48	1.37	26.2	2.57	1220
Fence	1.80	34.9	6.02	4.48	11.62	0.60	16.1	1.10	324
RSC1	2.09	38.9	7.47	2.48	12.72	0.58	15.2	0.91	427
Change Fence+RSC1		*-16%*	*nd*[1]	*-68%*	*-19%*	*-57%*	*nd*[1]	*-61%*	*-69%*
NT Stream									
Pre	1.33	45.1	9.21	7.40	27.11	1.14	34.5	2.06	612
Fence	1.80	34.9	7.06	3.28	25.13	0.49	28.4	0.91	203
Change		*-23%*	*-23%*	*-56%*	*-7%*	*nd*[1]	*nd*[1]	*-56%*	*-68%*
Millstone Creek									
Fence	1.81	34.9	8.75	5.39	3.17	2.11	0.97	8.55	229

[1] No difference at the 0.05 level per T-test.



(a)



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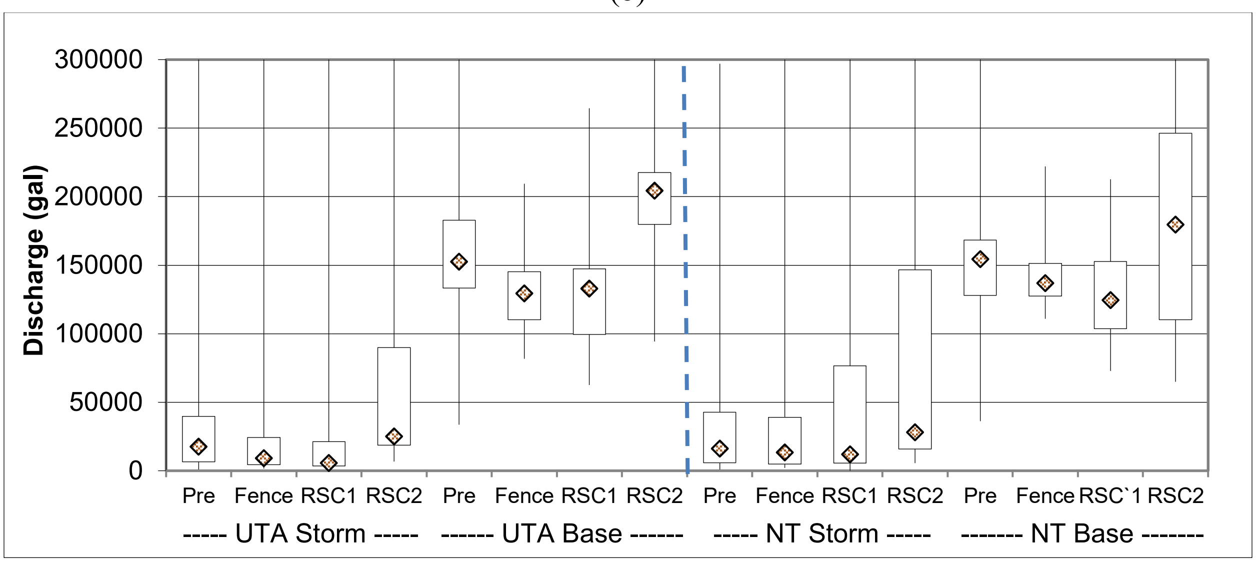

(c)

Figure 18. Boxplots of 2-week rainfall (a), total discharge (b) and storm and baseflow discharge (c).

The percent reduction in total export for each parameter for the UTA stream includes the Fence and RSC1 periods combined and is only shown for either the UTA or NT stream when the 2-week loads were significantly different (0.05 level of significance) between periods based on a T-test (Table 4). Reductions of TKN, NOx-N, NH_3-N, TP, and TSS total export for the UTA stream ranged from 19 to 69% with the reduction in NOx-N being the lowest at 19%. The low NOx-N effectiveness was anticipated as the LEF was not expected to treat groundwater influx, which was likely the largest source of NOx-N stream load. The much greater NOx-N loading compared to TKN and the relatively small reduction in NOx-N loading, likely contributed to the decrease in TN export (40%) being not significant. The TKN, NH_3-N, TP, and TSS reductions can be attributed to a treatment effect of the LEF, as they were significantly different from the Pre period and were considerably greater than the decrease in discharge.

For the NT stream, there was a 23% decrease in total discharge from the Pre to Fence periods. The total loads for TKN, TP, and TSS were significantly lower during the Fence compared to the Pre period and the decrease in loads was much greater than discharge thereby indicating that the LEF was effective at reducing export in the NT stream. By comparing export rates for NH_3-N the LEF appears to be effective (57% reduction); however, statistical analysis revealed that the loads for the Pre and Fence periods were not significantly different (likely due to greater variability). The similar and statistically significant reduction in NH_3-N for the UTA stream lends strong evidence that the LEF was effective at reducing NH_3-N export even if the reduction for the NT stream was not significant. Both the UTA and NT streams had relatively small (19 and 7%) reductions in NOx-N export indicating that the LEF was not effective at reducing NOx-N export rates.

Comparing the UTA and NT streams, the percent reductions in TKN, NOx-N, TP, and TSS were similar given the inherent variability nonpoint source pollution. Thus, these data provide considerable evidence that the LEF was effective at reducing TKN, NH_3-N, TP, and TSS load and export from the two streams. An estimate of the cost-effectiveness of the LEF was also computed and is in the NCSU Extension Publication shown in Appendix D.

From a watershed perspective, the TKN, NOx-N, TN, TP, and TSS export rates for the UTA and NT streams during the Pre period were much greater than those from the Mill-dn station indicating that these streams were contributing disproportionately to the pollutant load of the Creek. However, after the implementation of the LEF export rates for all but NOx-N and TN were similar to those of Mill-dn. These data indicated that additional mitigation measures focused on reducing NOx-N load/export were needed.

Groundwater concentrations

The LEF was not expected to treat groundwater, so the data presented here are not intended to assess the effectiveness of the LEF, but only to help explain and/or confirm the surface water results. Boxplots of TKN, NH_3-N, NOx-N, and TP concentrations in groundwater samples are shown in Figures 19 to 22 along with the median concentration of baseflow for the period (red asterisk). Concentrations of TKN in the streambank well on UTA (UTG1) were greater than the upland well (UTG2) during the Pre and Fence periods, but then concentrations in UTG2 increased dramatically while those in UTG1 decreased during the RSC1 period, resulting in much greater TKN concentration in UTG2 compared to UTG1 (Figure 19). The reason for the dramatic increase was unknown, but could be related to the increase in the groundwater table associated with constructing the RSC on the NT stream (see Figure 23 in Effectiveness of the RSCs section below) thereby providing access to organic nitrogen in soil that previously was above the water table. Median concentrations of TKN in UTA baseflow were greater than those of the streambank well (UTG1) during the Pre period decreasing steadily to about equal to the UTG1 during the RSC1 period. This indicates that readily available surface sources of TKN in and near the surface water were basically depleted by the time the RSC1 period began. It should be noted that the groundwater wells were only on one side of the UTA stream; therefore, groundwater influx from the other side, which is unknown, could significantly affect the surface water TKN concentrations.

Concentrations of TKN in the groundwater wells of the NT stream (NGR1 and NGR2) during the Pre and Fence periods were less than those of the UTA stream, nearly the same from upland to streambank, and changed very little from the Pre to Fence periods. Median TKN concentrations in the NT stream were greater than those of the streambank well (NGR1) for the Pre and Fence periods, but like the UTA, the difference narrowed during the Fence period (Figure 19). Like the UTA, groundwater influx from only one side was monitored, but it is likely that the unmonitored side was similar to this because vegetation and management were the same.

Concentrations of NH_3-N in groundwater for the UTA wells were greater in UTG2 compared to UTG1 for all three periods, but generally decreased in both wells from the Pre to RSC1 period (Figure 20). Similarly, NH_3-N in the UTA stream baseflow decreased dramatically from the Pre to RSC1 period thereby suggesting a decrease in the influx of NH_3-N from sources other than groundwater.

Like TKN, concentrations of NH_3-N in the groundwater wells of the NT stream were less than those of the UTA stream, nearly the same from upland to streambank, and changed very little from the Pre to Fence periods (Figure 20). Median NH_3-N concentrations in the NT stream were greater than those of the NGR1 and NGR2 for the Pre and Fence periods with the difference narrowing slightly during the Fence period.

For UTA, concentrations of NOx-N in the streambank well were much greater than those in the upland well for all three periods, while the NOx-N concentrations for both increased during the RSC1 period compared to the other periods (Figure 21). The increase in NOx-N concentrations from upland to streambank during the Pre and Fence periods was likely related to NOx-N in stream water interacting with the shallow groundwater of UTG1; however, the reason for the increase in NOx-N concentrations at both wells, and especially UTG1 to greater than the stream median, during the RSC1 period is unknown, but could be related to the increase in water table elevations associated with the RSC on the NT stream.

Concentrations of NOx-N in the NT wells were similar to those of the UTA stream and, like the UTA, they were greater in the streambank well (NGR1) compared to the upland well (NGR2) likely due to the interaction with the high NOx-N concentrations in the stream water (Figure 21). Concentrations of NOx-N in both wells decreased from the Pre to Fence period, while the median NOx-N concentration in the stream increased slightly. The reason for this divergence is unknown, but as stated previously, groundwater influx from only one side was monitored and the LEF was not designed/expected to treat subsurface flow.

Concentrations of TP in groundwater wells decreased from upland to streambank along UTA for all three periods (Figure 22) with lowest concentrations in both wells occurring during the RSC1 period. For the Fence and RSC1 periods, the TP concentrations in both groundwater wells decreased more rapidly than those of UTA baseflow indicating a possible depletion of excess TP in the soil and groundwater. Even after the relatively dramatic decreases in groundwater and baseflow, TP concentrations were still greater than those of the NT stream. The considerable and consistent decreases in TP concentration indicated that the LEF may be effective at reducing groundwater TP concentration, especially after several years.

Groundwater TP concentration for the NT wells decreased slightly from the Pre to the Fence period with stream baseflow TP concentrations decreasing nearly the same. These decreases combined with the considerable decreases of TP in the wells on UTA lend strong evidence of a treatment effect of the LEF.

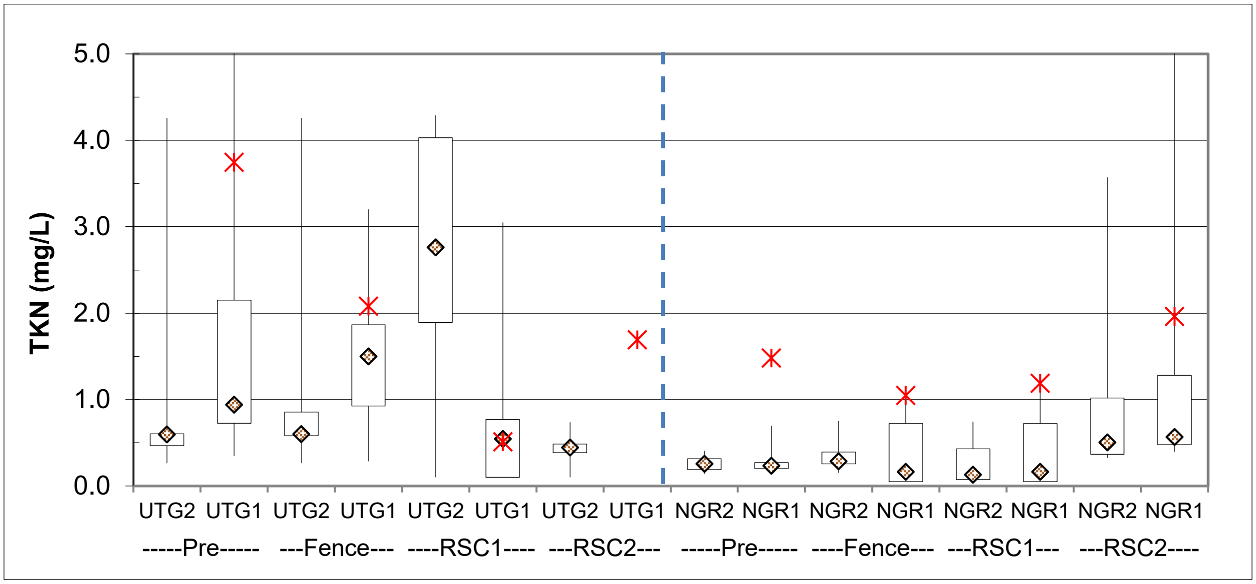

Figure 19. TKN concentration in groundwater (X is median nonstorm/baseflow concentration).

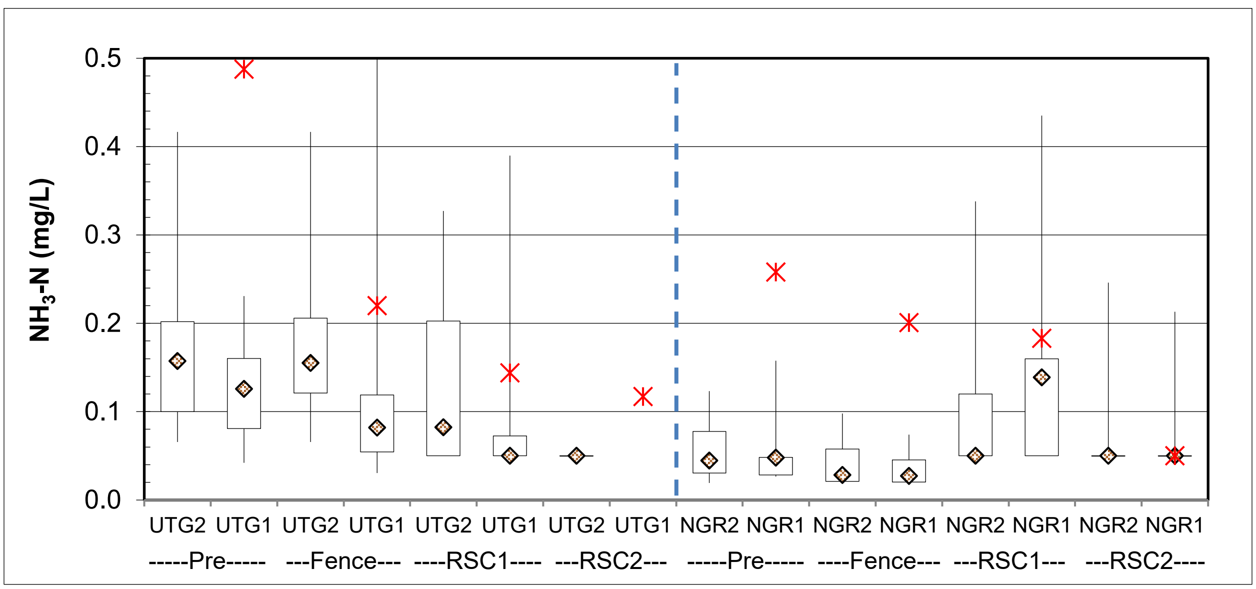

Figure 20. NH_3-N concentration in groundwater (X is median nonstorm/baseflow concentration).

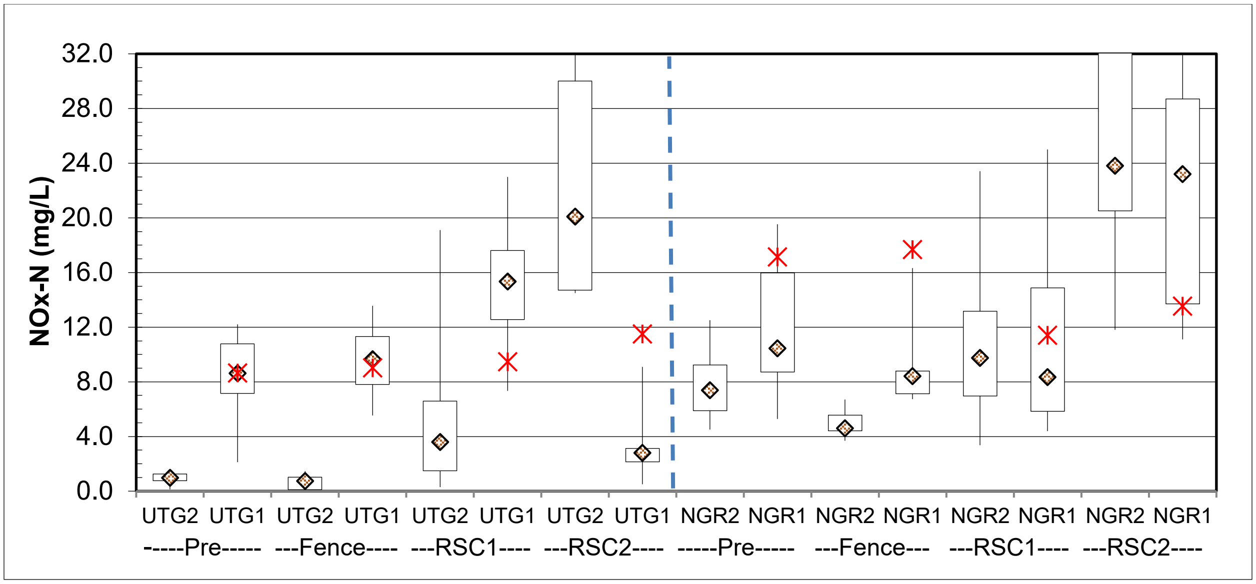

Figure 21. NOx-N concentration in groundwater (X is median nonstorm/baseflow concentration).

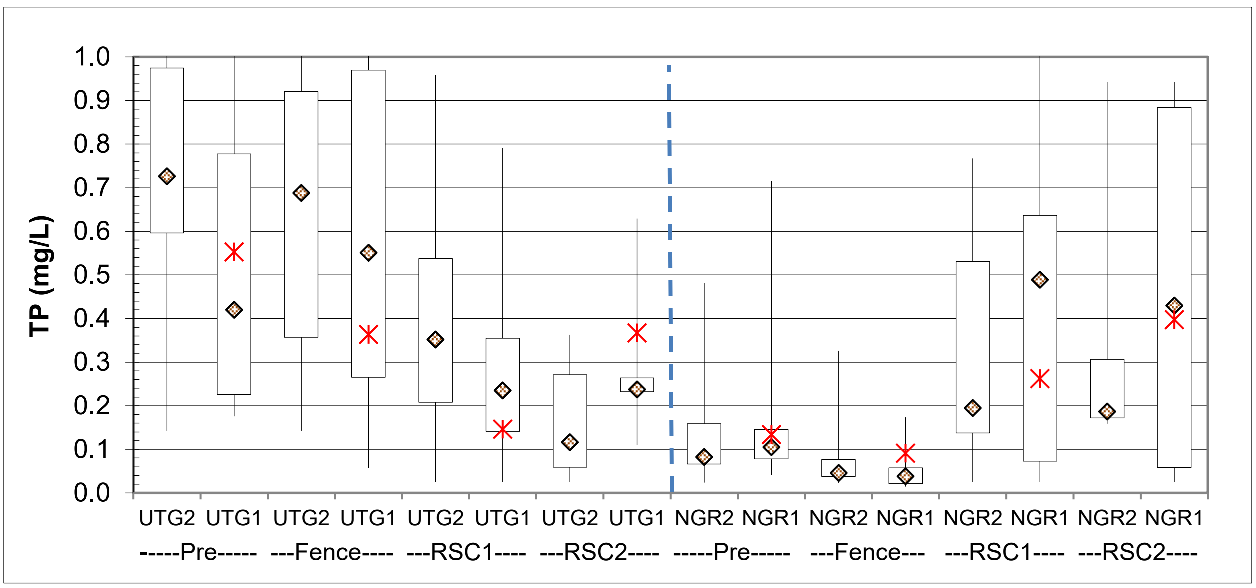

Figure 22. TP concentrations in groundwater (X is median nonstorm/baseflow concentration).

Effectiveness of Regenerative Stormwater Conveyance (RSC)

For the evaluation of the NT RSC, the 'Fence' period (Table 5) is the pre-restoration or calibration period in the paired watershed design with the RSC1 period the treatment. The 2-week load data for the UTA stream during these two periods were used as the 'control', which was used to account for changes in loads resulting from natural variability as there was no treatment (land use and management and agricultural activities remained the same) in the UTA watershed during these periods.

Table 5. Monitoring Data for Regenerative Stormwater Conveyance (RSC) Evaluation.

	Discharge	TKN	NOx-N	NH_3-N	TN	TP	TSS
	in/yr	------------------------		lb/ac-yr		------------------------	
Nonstorm Export NT Stream							
Fence	5.80	1.55	22.88	0.31	24.43	0.16	13
RSC1	5.49	2.66	13.56	0.37	16.23	0.59	63
Total Export NT Stream							
Fence	7.06	3.28	25.13	0.49	28.41	0.91	203
RSC1	8.95	4.74	16.45	1.01	21.19	1.75	275
Nonstorm NT Stream							
Decrease[1] (%)	*10%*	*-72*	*41%*	*nd[2]*	*25%*	*-240%*	*-390%*
Total NT Stream							
Decrease[1] (%)	*nd[2]*	*-88%*	*42%*	*nd[2]*	*18%*	*-276%*	*-389%*
Nonstorm Export UTA Stream							
RSC1	5.2	1.13	11.22	0.40	12.36	0.50	35
RSC2	7.5	6.25	19.61	1.71	25.86	1.03	45
Total Export UTA Stream							
RSC1	7.5	2.48	12.72	0.58	15.20	0.91	427
RSC2	11.6	7.85	26.65	0.49	34.51	2.40	213
NT Stream							
RSC2: Nonstorm	6.8	4.41	21.35	0.24	25.76	0.87	57
RSC2: Total	11.6	7.85	26.65	0.49	34.51	2.40	213
Nonstorm UTA Stream							
Reduction[1] (%)	*-35%*	*nd[2]*	*-53%*	*-151%*	*-73%*	*-133%*	*-150%*
Total UTA Stream							
Reduction[1] (%)	-48%	*nd[2]*	-58%	-223%	-71%	-156%	*nd[2]*

[1] Percent reduction computed using the LS means analysis.
[2] No significant difference using ANCOVA and LS means analyses results.

Groundwater/water table elevation

The construction of the RSC on the NT stream raised the channel elevation 3-4 ft feet, which raised the corresponding groundwater table or groundwater WSE in the NT wells (NGR1 and NGR2) during the RSC1 and RSC2 periods (Figure 23). Also, soil from the stream channel was spread along the uplands raising the land elevation 0-1 ft in many places. For example, the land surface elevation at NGR2 (upland well) was 458.06 ft before and 458.8 ft after the RSC. The WSEs shown in Figure 23 were manual measurements of WSE made during well sampling visits, while the continuous measurements made by HOBO sensors are graphed in Appendix B.

Comparing streams, the WSE of groundwater along the UTA was generally 3-4 ft higher than the NT during the Pre and Fence periods and nearly the same for much of the RSC1 and RSC2 periods. The water table elevation at UTG2 increased 4+ft during the winter of 2023 and then remained at about the same elevation during the RSC2 period. Some increase in WSE during the RSC2 period was expected given that UTG2 was destroyed during construction of the RSC and reinstalled 15-25 ft upslope and 1-2 ft higher in elevation of its previous location; however, at least some of the increase may also be attributed to the RSC raising the water table elevation of the NT stream. The higher water table at UTG2 near the end of the RSC1 and during the RSC2 periods indicated a considerable change in the groundwater dynamics on the UTA stream.

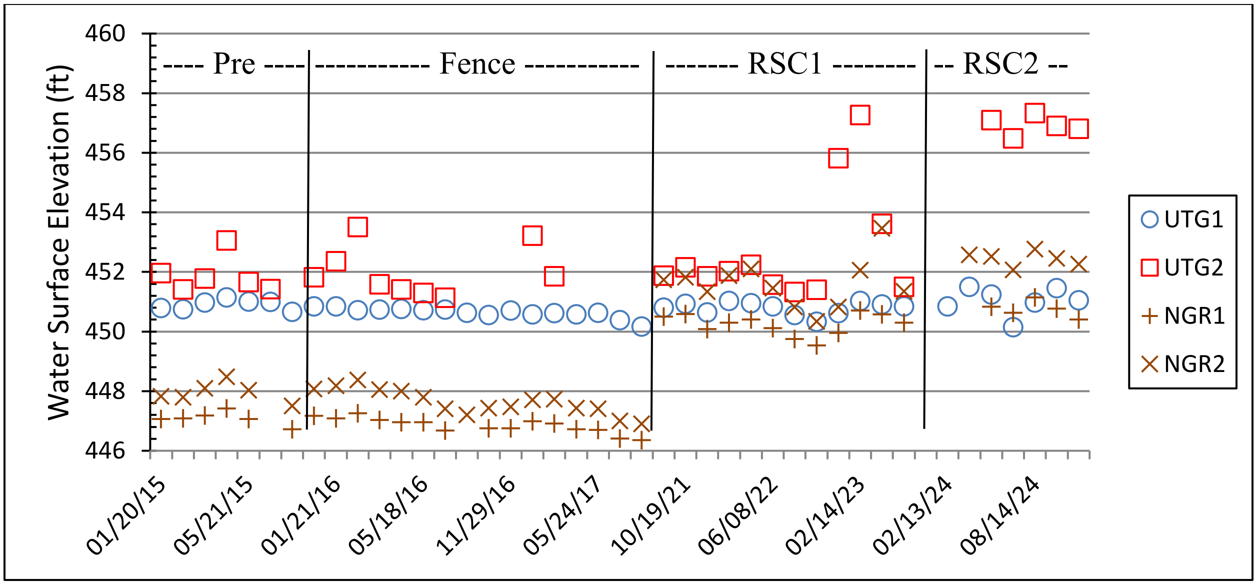

Figure 23. Groundwater levels along UTA and NT streams.

For NGR1 and NGR2 during the Pre and Fence periods, groundwater table elevations track closely, in that the water table elevation at the upland well (NGR2) was, on average, ~0.8 ft higher than that of NGR1. The average difference increased to ~1.5 ft during the RSC1 and RSC2 periods. The reason for the increase is unknown, but could, at least partly, be attributed to moving the NGR1 well to a new location (it's original location was destroyed during construction of the RSC) or possibly the increase in the soil surface elevation as soil from the RSC construction was spread on the upland area.

For seasonal trends, the WSEs for NGR1, NGR2, and UTG1 tended to increase from its lowest elevation in late summer or early fall to its highest elevation in late winter or early spring with some temporary spikes during large storm events. The WSEs for UTG2 varied considerably more than the other three wells, so no trend was discernable. The reason for the variability was unknown, but could be related to the fact that it was only about 15-20 ft from the streambank and the soil around the well was rocky which limited the (when installed small rocks were extracted from the borehole and rocks limited the depth to about 7 ft.).

In regard to longer term trends over the Pre and Fence periods, the groundwater table elevations for NGR1, NGR2, and UTG1 decreased slightly to each well's lowest elevation in October 2017. During the RSC1 and RSC2 periods, there were no obvious trends.

