Division of Mitigation Services

Water Quality Report

Buckwater Mitigation Site (Project ID # 97084)

NORTH CAROLINA
Department of Environmental Quality

Abstract

The objective of this work was to examine the effect of stream restoration on water quality for two tributaries, T3 and T4, that are part of the Buckwater Mitigation Project. The Division of Mitigation Services (DMS) contracted the Buckwater restoration project with Wildlands Engineering Inc., in 2017. Construction was completed in April 2019. Reach T3 is being monitored for fecal coliform bacteria (FCB), whereas Reach T4/T4B is being monitored for total suspended residue (TSS), all forms of nitrogen, total phosphorous (TP), and FCB. Pre-restoration monitoring occurred for approximately 1 year, with approximately 2 years of post-restoration monitoring completed at the time of this report update. Reach T3 demonstrated a 33% (*p value* < 0.05) mean reduction in FCB at the downstream station (Station BW-5) with a median reduction of 53%. The downstream treatment station (Station BW-4) on Reach T4 demonstrated significant reductions in all water quality parameters. Total organic nitrogen (TON), ammonia (NH_3), TP, TSS, and FCB demonstrated statistically significant reductions, (*p value* <0.05), ranging from 70-79%. Nitrate + Nitrite (NOx) and total nitrogen (TN) demonstrated statistically significant reductions (*p value* <0.05) of 45% and 64%, respectively. Differences in the variance before and after construction at treatment stations are also discussed.

Introduction

Improvement in water quality is routinely cited as a goal or expected outcome in stream mitigation plans but is rarely monitored (Palmer et al. 2007). Over the past 2 decades, demonstration of the efficacy of restoration practices in terms of generating improvement in apex functions such as biology and water quality have varied and causal attribution of different restoration approaches has been limited (Craig et al., 2008; Palmer et al. (2014); Newcomer Johnsen et al., (2016); Lammers and Bledsoe (2017); Palmer et al. (2014). Coincident over this period was the requirement of objective and verifiable ecological performance standards for mitigation as part of the 2008 federal mitigation rule (DOD-USACE 33CFR Parts 325 and 332; USEPA 40CFR Part 230). Additionally, the North Carolina (NC) Interagency Review Team (IRT) updated monitoring guidelines in 2016 for the USACE (United States Army Corps of Engineering) Wilmington District, encouraging and incentivizing the measurement of water quality and biological parameters as part of mitigation monitoring. The level of effort and expertise associated with monitoring these parameters with adequate rigor across many reaches and projects can be intensive and costly.

In response, the DMS (Division of Mitigation Services) Science and Analysis unit initiated a monitoring program to measure water quality, before and after restoration over a range of project reaches that typify more contemporary project attributes and practices in NC mitigation. The intent of this work is to provide a suite of case examples that span a range of reach and watershed scales and stressor distributions, thereby capturing a gradient of signal to noise in the watershed. In the case of stream restoration, signal to noise indicates the degree of difference (signal) between the existing condition and the restored condition in terms of water quality improvement. The ability to resolve differences pre-post is affected by other variables to include scale and variation (noise) in the contributing watershed. Association of these variables with outcomes of change detection in water quality can provide context for the development of mitigation project goals that are more informed and spatially tailored at scales finer than the overall project level. This report summarizes the results to date from two reaches for the Buckwater Mitigation Project in Orange County, NC.

Study Area

The Buckwater Mitigation Site is in the Piedmont physiographic region, approximately 5 miles northeast of Hillsborough, NC in Orange County (**Link to interactive map**). The project drains to the Eno River and ultimately to the Falls Lake water supply watershed, which has been designated a nutrient sensitive water. The site lies within the Slate Belt geologic unit, characterized by cleaved surficial slate with coarse-grained intrusive granites. Reach soils are predominantly Chewacla and Appling sandy loam with the contributing drainage dominated by Herndon silty loam.

Prior to restoration, the primary stressors were livestock grazing and channel straightening. Agricultural activity remained high through the 1990s with several thousand beef cattle and three hog houses. At the time of restoration, approximately 130 cows grazed three properties surrounding the conservation easement. Non-forested areas not used for pasture were used for cultivating hay. There were several ponds along Buckwater Creek, T3, T4, and T5 that were built between 1938 and 1955 to provide irrigation and drinking water for the livestock. Livestock frequented these ponds likely contributing to their eutrophication. See Figure 1 for pre-construction land use-land cover distributions by station. Areas within the project boundary were restored and protected as part of the project.

The overall project easement is 52 acres encompassing 17,295 feet of restoration and multiple levels of enhancement (Figure 1) all of which included cattle exclusion fencing. Tributaries T3 and T4 were monitored for water quality (Figure 2). Tributary T3 is comprised of 1274 feet of restoration and 863 feet of enhancement and is bounded by water quality station BW-1 at its upper extent (drainage area – 80 ac.) and Station BW-5 at its lower extent (drainage area - 138 ac.). Reach T4/T4B is comprised of 1813 feet of restoration and 155 feet of enhancement and is bounded by water quality Station BW-3 at its upper extent (drainage area - 39 ac.) and Station BW-4 at its lower extent (drainage area - 77 ac.). Outside the project easement livestock remain the primary stressors post-construction (Figure 2).

Methods

Sampling and Analytical Approach

The downstream station was sampled pre-construction weekly for 11 months between June 2017 and May 2018 with the upstream station monitored for nearly 2 years between June 2017 and April 2019. The upstream station is in an intermittent reach, periodically dry and above the project boundary permitting monitoring to continue during construction. Construction took place between May 2018 and April 2019. The first post construction monitoring period took place over approximately 2 years between June 2020 and May 2022 (monitoring years 1-3 post-construction). These data are the subject of this report. Sampling will recommence in 2024 for 2 years capturing monitoring years 5-7 and an update to this report will be produced. Samples for FCB were collected via grab sampling, pointing the sterile bottle mouth upstream, and then stored on ice. Nutrient and TSR samples were collected with ISCO series 6700/6712 automated samplers using flow proportional composite sampling with storm and baseflow collected independently. Nutrient samples were pre-preserved with 1:3 H_2SO_4 (sulfuric acid) in the sampler's collection bottles to achieve a pH<2. Composite samples were collected from each sampler every 1 to 2 weeks over the monitoring periods. Samples were analyzed by the NC DEQ central chemistry laboratory using certified methods from Standard Methods (SM) for the Examination of Water and Wastewater and EPA methodologies as per the following:

Fecal coliform - Membrane Filter (FCB)	SM 9222-D-1997
Total Suspended Residue (TSS)	SM2540 D-1997
Total Phosphorous (TP)	EPA 365.1 Rev. 2.0
Nitrate-Nitrite as N (NOx)	EPA 353.2 Rev. 2.0
Total Kjeldahl Nitrogen (TKN)	EPA 351.2 Rev. 2.0
Ammonia (NH_3)	EPA 350.1 Rev. 2.0

Discharge and Loading

Stage in feet (ft.) was recorded continuously by using a self-correcting ISCO pressure transducer instream probe with a data conversion module (ISCO 720) logging average stage at 15 min intervals. Stage intervals and flow pacing were programmed to separate base and storm flow and capture storm peaks appropriately. Rainfall in inches was captured on one of the site samplers with an ISCO 674 digital tipping bucket rain gauge and summed at intervals of 15 minutes. A stage-discharge relationship for Stations BW-3 and BW-4 was established pre-restoration using the ISCO stage data and rectangular weirs built in the channel. The relationship was programmed into the ISCO to produce a discharge record. Post restoration discharge data had to be captured via dilution gauging (USGS, Open File report 84-136) for Station BW-4 within the restoration treatment area, because the construction of a weir in the newly restored stream was not feasible. DMS will utilize dilution gauging in most cases moving forward, because it does not require building structures in the channel and it is cost effective, reliable, and rapid. It also effective in small, shallow channels, where impeller type flow meters are not viable. Annualized loadings will be incorporated in future report updates.

Data Analysis

Each station's water quality data were visualized using box plots and were statistically compared via non-parametric hypothesis testing (Wilcoxon Rank Sum) and other summary statistics (e.g., median, mean, standard deviation, etc.). Data were analyzed without log transformation using R statistical software.

Results

The pre-restoration concentrations at the downstream station, BW-4, on reach T4 represents the effect of the reach stressors and were an order of magnitude higher than the upstream control station, BW-3 (Figure 3; Table 1). Post-restoration water quality concentrations at BW-4 were significantly reduced from pre-restoration concentrations for all parameters (*p value* < 0.05; Table 1). Median reductions at BW-4 ranged from 79% for TP, with NOx exhibiting a 45% reduction (Figure 3; Table 1). These results represent a 2-3-fold decrease in pollutant concentrations. Based on upstream median concentrations (Station BW-3) generally increased from pre-construction to post-construction, with percentage increases ranging from 0% (NH_3) to 415% (TSS) (Table 1). Upstream concentrations were significantly different between pre- and post-restoration conditions for NOx and TSS only (Table 1). Reach T3 FCB exhibited a median reduction at the downstream station, BW-5 of 53% (*p value*=0.0015).

The coefficient of variation (CV) was also calculated and is the standard deviation expressed as a percentage of the mean. This normalizes the variation facilitating comparisons between stations and timeframes. It is particularly useful when two distributions subject to comparison differ significantly in their magnitude (e.g., Station BW-3 and BW-4 in pre-restoration phase). The CV decreased after restoration for both stations on reach T4 except for TSS at BW-4 (Figure 3; Table 1), demonstrating a reach wide reduction in variability post-restoration. However, the CV for FCB on reach T3 (station BW-5) demonstrated a marked increase (90%) in the post-restoration phase. Detailed tabulated summary statistics representing each distribution can be found in Table 2 along with the raw data in time series in Figure 4.