Surface water concentrations:

For the NT stream, the median concentration of TKN, TN, NH_3-N, TP, and TSS in storm flow decreased considerably from the Fence to RSC1 periods (Figures 11-16) thereby indicating a treatment effect of the RSC; however, corresponding concentrations in the UTA stream (control) also decreased, which suggested at least some of the decreases were the result of other factors. Further, median stormflow TKN, NH_3-N, and TP concentrations of UTA increased slightly from the RSC1 to RSC2 periods indicating no confirming reduction associated with the RSC on the UTA. Conversely, median TSS concentrations in stormflow for both streams continued to decrease from RSC1 to RSC2 suggesting a treatment effect of the RSCs. Stormflow NOx-N concentrations for UTA and NT decreased from Fence to RSC1, but then increased during RSC2 to a median concentration greater than the Fence period. Hence, these data show that the RSCs were not effective at reducing NOx-N concentrations in stormflow. This was expected as there was little to no water storage in the RSC and no other mechanism for treatment of storm water.

For NT baseflow, concentrations of TKN, TN, NOx-N, and NH_3-N generally decreased or stayed about the same from the Fence to the RSC1 period. The considerable decrease in NOx-N concentrations provide strong initial evidence of a treatment effect of the RSC, but the increase in concentrations to RSC2 and the increase for the UTA from the RSC1 to RSC2 periods detracts from the initial evidence. The increase in NOx-N concentration from RSC1 to RSC2 could be the result decreased denitrification as the dissolved organ carbon from the wood chips in the soil media of the RSC was depleted (see ground water section below).

One of the primary goals of the monitoring was to document change in TN concentrations associated with the RSC to validate the goal of reducing TN concentrations by 20% as stated in the Mitigation Plan. While not shown in Figure 13, the mean TN concentrations were similar to the medians shown. The reduction in nonstorm and storm mean TN concentration from the Fence to the RSC1 period was 27% and 43%, which according to a T-test was statistically significant (at 0.05 level). If concentrations from the RSC1 and RSC2 periods are combined the reduction in the mean nonstorm and storm falls to 22% and 38%, which both were also statistically significant per a T-test. Hogs were absent from the farm from sometime during the Fall of 2021 to 6/21/22; therefore, hog waste application to the pasture during the RSC1 period was also likely diminished or absent, which could explain the low nonstorm and storm TN concentrations for the RSC1 period for both the UTA and NT streams and the increase from RSC1 to RSC2 (Figure 13). Using either the RSC1 alone or combined RSC1 and RSC2, shows that the goal of reducing nonstorm and storm TN concentrations by at least 20% by implementing an RSC was met for the NT stream.

For the UTA, mean nonstorm and storm TN concentration increased by 29% and 4% from the combined Fence and RSC1 period to the RSC2 period; however, only the nonstorm increase was statistically significant according to a T-test. Therefore, the goal of reducing the TN concentration by 20% was not reached on UTA. Both the nonstorm and storm TKN and the NOx-N concentrations for UTA increased from the RSC1 to the RSC2 periods (Figures 11 and 12) indicating that the RSC was not effect. Several possible reasons for this are that 1) the concentrations were less than those of the NT stream indicating that possibly there is a NOx-N concentration below which the RSC is not effective, 2) the nonstorm and storm discharge for UTA during the RSC2 period (Figure 18c) was considerably greater than any other period, which could indicate that high flows reduce the effectiveness of the RSC, 3) the monitoring period for the UTA was too short (<1yr) to characterize/document the effectiveness of the RSC, and/or 4) vegetation on the UTA was much slower to establish (documented by visual observation) than on the NT, which would reduce nutrient uptake, provide less shading of the channel thereby promoting greater algae growth, and facilitate faster water movement in and along the channel. However, the definitive reason for the ineffectiveness of the RSC on UTA is unknown.

For TP, concentrations increase from Fence to RSC1 and to RSC2 for the NT stream and from RSC1 to RSC2 for UTA providing evidence of a negative effect of the RSC. This negative effect could be attributed to phosphorus being added to the watershed from the RSC soil media and/or fertilizer applied to the uplands to promote vegetation growth. The TSS concentration in baseflow increased from Fence to RSC1 and RSC2 on the NT stream and from RSC1 to RSC2 on the UTA indicating a negative effect of the RSC; however, observation indicated that much of the TSS in samples during the RSC1 and RSC2 periods was fine, suspended organic matter and not soil particles. To validate and quantify this observation, the volatile suspended solids (VSS) for 11 TSS samples (3 storm and 8 nonstorm) were determined. Results showed that 16-20% of the TSS in storm samples and 14-29% of the TSS in baseflow samples was VSS. In general, little to no fine suspended organic matter was observed in samples collected prior to the construction of the RSC.

Surface water loads for the NT stream

Discharge and total loads/export for the evaluation of the RSC on the UTA and NT streams are shown in Table 5. The nonstorm loads were analyzed separately because the RSCs were expected to have the greatest effect on baseflow. For the NT stream, export rates for TKN, NH_3-N, TP, and TSS increased from the Fence to the RSC1 period.

The ANCOVA using 2-week TKN nonstorm and total loads for NT showed that both increased significantly from the Fence to RSC1 periods (Table 5). Export of NOx-N in nonstorm discharge decreased significantly (by 41%), while total NOx-N export decreased by a similar percentage (42%). The similar percentages show that nearly all the decrease occurred for nonstorm discharge, which was expected given the NOx-N treatment mechanism was denitrification, which occurs primarily in groundwater and nearly all nonstorm discharge was groundwater influx to the stream. There was no significant difference in baseflow or total NH_3-N export between the Fence and RSC1 periods. Nonstorm and total TN export decreased (25% and 18%) significantly from the Fence to the RSC1 period mainly due to the decrease in NOx-N export. Note that the percent decrease was computed using the LS means statistical analysis, which assesses the percent difference in loads at the combined middle of the population of loads. This percent decrease often does not equal the arithmetic percent difference, but is more representative of the total population of load data.

The results of the ANCOVA for TP and TSS showed that baseflow and total export for both increased significantly from the Fence to RSC periods. An increase was expected given the disturbance caused by the construction of the RSC; however, the magnitude of the increases was greater than expected. For TP, leaching of phosphorus from the wood chip mulch and/or movement of TP from the surrounding soil (fertilizer was applied to help establish vegetation after RSC construction) could account for much of the increase in TP export as there was phosphorus in the soil (0.06 lb P/ton soil) and erosion was occurring as evidenced by the increase in TSS export and visual observation. The 390% increase in baseflow TSS export was unexpected given that soil erosion and sediment transport occur primarily during storm events. A possible explanation for at least some of the increase was that a significant portion of the TSS was fine organic matter particles suspended in the stream or deposited on the streambed. To test this, 8 samples of were analyzed for volatile suspended solids (VSS) in addition to TSS with the results showing that 17 to 26% of the mass of TSS was VSS. It should be noted that the 8 samples analyzed did not, based on personal observation, contain the greatest amount of OM compared to other samples. The method of sampling and the very shallow water may have contributed to more of the fine organic matter in samples than perhaps was representative. Because of the shallow water, the sampler intake had to be close to the streambed where during the sampler's backflushing some of the organic matter deposited on the streambed was disturbed and then sucked into the sampler during sample collection. It is also possible that fine soil sediment from the upland areas was deposited in the RSC channel during storm events and then was transported in baseflow discharge to the monitoring station. The 389% increase in total TSS export was less than baseflow export, which indicates that TSS export during storms (from mostly soil erosion) did not increase significantly. This further supports that assumption that much, if not most, of the increase in nonstorm TSS export was OM.

While changes in the covariates rainfall and discharge are accounted for by the UTA data (control watershed/stream), it is nonetheless useful to assess their changes over the two periods. An ANOVA on the 2-week rainfall totals documented no significant difference in rainfall between the Fence and RSC1 periods (Table 4). ANCOVA and LS means tests on the 2-week discharge volumes documented a statistically significant 10% decrease in nonstorm discharge in the NT stream from the Fence to RSC1 periods, while total discharge was not significantly different between the periods. The decrease in nonstorm discharge was expected given that the stream channel was raised by nominally 3-4 ft for the RSC. This would reduce the groundwater gradient to the NT stream resulting in a decrease in groundwater flow to the stream. A subsequent increase in storm discharge must also have occurred to keep the total discharge for the NT stream unchanged. This was also expected given that the land/soil was disturbed and vegetation removed during construction of the RSC. While vegetation began to grow back immediately, there were areas of sparse to no vegetation in the NT stream's riparian corridor during the RSC1 monitoring period. The effect of time for vegetation to establish and proliferate on pollutant export rates was demonstrated on the UTA as the rates decreased considerably from the Fence to RSC1 period without any additional restoration practices. Hence, it is likely that pollutant export rates will decrease as vegetation proliferates in the riparian corridor of the NT stream.

Surface water loads for the UTA stream

The RSC on the UTA stream was constructed between the RSC1 and RSC2 periods, so the loads for the NT stream during the two periods were used as a control. This may be problematic as even though there was no treatment on the NT during RSC1 and RSC2, the effectiveness of the RSC and other hydrologic changes/adjustments from the RSC construction were still occurring, which could add to the effect of natural variability (which is what the control is intended to account for).

Nonstorm discharge and pollutant export rates for UTA increased from RSC1 to RSC2 with rates for TKN, NH_3-N, TN, and TP more than doubling and the NOx-N rate increasing by 53%, while the discharge increased by just 35% (Table 5). Except for TSS, considerable increases also occurred for total export from UTA from RSC1 to RSC2. This provides evidence of a negative effect of the RSC on pollutant export from UTA, which was likely due to soil disturbance associated with construction and the subsequent lack of vegetation on the upland areas of the riparian corridor. However, export rates for TKN, NOx-N, TN, and TP from the NT stream increased from RSC1 to RSC2 in spite of considerable vegetative growth, indicating that at least some of the increase could be due to changes in climatic conditions. In addition, the management of the pasture (upslope of the riparian corridor) varied as due to a change in companies, hogs were absent from the farm from about 6/1/21 to 6/21/22; therefore, hog waste application to the pasture during this period (RSC1) was also likely diminished or absent, which could explain the increases in export from RSC1 to RSC2.

Results of an ANCOVA of 2-week loads at UTA suggested that increases in nonstorm discharge and export rates of NOx-N, NH_3-N, TN, TP and TSS were significant even when using the data from the NT stream to account for the natural variability (Table 5). For total export, ANCOVA results were similar, except that the increase in TSS export was not significant (Table 5 bottom row). Thus, these results show that the RSC implemented on the UTA was not effective at reducing pollutant loads even those for NOx-N, which is what it was designed for. The reason for this was unknown, but could be related to one or more of the following factors: 1) much lower NOx-N concentrations in surface/stream water, 2) a difference in the RSC media as a different supplier was used, 3) greater nonstorn and storm discharge during the RSC2 period, 4) short monitoring duration (<1yr) combined with the control (NT stream) not being a true control stream (as it was still stabilizing), and 5) subsurface flows moving more rapidly along the bottom of the trench to the outlet (thereby reducing time for nitrification) because the boulder/rock structures may not have extend vertically to the bottom of the media trench (design called for boulders to contact the bottom of the trench, but it was not a construction specification). In contrast, an on-site engineer made sure that all boulder structures in the NT RSC extended to the bottom of the trench and forced intermittent pooling of water behind the structure, which may increase the travel time through the media.

<u>Groundwater concentrations</u>

Changes in groundwater can have a significant effect on particularly nonstorm surface water concentrations and loads, so it is helpful to assess trends in these concentrations. For the UTA stream, the RSC was implemented between the RSC1 and RSC2 periods so the Pre, Fence, and RSC1 periods will be compared to the RSC2 period (treatment). The relatively high TKN concentration for UTG2 during the RSC1 period (Figure 19) could have been due to issues with the well as several samples were milky white and had a limited volume (little water in well). Further, TKN concentrations in the new well, installed during RSC2 in the same vicinity, had much lower concentrations, which were similar to the concentrations measured during the Pre and Fence periods. It is also possible that raising the groundwater table in the NT stream during the RSC1 period (Figure 23) changed the groundwater flow in a way that introduced new sources of nitrogen to the UTA groundwater. The new well installed along the stream (UTG1) during the RSC2 period also seemed to have issues or was installed in an anomalous location as many samples were turbid and limited in volume with a median TKN concentration (not shown in Figure 19) of 37.1 mg/L (four samples). It could be that there was a lot of organic matter in the soil around this well that was rich in organic nitrogen. Thus, it appears that the effect of the RSC on groundwater could not be determined due to possible issues with the UTG1 well.

For the NT stream, groundwater TKN concentrations were generally less than those of UTA (Figure 19). During the Pre and Fence periods TKN concentrations in NGR2 and NGR1 were similar, although the median concentration for NGR1 decreased during the Fence period thereby indicating a possible treatment effect of the LEF. The median nonstorm TKN concentration in stream samples also decreased from the Pre period adding evidence to a treatment effect of the

LEFThe groundwater and nonstorm median stream concentrations remained low during the RSC1 period, but increased during the RSC2 period to levels greater than the Pre period. The reason for this is unknown as no treatment/disturbance occurred on the NT Stream during either the RSC1 or RSC2 periods. Thus, it appears that neither the LEF nor the RSC had a significant effect on TKN concentrations in groundwater.

For NH_3-N in the UTA wells, groundwater concentrations were generally less for UTG1 compared to UTG2 for the Pre, Fence, RSC1, and RSC2 periods with concentrations in both wells decreasing for each successive period (Figure 20). Median concentrations of surface water followed a similar decreasing trend with the largest decrease occurring from the Pre to Fence periods. The median NH_3-N concentration in UTG1 during the RSC2 period was 23.4 mg/L (not shown in graph because likely problematic), which like the TKN concentration, is very high. The reason for this was unknown.

For NH_3-N in the NT, groundwater concentrations were similar from NGR2 to NGR1 and decreased slightly from the Pre to Fence period, but then increased during the RSC1 period only to decrease to levels equal to the Pre period during the RSC2 period. The actual concentrations during the RSC2 period may have been less in both wells as 8 of the 10 samples collected had concentration less than the reportable level (RL). Median surface water NH_3-N concentrations decreased for each successive period suggesting that the increase in concentrations for NGR1 during the RSC1 period was not the result of surface water intrusion into the groundwater well. Ground and median surface water NH_3-N concentrations for UTA suggested a treatment effect for both the LEF and RSC, which is also supported by nonstorm surface water concentrations for the NT stream; however, groundwater concentrations in the NT wells reflected a possible treatment effect for the LEF, but little to no treatment effect for the RSC. The consistent decrease in median nonstorm NH_3-N concentrations over time could also simply be attributed to the removal of sources of NH_3-N and the depletion of existing reserves of NH_3-N within both the stream corridors.

For NOx-N in UTA, groundwater concentrations increased from UTG2 to UTG1 during the Pre, Fence, and RSC1 periods suggesting little to no groundwater treatment as it moved from the upland area to the stream (Figure 21). The NOx-N concentration in both UTG2 and UTG1 increased considerably during the RSC1 period with the concentration in UTG2 continuing to increase in the RSC2 period. The cause of the increase is unknown, but could be related to the increase in the groundwater table and subsequent changes in groundwater dynamics associated with the implementation of the RSC on the NT stream (Figure 23). The large decrease in concentrations from UTG2 to UTG1 during the RSC2 period could be the result of enhanced denitrification associated with the RSC installation on UTA, especially given that the groundwater concentrations were less than the median surface water concentration (shallow near-stream groundwater was likely not diluted by surface water).

For the NOx-N in the NT stream groundwater, concentrations increased from NGR2 to NGR1 during the Pre and Fence periods (Figure 21). The greater concentration near the stream suggested that there was little to no denitrification occurring in the riparian zone along the NT stream. Conversely, during the RSC1 period, NOx-N concentrations decreased from NGR2 to NGR1, indicating possible treatment by enhanced denitrification. Additional evidence for this was that the water level (table) was mostly lower than the root zone in the buffer (due to a severely incised stream channel) during the Pre and Fence periods and the total organic carbon (TOC) in 3 samples from the NGR1 well were all less than 1.73 mg/L, whereas during the RSC1 period the TOC concentrations were 3 to 6 mg/L. Low TOC (<2 mg/L) in groundwater tends to inhibit denitrification as Spruill et. al (1997) reported that water in shallow aquifers in eastern NC with more than 2-3 mg/L of dissolved organic carbon (DOC) had NO_3-N concentrations of less than 2 mg/L, while aquifers with lower DOC had much higher NO_3-N concentrations. More recent laboratory studies indicate that DOC concentrations in the 4-8 mg/L range significantly improve denitrification rates (Knies, 2009). The NOx-N concentrations in both wells increased considerably during the RSC2 period with the level in the NGR1 wells still slightly less than that of the NGR2 well. The TOC in a sample from NGR1 during RSC2 revealed that the concentration had dropped to 1.82 mg/L, which was less than adequate for enhanced denitrification. Therefore, the increase in NOx-N during the RSC2 period may be attributed to depletion of the initial carbon source in the RSC. Continued growth of woody vegetation along the stream channel should restore at least some carbon to the stream channel and hopefully increase denitrification. The median surface water concentration was less than that of NGR1 during the RSC2 period, but still increased from the RSC1 period. The reason for these trends was unknown.

For TP in the UTA wells during the RSC2 period, concentrations continued to decrease from previous periods for UTG2, but stayed nearly the same for UTG1 (Figure 22). The median surface water concentration increased considerably during RSC2 after falling during each of the previous three periods, which could have contributed to the increase in TP concentration for UTG1. Further, soil or organic matter rich TP could have been placed in close proximity to the well during construction of the RSC. Even though TP concentrations at UTG1 are greater than UTG2 during RSC2, they are still nearly equal to those of UTG1 during RSC1; thus, these data show that increased TP concentration in nonstorm surface water was likely not the result of increased TP in groundwater and that the RSC had little to no effect on groundwater TP concentrations. Conversely, the continued decrease in TP concentrations for UTG2 through the RSC2 period indicated that the lack of a decrease in UTG1 in the RSC2 period may be due to the RSC construction.

For the NT wells, TP concentrations increased in both wells during RSC1 and RSC2 compared to the earlier periods with the increase in NGR1 being much greater than NGR2 (Figure 22). The increase in NGR2 could have resulted from a combination of nutrient-rich soil from the channel being spread on the uplands and fertilizer application on uplands to establish vegetation. The increase in TP for NGR1 can be attributed to fertilizer application and possible TP in imported soil media and wood chip mulch. The median nonstorm surface water TP concentration also increased during RSC1 and RSC2. These data indicate that the increase in TP in surface water was likely due to the construction of the RSC; however, the increase may only be temporary as vegetation and depletion should result in decreases in the near future. Further, changes in construction practices and materials could likely minimize TP increases

As part of companion project, ground and surface water grab samples collected from UTG1, UTA, NGR1, and NT were analyzed for dissolved P (DP) and fecal coliform (FC) during the Fence and RSC1 periods. Boxplots of the results are shown in Figures 24 and 25. For UTA, median concentrations of DP remained about the same from the Fence to the RSC1 period, which was expected given that no treatment occurred in that watershed. For the NT stream, median OP concentrations remained similar during the Fence and RSC1 periods for NGR1, but decreased for nonstorm samples collected from the NT stream. Statistical analyses of the nonstorm concentrations using ANCOVA revealed that there was a significant decrease in DP concentrations in samples from the NT stream relative to the UTA stream and an LS means test confirmed the significant decrease and quantified it at 37.1%. Because changes in discharge can often result in changes in concentration, the 2-week nonstorm discharges were analyzed using ANCOVA and LS means tests. Results showed no significant difference in nonstorm discharge during the two periods thereby providing additional evidence that the decrease in DP was due to a treatment effect of the RSC. The reason for the decrease in DP and increase in TP from the Fence to RSC1 period is unknown, but could be related to the increase in fine floating organic matter in samples (documented via observation) as noted in the TKN section above. The rationale is that the suspended organic matter increased TP concentrations while not affecting OP concentrations.

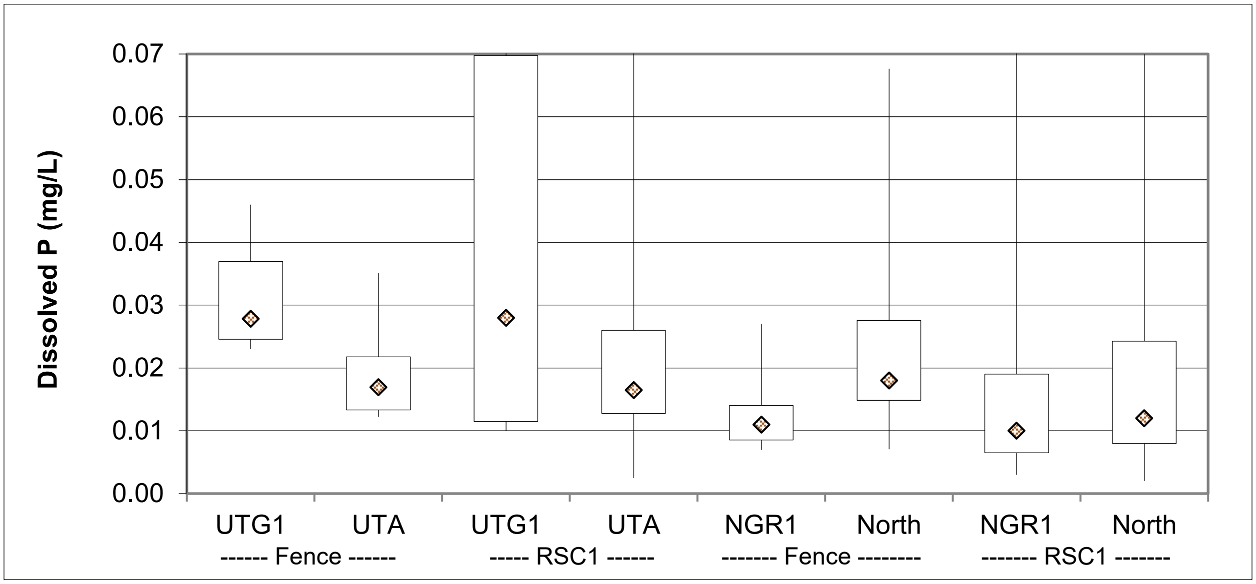

Figure 24. Ground and surface water DP concentrations.

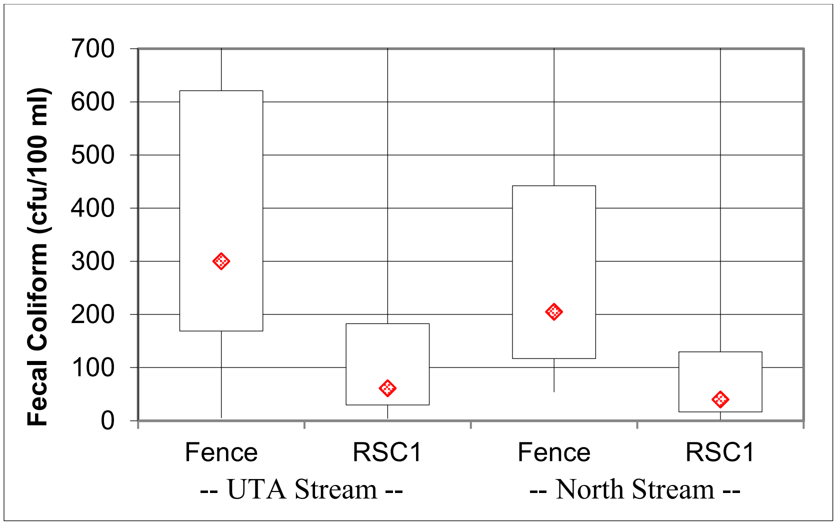

Figure 25. Surface water FC levels/concentrations.

Boxplots of FC data show a considerable decrease in levels on both streams from the Fence to RSC1 periods. Because the decrease for UTA with no treatment was as great as the one for NT, it cannot be attributed to the RSC but was likely the result of continued reductions associated with the LEF and depletion of residual FC populations along minimization of new FC entering the riparian corridor.

Subsurface Flow Dynamics

Temporal pattern

Figure 26 presents the hourly measured surface and subsurface flow rates, normalized by their respective mean flow rates observed during each measurement period, along with the corresponding rainfall rates. The estimated surface and subsurface flow rates and the corresponding groundwater elevation data from the wells are presented in Figure 26 and 27, respectively. Both subsurface and surface flow rates increased following each rainfall event. However, the pattern of increase varies across different seasons. During the fall measurements (November and December 2023), the rise in subsurface flow started instantaneously during the storm and persisted even after the surface flow receded, which can be attributed to the buffer effect resulting from the time required for water from the catchment area to reach the measurement locations. The duration over which the increase in the subsurface flow rates persists depended also on the rainfall pattern and temporal distribution.

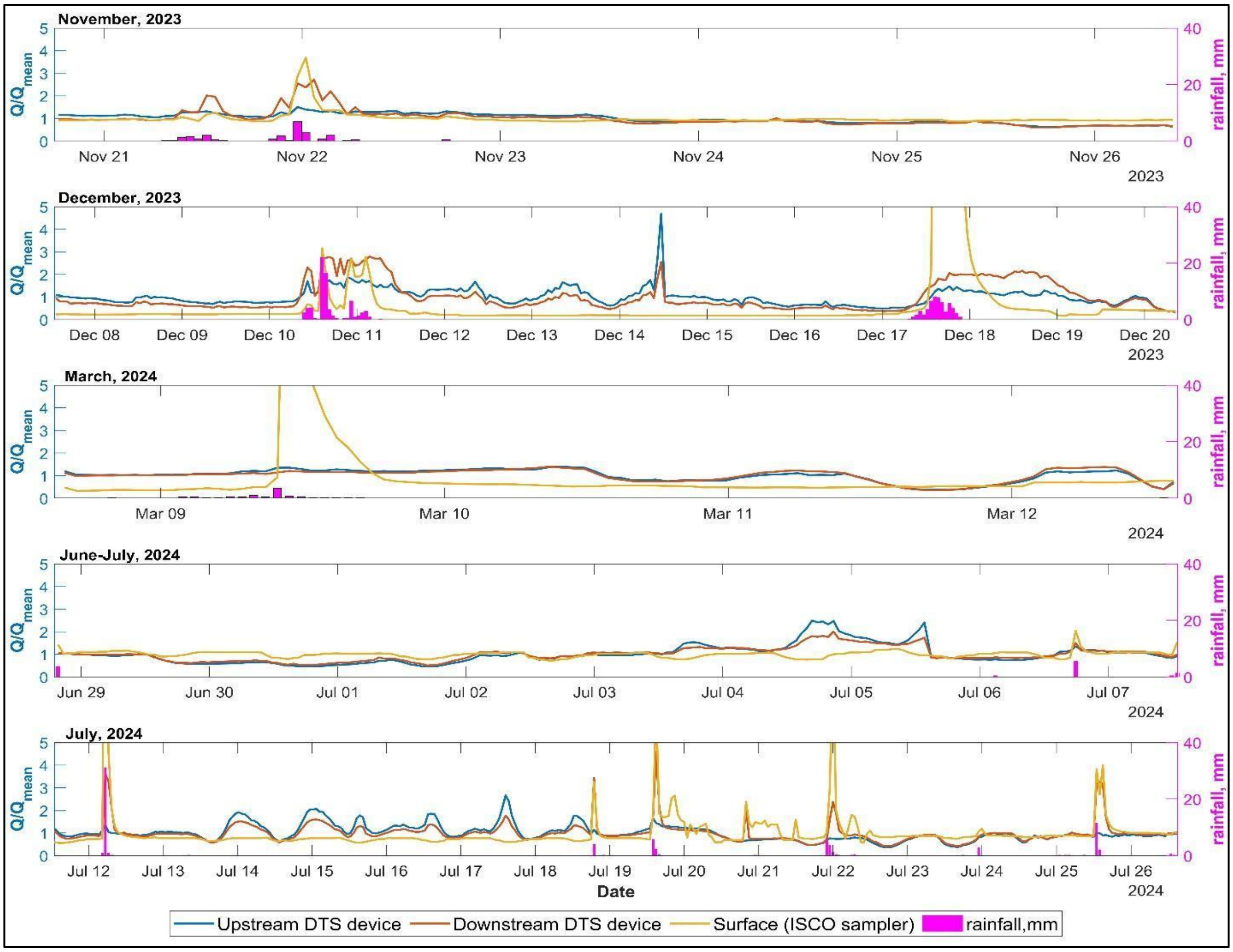

Figure 26. Measured surface and subsurface flow rates normalized by the mean flow rates observed over each measurement period (left axis), and the hourly rainfall rates in mm/hour (right axis)

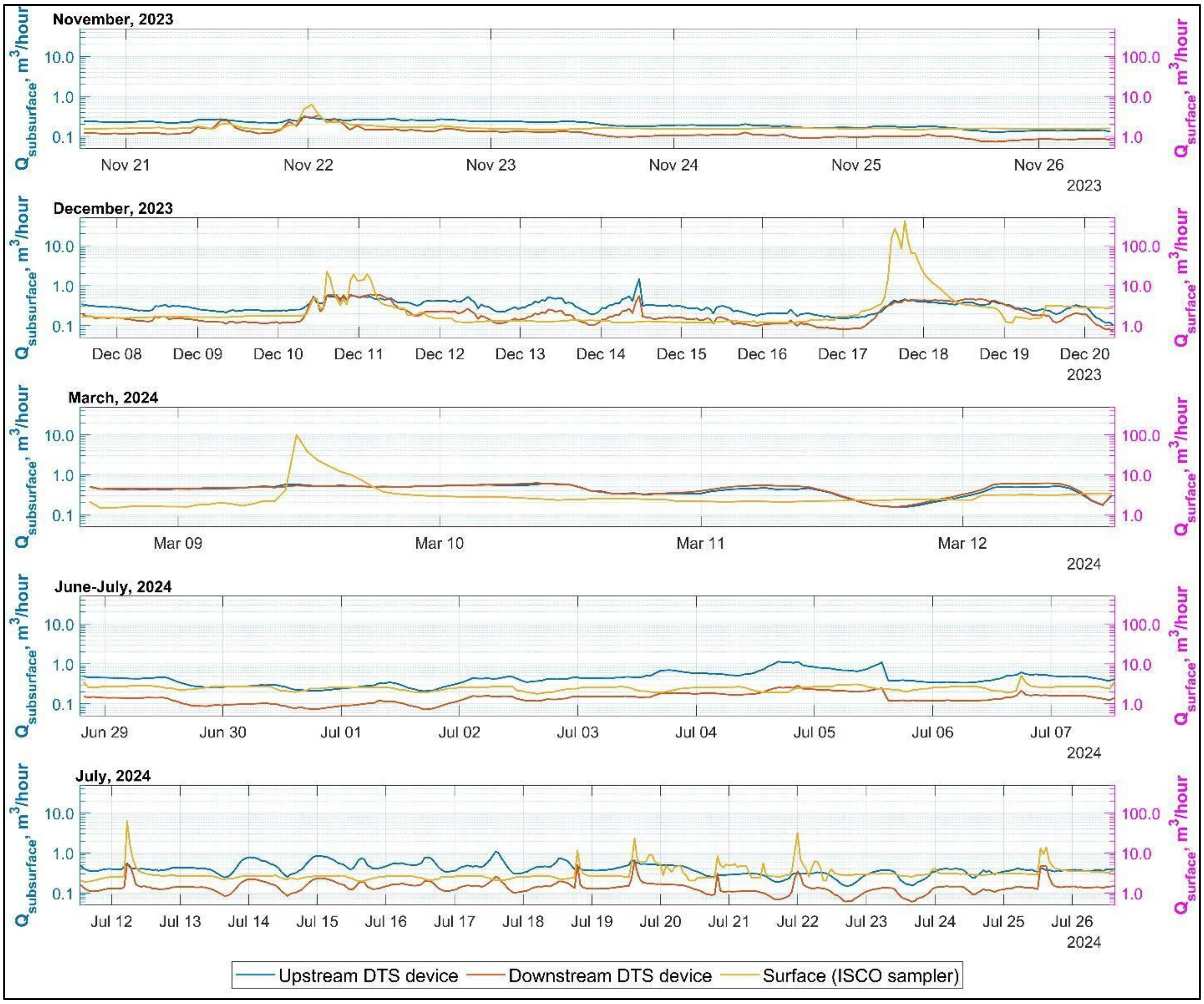

Figure 27. The measured surface flow rate (semi-logarithmic left axis) and subsurface flow rates (semi-logarithmic right axis) over each measurement period.

The mild storm in March 2024 did not produce an immediate effect on subsurface flow rates; however, it resulted in a significant surface flow surge that peaked at 100 m^3/hour. Minor delayed variations in subsurface flow rates were observed a few days after the storm. This lack of immediate response is likely attributable to the site being fully saturated from previous storms prior to the monitoring period, as indicated by groundwater levels in the wells, which were nearly coincident with the ground surface (Figure 28). In March 2024, groundwater levels at the upstream location were slightly higher than those at the downstream location, a pattern not observed during other monitored storms, further supporting the notion that the site remained saturated throughout this period. The saturation conditions in March 2024 explain why similar flow rates were recorded at both monitoring locations, as nearly all water from this mild rainfall event was transferred to surface flow via surface runoff.

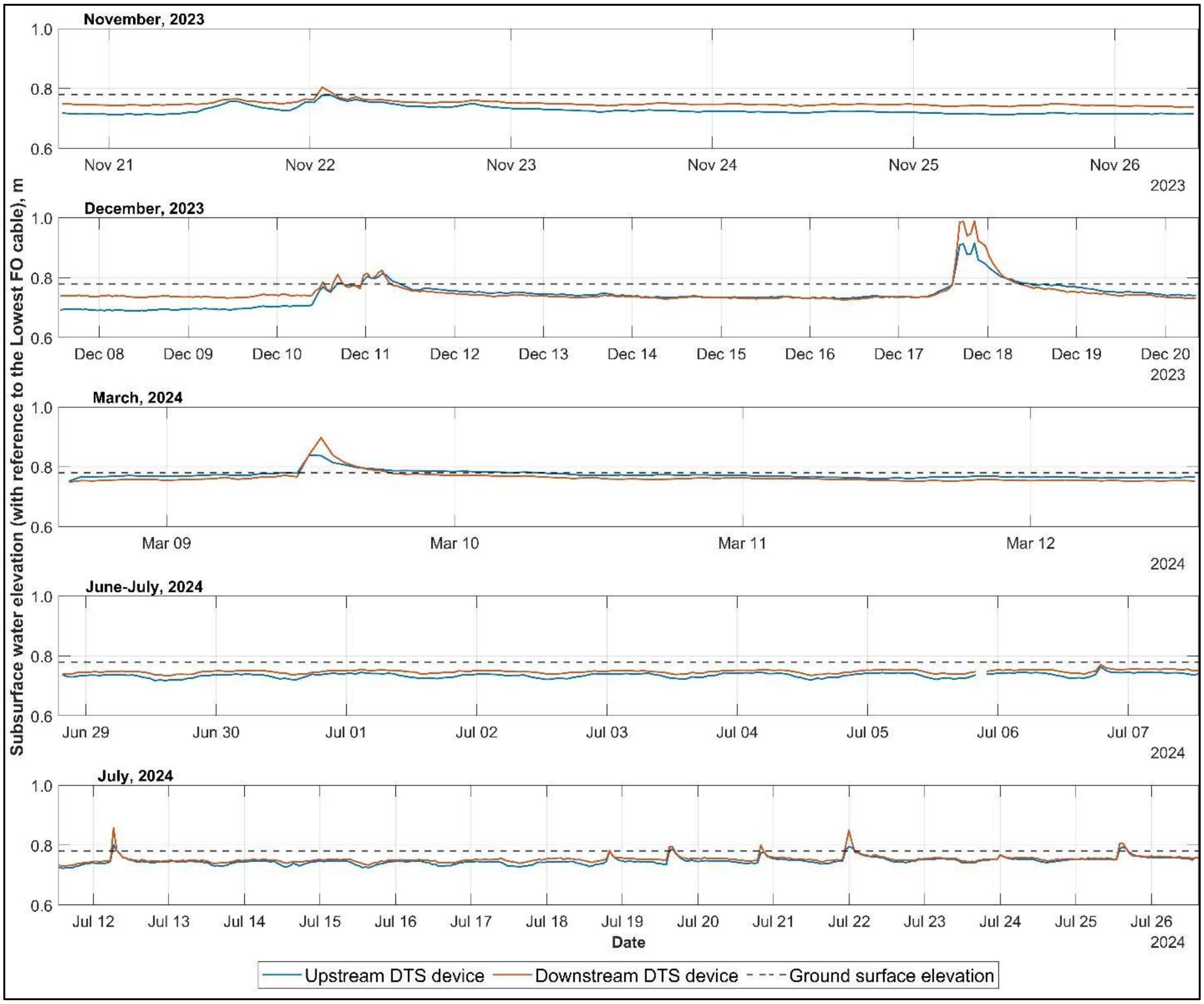

Figure 28. The groundwater levels observed at both measurement locations over the measurement periods referenced to the surface ground elevations

During the summer measurements in June and July 2024, minor instantaneous increases in subsurface flow were observed immediately after recorded storms. However, delayed increases occurred at various later time intervals, indicating differing arrival times for water from distinct segments of the catchment draining into the two measurement locations. This variation in response patterns may be attributed to the upper soil layers of the catchment being relatively dry before the summer storms, which resulted in lower unsaturated hydraulic conductivity and, consequently, longer response times.

Partitioning of the surface and subsurface flows

Figure 29 presents the partitioning of surface and subsurface flow over the monitored duration, while the statistics for each monitoring period are summarized in Table 6. Minimal subsurface-to-surface flow ratios were observed immediately after each storm, as the surge in surface flow significantly exceeded the magnitude of subsurface flows. However, as surface water receded, the ratio of subsurface flow relative to surface flow began to increase. This behavior confirms that the efficiency of the RSC in treating the initial flow surge from any given storm is minimal; however, their efficiency improves afterward. The overall mean and standard deviation of subsurface-to-surface flow ratios at the upstream and downstream monitoring locations were 15.86 ± 8.57% and 7.80 ± 5.17%, respectively. A maximum ratio of 117.67% was observed on December 14, 2023, at the upstream monitoring location, indicating that subsurface flow exceeded the corresponding surface flow at that time.

Table 6. Statistics of the subsurface to surface flow ratio for the NT monitoring locations.

	Upstream (NST1) Discharge ratio			Downstream (NST2) Discharge ratio		
	Minimum (%)	Mean (%)	Max (%)	Minimum (%)	Mean (%)	Max (%)
November 2023	4.59	12.41	17.47	4.64	7.32	12.50
December 2023	0.11	16.77	117.67	0.11	9.91	44.37
March 2024	0.58	16.54	29.61	0.54	17.50	30.13
June-July 2024	8.69	18.69	58.72	3.10	5.80	13.27
July 2024	0.88	14.55	52.50	0.84	4.83	12.40

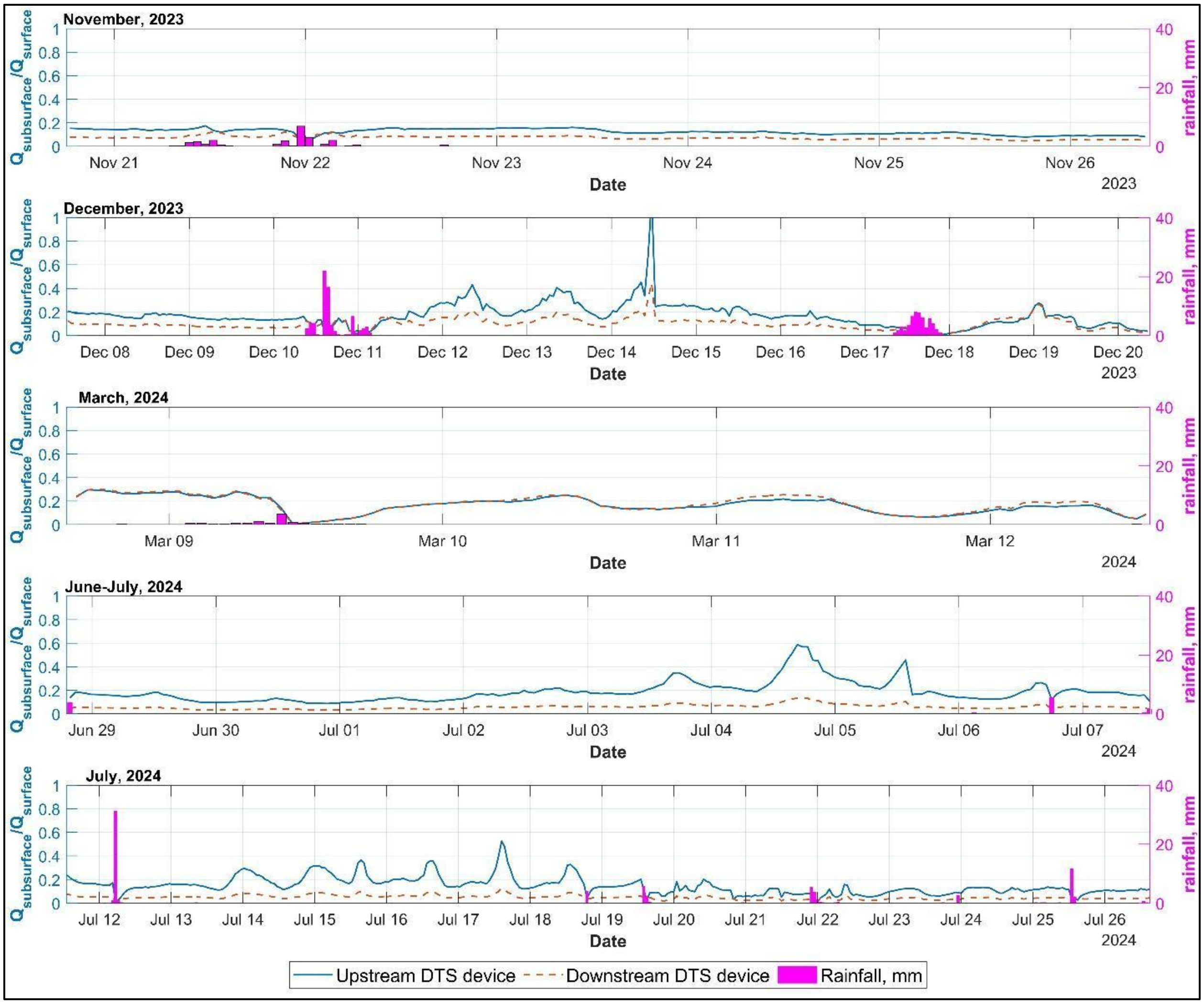

Figure 29. The partitioning of the surface and subsurface flows

<u>2D Pattern of the Subsurface fluxes</u>

The FO cable flux monitoring system provides unprecedented insight into the 2D flow spatial pattern through the RSC material, which can be used to detect any preferential flows and to optimize the RSC design to improve its treatment capacity. The mean flux observed through the two monitoring locations (Figure 30) revealed a consistent pattern over the five monitoring intervals. At the upstream monitoring location, the largest water fluxes were observed at depths between 0.66 to 1.3 ft (0.2 to 0.4 m) from the ground surface. On the contrary, the largest water fluxes at the downstream monitoring location depths were observed at the bottom of the monitored depth (depths >2 ft or 0.6 m) from the ground surface. These higher water flux patterns can be attributed to lower compaction density at these layers.

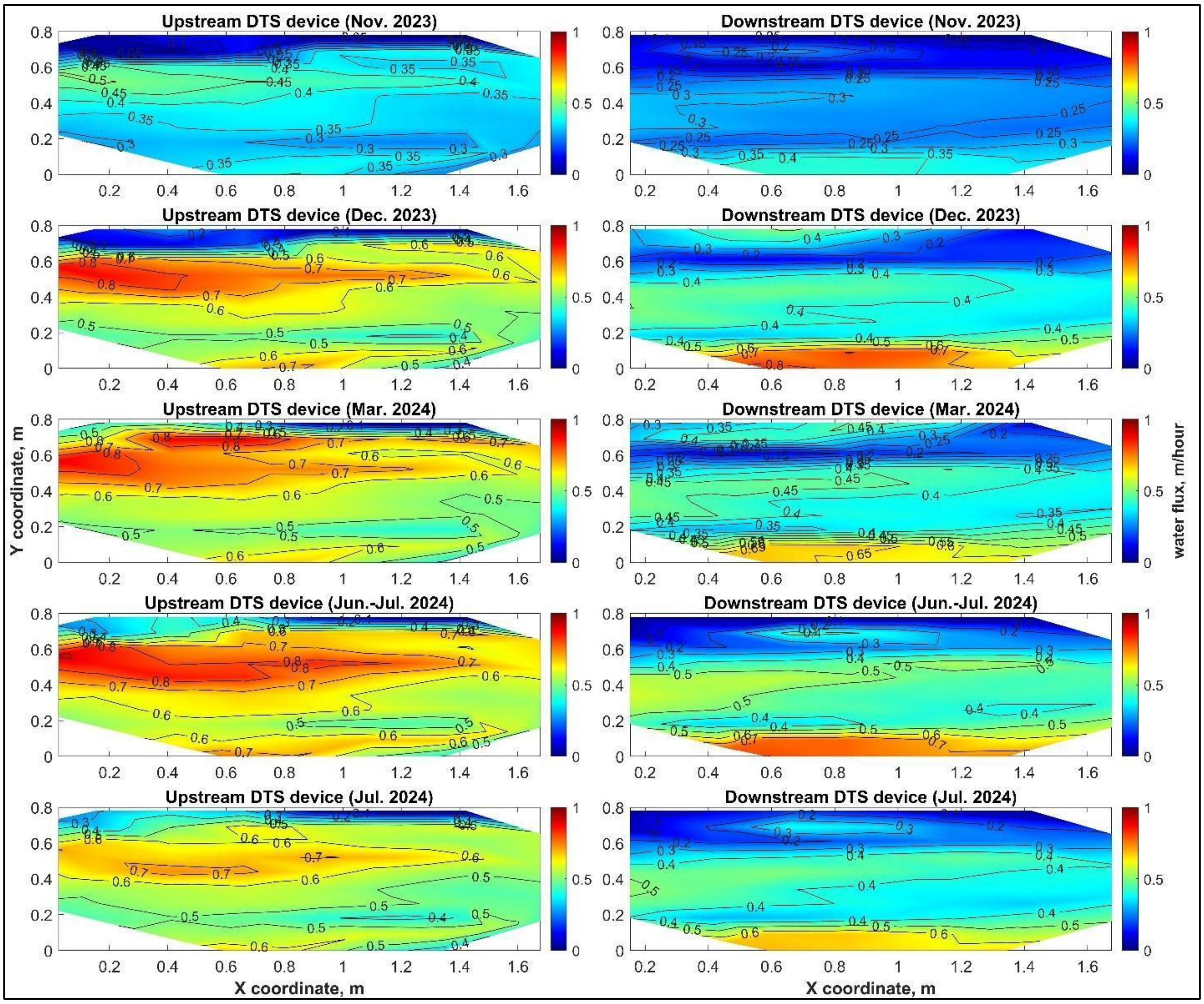

Figure 30. The average fluxes observed at the five monitoring intervals at both the upstream and downstream monitoring locations

Effectiveness of the Wetland (WET)

The following two factors must be considered when interpreting/evaluating the results of the wetland monitoring: 1) inflow was not monitored and 2) monitoring during medium to high stormflow was problematic due to bypass (high flows can bypass the wetland and/or overflow the wetland and flow directly into Millstone Creek thereby also bypassing the outlet monitoring station) and backwater (water from Millstone Creek backed up the wetland outlet channel to the monitoring station) resulting in a high level of uncertainty in discharge measurements and samples. Therefore, the focus of the evaluation of monitoring results will be on nonstorm monitoring data, which is also appropriate given that the wetland was not expected to provide significant treatment during medium to high storm flows.

Nonstorm discharge concentrations

Concentrations of TKN in nonstorm discharge generally increased from the UTA and NT to the outlet of the wetland (WET) during both the RSC1 and RSC2 periods (Figure 31); however, the increase was much greater during the RSC2 period. The reason for the increase was unknown, but could be related to the large increase in fine particles of organic matter (OM) observed in samples collected during the end of the RSC1 period through the RSC2 period. The OM in samples was observed to be greatest after extended periods with no significant storm events indicating that it tended to build up during periods without storms and then was flushed downstream during significant storm flow. For NOx-N, median concentrations in nonstorm discharge from the wetland were 3-5 mg/L less than those from the UTA and NT during both periods, while the spread of the interquartile ranges were similar for the three stations during both periods (Figure 31). This indicates a possible treatment effect of the wetland for NOx-N. For NH_3-N, median concentrations in outflow from the wetland were slightly greater than UTA and NT for both periods thereby providing no indication of treatment (Figure 32).

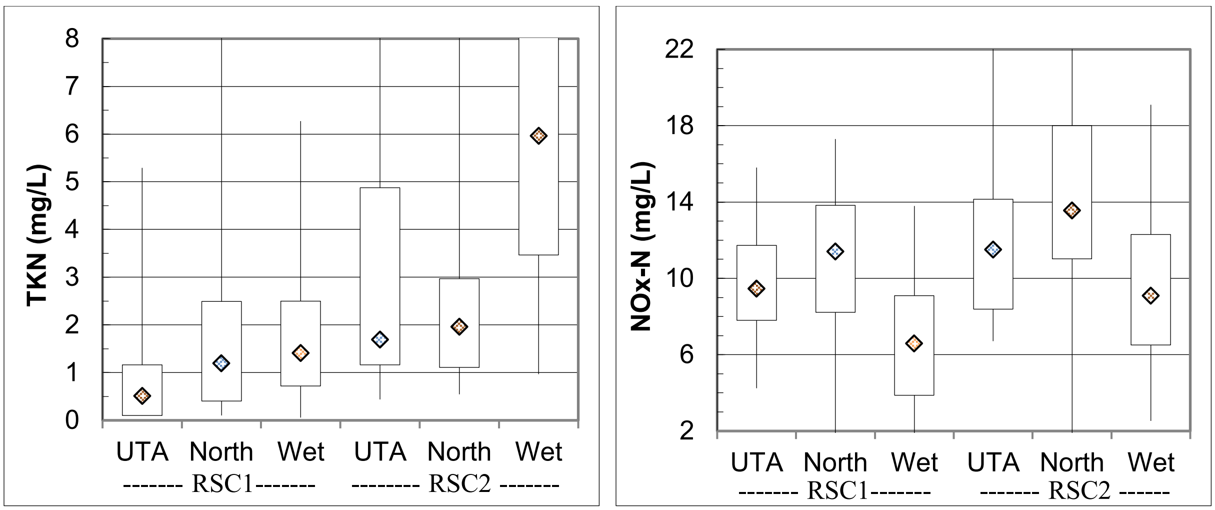

Figure 301. TKN (left) and NOx-N (right) in nonstorm discharge from the streams and wetland.

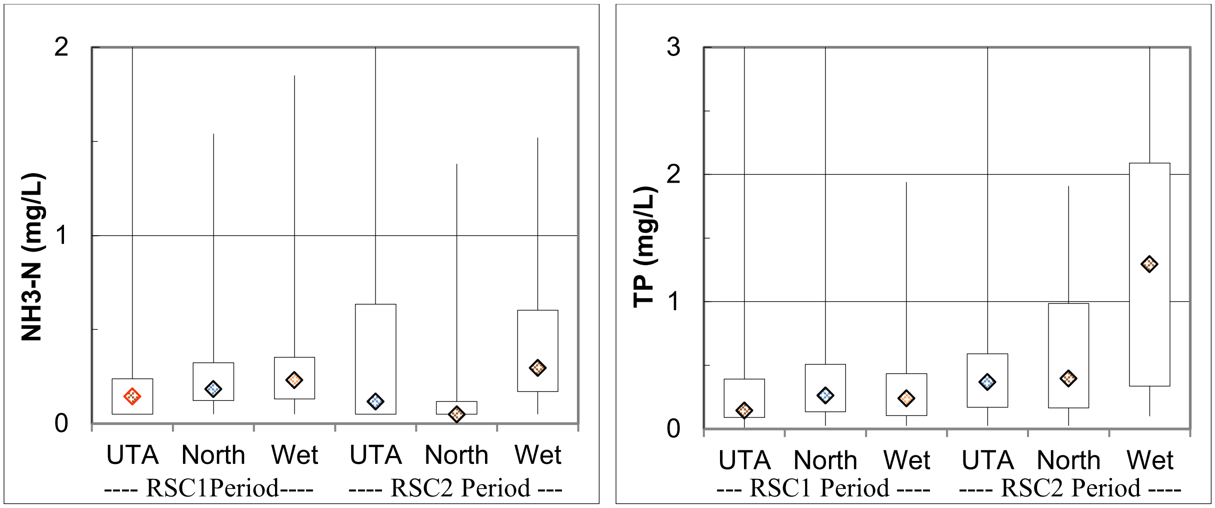

Figure 312. NH_3-N (left) and TP (right) in nonstorm discharge from the streams and wetland.

For TP, the median concentration for wetland outflow was more than the UTA, but less than NT during the RSC1 period increasing to considerably greater than both the UTA and NT during the RSC2 period (Figure 32). The definitive reason for the increase during the RSC2 period is unknown, but could be related to the marked increase in fine, floating OM in nonstorm samples during the RSC2 period (the OM likely contributed to TP in lab analysis). Further evidence of the presence of OM is shown in the large increase in TSS concentrations in outflow from the wetland during the RSC2 period (Figure 33). To attempt to quantify the mass of OM, three samples of TSS in wetland outflow were analyzed for volatile suspended solids (VSS) with the results showing that 15 to 30% of the mass of TSS was VSS. It should be noted that the three samples analyzed did not, based on personal observation, contain the greatest amount of OM compared to other samples. Therefore, the TP and TSS concentration data cannot be used to determine the effectiveness of the wetland at reducing TP and TSS.

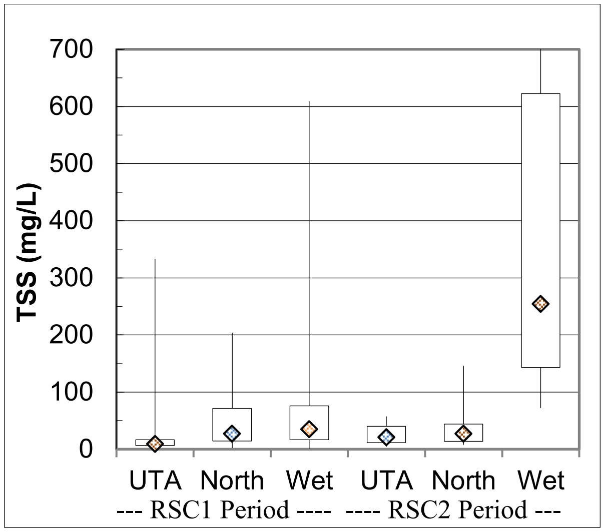

Figure 323. TSS in nonstorm discharge from the streams and wetland.