Table 1 – Summary of Change Before and After Construction on Reach T4

Upstream Station BW-3

Stats	TN	TON	TKN	NH_3	NOx	TP	TSS
% Change Median	37.0%	26.5%	27.8%	0.0%	100.0%	25.0%	415.4%
% Change Mean	2.6%	6.4%	-9.6%	-21.2%	37.1%	-17.8%	95.6%
CV % Change	-39%	-41%	-63%	-57%	-29%	-68%	-58%
Wilcoxon Rank (*p*-value)	*0.066*	*0.120*	*0.183*	*0.833*	***0.018***	*0.082*	***0.001***

Downstream Station BW-4

Stats	TN	TON	TKN	NH_3	NOx	TP	TSS
% Change Median	-64.2%	-75.4%	-78.5%	-69.6%	-45.2%	-79.2%	-74.1%
% Change Mean	-65.8%	-77.2%	-78.1%	-83.7%	-45.6%	-79.2%	-51.9%
CV % Change	-40%	-32%	-33%	-22%	-10%	-3%	66%
Wilcoxon Rank (*p*-value)	**1.2E-13**	**9.2E-10**	**8.3E-10**	**4.2E-07**	**4.2E-06**	**2.8E-09**	**6.8E-05**

Discussion

Comparing pre- and post-construction data between upstream and downstream stations has demonstrated marked improvements in water quality (Figure 3; Table 1) because of the restoration measures applied. These improvements were realized even with the pre-post increases noted at the upstream stations. Based on observations, the latter was possibly in part due to periodic sediment accumulations in the channel against the weir at station BW-3. Cattle exclusion is a commonly applied agricultural best management practice (i.e., BMP) that has been shown to reduce channel erosion, FCB contamination, and nutrient inputs (Line, et al., 2000; Grudzinski, et al., 2005). TSS and TP had among the greatest downstream reductions in concentrations between pre- and post-construction (i.e., 74% and 79%, respectively). These parameters are associated with sediment and may allude to the contribution that restoration provides in the reduction of bank erosion. Given the timeframes of project implementation separation of reductions attributable to cattle exclusion and stream restoration practices was not possible.

The reductions in TN were 10-15% less than those observed for TP and TSS, but still significant (Table 1). The lesser reduction in TN was driven by the lower magnitude of the reduction in $NO_{x,}$ which was approximately 45%. NO_x is not above trace quantities in livestock manure, rather it is generated by the degradation of organically bound nitrogen from manure and then enters groundwater via microbially mediated nitrification in soils. The lesser reductions of NOx may therefore be a function of time-varied cattle pressure outside of the easement, which could continue to contribute to groundwater levels of NO_x. Agricultural landscapes are known to accumulate nitrogen in soils and groundwater, and changes in the net contributions of these reservoirs may operate on a decadal timescale (Puckett et al., 2011; Van Meter et al., 2016).

Another question of interest is whether restoration reduces the variability in water quality parameters. The CV for all parameters on T4 decreased at BW-3 (upstream) and BW-4 (downstream) post-restoration except for TSS at BW-4. In its restored state T4 also undergoes more frequent drying and re-wetting cycles, which may contribute to temporal variability of the observed concentrations depending on antecedent conditions (Austin et al., 2010; Saltarelli et al., 2021). Based on weekly observations the TSS variation may have also been driven by the accumulation of organic flocculent in the riffle at the downstream sampling point. This was the result of increased sunlight in the understory combined with the significant hydrological reconnection of the stream and floodplain. These conditions led to a much greater herbaceous density in the post construction period to include Juncus spp. and other herbaceous plants spanning the channel in many locations. The resulting change in hydraulics promoted the accumulation of organic material and periphyton, particularly in low flow conditions, which increased the variability in solids within baseflow samples. Currently, the coincidence of the upstream and downstream CV reductions does not allow us to develop conclusions regarding the effect of restoration on the CV at Buckwater. The comparison of variability will be revisited at future updates as monitoring continues.

The reductions in all parameter concentrations at the downstream station were evident a year after construction and with possible exception of NO_x have consistently persisted throughout the post-construction monitoring period thus far (Figure 4). Overall median NO_x concentrations were clearly lower than that of the pre-construction period but increases in NO_x were observed from late fall to early spring coincident with the seasonal recession and dormancy of vegetation. This was the case for 2021 but appeared even more acute in 2022.

Collectively, these data and observations suggests that the cumulative effect of the restoration practices employed may provide rapid and potentially sustained reductions in fluxes of physicochemical water quality parameters. However, the data and observations also indicate the dynamics may adjust as vegetative succession occurs throughout the easement. These examples illustrate how the multifactorial determinants of in-stream nutrient concentrations can change with time in a restoration setting. Given the fluctuating relative importance of these factors, and the likelihood that restoration sites have variable timeframes for transitioning into a new steady-state, continued monitoring should occur to detect any divergence from these current observations.

Reach T4 and its watershed represent a high signal to noise condition. This is characterized by an intense stressor condition in the pre-construction phase between stations BW-3 and BW-4 contrasted with robust protection and treatments applied as part of the restoration (i.e., strong signal). Coincident with this, the stressors within the contributing watershed (above BW-3) are comparatively lower (i.e., mostly forested - low noise). This contrast makes it more likely to be able to detect and resolve difference between stations and time periods (Figure 5.). DMS is monitoring other project reaches that span a gradient of signal to noise to understand the combination of reach and watershed characteristics that facilitate reliable detection of change in the context of mitigation in North Carolina. DMS is also positioned to monitor stream reaches across timeframes that extend past mitigation monitoring timeframes and published research sampling regimes. DMS intends to continue monitoring T4 in 2 additional post-construction periods in 2024-2026 (elapsed years 5-6 post-restoration) and 2028-2029 (elapsed years 9-10 post-restoration) to document and characterize the dynamics and sustainability of water quality changes in response to restoration. Reach T3 will be monitored again for FCB in 2024-2026 (elapsed years 5-6 post-restoration)