Storm discharge concentrations

While sample concentrations from large and intense storms were not included for reasons stated above, it is nonetheless useful to examine the rest of the storm event concentrations to assess the effectiveness of the wetland. Median storm event TKN concentrations for WET compared to UTA and NT during the RSC1 period, but then increased dramatically during RSC2 (Figure 34). The definitive reason for the increase is unknown, but the high TKN concentrations (mean= 7.27 mg/L) occurred from May through July, 2024 during which time peak discharges were relatively low (<250 gpm) whereas, after a large event on August 8, 2024, which washed the OM out of the wetland, TKN concentrations were markedly less (mean= 2.60 mg/L). For NOx-N, median concentrations in WET samples were generally equal to or greater than UTA and NT (Figure 34) thereby indicating no treatment, which was expected as there was little storage in the wetland and so stormwater passes right through it without treatment. Therefore, these data provide no definitive evidence that the wetland was effective at treating incoming nitrogen in storm discharge.

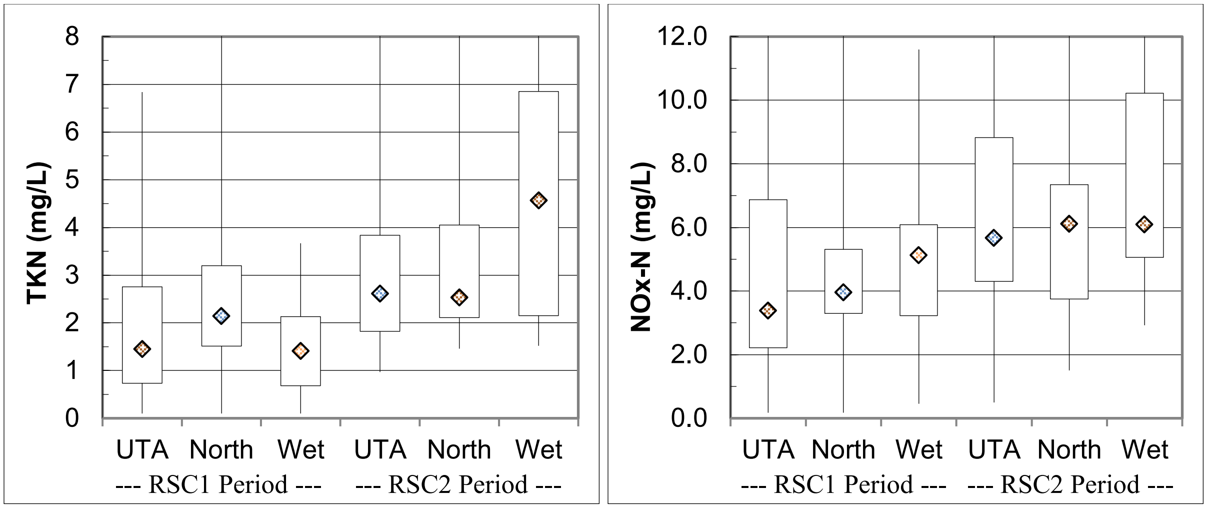

Figure 34. TKN (left) and NOx-N (right) in storm discharge from the streams and wetland.

For TP, the median concentration at WET was less than UTA and NT for both RSC1 and RSC2 (Figure 35). Similarly, TSS concentrations at WET were less than the UTA and NT during the RSC1 period and less than UTA and about the same as NT during the RSC2 period (Figure 35). The TSS data further highlights the possible effect of OM on TSS concentrations as little OM was observed in storm TSS samples from WET and those concentrations were less or about the same as those from UTA and NT. Hence, these data indicate a treatment effect of the wetland for moderate and smaller storms.

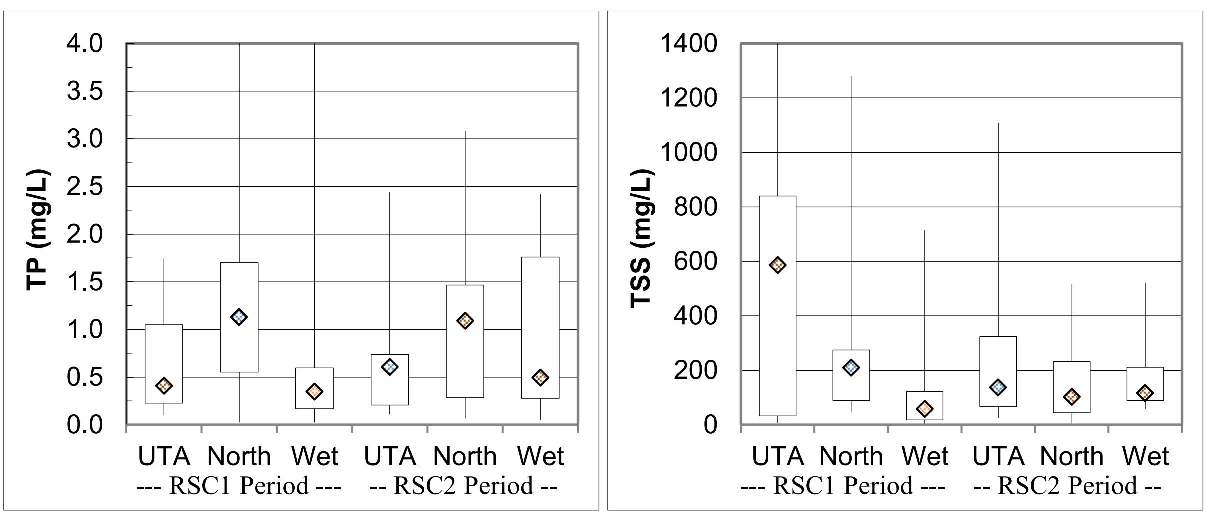

Figure 335. TP (left) and TSS (right) in storm discharge from the streams and wetland.

Nonstorm loads/export rate

Nonstorm inflow export rates for the wetland are shown in Table 7. Export rates increased from RSC1 to RSC2 for both the inflow to and outflow from the wetland. This was not expected as the RSCs implemented on the UTA and NT streams were expected to decrease nutrient and sediment export from the streams resulting in less inflow to the wetland; however, increased rainfall and the lingering effects of construction likely resulted in greater export during the RSC2 period.

Table 7. Nonstorm Discharge and Export for Wetland (WET) Effectiveness Evaluation.

	Discharge in/yr	TKN	NOx-N	NH_3-N	TN	TP	TSS
		----------------------		lb/ac-yr	-------------------------		
RSC1 Period							
Inflow[1]	-	1.96β[2]	12.2β	0.38β	14.2β	0.56β	50β
Outflow	6.3	2.44β	9.1α	0.46β	11.6α	0.55β	100α
RSC2 Period							
Inflow[1]	-	4.76β	20.1β	0.51β	24.9β	0.81β	51β
Outflow	6.1	8.73α	13.1α	0.53β	21.8β	1.83α	517α
Reduction (%)							
RSC1		-	*24.2*	-	*17.3*	-	*-104*
RSC2		*-86.4*	*33.7*	-	-	*-130*	*-935*
RSC1+RSC2		*-58.2*	*28.3*	-	*14.3*	*-51.3*	*-371*

[1] Includes loads from UTA and NT plus estimated load from 8.02 acres not monitored.
[2] Numbers with the same symbol are not significantly different at 0.05 level.

Regarding effectiveness, the nonstorm export rates show that the wetland was not effective at reducing inflow loads of TKN, NH_3-N, and TSS during the RSC1 period as outflow export rates were greater than inflow; however, according to paired t-tests only TSS was significantly greater (Table 7). Conversely, the wetland was effective at significantly reducing NOx-N and TN. The NOx-N reduction was expected as denitrification in the saturated and carbon-rich soil of the wetland resulted in a reduction in NOx-N loading/export, which made up the majority of the TN reduction.

During the RSC2 period, the effectiveness of the wetland decreased, especially for TKN, TP, and TSS (Table 7). As stated earlier, the large increase in TKN, TP, and TSS from inflow to outflow during the last month of the RSC1 period and the entire RSC2 period was likely attributable to fine OM observed in samples of outflow from the wetland. Conversely, the effectiveness of the wetland at reducing NOx-N loads increased, but it was not enough to offset the increase in TKN export from the wetland.

In summary, while the wetland reduced NOx-N loads/export by 28.3%, the monitoring data showed that it was not effective at reducing TKN, NH_3-N, TP, or TSS. The reason for this could be due to fine floating organic matter originating in the wetland or to the absence of inflow monitoring, which necessitated estimates of inflow loads.

Surface and Groundwater Temperature

While temperature measurements were made at 20- or 30-minute intervals, to simplify the time series presentations in this report, the average monthly air and water temperatures were computed for the surface and ground water monitoring sites (see Appendix A). Time series graphs of air and water temperatures at NT, UTA, UTB, and Millstone are presented in Figures

36 to 41. To help illustrate some of the relationships within the monthly data, graphs of daily mean air versus water temperatures grouped by seasons are included in Appendix B (Figures B1-B4).

For North, monthly mean temperatures in the upland well (NGR2) varied the least over the time during the Pre and Fence periods (Figure 36), which was expected given that it was deeper groundwater (greater than 10ft deep). The temperature in the streambank well (NGR1) and the stream water had similar annual cycles over time, but had much greater amplitudes than that of NGR2. Generally, the temperature of the NT stream was slightly less than NGR1 during the colder, winter months and slightly greater during the warmer, summer months. This was expected given that the stream water had more contact with the air, which tended to increase its temperature during summer and decrease it during winter (Figure B1). This is a natural phenomenon as ground water enters the stream at basically the same temperature year-round (58-62 ºF) and when the air temperature is greater, the surface water in the stream warms and when it is colder it cools. These trends continued through the RSC1 and RSC2 periods (Figure 37).

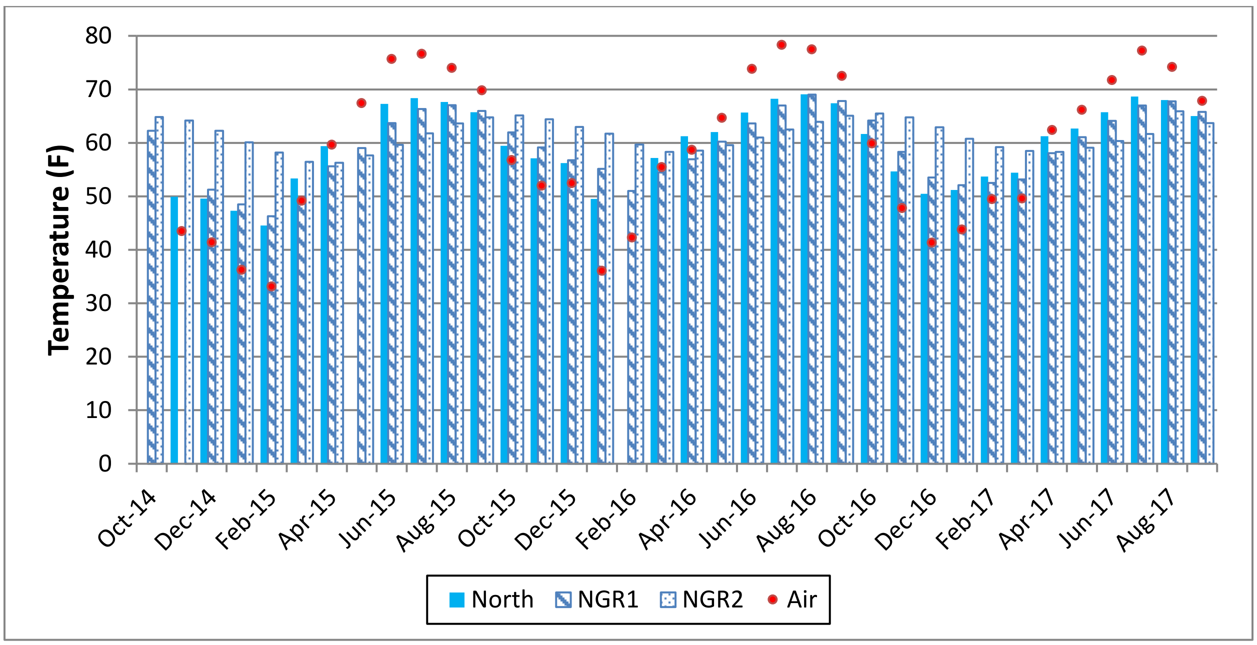

Figure 36. Air and water temperatures for NT surface and ground water during the Pre and Fence periods.

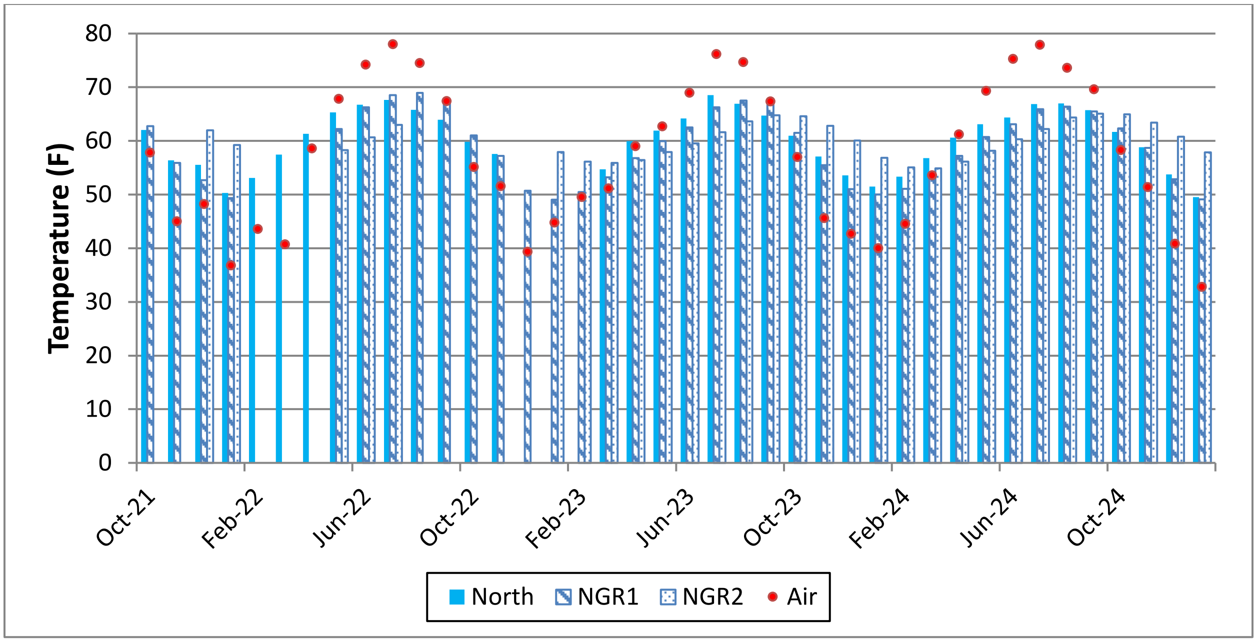

Figure 347. Air and water temperatures for NT surface and ground water during the RSC1 and RSC2 periods.

To assess whether the RSC had an effect on the temperature at NT, manipulation of the data was required. Because air and water temperatures vary significantly by month, it is not appropriate to compare periods in time to document a trend from one site, unless they include the same months of the year. For example, the RSC1 period included monitoring during 3 Julys, 3 Augusts, and 3 Septembers, whereas the Fence period included only 1 of each month; therefore, the RSC1 period is likely to have significantly greater water temperature overall compared to the Fence period. However, the paired watershed approach and analyses is designed to account for this by employing a control (UTA for RSC1). In using the UTA data as a control, only days during which both UTA and North had temperature data were used. An ANCOVA and LS means analyses were conducted on the average daily water temperatures at UTA and North. These analyses documented a significant increase (2.33%) in water temperature from the Fence to RSC1 period. This was expected as the construction of the RSC removed nearly all the tree canopy along the North stream and created unshaded pools of water, which tend to facilitate water heating as the ponded water absorbs the sun's radiant energy. As shading increases along the North stream over time, water temperatures should decrease.

It is also informative to assess water temperature along the length of the North stream. During the RSC1 and RSC2 periods (Figure 38), the highest (during summer) and lowest (during winter) monthly water temperatures occurred at the most upstream (NST1) monitoring gage. The most downstream monitoring station (North/NT) appeared to have the least temperature variation, which initially seems counterintuitive as water flowing downstream is retained in several pools where it is exposed to solar radiation; however, the temperature could be influenced more by the influx of groundwater along the stream channel and to the growing vegetation providing shade for the stream channel. Several wet areas 10 to 20 ft upslope from the stream channel were observed downstream of NST1 where water appeared to come out of the ground and seep down to the stream.

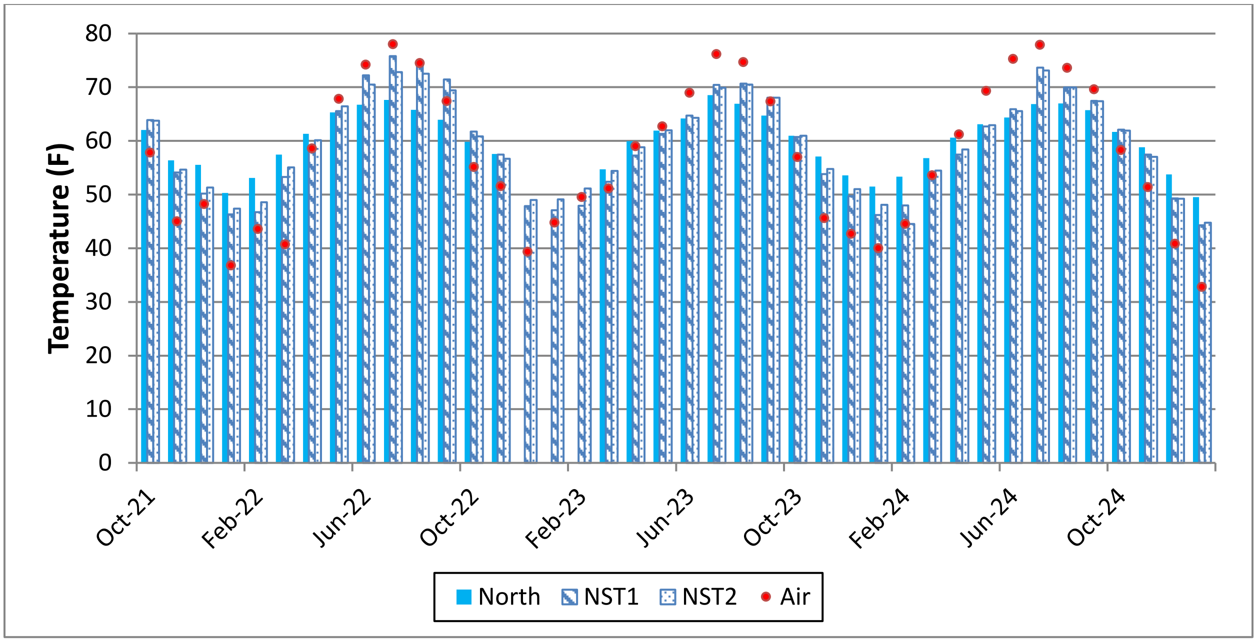

Figure 38. Air and water temperatures for NT surface water during the RSC1 and RSC2 periods.

For the UTA stream, there were much less temperature data for the upland well (due to it being dry for several months) and stream UTA (due to sensors that malfunctioned). The trends and absolute values in monthly average temperatures during the Pre, Fence, and RSC1 periods were similar to those of the NT stream (Figure 39). During RSC2, the trend of the stream temperature (UTA) being greater than the upland groundwater temperature (UGW2) in summer and less in winter continued; however, the stream temperature (UTA) was consistently less than the near stream groundwater (UGW1) for the whole period (Figure 40). The reason for this was unknown, but water quality data from UGW1 during the RSC2 period were seemingly inexplicable, leading to questioning whether the data were representative. During the summer of the RSC2 period, the monthly temperature for UTA increased compared to the summer of 2022. This was likely due to the removal of trees (and their shading) during the construction of the RSC. The daily mean temperature of the UTA showed the opposite effect of the NT when compared to air temperatures (Figure B3). The UTA showed warming of stream temperatures during summer and cooling during Fall, Winter and the cooler days of Spring, moving closer to the air temperature (Figure B3).

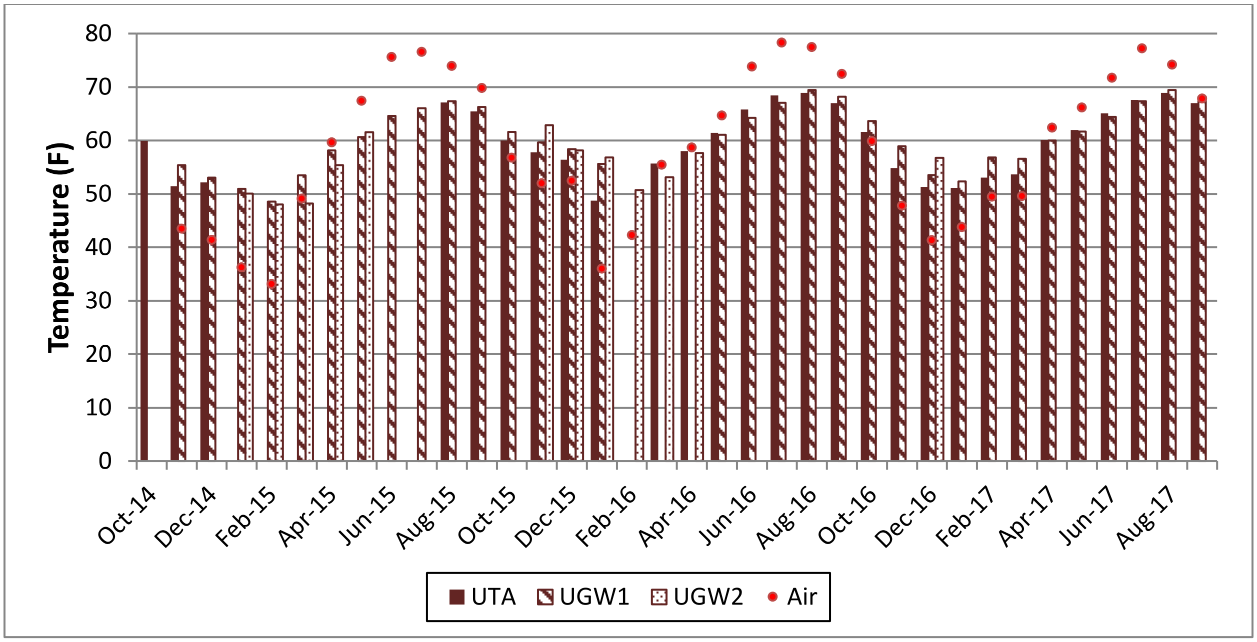

Figure 39. UTA stream, ground water, and air temperatures during the Pre and Fence periods.

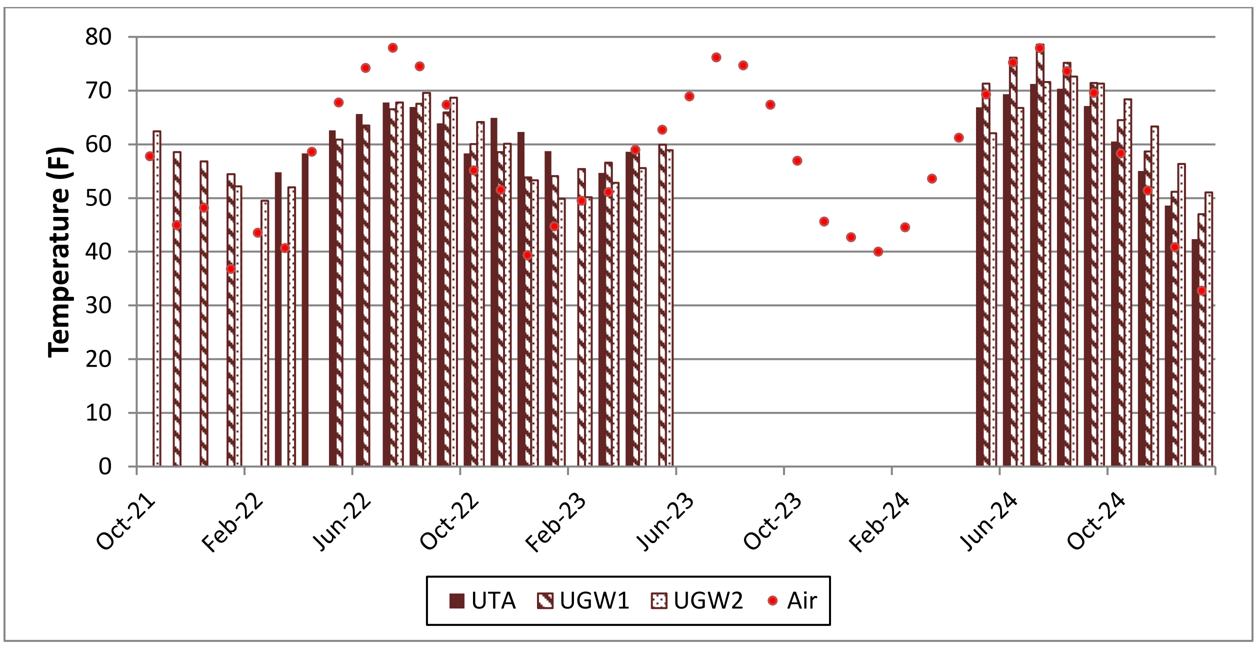

Figure 40. UTA stream, ground water, and air temperatures during the RSC1 and RSC2 periods.

For Millstone Creek (Mill), the monthly mean water temperature tracked the air temperature quite closely even though there was no evidence of the sensor being exposed to the air during any significant period of time (Figure 41). The fact that the mean water temperature during summer and early fall was nearly as high or higher than the air temperature was likely the result of slow-moving water that had ample time to contact the air and be warmed by solar radiation (trees were removed during restoration). In addition, there was at least one large pond upstream of the monitoring station, in which standing water could warm to the temperature of the ambient air or greater. In fact, during August to December of each year the monthly mean water temperatures were greater than the air temperature (Figure B4).

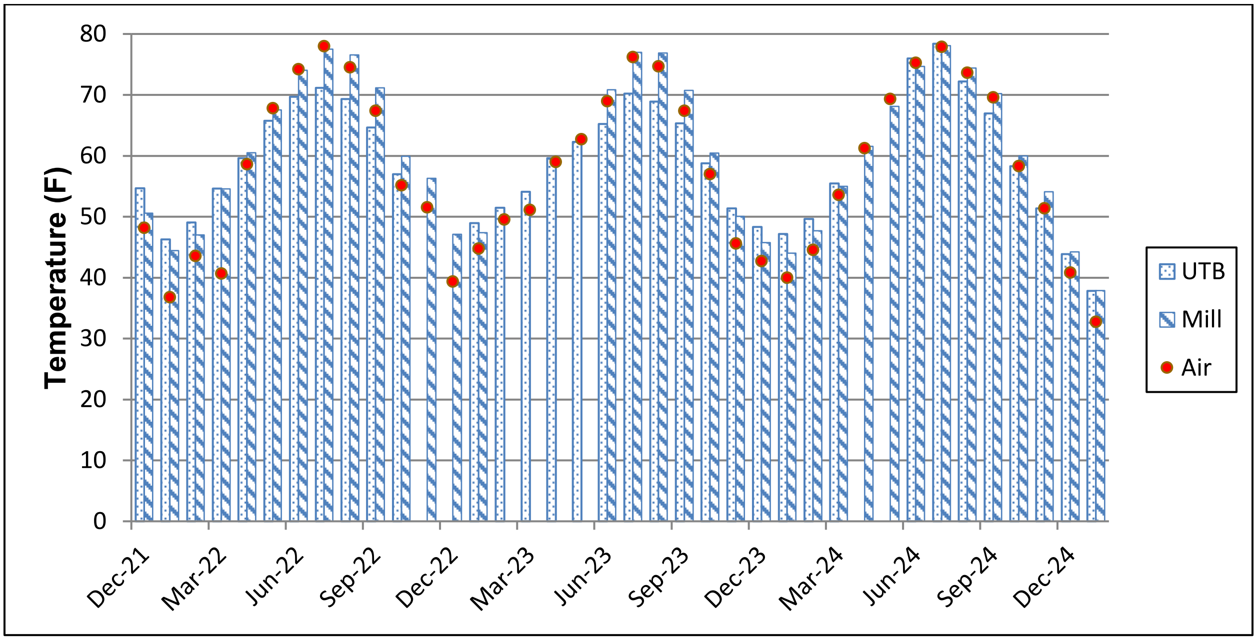

Figure 41. Stream temperatures at Mill and UTB during the RSC1 and RSC2 periods.

The effect of the stream restoration on the water temperature of Millstone Creek cannot be definitively assessed because there was no pre-restoration monitoring at this site; however, there was a limited period of monitoring at a site (Mill-dn) about 200-400 ft downstream. The trends in monthly mean temperatures from this downstream site were similar to the post-restoration data in that the water temperature tracked relatively closely to the air temperature and water temperatures were greater than air from August to December (Figure 42). The relationships between air and water temperature during each season appeared to change very little, if any, from the Fence to RSC1 and RSC2 periods (Figure B4). Thus, these data suggest no effect of the stream restoration on the water temperature of Millstone Creek.

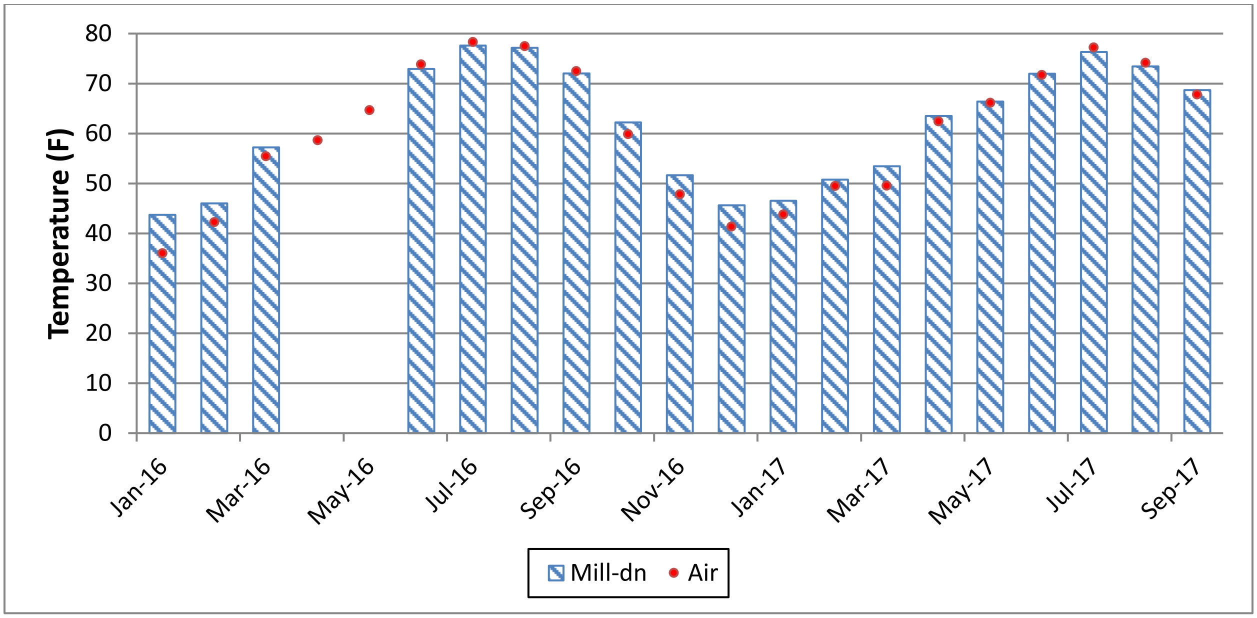

Figure 42. Water temperatures for downstream site on Millstone Creek before stream restoration.

Monthly water temperatures at the UTB stream gage during 2021 to 2023 were generally less than that of Mill except for winter months when the temperatures at the Mill gage were less (Figure 41). For 2024, temperatures at UTB appeared to increase especially in June and July when they were nearly equal to Mill. This may be attributed, at least in part, to an increase in temperature of UTA as stated above.

Water Surface Elevations/Levels

The WSEs on the UTA and NT streams were monitored during the RSC1 and RSC2 periods to document whether surface water flow ceased at any time after the installation of the RSCs. As stated above, this monitoring was difficult/problematic due to the small stream with very shallow surface flow and a shifting streambed.

Discharge monitoring near the downstream confluence of the two streams at stations UTA and NT documented that surface discharge was continuous throughout the duration of the monitoring, but upper reaches of the streams may have been dry. For the NT stream, WSEs monitored at the upper stream gage (NST1) were greater than the controlling stream bed (elevation=454.43 ft) for all of the project, except for a period near the beginning of the RSC1 period in late 2021 and early 2022 as well as during September to December of 2022 when the fiber optic cable was installed (Figure B5 top). The installation of the fiber optic cable in fall 2022 (illustrated by the flat line for NST1 in Figure B5, top) introduced uncertainty to all previously measured WSEs as the excavation to bury the FO cable system changed the elevation of the streambed. Also, water was pumped out of the stream to install the cable thereby creating an artificial drop in the WSEs that took an extended time to recover. Because the streambed was surveyed in 2024 after the excavation, it is unknown if the bed was lower prior to the excavation. No surface flow was observed during a visit on 10/25/22, but surface flow was observed during all other visits.

For the stream gage on the downstream third of the NT stream (NST2), monitored WSEs during the entire project were greater than the controlling stream bed elevation (Figure B5 bottom). This was consistent with the observations of surface discharge made during the 15 visits to the site during the project. Thus, these WSE measurements show that the implementation of the RSC did not result in the cessation of surface discharge even though the streambed was raised several feet, thus a loss of perennial stream did not occur.

For the streamgage on UTA, surface discharge was observed during each of the 12 visits to the site. Continuous monitoring indicated that the WSE was less than the controlling streambed structure in September and October 2024; however, surface discharge was observed on 9/11/24, 10/8/24 and 11/5/24 (Figure B6); therefore, it is likely there was an error in the level measurements during these periods. As stated previously, the very shallow flow makes measurement of surface flow problematic/difficult for this small stream. Observations and monitoring measurements show that continuous surface water discharge was maintained on UTA after the implementation of the RSC again confirming no loss of perennial stream.

For the UTB stream reach, observations during the 15 site visits and monitoring data documented continuous surface discharge (Figure B7). The brown dashed line indicates the elevation of the WSE-controlling downstream structure (log across stream). It is apparent that several WSE measurements were less than the elevation of the structure thereby indicating no surface discharge. However, given the excess variability and observation of surface flow during the 12/20/22 and 2/14/23 visits to the site, the WSE measurements shown on the figure from 11/1/22 to 2/15/23 were likely erroneous. Similarly, the WSE measurements shown for 7/1/24 to 7/15/24 were also likely erroneous. The red dashed line indicates the elevation of bankfull, so during the 3+ years of the project the bankfull discharge was exceeded at least 5 times.

For Millstone Creek, the surface discharge controlling structure elevation was not surveyed, because the creek is perennial and surface discharge was observed during each of the 15 project visits (Figure B8). Given the red dashed line on Figure B8 represents the elevation of bankfull discharge, the water surface exceeded this elevation at least 23 times during the 3+ years of monitoring.

Specific Conductivity Levels

Boxplots of specific conductivity (Cond) measurements for the UTA and NT streams are shown in Figure 43. The two boxplots labeled RSC1 were for the spring of 2022 and 2023, which were both during the RSC1 monitoring period. For UTA, medians decreased slightly each period from the Pre to RSC1 and then more dramatically in RSC2. The measurements during RSC2 were uncertain as the in-situ probe began making suspect measurements and quit working on June 4, 2024. For the NT, there was a dramatic decrease in Cond from a relatively high level during the Pre period to a relatively low level during the RSC1 period. In general, the Cond during the Pre period was indicative of high pollutant concentrations and/or salts in the water whereas the median level during the RSC1 period for both streams was indicative of good quality water. Hence, at least for the NT stream, the combination of the LEF and RSC was effective at reducing the conductivity of the stream water.

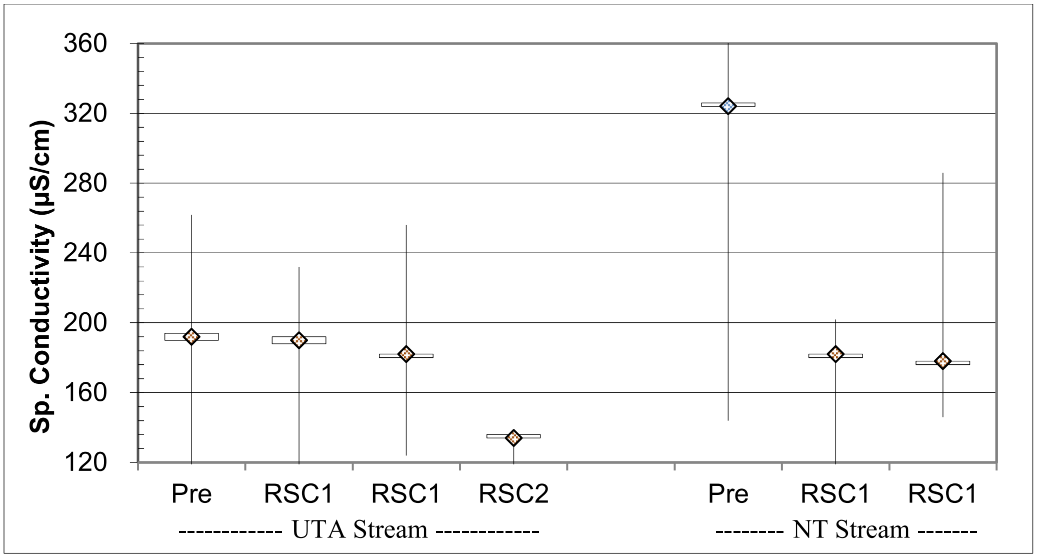

Figure 43. Specific conductivity for the NT and UTA streams.

SUMMARY AND CONCLUSIONS

The discharge of two adjacent streams (UTA and NT) originating in a beef cow pasture in the Piedmont region of NC were monitored from 8/5/14 to 3/4/25 with several interruptions for construction of livestock exclusion fencing (LEF) and regenerative stormwater conveyance (RSC) measures. The monitoring included continuous rainfall and discharge measurements at the downstream end of both streams along with the collection and analyses of flow-proportional samples. The water temperature and water surface elevation at seven project stream sites, including UTA and NT were monitored continuously throughout much of the project. Ground water temperature and elevation along each stream were also monitored and samples of ground water were collected and analyzed to document water quality. Outflow from a wetland downstream of the confluence of UTA and NT was also continuously monitored and sampled. Subsurface flow in the RSC on NT was also monitored using a fiber optic (FO) cable system. From the monitoring data the following conclusions/lessons were drawn:

- The LEF reduced TKN, NH_3-N, TP, and TSS pollutant loads/export from both streams monitored by 56 to 69%, while reducing NOx-N by 7 to 19%.
- The LEF is a relatively cost-effective measure for reducing nitrogen and phosphorus loads in streams when compared to urban stormwater control measures.
- The effectiveness of the LEF on one stream improved over the 3-5 years of monitoring indicating that the long-term effectiveness of the LEF may be greater than these short-term results show.
- Monitoring results showed that NOx-N load/export in the NT stream decreased by 42% following the implementation of the RSC, but NOx-N export actually increased for the UTA stream following the RSC's construction; however, the increase may have been the result of increased rainfall and/or continuing changes/adjustments in the control watershed (paired watershed analysis) or a short monitoring duration (<1yr), which can affect the statistical analysis.

- Mean total nitrogen concentrations in nonstorm and storm samples decreased after the RSC on the NT stream was implemented by 22% and 38%, both of which were statistically significant.
- Consistent decreases in groundwater TP concentrations on the UTA stream following the LEF suggested that the LEF may be effective at reducing TP in groundwater.
- Subsurface flow contributions to total discharge on the NT stream were highly variable, increasing significantly after storm peaks, thus reinforcing the role of RSCs in sustaining water treatment processes after surface flow diminishes.
- Surface discharge was maintained in the downstream half of both NT and UTA following the implementation of the RSC, even though the RSC on NT raised the streambed 3-4 feet.
- The wetland reduced nonstorm NOx-N loads/export by 28%, but increased TKN, TP and TSS loads/export by 51 to 371%. The increased export can likely be attributed to increased fine organic matter in the wetland discharge as further analyses of sediment samples revealed that 15-30% of the TSS was volatile solids.
- Daily mean water temperature at the downstream end of the NT stream increased by 2.33% following the implementation of the RSC.
- Specific conductivity levels of the NT stream decreased markedly (from >320 µS/cm to ~180 µS/cm) after the LEF and the RSC were implemented.

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APPENDICES

Appendix A: Rainfall and Sample Data

Table A1. Stream Storm and Nonstorm Sample Concentrations for UTA.

		********* Storm Samples **********					********* Nonstorm Samples **********				
Date	Rain in	TKN mg/L	NOx mg/L	NH3 mg/L	TP mg/L	TSS mg/L	TKN mg/L	NOx mg/L	NH3 mg/L	TP mg/L	TSS mg/L
7/10/14	0.12										
7/15/14	0.78										
8/5/14											
8/12/14	2.07	8.95	0.58	0.38	3.25	4228					
8/18/14											
9/4/14	1.32										
9/9/14											
9/13/14	0.31										
9/18/14	0.35										
9/22/14											
10/9/14											
10/13/14	0.51										
10/15/14	0.80										
10/23/14							1.96	7.38	0.76	0.47	na
11/1/14	0.64										
11/4/14							2.03	7.80	0.29	0.22	115
11/17/14	0.94										
11/20/14							5.63	7.66	0.37	1.09	70
11/26/14	1.20										
12/2/14							2.05	7.10	0.52	0.36	84
12/18/14							1.24	7.71	2.42	0.12	42
12/24/14	1.88										
12/29/14	0.99	5.75	3.46	0.46	1.56	639					
1/6/15							0.33	9.16	0.03	0.05	18
1/12/15	1.33	9.63	9.69	0.43	2.08	484					
1/20/15											
1/23/15	0.96	14.7	6.77	1.38	3.15	1284					
2/4/15											
2/9/15	0.74										
2/23/15							2.87	8.56	0.46	0.77	745
2/27/15	0.65										
3/1/15	0.47										
3/5/15	0.69	12.6	11.10	0.32	2.21	776					
3/9/15							6.20	9.10	0.42	0.95	107
3/14/15	0.26										
3/19/15	0.64										
3/23/15							4.35	9.57	0.32	0.51	47

3/26/15	0.24										
3/30/15	0.20						3.15	8.66	0.96	0.22	34
4/9/15							3.92	9.50	0.43	0.38	26
4/14/15	0.79										
4/15/15	1.02										
4/19/15	0.92	17.10	8.60	0.97	4.20	480					
4/22/15											
5/1/15	1.19	13.87	9.41	1.58	2.66	196					
5/7/15											
5/19/15	1.34	13.93	7.33	0.61	3.46	2378					
5/21/15											
6/2/15							15.53	6.45	1.37	5.80	
6/2/15	0.22										
6/9/15	0.73	44.3	3.52	2.97	13.71	14262					
6/17/15	0.55										
6/17/15							26.68	4.20	5.22	5.15	667
6/18/15	0.62										
6/25/15	2.87										
6/26/15	1.08										
6/27/15	1.65	16.52	1.49	1.17	5.51	5050					
6/30/15							11.05	18.16	0.84	2.45	328
7/5/15	0.87										
7/13/15	1.04	13.24	2.85	0.78	3.98	2378					
7/17/15							4.46	8.52	0.43	0.60	133
7/30/15							7.54	9.37	0.39	1.21	297
8/6/15	0.88										
8/12/15							4.02	9.15	0.576	0.601	185
8/19/15	1.00										
8/26/15							3.56	8.63	1.12	0.62	50.4
8/31/15	1.01	15.03	8.34	3.36	1.34	219					
9/9/15							1.66	9.43	0.19	0.18	44.1
9/10/15	0.42										
9/23/15							9.55	9.20	3.53	1.39	142
10/1/15	0.83										
10/2/15	1.98	4.21	3.17	0.79	1.38	367					
10/7/15							5.42	7.70	0.71	1.07	105.4
10/21/15							1.79	9.03	0.40	0.22	41.9
10/28/15	1.32										
11/2/15	2.18	2.44	2.84	0.40	0.70	453					
11/4/15							0.67	8.11	0.20	0.07	0.54
11/6/15	0.54										
11/9/15	1.25	5.59	8.09	3.27	0.90	68					
11/18/15							0.94	10.50	0.52	0.09	12.5
11/19/15	2.01	3.49	3.92	0.42	1.26	691					
12/2/15											

12/16/15							0.75	10.38	0.19	0.12	20.3
12/17/15	1.12										
12/22/15	1.64										
12/23/15	1.34										
12/28/15	0.65										
12/30/15	1.89	3.35	6.09	0.40	1.54	3968					
1/7/16											
1/21/16							0.60	10.84	0.08	0.16	22
2/3/16	1.04	8.59	7.68	0.58	2.36	1622					
2/8/16							0.91	10.75	0.13	0.11	26
2/16/16	1.30										
2/23/16	0.93										
2/25/16											
3/9/16							6.53	10.90	0.48	0.99	81
3/24/16							0.75	10.38	0.08	0.15	17
3/27/16	1.17										
3/31/16	0.21	7.02	3.44	0.56	2.71	1099					
4/5/16							1.06	10.07	0.16	0.17	19
4/21/16							2.29	10.76	0.19	0.69	17.8
5/3/16	1.10	13.5	5.13	0.33	2.46	1604					
5/3/16							1.13	10.06	0.12	0.11	13
5/12/16	0.72	4.19	7.46	0.35	1.75	442					
5/18/16							8.55	9.16	2.15	1.15	103
5/21/16	0.41	13.83	3.19	1.12	3.48	1930					
5/31/16							3.46	9.12	0.31	0.69	71.2
6/15/16							1.28	9.22	0.85	0.17	17.1
6/15/16	1.06	11.90	3.44	1.12	2.95	3020					
6/28/16							2.44	8.64	0.19	0.46	35.6
7/2/16	0.58										
7/13/16							3.15	8.37	0.33	1.24	150
7/26/16							1.75	8.99	0.66	0.31	298
8/2/16	0.43										
8/8/16	1.35	12.00	3.49	0.78	4.01	1768					
8/10/16							10.03	8.22	0.67	2.32	375
8/23/16							5.02	8.85	0.40	1.10	70.8
9/1/16	0.71										
9/7/16							11.56	8.65	0.37	2.07	325
9/19/16	2.16	6.44	2.60	0.38	1.72	967					
9/20/16							2.64	8.67	0.22	0.45	40.8
9/27/16	1.23										
9/29/16	0.81	2.89	8.58	0.81	0.58	77					
10/6/16							1.99	8.28	0.58	0.35	23.7
10/8/16	3.14	7.07	2.95	0.93	2.66	1513					
10/18/16							0.99	8.87	0.07	0.14	78.1
11/1/16							0.66	9.35	0.09	0.08	7.1

11/15/16							0.94	9.62	0.06	0.14	6.5	
11/29/16							0.55	9.26	0.07	0.12	7.7	
12/13/16							0.58	8.94	0.18	0.06	2.4	
1/2/17	1.18											
1/3/17	0.54	5.86	4.22	0.39	1.94	518						
1/4/17							0.40	9.73	0.04	0.04	7.0	
1/19/17							2.90	9.48	0.51	0.66	66.9	
1/23/17	0.52	4.31	4.48	0.36	1.46	618						
1/31/17							1.39	9.58	0.10	0.55	4.0	
2/14/17							1.11	9.76	0.07	0.21	6.5	
2/28/17							1.47	10.10	0.08	0.27	15.6	
3/1/17	0.75	4.78	5.46	0.52	1.40	548						
3/14/17							2.17	9.84	0.27	0.36	19.6	
3/28/17							4.29	9.88	0.36	0.76	51.1	
4/3/17	0.58											
4/6/17	0.76	11.27	3.36	0.34	3.96	1009						
4/11/17							3.05	8.84	0.25	0.73	37.5	
4/23/17	0.81											
4/24/17	1.96	3.48	3.09	0.14	1.28	167						
4/25/17							4.15	8.79	0.63	0.68	37.0	
5/1/17	0.92											
5/5/17	0.63	11.81	3.45	0.61	2.88	656						
5/10/17							3.94	8.84	0.22	1.05	91.7	
5/24/17							1.82	8.86	0.14	0.36	29.4	
5/25/17	1.24	5.33	2.94	0.35	2.03	625						
6/7/17							2.50	8.70	0.06	0.66	40.0	
6/19/17	0.77											
6/20/17							4.08	8.63	0.22	0.77	76.1	
7/5/17							0.54	8.53	0.15	0.06	1.5	
7/17/17	1.48											
7/18/17												
8/1/17							1.90	8.67	0.35	0.23	16.7	
8/8/17	0.87	11.34	2.65	1.10	2.45	1277						
8/15/17							3.55	8.36	0.43	0.65	77.3	
8/30/17							2.21	8.58	0.34	0.37	100	
9/1/17	1.06	12.19	1.29		1.83	1243						
9/13/17							1.46	8.24	0.12	0.18	34.9	
9/26/17							2.18	8.82	1.08	0.23	7.8	
10/11/17							1.01	9.04	0.28	0.08	4.7	
10/23/17	1.13	4.11	4.40	0.19	0.91	294						
10/26/17							7.60	9.12	3.11	1.71	18.0	
6/12/21												
6/29/21							~~1.82~~	~~7.63~~	~~0.57~~	~~0.85~~	~~100.9~~	-
7/2/21	~~0.62~~	-	-	-	-	-						
7/8/21	~~1.52~~	-				-						

7/9/21	~~0.27~~	-	~~0.26~~	~~3.33~~	-	~~833~~					
7/13/21							1.16	7.65	0.21	0.42	36.9
7/19/21	1.63										
7/27/21							**0.10**	4.89	0.14	0.12	17.3
8/7/21	1.57	1.03	0.45	0.39	0.12	498					
8/10/21							**0.10**	6.56	0.13	0.50	15.8
8/18/21	0.64										
8/24/21							4.64	7.86	2.11	0.941	50.0
9/1/21	0.83										
9/7/21											
9/8/21	0.46										
9/9/21	0.25										
9/21/21							**0.10**	13.00	**0.05**	0.121	33.6
9/22/21	2.86	4.93	3.94	0.60	0.83	676					
10/5/21							0.25	10.20	0.14	0.322	10.0
10/9/21	1.32										
10/19/21							**0.10**	10.80	0.14	0.055	10.6
11/2/21							0.22	12.40	**0.05**	0.090	6.9
11/16/21							0.76	4.88	0.27	0.132	12.2
11/22/21	0.34										
11/30/21							0.68	10.50	0.11	0.106	11.0
12/14/21								11.40			10.7
12/19/21	0.61										
1/2/22	2.28	2.77	2.83	0.20	0.32	900					
1/4/22							0.56	14.00	**0.05**	0.186	8.5
1/9/22	0.57										
1/17/22	0.57										
1/18/22							0.16	9.16	**0.05**	0.091	6.0
2/1/22							0.30	12.40	**0.05**	0.62	6.2
2/7/22	0.33										
2/15/22							1.02	10.10	0.13	0.382	25.4
3/1/22							0.74	11.70	**0.05**	0.100	8.2
3/12/22	1.16	3.02	7.78	**0.05**	0.29	228					
3/15/22							1.37	4.25	0.54	0.272	8.5
3/16/22	2.04	3.64	0.18	0.41	0.47	785					
3/29/22							2.64	4.41	0.60	0.116	10.6
3/31/22	0.76										
4/12/22							0.21	8.37	0.17	0.198	10.7
4/18/22	1.74	1.54	2.57	0.15	1.15						
4/26/22							0.31	11.90	0.23	0.107	6.8
5/7/22	0.53										
5/10/22							1.27	13.60	0.25	1.410	1.4
5/23/22	0.68										
5/24/22							0.51	14.10	0.17	0.066	8.0
5/27/22	0.80										

6/8/22							0.86	11.40	0.19	**0.025**	7.0
6/8/22	0.94										
6/21/22							1.59	7.44	0.48	0.059	6.4
6/29/22	0.73										
7/5/22							0.78	9.29	0.18	0.131	9.5
7/10/22	0.65										
7/19/22							3.07	12.70	0.248	**0.025**	4.6
8/2/22							0.56	13.80	**0.05**	0.146	9.5
8/6/22	1.00										
8/16/22							0.13	12.80	**0.05**	**0.025**	4.1
8/30/22							**0.10**	11.50	0.128	**0.025**	2.8
9/10/22	0.52										
9/13/22							0.65	7.74	**0.05**	0.075	2.9
9/27/22							1.23	9.28	**0.05**	0.102	6.6
9/30/22	3.08	2.26	4.21	0.22	0.10						
10/11/22							**0.10**	14.80	0.191	0.088	4.9
10/25/22							**0.10**	9.61	**0.05**	0.057	8.8
11/8/22							**0.10**	10.20	**0.05**	0.172	1.5
11/11/22	1.23										
11/15/22	0.45										
11/22/22							0.10	10.20	**0.05**	0.136	4.0
11/25/22	1.13	0.86	6.77	**0.05**	0.35	12.3					
11/27/22	0.78										
11/30/22	0.61										
12/6/22							0.27	11.80	0.183	0.686	7.94
12/15/22	1.22	0.39	10.10	0.16	0.21	24.2					
12/20/22							0.80	11.60	**0.05**	0.076	2.67
12/22/22	1.04	0.19	12.20	**0.05**	0.10	35.7					
1/4/23							**0.10**	6.49	0.106	0.474	23.3
1/4/23	0.27										
1/12/23	0.47	**0.10**	6.90	**0.05**	1.05	16.7					
1/18/23							0.10	7.80	0.118	0.116	52.8
1/22/23	0.78	0.69	4.35	0.27	0.33	820					
1/25/23	0.82										
1/31/23							**0.10**	8.72	0.299	2.37	107
2/12/23	1.62	1.36	2.27	0.22	0.86	1660					
2/14/23							**0.10**	8.59	0.134	0.270	84.6
2/28/23							1.54	8.41	0.165	0.404	82.7
3/2/23	0.47										
3/14/23							5.29	7.67	0.541	0.502	102
3/27/23	0.72	6.84	2.16	1.14	1.74	2260					
3/28/23							3.10	5.53	1.13	0.589	333
4/7/23	3.44										
4/8/23	1.48										
4/11/23							0.32	7.81	0.12	0.010	