Figures and Tables

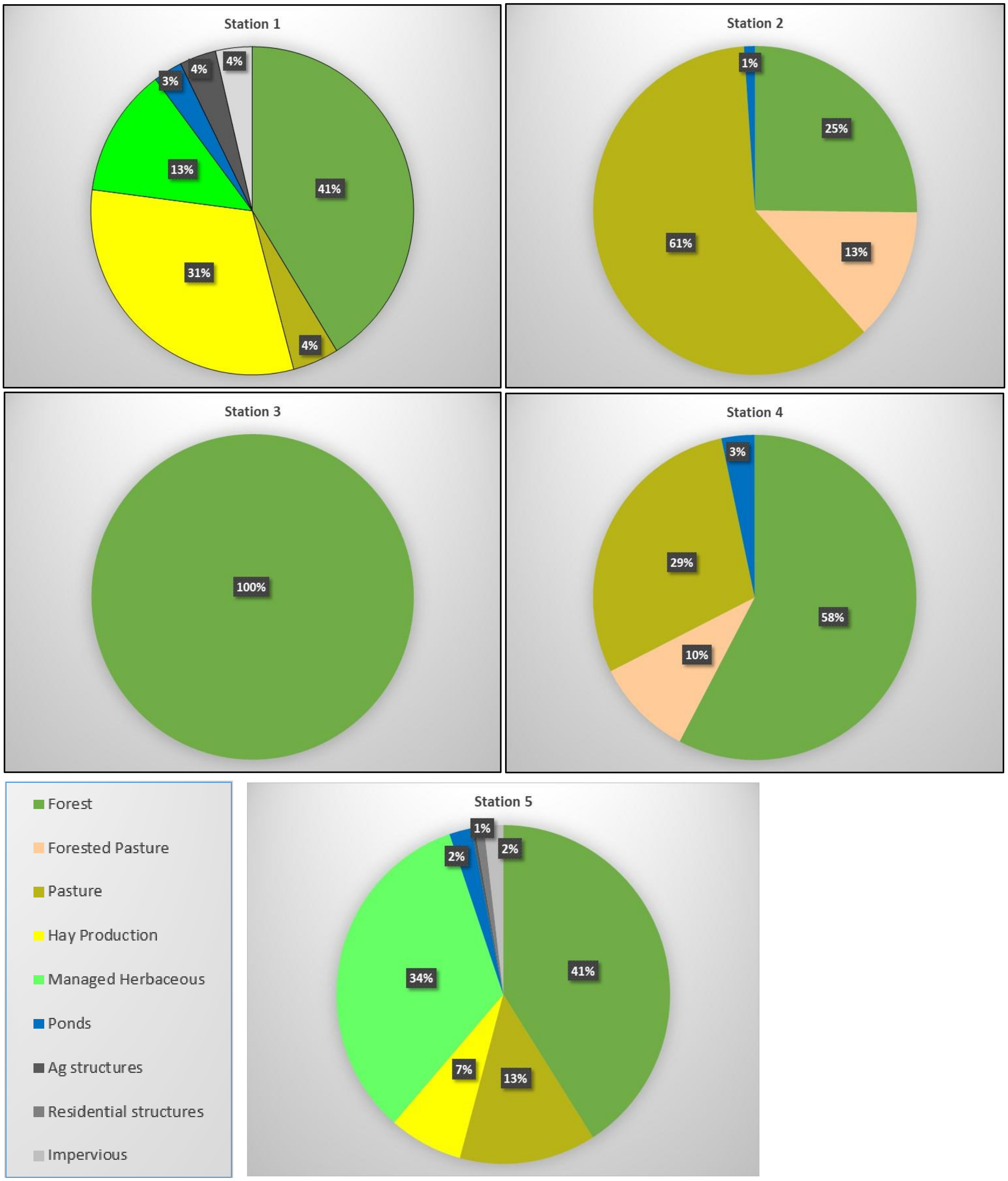


Figure 1. Land use-land cover proportions for contributing watershed areas across each sampling station.