4/22/23	1.14	2.71	2.20	0.23	1.05	7.3					
4/25/23							0.18	8.40	0.168	0.149	9.2
4.28/23	1.24										
4/30/23	1.20	0.56	7.65	**0.05**	0.19	82.1					
5/9/23							3.91	11.60	2.17	4.29	7.3
5/16/23	0.50										
5/23/23							0.42	15.80	0.21	0.261	4.5
5/28/23	1.02										
6/6/23							0.71	7.88	0.147	0.38	15.6
6/19/23	0.75										
6/20/23											
6/22/23	1.50	2.15	2.63	0.44	1.30	1000					
6/23/23	0.40										
6/24/23	1.58										
6/26/23	1.58										
7/1/23	1.34										
7/3/23							1.16	8.53	1.25	0.177	33.0
7/8/23	2.06	1.34	1.24	0.32	1.11	693					
7/9/23	0.99										
7/18/23							1.30	9.31	0.93	0.196	9.6
8/1/23							**0.10**	7.01	0.10	1.075	10.3
8/10/23	0.80										
8/15/23											
3/26/24							13.50	6.84	7.8	1.45	29.5
3/27/24	1.86	13.00	**0.50**	5.82	0.68	1109					
4/9/24							4.86	9.30	3.9	0.659	21.4
4/11/24	0.40										
4/23/24							1.48	14.70	**0.05**	0.213	20.5
5/5/24	2.38	1.83	4.21	0.39	0.21	286.7					
5/6/24	0.43										
5/7/24							7.43	6.71	**0.05**	0.06	38.1
5/14/24	1.12	11.70	5.50	0.55	1.67	73.0					
5/18/24	0.71										
5/21/24							2.00	15.70	0.771	0.577	50.0
5/26/24	0.75	1.82	14.10	0.71	0.61						
6/4/24							0.48	16.30	**0.05**	0.12	12.5
6/18/24							2.28	8.32	0.298	0.407	33.0
7/2/24							1.75	12.30	0.589	0.49	46.6
7/7/24	0.86										
7/12/24	1.84		5.84	5.46	2.44	416					
7/16/24							1.63	6.74	0.111	0.315	47.1
7/18/24	0.63										
7/19/24	0.90										
7/20/24	0.54										

7/21/24	1.05	3.96	1.37	0.58	0.64	440					
7/25/24	0.83										
7/29/24	2.01										
7/30/24							0.44	11.50	**0.05**	0.121	10.4
8/8/24	3.74	2.21	3.76	0.13	2.01	187.0					
8/14/24							0.83	13.40	0.184	**0.025**	5.1
8/27/24							1.24		**0.05**	0.474	10.3
9/1/24	1.66	1.01		0.15	0.20						
9/11/24							0.68	9.48	**0.05**	0.083	10.2
9/16/24	2.22	0.97	6.36	**0.05**	0.13	25.8					
9/24/24							1.36	6.92	0.111	0.63	20.6
9/24/24	0.80										
9/27/24	1.10	1.99	4.57	0.32	0.60	87.0					
9/30/24	0.44										
10/8/24							0.66	13.60	**0.05**	0.227	4.3
10/22/24							4.06	7.39	1.34	0.894	11.8
11/5/24							6.45	12.20	2.54	2.32	17.1
11/14/24	1.02	1.70	11.40	**0.05**	0.80						
11/19/24							1.40	12.10	0.231	0.188	8.2
12/3/24							3.13	8.57	0.116	0.576	53.1
12/11/24	1.39	3.01	4.99	0.11	0.13	80					
12/17/24							4.91	16.90	**0.05**	0.197	26.2
12/28/24	0.63										
1/7/25							1.24	9.64	**0.05**	0.426	26.2
1/11/25	0.30	3.10	9.94	**0.05**	0.60	48					
1/21/25							17.50	8.44	3.2	0.327	57.4
1/31/25	0.69	3.46	9.10	2.88	0.11	50					
2/4/25							6.14	19.50	0.288	3.24	46.2
2/12/25	2.63	5.17	8.01	0.44	0.24	294					
2/18/25							0.94	22.10	0.118	0.118	15.4
3/4/25											

Note: Numbers in bold are half of the reportable limit, brown shade indicates date of retrieval.

Table A2. Rainfall and Sample Concentrations for NT.

		******* Storm Samples *******					******* Nonstorm Samples *******				
Date	Rain in	TKN mg/L	NOx mg/L	NH3 mg/L	TP mg/L	TSS mg/L	TKN mg/L	NOx mg/L	NH3 mg/L	TP mg/L	TSS mg/L
8/5/14							0.39	18.00	0.07	0.05	6
8/12/14	2.07	3.31	4.28	0.21	3.24	2251					
8/18/14											
9/4/14	1.32										
9/9/14											
9/13/14	0.31										
9/18/14	0.35										
9/22/14											
10/9/14											
10/13/14	0.51										
10/15/14	0.80										
10/23/14											
11/1/14	0.64										
11/4/14							3.24	7.49	1.75	0.53	na
11/17/14	0.94										
11/20/14							3.04	15.65	0.48	0.35	44
11/26/14	1.20										
12/2/14											
12/18/14							2.93	15.05	0.42	0.37	143
12/24/14	1.88										
12/29/14	0.99										
1/6/15							1.10	18.55	0.08	0.12	44
1/12/15	1.33	na	na	na	na	na					
1/20/15							2.19	17.51	0.34	0.25	146
1/23/15	0.96										
2/4/15							1.17	17.96	0.04	0.07	28
2/9/15	0.74										
2/23/15							0.82	17.84	0.11	0.06	4
2/27/15	0.65										
3/1/15	0.47	5.83	5.35	0.49	2.25	582					
3/5/15	0.69										
3/9/15							2.57	15.27	0.34	0.50	131
3/14/15	0.26										
3/19/15	0.64										
3/23/15							0.83	18.39	0.30	0.17	8
3/26/15	0.24										
3/30/15	0.20										
4/9/15		na	na				0.68	18.09	0.15	0.08	12
4/14/15	0.79										
4/15/15	1.02										
4/19/15	0.92	6.91	15.43	0.47	0.83	422					
4/22/15							1.99	13.11	0.38	0.14	34
5/1/15	1.19										

5/7/15							2.09	16.97	0.42	0.47	52
5/19/15	1.34	11.53	14.44	0.58	2.82	2025					
5/21/15							8.33	16.04	0.57	0.67	57
6/2/15							1.49	18.67	0.46	0.15	25
6/2/15	0.22										
6/9/15	0.73										
6/17/15	0.55										
6/17/15							3.18	17.18	0.49	0.62	111
6/18/15	0.61										
6/25/15	2.87										
6/26/15	1.08										
6/27/15	1.65										
6/30/15							1.47	8.23	0.18	0.12	23
7/5/15	0.87										
7/13/15	1.04										
7/17/15							1.36	18.04	0.11	0.13	54
7/30/15											
8/6/15	0.88	14.66	5.11	2.50	4.70	2655					
8/12/15							1.91	17.55	0.20	0.20	32
8/19/15	1.00	12.04	4.69	1.56	4.11	2994					
8/26/15							1.73	16.64	0.43	0.12	13
8/31/15	1.01										
9/9/15							1.06	17.39	0.23	0.06	7
9/10/15	0.42										
9/23/15							1.14	16.95	0.15	0.10	12
10/1/15	0.83										
10/2/15	1.98	5.72	4.41	1.09	2.41	706					
10/7/15							1.57	16.08	0.24	0.14	7
10/21/15							0.62	17.53	0.16	0.05	2
10/28/15	1.32										
11/2/15	2.18	3.60	3.87	0.33	2.25	55					
11/4/15							0.83	17.11	0.17	0.08	1
11/6/15	0.54	3.65	8.09	0.55	1.43	196					
11/9/15	1.25	1.52	14.37	0.19	0.44	12					
11/18/15							0.81	17.08	0.27	0.09	2
11/19/15	2.01	3.32	2.17	0.75	1.92	5					
12/2/15											
12/16/15							6.33	17.57	3.64	1.89	0
12/17/15	1.12										
12/22/15	1.64										
12/23/15	1.34										
12/28/15	0.65										
12/30/15	1.89										
1/7/16							1.92	16.28	0.32	0.16	6
1/21/16							0.83	17.98	0.15	0.08	4
2/3/16	1.04	9.31	4.55	0.91	3.16	1112					
2/8/16							0.96	17.70	0.08	0.08	21
2/16/16	1.30	9.83	5.79	1.13	3.36	1663					

2/23/16	0.93										
2/25/16							0.52	19.09	0.07	0.06	2
3/9/16							0.97	19.33	0.82	0.08	7
3/24/16							0.51	19.11	0.09	0.05	17
3/27/16	1.17	5.26	13.09	0.63	1.51	524					
3/31/16	0.21										
4/5/16							1.22	18.73	0.33	0.17	9
4/21/16							0.58	19.62	0.11	0.06	4
5/3/16	1.10	2.06	17.47	0.19	0.33	129					
5/3/16							0.98	19.06	0.12	0.07	4
5/12/16	0.72										
5/18/16							1.04	17.54	0.24	0.12	10
5/21/16	0.41	8.80	5.12	0.80	4.24	1023					
5/31/16							1.56	17.95	0.22	0.17	1
6/15/16							0.89	17.48	0.29	0.08	64
6/15/16	1.06	10.12	2.13	1.44	3.16	2304					
6/28/16							0.65	18.72	0.10	0.05	6
7/2/16	0.58										
7/13/16							1.33	15.97	0.37	0.11	16
7/26/16							1.05	18.67	0.20	0.12	2
8/2/16	0.43										
8/8/16	1.35	6.75	5.32	0.79	2.56	1257					
8/10/16							0.86	17.09	0.25	0.10	6
8/23/16							1.24	16.43	0.24	0.09	9
9/1/16	0.71										
9/7/16							0.96	18.08	0.12	0.07	4
9/19/16	2.16	3.50	13.11	0.46	0.99	359					
9/20/16							1.16	17.17	0.15	0.09	3
9/27/16	1.23										
9/29/16	0.81	2.26	11.20	0.21	1.06	79					
10/6/16							0.85	17.41	0.15	0.08	5
10/8/16	3.14	5.75	9.51	0.55	3.37	553					
10/18/16							0.77	17.99	0.12	0.09	2
11/1/16							1.40	19.01	0.19	0.46	6
11/15/16							1.16	18.77	0.13	0.09	4
11/29/16							0.67	17.74	0.15	0.07	4
12/13/16							0.62	17.32	0.07	0.06	1
1/2/17	1.18										
1/3/17	0.54	6.71	8.28	0.38	2.99	557					
1/4/17							1.07	18.41	0.19	0.11	7
1/19/17							1.25	18.52	0.11	0.13	6
1/23/17	0.65	5.68	3.17	0.47	2.83	474					
1/31/17							0.71	18.25	0.11	0.08	0
2/14/17							0.84	18.09	0.14	0.08	3
2/28/17							0.65	18.58	0.12	0.06	3
3/1/17	0.75	7.28	7.61	0.86	1.48	768					
3/14/17							3.25	18.78	0.42	1.50	6
3/28/17							0.91	18.33	0.16	0.08	1

4/3/17	0.58										
4/6/17	0.76										
4/11/17											
4/23/17	0.81										
4/24/17	1.96	3.64	3.94	0.41	2.33	99					
4/25/17							1.44	16.39	0.30	0.19	2
5/1/17	0.92										
5/5/17	0.63	7.87	4.32	0.79	3.00	656					
5/10/17							1.19	15.71	0.32	0.14	**1**
5/24/17							2.10	15.56	0.68	0.24	30
5/25/17	1.24	5.25	2.08	1.50	2.87	172					
6/7/17							0.80	16.79	0.20	0.09	11
6/19/17	0.77										
6/20/17							0.99	17.67	0.12	0.09	15
7/5/17							1.04	14.69	0.39	0.09	**1**
7/17/17	1.48	9.64	4.27	0.74	2.31	1284					
7/18/17							2.69	15.29	0.41	0.43	27
8/1/17							1.77	15.25	0.64	0.15	14
8/8/17	0.87										
8/15/17							1.82	14.72	0.53	0.18	9
8/30/17							1.33	14.73	0.37	0.11	3
9/1/17	1.06	7.50	6.58	1.19	1.95	908					
9/13/17							2.33	14.82	0.49	0.21	22
9/26/17							1.74	15.15	0.28	0.16	45
10/11/17							2.64	13.08	0.35	0.26	30
10/23/17	1.13	5.18	7.78	0.98	1.77	537					
10/26/17							1.52	16.78	0.20	0.20	18
7/13/21							0.31	8.92	0.21	0.28	14
7/19/21	1.63										
7/27/21							2.05	10.12	0.28	0.37	25
8/7/21	1.57	1.05	1.72	0.15	0.33	394					
8/10/21							0.32	1.67	0.12	**0.03**	39
8/18/21	0.64	18.20	6.42	0.59	**0.03**	253					
8/24/21							**0.10**	7.64	0.16	0.12	6
9/1/21	0.83	1.51	4.81	0.21	0.11						
9/7/21							**0.19**	14.07	0.17	0.08	4
9/8/21	0.46										
9/9/21	0.25										
9/21/21							0.92	13.80	0.14	0.16	35
9/22/21	2.86	2.88	14.00	0.19	1.92	306					
10/5/21							0.21	11.60	**0.05**	0.12	8
10/9/21	1.32	0.60	4.85	**0.05**	0.18	45					
10/19/21							0.31	11.90	**0.05**	0.08	9
11/2/21							0.78	15.90	0.10	0.10	8
11/16/21							0.42	5.07	**0.05**	0.08	9
11/22/21	0.34										
11/30/21							0.66	9.78	0.12	0.15	7
12/14/21								10.54			31

12/19/21	0.61										
1/2/22	2.28	2.14	4.57	0.17	2.06	520					
1/4/22							0.34	16.60	**0.05**	0.39	34
1/9/22	0.57										
1/17/22	0.57										
1/18/22							2.43	11.90	0.18	0.32	102
2/1/22							4.94	9.65	0.91	0.91	19
2/7/22	0.33										
2/15/22							5.04	11.10	0.55	0.33	na
3/1/22							1.67	15.60	0.27	0.48	85
3/12/22	1.16	3.77	2.90	0.25	1.48	228					
3/15/22							5.29	5.98	0.33	0.08	22
3/16/22	2.04	2.44	0.18	0.31	1.32	263					
3/29/22							8.53	4.68	1.54	0.54	28
3/31/22	0.76										
4/12/22							1.07	9.41	0.32	0.25	18
4/18/22	1.74	1.51	6.40	0.32	0.25	52					
4/26/22							0.26	10.70	0.24	0.26	17
5/7/22	0.53										
5/10/22							1.06	15.65	0.28	0.20	11
5/23/22	0.68										
5/24/22							0.36	14.30	0.18	0.06	2
5/27/22	0.80										
6/8/22							2.45	12.70	0.34	0.57	16
6/8/22	0.94										
6/21/22							0.97	8.28	1.12	0.09	15
6/29/22	0.73										
7/5/22							1.19	10.80	0.19	0.18	8
7/10/22	0.65										
7/19/22							2.51	12.30	0.18	0.09	37
8/2/22							1.27	13.90	**0.05**	0.32	21
8/6/22	1.00										
8/16/22							1.79	12.80	0.13	0.08	31
8/30/22							1.36	16.20	0.20	0.19	26
9/10/22	0.52										
9/13/22							2.48	11.10	**0.05**	0.28	86
9/27/22							0.95	11.90	0.17	0.21	na
9/30/22	3.08										
10/11/22							0.85	17.30	0.21	0.23	84
10/25/22							**0.10**	13.30	**0.05**	0.15	44
11/8/22							**0.10**	15.20	**0.05**	0.12	20
11/11/22	1.23										
11/15/22	0.45										
11/22/22							2.76	12.60	0.14	0.73	47
11/25/22	1.13	2.13	5.46	0.13	0.91	65					
11/27/22	0.78										
11/30/22	0.61										
12/6/22							2.02	12.40	0.32	3.32	69

12/15/22	1.22	1.57	5.97	0.28	1.05	59					
12/20/22							0.90	13.60	0.10	0.20	nes
12/22/22	1.04	2.80	5.16	0.60	1.33	258					
1/4/23							2.93	7.55	0.16	0.42	92
1/4/23	0.27	0.90	5.02	**0.05**	0.73	90					
1/12/23	0.47										
1/18/23							3.19	9.05	**0.05**	0.18	53
1/22/23	0.78	2.42	2.50	0.79	5.76	1280					
1/25/23	0.82										
1/31/23							4.89	7.50	0.16	0.57	77
2/12/23	1.62	5.87	3.34	1.26	2.60	260					
2/14/23							1.16	6.09	0.34	1.31	204
2/28/23							1.54	8.06	1.54	1.49	86
3/2/23	0.47										
3/14/23							7.34	11.20	0.49	1.55	
3/27/23	0.72	13.30	3.92	3.41	2.86	1240					
3/28/23											
4/7/23	3.44	2.08	3.44	0.28	0.90	190					
4/8/23	1.48										
4/11/23							2.08	7.35	0.20	0.41	
4/22/23	1.14	2.24	3.82	0.23	0.79	86					
4/25/23							0.99	7.58	0.31	0.40	193
4.28/23	1.24										
4/30/23	1.20	3.51	3.25	0.73	1.30	142					
5/9/23							13.90	16.90	0.40	1.42	
5/16/23	0.50										
5/23/23											
5/28/23	1.02	7.63	9.29	0.31	2.05						
6/6/23							3.00	7.68	0.34	2.31	
6/19/23	0.75										
6/20/23							0.10	12.90	0.20	0.33	
6/22/23	1.50	1.10	3.76	2.29	1.23	158					
6/23/23	0.40										
6/24/23	1.58										
6/26/23	1.58										
7/1/23	1.34										
7/3/23							0.40	7.15	0.14	0.15	14
7/8/23	2.06	1.53	1.13	0.34	1.13	139					
7/9/23	0.99										
7/18/23							3.33	15.10	0.14	1.34	94
8/1/23							1.46	14.00	0.58	1.41	199
8/10/23	0.80	**0.10**	3.96	0.22	0.38						
8/15/23											
11/21/23							**0.10**	8.55	**0.05**	0.55	
11/22/23	1.64										
12/5/23							1.32	5.98	**0.05**	0.30	38
12/10/23	2.16	2.15	1.50	0.28	0.30	157					
12/17/23	2.63										

12/19/23							2.03	14.09	0.89	0.46	34
12/26/23	1.72	1.98	8.09	0.24	1.11	35					
1/6/24	0.91										
1/9/24	1.29										
1/12/24	1.32										
1/16/24							0.77	22.10	0.45	0.06	8
1/25/24	0.52										
1/27/24	1.49	3.84	4.12	0.50	3.08	272					
1/30/24							0.33	7.91	**0.05**	0.20	6
2/12/24	0.52	4.63	1.96	0.33	0.16	193					
2/13/24							0.99	11.00	0.15	0.79	21
2/27/24							5.19	20.80	0.48	0.51	77
3/2/24	1.30	4.96	6.38	0.83	1.38	77					
3/9/24	0.76										
3/12/24							4.73	16.00	0.15	0.26	47
3/22/24	0.80	16.90	6.08	0.15	0.26						
3/26/24							1.74	10.80	**0.05**	1.44	16
3/27/24	1.86	8.00	2.37	**0.05**	1.72	271					
4/9/24							1.96	14.10	0.11	1.07	17
4/11/24	0.4	2.59	13.30	0.13	0.16	19					
4/23/24							1.95	18.00	**0.05**	0.95	37
5/5/24	2.38	2.30	5.54	0.12	1.85	93					
5/6/24	0.43										
5/7/24							5.29	10.30	**0.05**	**0.03**	27
5/14/24	1.12	3.86	7.10	**0.05**	0.07	33					
5/18/24	0.71										
5/21/24							1.56	18.00	0.76	1.01	70
5/26/24	0.75										
6/4/24							2.52	24.10	1.38	1.26	12
6/18/24							2.16	13.10	**0.05**	0.63	43
7/2/24							1.61	19.00	**0.05**	1.00	45
7/7/24	0.86										
7/12/24	1.84	1.69	9.39	0.36	0.43	360					
7/16/24							0.97	11.10	**0.05**	0.48	15
7/18/24	0.63										
7/19/24	0.90										
7/20/24	0.54										
7/21/24	1.05										
7/25/24	0.83	2.48	2.65	0.20	1.16	220					
7/29/24	2.01										
7/30/24							1.11	17.70	**0.05**	0.31	13
8/8/24	3.74	1.86	5.04	0.20	1.70	48					
8/14/24							0.55		0.17	**0.03**	9
8/27/24							0.98		**0.05**	0.12	11
9/1/24	1.66										
9/11/24							0.81	13.80	0.11	0.09	8
9/16/24	2.22	1.46	10.50	0.14	1.08	5					
9/24/24							9.46	9.11	0.14	0.58	146

9/24/24	0.80										
9/27/24	1.10	3.33	6.27	0.29	1.39	67					
9/30/24	0.44										
10/8/24							2.97	1.70	**0.05**	0.66	44
10/22/24							4.98	11.30	0.12	**0.03**	80
11/5/24							0.93	21.20	**0.05**	1.91	7
11/14/24	1.02										
11/19/24							2.00	18.00	0.12	0.23	26
12/3/24								13.30	**0.05**	0.32	28
12/11/24	1.39	2.44	6.16	**0.05**	0.30	113					
12/17/24							4.51	24.10	**0.05**	0.29	37
12/28/24	0.63										
1/7/25											
1/11/25	0.30										
1/21/25							7.26	13.10	0.30	0.14	61
1/31/25	0.69					517					
2/4/25							2.38	7.86	**0.05**	0.26	43
2/12/25	2.63										
2/18/25											
3/4/25											

Note: Numbers in bold are half of the reportable limit, brown shade indicates date of retrieval.

Table A3. Rainfall and Sample Concentrations for WET.

Date	Rain	******** Storm Samples ********					******* Nonstorm Samples *******				
	Rain	TKN	NOx	NH3	TP	TSS	TKN	NOx	NH3	TP	TSS
	in	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
9/29/21							0.98	7.49	**0.05**	0.08	26
10/5/21							**0.10**	7.82	**0.05**	0.06	11
10/9/21	1.32	**0.10**	8.83	**0.05**	0.08	6.3					
10/19/21							0.43	11.10	0.24	0.06	**0.5**
10/25/21	0.27										
10/28/21	0.40	0.86	9.94	0.23	0.15	4.6					
11/2/21							0.25	13.8	**0.05**	0.123	5
11/16/21							2.74	5.71	0.59	0.08	132
11/22/21	0.34	2.37	4.83	0.25	0.17	82.4					
11/30/21							0.44	10.50	0.13	0.27	16.7
12/14/21							1.40	10.30	0.48	0.25	7.1
12/19/21	0.62										
1/2/22	2.35	1.42	4.98	0.11	1.22	220					
1/4/22							0.88	12.50	0.14	0.43	4.4
1/9/22	0.57	0.77	11.60	0.10	0.18	11.6					
1/17/22	0.57										
1/18/22							0.06	9.09	**0.05**	0.10	6.0
2/1/22							**0.10**	10.60	0.29	0.52	17.0
2/7/22	0.55										
2/15/22							2.21	9.09	0.71	0.44	16.5
3/1/22							1.05	10.40	**0.05**	0.13	12.9
3/12/22	1.16	0.14	7.35	0.22	0.43	72.2					
3/15/22											
3/16/22	2.04	2.86	3.56	0.29	0.80	389					
3/29/22							2.15	7.44	0.32	0.21	30.6
3/31/22	0.76	2.77	6.02	0.54	0.23	57.7					
4/12/22							0.33	6.03	0.12	0.27	45.7
4/18/22	1.74	0.43	6.27	**0.05**	0.43	20.8					
4/26/22							1.41	8.91	0.17	0.14	35
5/7/22	0.53	1.04	7.49	0.20	0.09	54.2					
5/10/22							1.94	9.75	0.20	0.33	46.5
5/23/22	0.68										
5/24/22							1.92	8.95	0.18	0.05	40.6
5/27/22	0.80										
6/8/22							2.89	3.74	0.33	**0.03**	34.7
6/8/22	0.94										
6/21/22							2.56	3.65	0.53	**0.03**	48.9
6/29/22	0.73	1.65	4.42	0.31	**0.03**						
7/5/22							3.02	2.06	0.41	0.13	
7/10/22	0.65										
7/19/22							2.18	0.61	0.74	0.12	
8/2/22							1.34	1.64	0.16	0.70	69.4
8/6/22	1.00	1.45	5.85	0.11	0.33						

8/16/22							1.41	2.00	0.17	0.06	75.0
8/30/22							3.39	2.34	0.28	**0.03**	97.6
9/10/22	0.52										
9/13/22							4.60	0.36	0.11	0.98	77.5
9/27/22							1.17	2.83	0.12	0.16	69.4
9/30/22	3.08	3.67	3.52	**0.05**	0.37	19.5					
10/11/22							**0.10**	10.60	0.14	0.40	37.5
10/25/22							0.74	5.30	**0.05**	0.23	20.0
11/8/22							0.71	5.28	0.13	0.06	66.7
11/11/22	1.23	1.26	5.36	**0.05**	0.17	12.5					
11/15/22	0.45										
11/22/22							0.85	7.36	0.22	0.28	18.9
11/25/22	1.13	1.38	5.85	0.19	0.12	8.2					
11/27/22	0.78										
11/30/22	0.61										
12/6/22							1.19	7.73	0.31	0.20	14.8
12/15/22	1.22	3.33	6.81	0.25	0.30	15.9					
12/20/22							1.76	9.86	**0.05**	0.41	20.3
12/22/22	1.04	2.07	5.99	0.22	0.59	28.9					
1/4/23											
1/4/23	0.27	0.42	5.04	**0.05**	0.11						
1/12/23	0.47										
1/18/23							0.46	5.91	0.20	0.09	25.0
1/22/23	0.78	1.04	3.84	0.21	0.60	180					
1/25/23	0.82										
1/31/23							**0.10**	7.06	0.36	0.35	9.5
2/12/23	1.62	1.77	2.61	0.40	1.10	300					
2/14/23							6.27	0.24	0.40	0.17	26.1
2/28/23							0.33	4.98	0.12	0.12	13.0
3/2/23	0.47	1.44	5.20	0.44	0.22	17.9					
3/14/23							1.72	6.09	0.21	0.65	22.2
3/27/23	0.72	3.67	2.91	1.89	1.77	714					
3/28/23							2.24	4.27	0.30	1.14	142
4/7/23	3.44	2.73	0.46	0.34	0.99	260					
4/8/23	1.48										
4/11/23							2.98	4.39	0.39	0.28	145
4/22/23	1.14	2.31	2.11	0.30	0.44	112					
4/25/23							1.71	4.31	0.69	1.30	53.6
4.28/23	1.24										
4/30/23	1.20	1.07	3.30	0.58	1.14	80.8					
5/9/23							4.43	9.10	0.42	0.94	86.0
5/16/23	0.87	2.00	4.66	0.49	4.05	145					
5/23/23							3.38	7.49	0.25	0.55	78.7
5/28/23	1.02	0.24	5.99	0.26	0.33	42.6					
6/6/23							2.78	2.61	0.29	0.58	181.8
6/19/23	0.75	1.72	3.01	0.33	0.50	98.8					
6/20/23											
6/22/23	1.50	**0.10**	2.51	0.42	0.88	148					

6/23/23	0.40										
6/24/23	1.58										
6/26/23	1.58										
7/1/23	1.34										
7/3/23							0.93	3.06	0.32	0.27	170.0
7/8/23	2.06	0.18	1.50	0.30	0.59	121					
7/9/23	0.99										
7/18/23							2.31	7.66	0.32	1.94	159.1
8/1/23							3.32	4.45	1.85	0.95	609.4
8/10/23	0.80										
8/15/23											
4/23/24							4.66	9.35	1.12	1.02	255
5/5/24	2.38										
5/6/24	0.43										
5/7/24							4.76	4.59	0.73	0.22	114
5/14/24	1.12	7.08	4.81	0.93	0.43	117					
5/18/24	0.71										
5/21/24							7.26	9.09	0.91	1.76	650
5/26/24	0.75	6.62	12.00	1.34	1.23	263					
6/4/24							7.33	9.88	0.79	6.16	1240
6/18/24							8.00	6.50	0.51	2.60	503
7/2/24							19.90	6.50	0.63	1.85	817
7/7/24	0.86										
7/12/24	1.84	8.03	6.18	0.35	2.10						
7/16/24							4.67	2.53	0.34	0.84	740.0
7/18/24	0.63										
7/19/24	0.90										
7/20/24	0.54										
7/21/24	1.05	8.10	2.92	0.16	0.50	160.0					
7/25/24	0.83										
7/29/24	2.01										
7/30/24							0.97	8.03	0.25	1.48	81.3
8/8/24	3.74										
8/14/24							2.94	10.10	0.24	0.84	72.2
8/27/24							4.88		0.20	2.42	117.2
9/1/24	1.66	2.08		**0.05**	2.42	73.7					
9/11/24							3.45	8.39	0.13	0.41	128.1
9/16/24	2.22	2.22	6.38	0.16	0.12	57.1					
9/24/24							3.20	5.15	0.16	0.31	94.2
9/24/24	0.80										
9/27/24	1.10										
9/30/24	0.44										
10/8/24							3.50	13.00	**0.05**	0.18	207.1
10/22/24							7.35	5.41	0.14	0.13	795.2
11/5/24							16.80	9.46	0.41	3.20	700.0
11/14/24	1.02	1.52	11.50	0.12	2.29	520					
11/19/24							13.10	12.30	0.84	0.72	540.0

12/3/24							1.20	8.76	0.24	0.18	200.0
12/11/24	1.39	4.57	5.81	**0.05**	0.05	103					
12/17/24							8.82	16.90	**0.05**	2.40	186.7
12/28/24	0.63										
1/7/25							11.70	10.40	0.39	2.17	276.5
1/11/25	0.30										
1/21/25							9.46	7.08	**0.05**	0.10	276.9
1/31/25	0.69										
2/4/25							7.05	17.60	0.21	1.80	232.7
2/12/25	2.63										
2/18/25							2.39	19.10	0.49	1.11	212.5
3/4/25											

Note: Numbers in bold are half of the reportable limit, brown shade indicates date of retrieval.

Table A4. UTA Groundwater Sample Concentrations.

	UTG1: Streambank Well Samples					** UTG2: Upland Well Samples **				
Date	TKN mg/L	NOx mg/L	NH3 mg/L	TP mg/L	OP mg/L	TKN mg/L	NOx mg/L	NH3 mg/L	TP mg/L	OP mg/L
11/20/14	10.41	12.21	0.15	13.36	0.014	na	na	na	na	
12/18/14	0.96	8.37	0.09	0.46	na	na	na	na	na	
1/20/15	0.77	8.86	0.14	0.38	na	0.60	1.48	0.08	0.69	
2/23/15	2.59	2.13	0.20	0.66	0.050	na	1.26	0.15	1.71	
3/23/15	2.00	5.83	0.23	1.13	0.027	0.47	1.21	0.21	0.57	0.01
4/22/15	0.58	10.51	0.05	0.23	na	0.26	0.75	0.07	0.14	na
5/21/15	0.92	7.58	0.11	0.21	0.027	0.61	0.76	0.16	1.04	na
11/18/15	0.35	11.57	0.04	0.18	na	4.26	0.12	0.42	0.77	
1/21/16	1.36	10.45	0.08	0.95	na	1.30	0.10	0.20	1.60	
2/25/16	2.06	6.54	0.08	1.15	na	0.60	0.08	0.22	0.49	
3/24/16	0.47	9.56	0.09	0.30	na	na	na	na	na	
4/21/16	0.59	10.75	0.08	0.27	na	na	0.07	0.16	0.80	
5/18/16	1.50	9.11	0.13	1.00	na	na	na	na	na	
7/13/16	2.89	6.76	0.53	2.64	na	na	na	na	na	
9/7/16	1.86	8.86	0.07	0.82	0.029	na	na	na	na	
10/6/16	1.05	5.99	0.03	0.26	0.046	na	na	na	na	
11/29/16	1.76	11.74	0.12	0.55	0.023	na	na	na	na	
1/4/17	1.87	9.64	0.06	0.95	0.027	0.86	0.83	0.14	0.19	
1/31/17	0.28	13.26	0.04	0.06	na	0.58	0.21	0.10	0.23	
3/28/17	0.81	10.88	0.05	0.40	0.024	na	na	na	na	
5/24/17	1.16	5.53	0.05	0.25	0.040	na	na	na	na	
8/15/17	1.52	12.89	0.12	0.26	na	na	na	na	na	
10/11/17	3.20	13.57	0.27	0.99	na	na	na	na	na	
8/24/21	**0.10**	13.20	**0.05**	0.79	na	4.29	1.50	**0.05**	0.42	
10/19/21	**0.10**	15.30	**0.05**	0.08	na	4.03	6.58	0.12	0.23	
12/14/21	3.05	17.50	**0.05**	0.21	na	3.24	5.81	**0.05**	0.51	
2/15/22	**0.10**	17.90	**0.05**	0.18	0.010	**0.10**	17.50	**0.05**	0.62	
4/12/22	0.77	7.34	0.39	0.12	0.037	2.24	19.10	0.30	0.15	
6/21/22	0.78	17.30	**0.05**	**0.03**	0.019	4.25	3.59	0.33	**0.03**	
8/16/22	0.62	23.00	**0.05**	0.30	0.059	na	na	na	na	
10/25/22	0.47	22.80	0.22	0.26	0.200	na	na	na	na	
12/20/22	1.23	10.60	0.14	0.34	na	1.89	0.30	0.17	0.28	
2/14/23	**0.10**	7.86	**0.05**	0.48	0.010	0.72	1.55	**0.05**	0.96	
5/9/23	**0.62**	14.90	**0.05**	0.15	0.012	na	na	na	na	
6/20/23	**0.10**	15.40	**0.05**	0.40	0.102	2.76	1.31	nes	nes	
4/23/24	20.60	**0.50**	8.73	0.23	na	0.74	14.70	**0.05**	0.36	
6/18/24	na	3.12	23.40	0.26	na	**0.10**	30.00	**0.05**	0.27	
8/14/24	51.50	2.81	20.90	0.63	na	0.45	33.10	**0.05**	0.06	
10/22/24	39.50	2.15	30.20	0.24	na	0.49	20.10	**0.05**	**0.03**	
2/4/25	34.60	9.10	28.80	0.11	na	0.39	14.50	**0.05**	0.12	

Note: Numbers in bold are half of the reportable limit.

Table A5. NT Groundwater Sample Concentrations.

Date	*** NGR1: Streambank Well ***					***** NGR2: Upland Well *****				
	TKN mg/L	NOx mg/L	NH3 mg/L	TP mg/L	OP mg/L	TKN mg/L	NOx mg/L	NH3 mg/L	TP mg/L	OP mg/L
11/20/14	0.70	5.28	0.16	0.72	0.004	0.31	7.84	0.12	0.23	0.004
12/18/14	**0.15**	7.50	0.05	0.12	na	0.16	12.50	0.03	0.06	na
1/20/15	**0.14**	9.14	0.03	0.14	na	**0.14**	11.64	0.05	0.13	na
2/23/15	0.33	15.06	0.05	0.09	**0.004**	0.20	8.42	0.07	0.07	0.005
3/23/15	0.23	19.53	0.03	0.15	0.005	0.33	6.95	0.02	0.09	0.008
4/22/15	0.22	18.72	0.05	0.04	na	0.41	4.50	0.10	0.48	na
5/21/15	0.25	10.92	0.03	0.08	0.008	0.30	5.65	0.02	0.08	na
11/18/15	0.23	9.97	0.05	0.08	na	0.21	5.98	0.04	0.02	na
1/21/16	0.29	14.19	0.05	0.17	na	0.63	3.69	0.10	0.33	na
2/25/16	0.15	16.33	0.02	0.04	na	0.34	4.74	0.02	0.11	na
3/24/16	0.23	11.86	0.03	0.03	na	0.16	4.49	0.02	0.04	na
4/21/16	0.45	8.82	0.04	0.08	na	0.15	4.61	0.02	0.02	na
5/18/16	0.07	6.73	0.02	0.01	na	0.21	4.36	0.02	0.02	na
7/13/16	0.42	7.07	0.05	0.06	na	0.26	4.51	0.03	0.04	na
9/7/16	0.40	8.45	0.03	0.04	0.013	na	6.41	0.04	0.05	na
10/6/16	0.21	8.77	0.02	0.04	0.009	0.41	5.78	0.09	0.06	na
11/29/16	0.31	7.08	0.07	0.05	0.014	0.25	3.95	0.06	0.04	na
1/4/17	0.19	7.10	0.02	0.02	0.007	0.28	4.14	0.03	0.06	na
1/31/17	0.20	7.86	0.02	0.02	0.009	0.31	4.54	0.04	0.05	na
3/28/17	0.34	7.75	0.02	0.02	0.007	0.28	5.15	0.02	0.03	na
5/24/17	0.19	7.18	0.03	0.02	0.015	0.26	5.34	0.03	0.03	na
8/15/17	0.58	8.43	0.06	0.07	0.027	0.61	6.00	0.05	0.10	na
10/11/17	0.53	8.52	0.04	0.04	na	0.75	6.71	0.07	0.10	na
8/24/21	na	5.91	**0.05**	na	0.012	0.43	7.71	**0.05**	0.77	na
10/19/21	0.20	8.16	0.12	0.05	0.011	**0.10**	8.92	**0.05**	0.09	na
12/14/21	1.16	4.81	0.18	0.49	0.007	0.50	10.30	**0.05**	0.09	na
2/15/22	0.91	7.04	0.13	0.53	0.003	0.42	4.77	**0.05**	0.19	na
4/12/22	0.63	4.39	0.44	0.12	0.009	0.75	3.36	0.34	0.15	na
6/21/22	0.82	20.90	0.16	**0.03**	0.017	na	3.74	na	0.59	na
8/16/22	0.16	25.00	**0.05**	1.05	0.027	0.13	23.40	**0.05**	0.65	na
10/25/22	**0.05**	19.00	0.15	0.09	0.007	**0.05**	10.60	0.14	0.40	na
12/20/22	**0.05**	10.90	0.16	0.06	0.025	**0.05**	15.90	0.14	**0.03**	na
2/14/23	**0.05**	5.67	**0.05**	0.94	0.004	**0.05**	9.18	**0.05**	0.20	na
5/9/23	**0.05**	8.52	**0.05**	0.55	0.005	0.15	13.40	**0.05**	0.16	na
6/20/23	**0.10**	13.50	0.17	0.73	0.688	**0.10**	13.10	**0.10**	0.51	na
4/23/24	7.24	11.10	0.21	0.88	na	3.57	23.80	0.25	0.94	na
6/18/24	0.40	28.70	**0.05**	0.43	0.035	0.37	32.80	**0.05**	0.16	na
8/14/24	0.48	36.70	**0.05**	0.94	0.013	0.50	35.60	**0.05**	0.17	na
10/22/24	1.28	23.20	**0.05**	0.06	na	0.32	20.50	**0.05**	0.19	na
2/4/25	0.57	13.70	**0.05**	**0.03**	na	1.02	11.80	**0.05**	0.31	na

Note: Numbers in bold are half of the reportable limit.

Table A6. Rainfall, Discharge, and Sample Concentrations for Mill-dn.

Date	Rainfall in	Discharge gal	TKN	NOx-N	NH_3-N	TP	TSS
			---------- mg/L ----------				
12/17/15	1.20	29,499,000					
12/22/15	3.04	219,442,000					
12/29/15	2.53	154,463,000					
1/7/16			1.60	1.32	0.13	0.60	158
1/16/16	0.46	8,997,000					
1/21/16			0.57	2.41	0.16	0.10	9
1/25/16	0.51	16,930,000					
2/3/16	1.05	42,622,000					
2/8/16			1.04	1.75	0.15	0.33	62
2/16/16	1.32	63,425,000					
2/23/16	0.93	41,690,000					
2/25/16			1.89	1.74	0.11	0.58	142
3/9/16			0.59	1.72	0.07	0.11	20
3/14/16	0.15	4,040,000					
3/24/16			0.65	1.41	0.04	0.06	8
3/27/16	1.17	45,500,000					
3/31/16	0.21	470,000					
4/5/16			1.22	1.10	0.04	0.29	71
4/21/16			0.71	1.52	0.03	0.08	14
5/3/16	1.52	9,965,000					
5/3/16			0.95	1.61	0.07	0.17	29
5/5/16	0.78	8,676,000					
5/12/16	0.69	6,360,000					
5/18/16			1.43	1.21	0.17	0.33	39
5/21/16	0.40	31,458,000					
5/31/16			2.14	1.08	0.30	0.74	139
6/15/16			1.92	1.72	0.12	0.31	57
6/15/16	1.33	6,010,000					
6/28/16			1.18	1.58	0.23	0.26	48
7/2/16	0.58	4,171,000					
7/13/16			2.22	1.45	0.31	0.70	120
7/26/16	0.57	1,507,000					
7/26/16			1.57	1.92	0.75	0.25	26
8/2/16	0.68	9,942,000					
8/8/16	0.28	18,483,000					
8/10/16			2.61	1.02	0.20	1.08	308
8/23/16			1.75	1.80	0.38	0.35	321
9/1/16	1.54	1,616,350					
9/7/16			na	na	na	na	na
9/19/16	2.16	24,308,000					
9/20/16			3.52	1.17	0.53	1.14	348
9/27/16	1.23	24,308,000					
9/29/16	0.81	28,988,000					
10/6/16			1.52	0.94	0.25	0.38	63

10/8/16	3.22	62,781,900					
10/18/16							
11/1/16			0.57	1.53	0.11	0.07	42
11/15/16			7.49	1.22	0.44	2.22	114
11/29/16			0.47	1.53	0.12	0.07	24
12/5/16	0.91	8796000					
12/13/16			1.06	0.98	0.26	0.21	14
1/2/17	1.18	22,526,000					
1/3/17	0.54	37,466,000					
1/4/17			4.93	1.54	0.29	1.21	149
1/19/17			1.40	1.84	0.19	0.35	50
1/23/17	0.70	38,560,000					
1/31/17							
2/14/17			0.47	2.00	0.12	0.05	3.6
2/28/17			0.93	1.68	0.25	0.09	9.7
3/1/17	0.75	11,194,000					
3/14/17			1.34	1.38	0.17	0.31	111
3/28/17			1.38	1.17	0.18	0.20	35
4/3/17	0.58	7,504,000					
4/6/17	0.76	22,044,000					
4/11/17			2.44	0.87	0.26	0.70	161
4/23/17	0.74	4,282,000					
4/24/17	2.56	114,659,000					
4/25/17			3.23	1.07	0.24	0.82	267
5/1/17	0.91	13,079,900					
5/5/17	0.64	8,804,400					
5/10/17			1.65	1.27	0.25	0.42	65
5/24/17			13.9	1.93	12.96	0.17	46
5/25/17	1.24	22,343,000					
6/7/17			17.9	1.69	14.55	0.91	211
6/19/17	0.77	20,541,102					
6/20/17			4.98	1.85	4.60	0.25	84
6/21/17	0.5	11,583,800					
7/5/17			5.94	1.33	4.40	0.16	1.5
7/17/17	1.56	10,486,600					
7/18/17			13.64	14.72	8.46	1.68	520
7/18/17	0.37	7,271,340					
8/1/17			12.92	2.06	7.83	2.36	1155
8/8/17	1.13	1,488,060					
8/15/17			3.53	1.42	2.75	0.32	44
8/30/17							
9/1/17	1.26	20,389,100					
9/13/17			6.01	0.95	2.10	1.23	493
9/26/17			3.95	1.36	1.70	0.86	64
10/11/17			5.91	1.49	3.77	0.19	27
10/23/17	1.08	7,427,120					
10/26/17			4.00	1.20	2.37	1.01	129

Table A7. Monthly Mean Rainfall and Air and Water Temperatures.

Month	Rain in	Air ºF	North ºF	NST1 ºF	NST2 ºF	NGR2 ºF	NGR1 ºF	UTG1 ºF	UTG2 ºF	UTA ºF
Aug-21	3.46	75.95	71.92	na	na	na	na	na	67.88	na
Sep-21	4.48	68.65	67.46	na	na	na	na	na	65.33	na
Oct-21	0.67	57.79	62.01	63.89	63.77	na	62.74	na	62.41	na
Nov-21	0.47	44.99	56.38	54.14	54.66	na	55.89	58.53	na	na
Dec-21	1.31	48.19	55.54	50.17	51.32	61.96	52.71	56.80	na	na
Jan-22	3.91	36.78	50.27	46.29	47.38	59.25	49.36	54.44	52.16	na
Feb-22	1.09	43.56	53.10	46.70	48.58	na	na	na	49.50	na
Mar-22	3.13	40.68	57.42	53.27	55.09	na	na	na	51.99	54.80
Apr-22	2.00	58.60	61.30	58.76	60.13	na	na	na	na	58.32
May-22	2.92	67.80	65.29	65.55	66.47	58.29	62.22	60.87	na	62.61
Jun-22	2.74	74.20	66.75	72.24	70.49	60.66	66.24	63.51	na	65.66
Jul-22	2.23	78.00	67.62	75.80	72.82	62.99	68.52	66.52	67.81	67.81
Aug-22	1.74	74.50	65.78	74.66	72.54	na	68.94	67.55	69.59	66.94
Sep-22	2.60	67.39	63.94	71.45	69.40	na	66.99	65.91	68.66	63.90
Oct-22	2.63	55.13	59.85	61.74	60.83	na	61.05	60.05	64.18	58.28
Nov-22	4.31	51.52	57.54	57.44	56.66	na	57.20	58.56	60.09	64.90
Dec-22	3.12	39.36	na	47.88	48.98	na	50.74	53.83	53.33	62.31
Jan-23	2.94	44.73	na	47.07	49.08	57.91	49.04	54.06	49.83	58.73
Feb-23	2.59	49.52	na	47.91	51.11	56.11	50.50	55.42	50.16	na
Mar-23	1.45	51.11	54.70	52.41	54.41	55.93	53.24	56.57	52.85	54.70
Apr-23	8.24	58.98	59.96	57.29	58.81	56.41	56.80	58.39	55.59	58.60
May-23	1.93	62.72	61.95	61.32	61.95	57.95	59.96	59.91	58.90	
Jun-23	6.39	68.94	64.19	64.71	64.31	59.55	62.52	na	na	na
Jul-23	5.46	76.18	68.56	70.46	69.93	61.59	66.29	na	na	na
Aug-23	4.39	74.67	66.90	70.68	70.48	63.65	67.54	na	na	na
Sep-23	2.20	67.37	64.70	68.04	68.06	64.78	66.69	na	na	na
Oct-23	1.94	56.96	60.96	60.71	60.95	64.62	61.47	na	na	na
Nov-23	1.95	45.62	57.12	53.79	54.74	62.80	55.48	na	na	na
Dec-23	2.09	42.69	53.60	49.69	51.03	60.09	51.03	na	na	na
Jan-24	5.99	40.00	51.51	46.16	48.10	56.88	50.03	na	na	na
Feb-24	1.65	44.53	53.35	47.97	44.53	55.09	51.05	na	na	na
Mar-24	5.10	53.59	56.81	53.57	54.50	54.86	54.13	na	na	na
Apr-24	1.33	61.22	60.63	57.46	58.42	56.15	57.22	na	na	na
May-24	6.11	69.30	63.14	62.68	62.94	58.15	60.75	71.32	62.05	66.91
Jun-24	0.60	75.24	64.37	65.88	65.54	60.28	63.08	76.10	66.79	69.32
Jul-24	9.35	77.89	66.85	73.65	73.09	62.20	65.93	78.57	71.59	71.22
Aug-24	4.93	73.61	66.96	69.94	69.95	64.38	66.41	75.16	72.61	70.36
Sep-24	6.48	69.58	65.73	67.45	67.40	65.09	65.52	71.44	71.29	67.15
Oct-24	0.05	58.31	61.69	62.11	61.90	64.95	62.35	64.50	68.36	60.54
Nov-24	1.59	51.38	58.82	57.47	57.05	63.43	58.67	58.65	63.30	55.03
Dec-24	2.72	40.83	53.78	49.30	49.20	60.79	52.85	51.17	56.32	48.60
Jan-25	1.47	32.75	49.53	44.25	44.77	57.85	49.13	47.00	51.07	42.32

Appendix B: Temperature and Water Elevation Data Graphs.

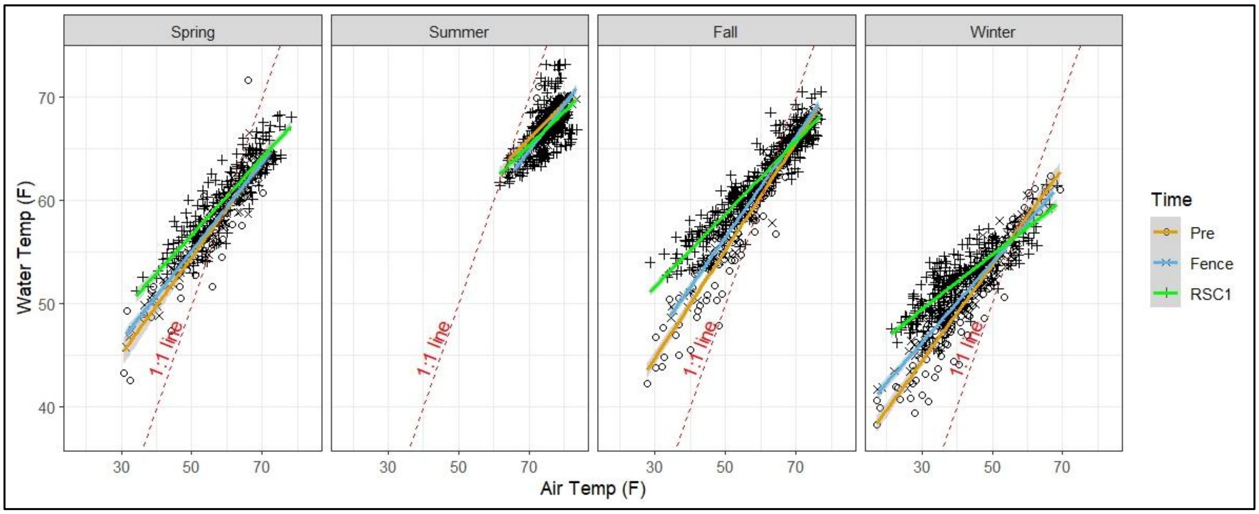

Figure B1. NT surface temperatures compared to air temperatures for the Pre, Fence and RSC1 periods.

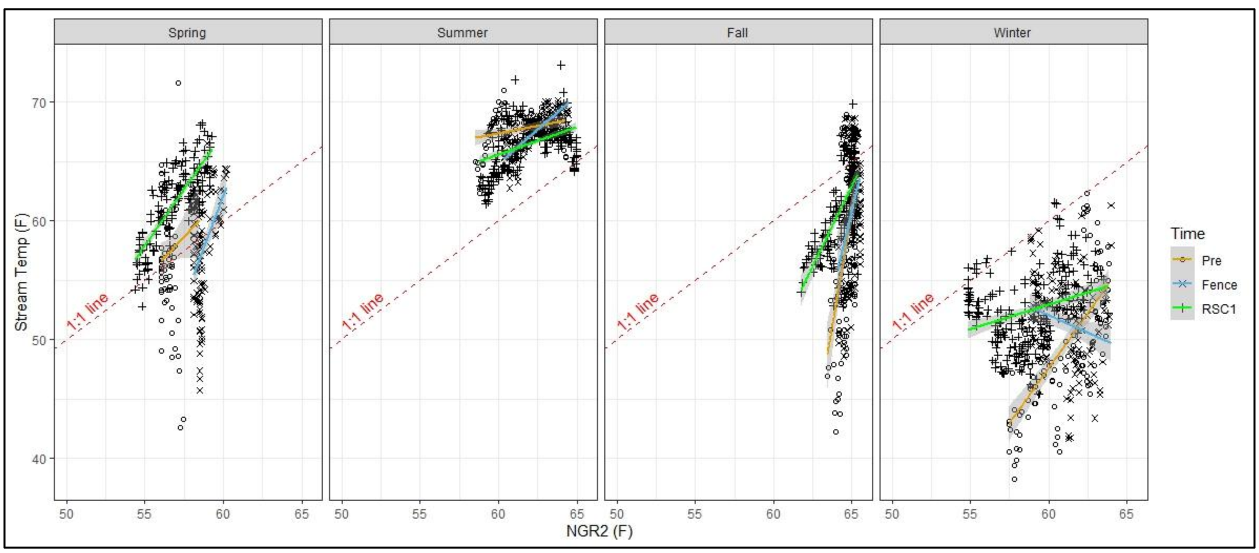

Figure B2. NT surface temperatures compared to groundwater temperatures (NGR2) for the Pre, Fence and RSC1 periods.