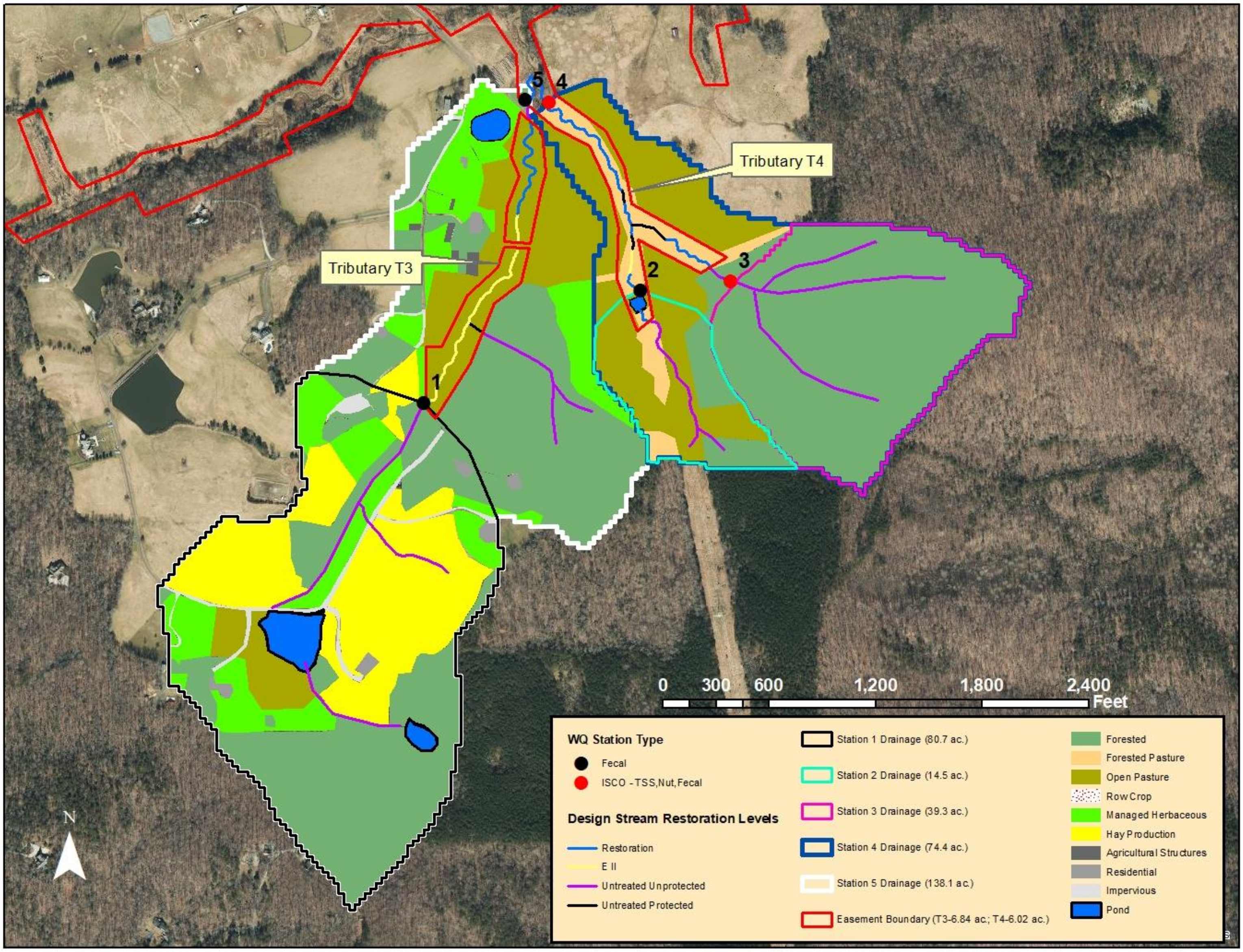
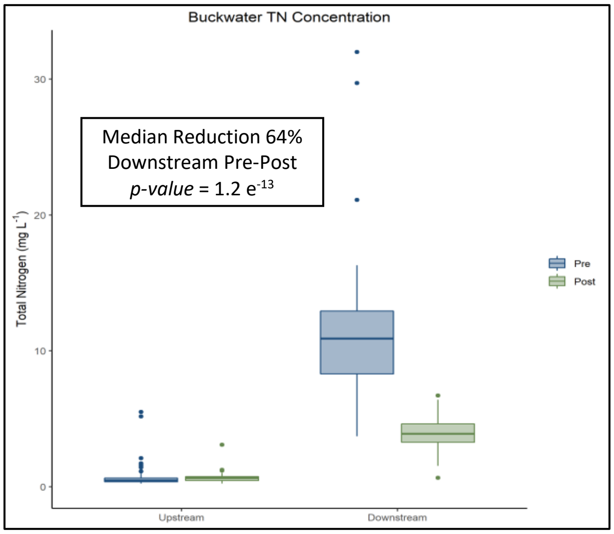
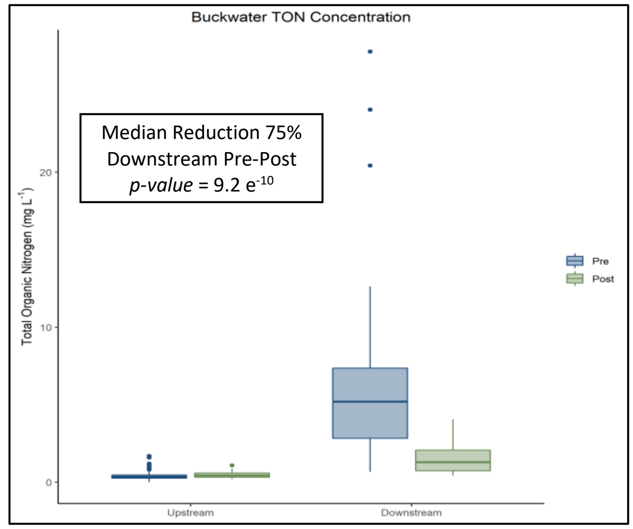
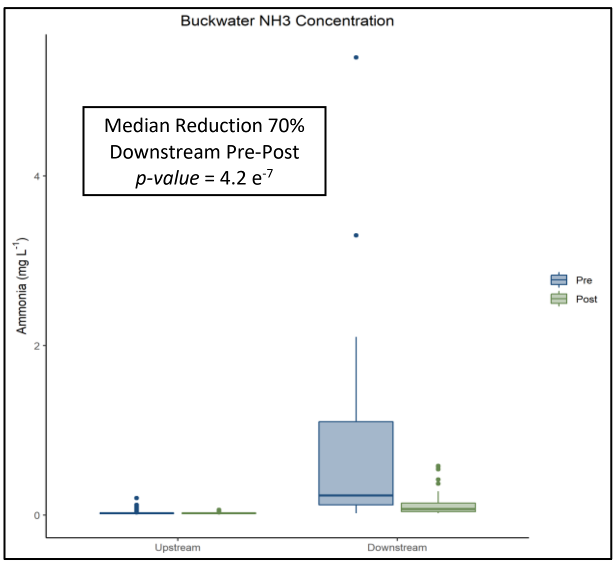
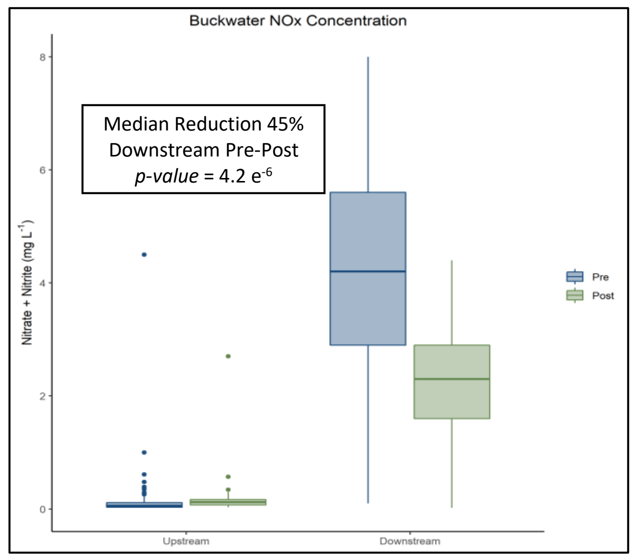


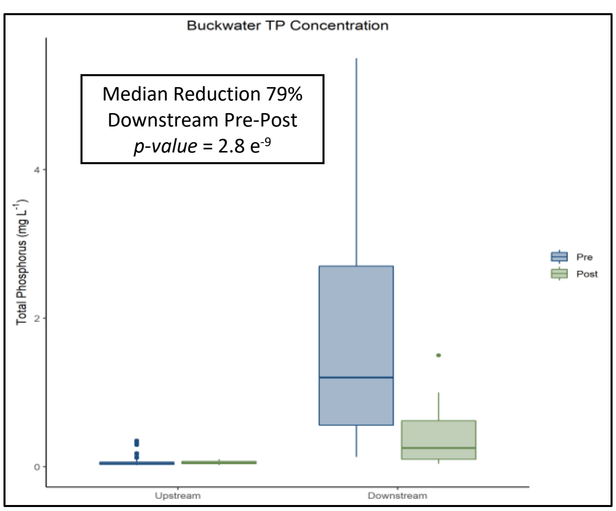
Figure 2. Map view displaying land use-land cover, restoration levels and sampling stations.

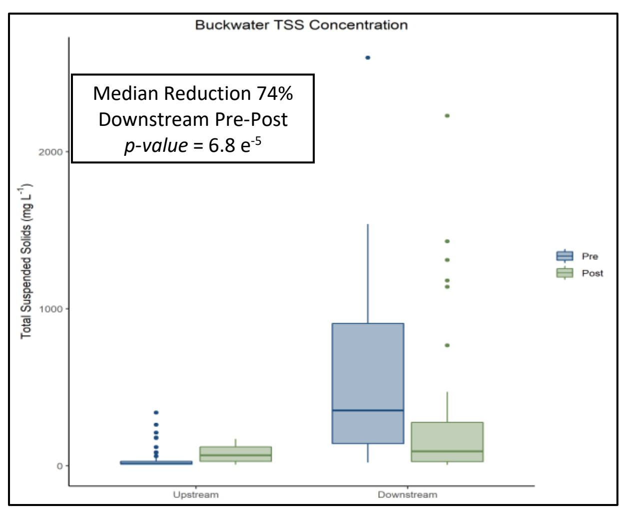

Buckwater TN Concentration
Median Reduction 64%
Downstream Pre-Post
p-value = 1.2 e-13
Total Nitrogen (mg L-1)
0
10
20
30
Upstream
Downstream
Pre
Post


Buckwater TON Concentration
Median Reduction 75%
Downstream Pre-Post
p-value = 9.2 e-10
Total Organic Nitrogen (mg L-1)
0
10
20
Upstream
Downstream
Pre
Post


Buckwater NH3 Concentration
Median Reduction 70%
Downstream Pre-Post
p-value = 4.2 e-7
Ammonia (mg L-1)
0
2
4
Upstream
Downstream
Pre
Post