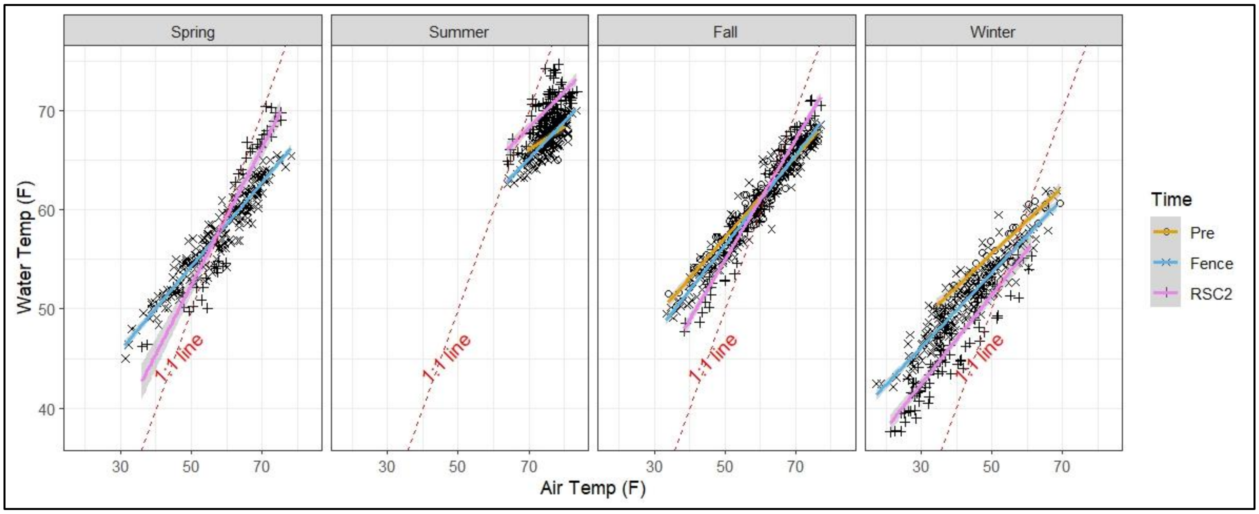

Figure B3. UTA stream temperatures compared to air temperatures for the Pre, Fence (includes the RSC1) and RSC2 periods.

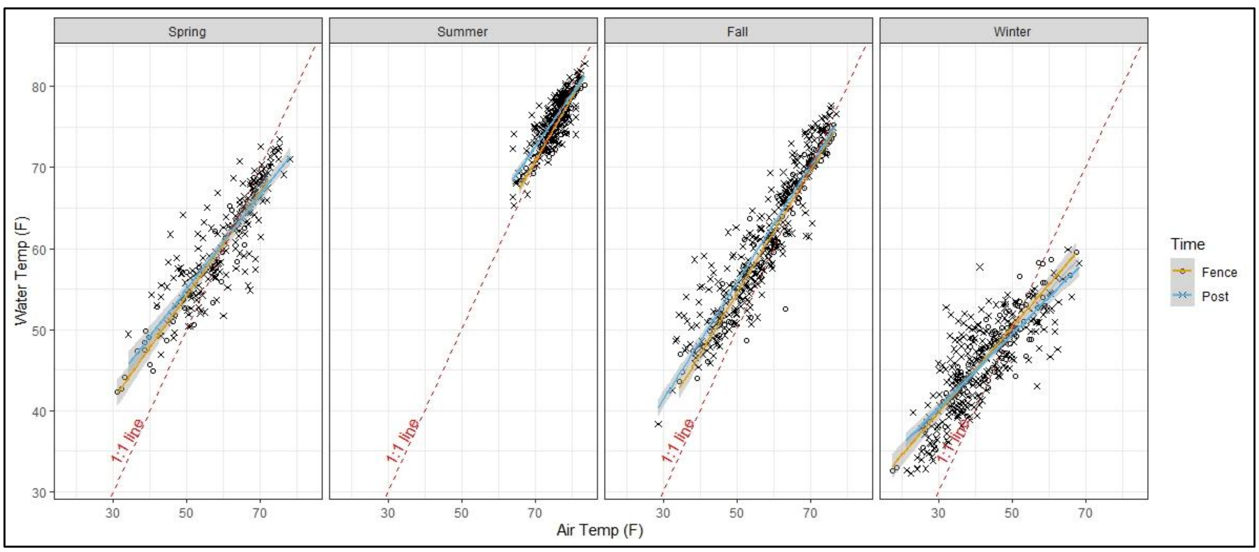

Figure B4. MC stream temperatures compared to air temperatures for the Fence and RSC1 and RSC2 (post-restoration) periods.

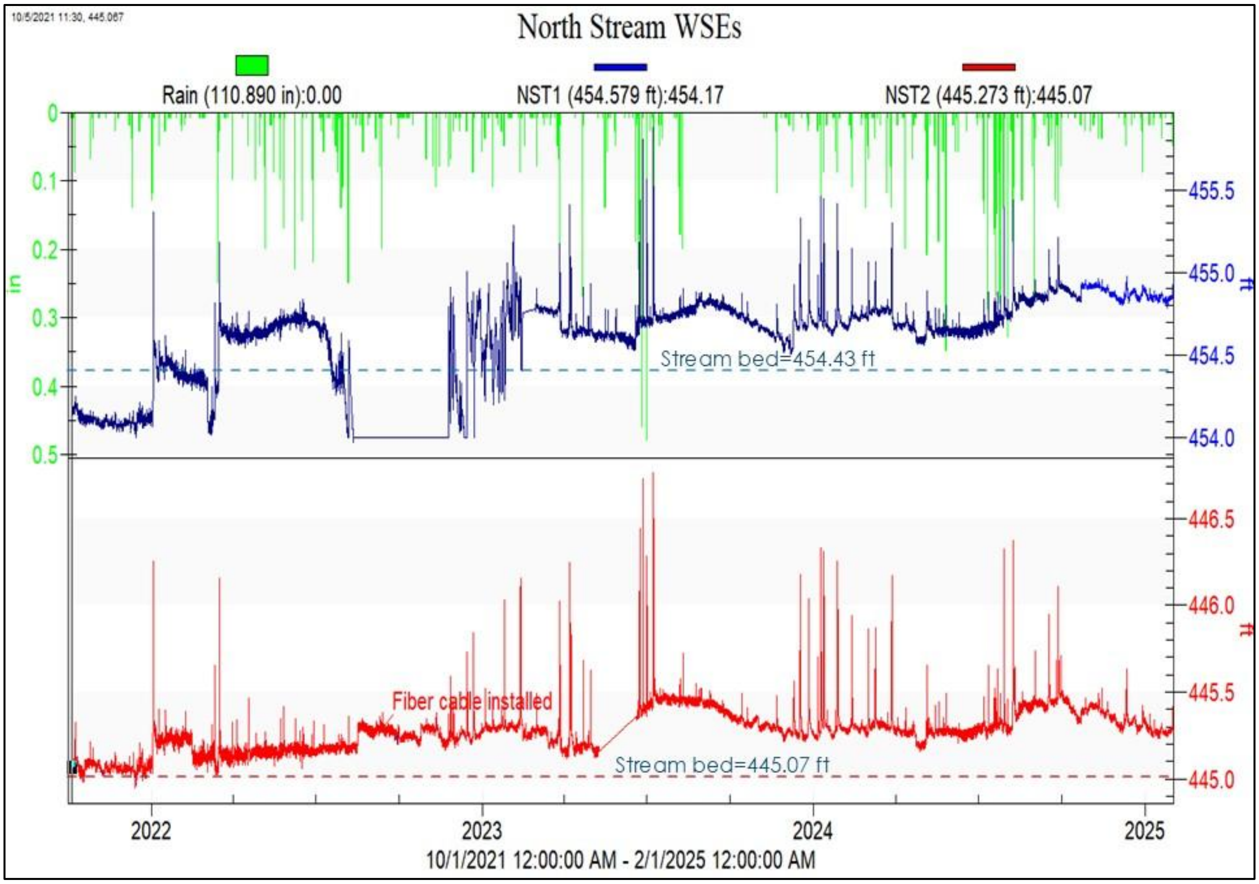

Figure B5. WSEs for NT stream gages.

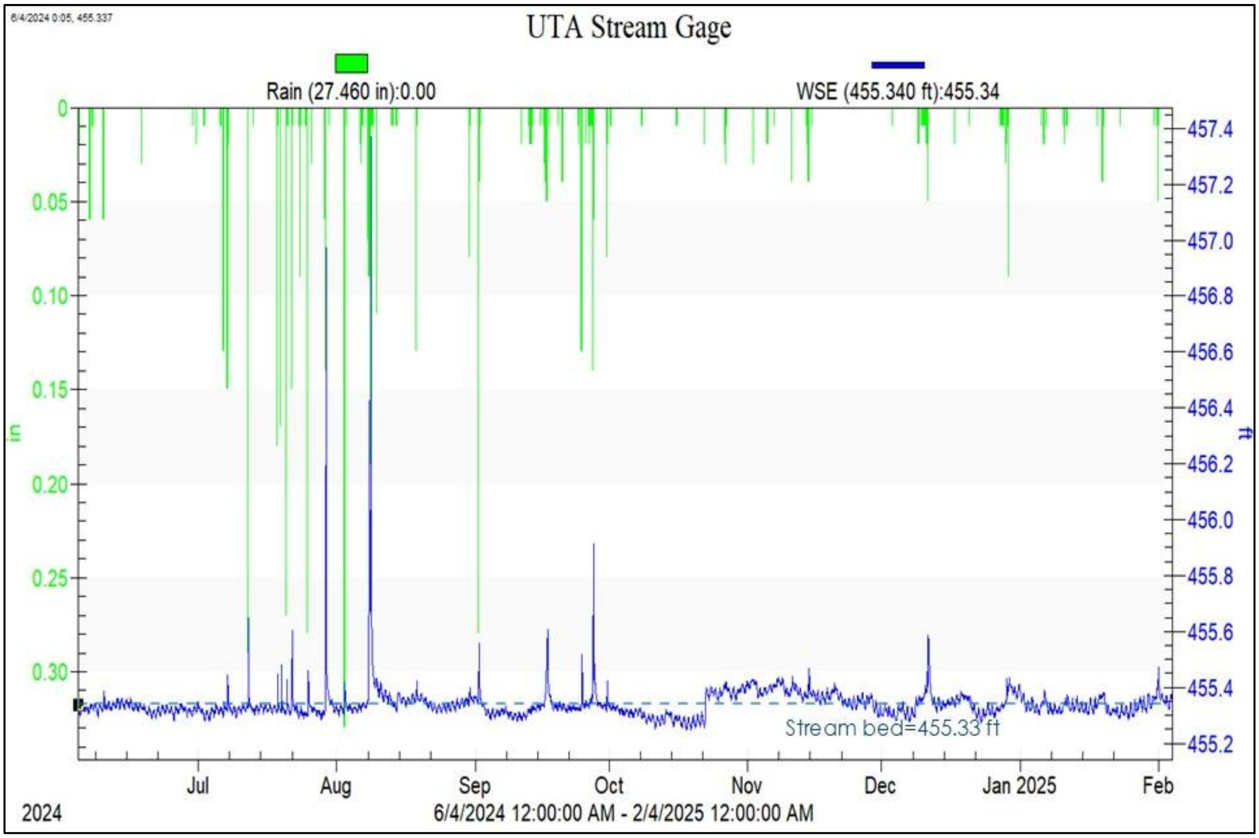

Figure B6. WSEs for UTA stream gage.

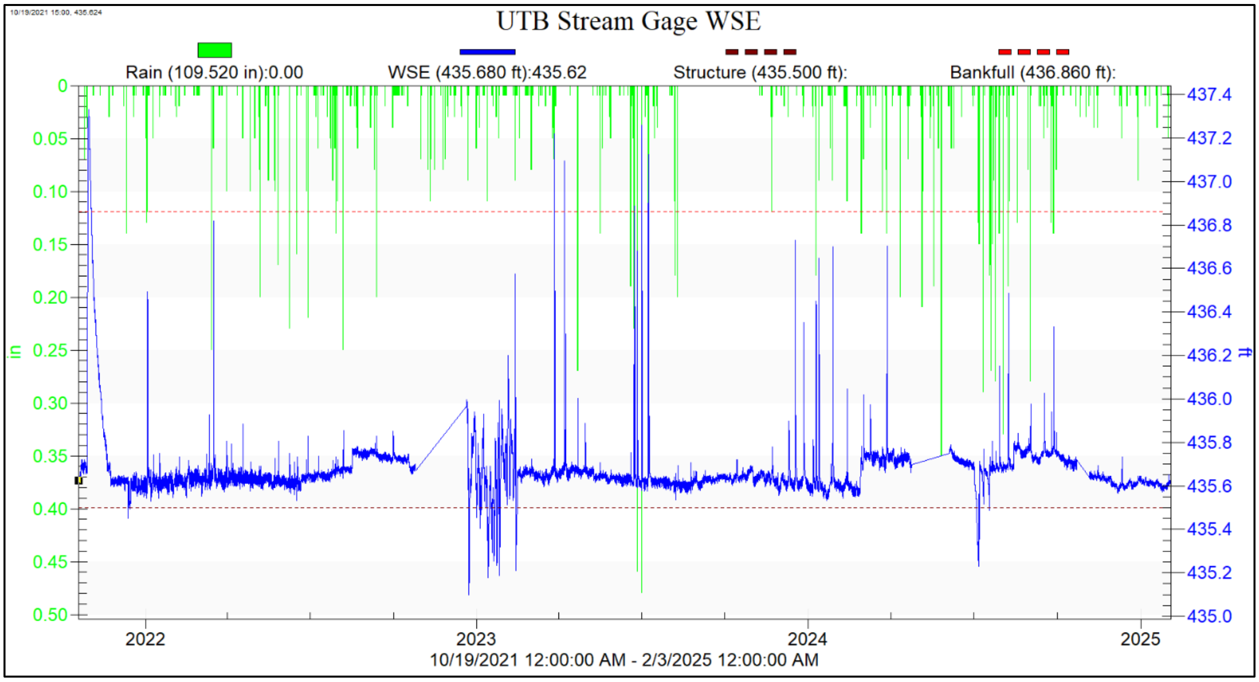

Figure B7. WSEs for UTB stream gage.

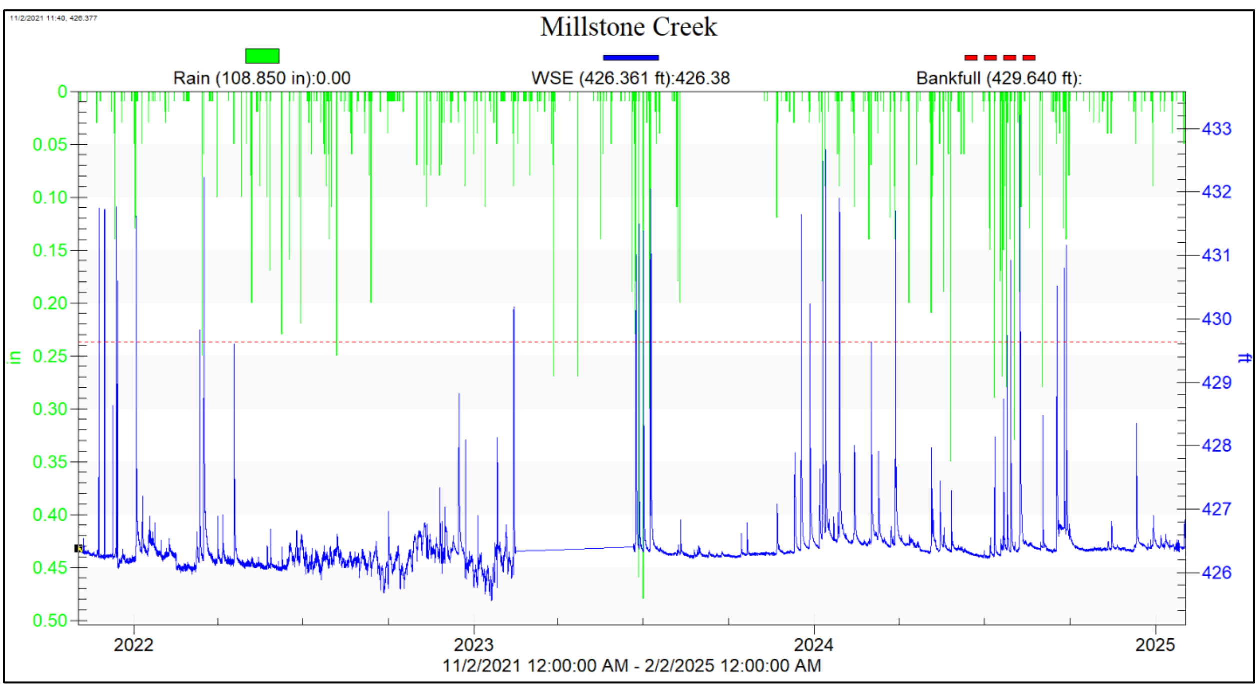

Figure B8. WSEs for Millstone Creek stream gage.

Appendix C: Quality Assurance Quality Control Data

Table C1. Quality Assurance/Quality Control Sample Results.

Date	Lab	Type	TKN	NH_3-N	NOx-N	TP
	CAAE	RL[1]	0.28	0.018	0.011	0.01
12/2/15	CAAE	Blank	<0.28	0.081	<0.011	<0.01
11/29/16	CAAE	Blank	<0.28	0.027	<0.011	<0.01
1/27/20	CAAE	Blank	<0.28	0.025	<0.011	<0.01
	Cameron	RL[1]	0.20	0.10	0.05	0.05
12/14/21	Cameron	Blank	0.31	<0.10	0.94	<0.050
4/26/22	Cameron	Blank	<0.20	<0.10	<0.05	0.069
5/21/24	Cameron	Blank	<0.20	<0.10	<1.00[2]	<0.050
1/27/20	Fisher Sci.	Standard	na	na	0.100	0.10
1/27/20	CAAE	Standard	na	na	0.111	0.10
6/4/24	Cameron	Duplicate	2.00	0.771	15.70	0.577
6/4/24	Cameron	Duplicate	2.14	0.820	12.90	0.450
Difference (%)			7%	6%	18%	21%

[1] Reportable limit.

[2] Reportable limit changed to 1.0 mg/L.

Appendix D: Livestock Exclusion Extension Publication

Livestock Exclusion NC STATE EXTENSION

Fencing: Lessons Learned

Reducing nitrogen and phosphorus levels in surface waters of North Carolina has become a priority, especially in watersheds that drain into nutrient impaired lakes, such as Jordan and Falls Lake. The agricultural community has renewed its efforts to implement best management practices (BMPs) that reduce nitrogen and phosphorus movement from agricultural land to water resources. One such BMP is livestock exclusion fencing.

Livestock exclusion fencing involves constructing a permanent fence along streams in livestock pastures that prevents animals from accessing the stream channel and the land adjacent to the stream (the riparian area). Excluding beef or dairy cattle from the stream channel and area immediately next to the stream has been shown to reduce nitrogen, phosphorus, pathogens, and sediment loads in streams by eliminating direct deposition of animal waste and the trampling of streambanks. This facilitates the growth of herbaceous and woody vegetation that filters runoff from upslope, stabilizes stream channels, and, in some cases, removes nitrate from the groundwater.

In two North Carolina beef cattle pastures with exclusion fencing, comparisons between pre and post-implementation monitoring of streams showed that nitrogen loads were reduced by 33% to 41%, phosphorus loads by 47% to 65%, and sediment loads by 60% to 74% (Line et al. 2016; Line and Doll 2023). Nitrogen was reduced by 78%, phosphorus by 76%, and sediment by 82% in a stream draining a dairy cow pasture with exclusion fencing (Line et al. 2000). Further, Wiseman et al. (2014) documented that nitrate in groundwater was significantly reduced within a riparian area 10 to 15 years after beef cows were excluded and trees planted. These substantial reductions, when multiplied across watersheds, can help achieve the mandated nutrient reduction goals from agricultural land.

These case studies, along with other research, help answer several common questions about the effectiveness of exclusion fencing:

1. How far from the stream channel does the fence need to be located?
2. Does the length of the whole stream channel need to be fenced?
3. What are the effects of limited grazing/vegetation management in the excluded area on water quality?

How far from the stream channel to fence?

Exclusion fencing (see Figure 1) has been shown to be effective in cases where it was implemented 10 ft from the top of the streambank (Line et al. 2016; Meals and Hopkins 2002; Galeone et al. 2006) to 100 ft (Line and Doll 2023; Line et al. 2000). The width, or distance from one side of the stream of the exclusion corridor, depends on the slope of the land, the type and density of the vegetation next to the stream (in the exclusion corridor), the slope and length of the area that drains to the stream, and the amount or intensity of the source of nutrients. In general, the steeper the slope (toward the stream), the less dense the ground vegetation in the exclusion corridor, and the longer and steeper the upslope contributing area, the wider the exclusion corridor must be to maximize the runoff treatment.

For example, the Line et al. 2016 study found that 10 ft from the streambank to the fence was adequate for maximum effectiveness when the land draining to the stream was less than 600 ft from the top of the slope to the stream and its slope was less than 3%. When the slope of the land draining to the stream was 5% to 8% and the length was as much as 600 ft from the top of the slope to the exclusion fence, Line and Doll (2023) found that fencing 50 ft to 90 ft from the streambank was highly effective with greater than 30% reduction in nitrogen loads and greater than 50% reduction in phosphorus and sediment loads. Dense herbaceous vegetation grew quickly in both exclusion corridors creating a vegetated buffer, which dispersed and filtered runoff from the upslope pasture.

There is a combination of slope length and steepness from which runoff can be too great and fast for a narrow exclusion corridor to provide adequate treatment. Runoff from long, steep slopes tends to concentrate before entering the exclusion corridor where it can flatten dense vegetation, which reduces treatment. For a dairy operation with high cow density and an intense source of nutrients, exclusion fence from 80 ft to 100 ft from the stream was found to be highly effective (Line et al. 2000). When biosolids and animal waste are regularly applied to the pasture, a wider exclusion corridor may be required because additional nutrient uptake and filtering by vegetation are needed to protect the stream. State and federal cost sharing programs that support exclusion fencing typically require a minimum of 10 ft from the streambank, although the distance can be greater in specific cases where there is a heavy use area upslope.

How much of the stream channel to fence?

For maximum effectiveness, the entire length of the observable stream channel should be fenced because treatment of runoff that becomes concentrated in a stream channel is ineffective. However, some streams begin as shallow intermittent channels, which if they are well-vegetated, may not need to be protected by fencing because the flow will often be shallow and the streambanks low. For example, in the Line et al. 2016 study, the upper 800 ft of the 2500 ft section of stream channel was not fenced because it had only wet-weather flows, was well-vegetated, and had streambanks of less than 1 ft high. The water quality monitoring results indicated that only some of the stream channel needed to be fenced. In the Line and Doll 2023 study, where the entire stream channel was fenced, the effectiveness of nutrient and sediment reduction was generally greater than in the Line et al. 2016 study, although the land slopes in the pasture were steeper. Both studies had similar beef cow grazing densities, soils, and waste applications. Thus, fencing the entire observable stream/waterway channel provided the best treatment. It is important to remember that the effectiveness of exclusion fencing decreases where the stream channel is small (less than 3 ft wide and 2 ft deep) and well-vegetated with intermittent flow.

Fencing even wet-weather waterways can help reduce nutrient, pathogen, and sediment export from a pasture to a stream. In some cases, obtaining cost-share support may require fencing the entire stream channel, as well as the degraded sections of the contributing waterways within the pasture.

What is the cost effectiveness of exclusion fencing?

Exclusion fencing is not a border fence, and can be less sturdy. One or two strands of electric fence are generally sufficient, although many landowners (including those in the three NC case studies) prefer a 4 to 5 strand, barbed wire fence with wooden posts for sturdiness and low maintenance. The Line et al. 2016 study found that the 5-strand barbed wire fence (see Figure 1) cost on average $2.83 per linear ft installed in 2011. In the Line and Doll 2023 study, a 6-strand barbed wire fence cost $2.90 per linear ft installed in 2015. Polywire and high tensile electric fence costs less, and woven wire more, although prices vary by location across the state. In addition to the fence, an alternate watering system (since the stream is inaccessible to the livestock), stream crossings, and gates can increase the cost. In the Line et al. 2016 study, the landowner already had an alternate watering system in the pasture, but needed a culvert stream crossing, which cost an additional $5,000. In the Line and Doll 2023 study, two pipe gates that cost $250 each were installed, along with two watering tanks and piping that cost $4000 each.

Where available, state cost-share programs, such as the North Carolina Agricultural Cost Share

Program (ACSP), will pay up to 75% of the cost of the exclusion fencing and the associated costs. When Cost-Share is used, there are technical specifications for the type and extent of fencing and the width of the exclusion corridor.

The Line et al. 2016 study found that annual reductions in total nitrogen (N) and phosphorus (P) loads from the 135-acre pasture were 568 and 233 lb/year. These reductions over 10 years (the typical Cost-Share contract length) as well as the crossing and fence costs yield a cost of $2.55 per lb N and $6.22 per lb of P removed. For the Line and Doll 2023 study, annual reductions were 359 and 62 lb/year for the 48 acres of pasture. These reductions over 10 years plus the costs of the fence, gates, and watering tanks yield a cost of $4.41 per lb N and $25.52 per lb of P removed. These are actual total costs (not the Cost-Share portion), and do not include design, maintenance, or land costs. The higher cost per pound removed in the Line and Doll (2023) study can be attributed to the cost of the alternate watering system and smaller pasture area. As a comparison, current nitrogen and phosphorus offset rates (amount paid to offset export of excessive N and P) for new development in NC range from $11.70 to $120.70 per lb N and from $171.90 to $640.30 per lb of P. Thus, livestock exclusion fencing is a relatively cost-effective strategy when compared to urban stormwater control measures.

Can vegetation inside the exclusion corridor be managed?

For maximum effectiveness, management of vegetation inside the excluded corridor should be minimal. Natural revegetation has been shown to provide a fast, effective way to stabilize the stream channel and adjacent land. Trees or shrubs can be planted in the exclusion corridor to create a wooded riparian buffer, which can enhance nitrogen removal (Wiseman et al. 2014), shade the stream, stabilize the streambanks, and provide wildlife habitat. However, some landowners, such as in the Line et al. 2016 study, do not allow any woody vegetation in the exclusion corridor and will cut it down. This did not appear to significantly reduce the water quality effectiveness of the exclusion. However, flash grazing, which allows livestock in the exclusion corridor for a day or week to manage vegetation, does have a significant, albeit short term, effect on the water quality effectiveness of the exclusion. In the Line and Doll 2023 study, cattle roamed unintentionally in the excluded corridor for several days in December, 2021. This resulted in a 5-fold increase in ammonia nitrogen concentrations during the corresponding two-week period. With a few exceptions, livestock are not allowed at any time in the exclusion corridor when NC Agricultural Cost Share program funds are used.

Are there other benefits to livestock exclusion?

One benefit of exclusion fencing is that it forces livestock to drink from the cleaner alternative watering sources upslope from the stream. Another benefit is that the fencing reduces the likelihood of livestock injury on the steep, unstable banks of stream channels. Young livestock are also prevented from accessing the muddy stream bottom where they can become stuck or fall down while navigating the streambanks. One final benefit is that livestock can be more easily observed when not in a stream channel.

Conclusion

Agricultural production practices such as allowing livestock unlimited access to streams in pastures can sometimes threaten water quality. The threat can be reduced by installing fencing that excludes livestock from direct access to stream channels. Research has shown that, in general, a relatively narrow (10 ft minimum from streambank) exclusion corridor is effective for more flat, more narrow pastures, while a wider exclusion corridor (50 to 90 ft from the streambank) for wider and steeper pastures is effective. Other factors such as animal density and waste application to the pasture may also affect the width of the corridor. Cost-share programs may be available to off-set the costs of livestock exclusion, which include fencing, alternative water sources, gates, and stream crossings.

Livestock health and well-being may also be improved by blocking access to the stream.

Livestock exclusion fencing is a great example of a BMP that allows producers to maintain a high level of agricultural production while also preserving water quality.

Figure 1. Exclusion fence 10 ft (top) and 50 to 90 ft (bottom) from streambank.

AttributionSource: Daniel Line

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