Buckwater NOx Concentration
Median Reduction 45%
Downstream Pre-Post
p-value = 4.2 e-6
Nitrate + Nitrite (mg L-1)
0
2
4
6
8
Upstream
Downstream
Pre
Post


Buckwater TP Concentration
Median Reduction 79%
Downstream Pre-Post
p-value = 2.8 e-9
Total Phosphorus (mg L-1)
0
2
4
Upstream
Downstream
Pre
Post


Buckwater TSS Concentration
Median Reduction 74%
Downstream Pre-Post
p-value = 6.8 e-5
Total Suspended Solids (mg L-1)
0
1000
2000
Upstream
Downstream
Pre
Post

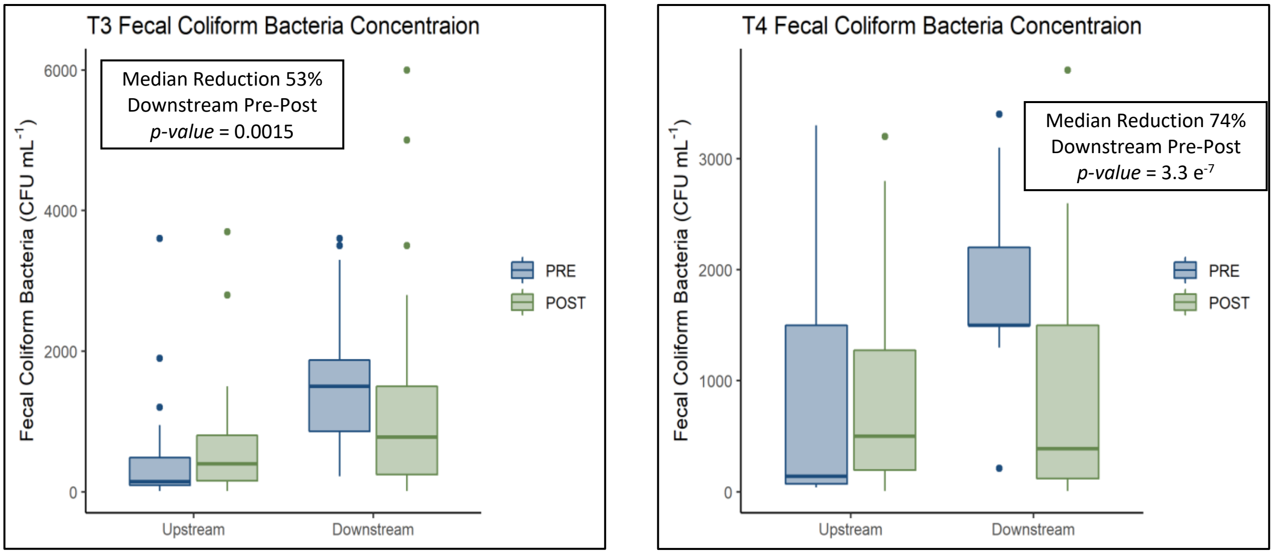


Figure 3. Pre-Post distributions and differences by water quality parameter.

Table 2. Table displaying distributions up and downstream, pre- and post-restoration for reach T4.

Upstream

Pre-Buckwater: Upstream

Stats	TN	TON	TKN	NH_3	NOx	TP	TSS
Min	0.23	0.00	0.20	0.02	0.02	0.02	6.2
Q1	0.36	0.25	0.27	0.02	0.03	0.03	9.4
Median	0.46	0.34	0.36	0.02	0.06	0.04	13.0
Mean	0.74	0.44	0.54	0.03	0.19	0.07	39.7
Q3	0.63	0.46	0.51	0.02	0.12	0.06	28.0
Max	5.51	1.68	4.90	0.20	4.50	0.35	339.0
Std. Dev.	0.95	0.35	0.67	0.03	0.59	0.08	65.9
CV%	128	80	123	104	306	114	166
n	60	59	60	60	60	60	59

Post-Buckwater: Upstream

Stats	TN	TON	TKN	NH_3	NOx	TP	TSS
Min	0.24	0.18	0.20	0.02	0.03	0.02	6.2
Q1	0.45	0.31	0.33	0.02	0.07	0.04	28.0
Median	0.63	0.43	0.46	0.02	0.12	0.05	67.0
Mean	0.76	0.47	0.49	0.02	0.26	0.06	77.7
Q3	0.74	0.58	0.61	0.02	0.17	0.07	120.0
Max	3.08	1.08	1.10	0.06	2.70	0.10	170.0
Std. Dev.	0.60	0.22	0.22	0.01	0.57	0.02	53.9
CV%	79	47	45	44	216	37	69
n	21	21	21	21	21	21	21

Stats	TN	TON	TKN	NH_3	NOx	TP	TSS
% Change Median	37.0%	26.5%	27.8%	0.0%	100.0%	25.0%	415.4%
% Change Mean	2.6%	6.4%	-9.6%	-21.2%	37.1%	-17.8%	95.6%
Wilcoxon Rank (*p*-value)	*0.066*	*0.120*	*0.183*	*0.833*	***0.018***	*0.082*	***0.001***

Downstream

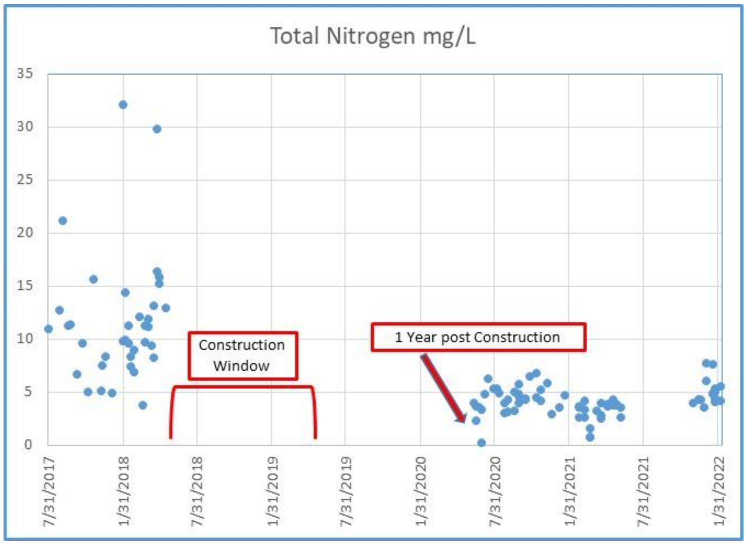
Pre-Buckwater: Downstream

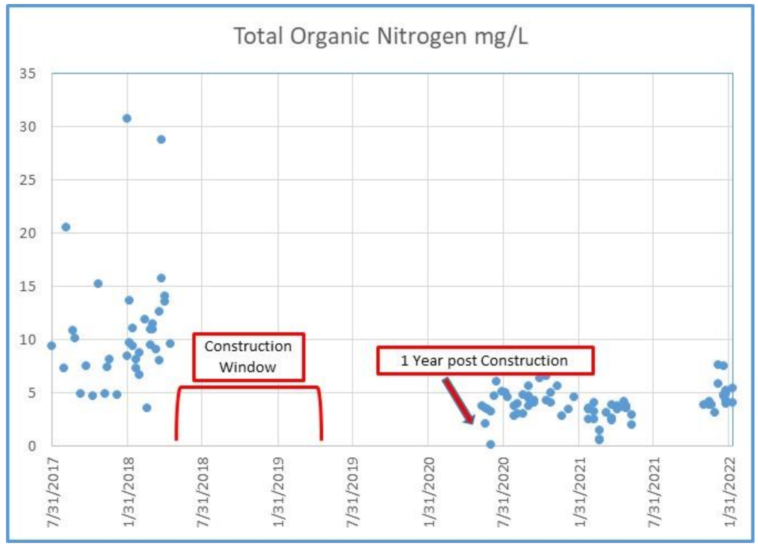
Stats	TN	TON	TKN	NH_3	NOx	TP	TSS
Min	3.70	0.67	0.69	0.02	0.10	0.13	21.0
Q1	8.30	2.83	3.00	0.12	2.90	0.56	140.0
Median	10.90	5.20	6.50	0.23	4.20	1.20	352.0
Mean	11.57	6.65	7.39	0.74	4.18	1.75	555.9
Q3	12.92	7.35	8.70	1.10	5.60	2.70	906.0
Max	32.00	27.80	29.00	5.40	8.00	5.50	2600.0
Std. Dev.	5.91	6.10	6.37	1.08	2.07	1.54	556.8
CV%	51	92	86	146	50	88	100
n	37	37	37	37	37	37	37

Post-Buckwater: Downstream

Stats	TN	TON	TKN	NH_3	NOx	TP	TSS
Min	0.66	0.42	0.47	0.02	0.02	0.04	5.9
Q1	3.27	0.72	0.88	0.04	1.60	0.10	26.5
Median	3.90	1.28	1.40	0.07	2.30	0.25	91.0
Mean	3.96	1.51	1.62	0.12	2.28	0.36	267.2
Q3	4.62	2.06	2.20	0.14	2.90	0.62	276.0
Max	6.70	4.04	4.20	0.58	4.40	1.50	2230.0
Std. Dev.	1.21	0.94	0.94	0.14	1.02	0.31	445.5
CV%	31	62	58	114	45	85	167
n	49	49	49	53	53	53	50

Stats	TN	TON	TKN	NH_3	NOx	TP	TSS
% Change Median	-64.2%	-75.4%	-78.5%	-69.6%	-45.2%	-79.2%	-74.1%
% Change Mean	-65.8%	-77.2%	-78.1%	-83.7%	-45.6%	-79.2%	-51.9%
Wilcoxon Rank (*p*-value)	**1.2E-13**	**9.2E-10**	**8.3E-10**	**4.2E-07**	**4.2E-06**	**2.8E-09**	**6.8E-05**


Total Nitrogen mg/L
35
30
25
20
15
10
5
0
Construction Window
1 Year post Construction
7/31/2017
1/31/2018
7/31/2018
1/31/2019
7/31/2019
1/31/2020
7/31/2020
1/31/2021
7/31/2021
1/31/2022


Total Organic Nitrogen mg/L
35
30
25
20
15
10
5
0
Construction Window
1 Year post Construction
7/31/2017
1/31/2018
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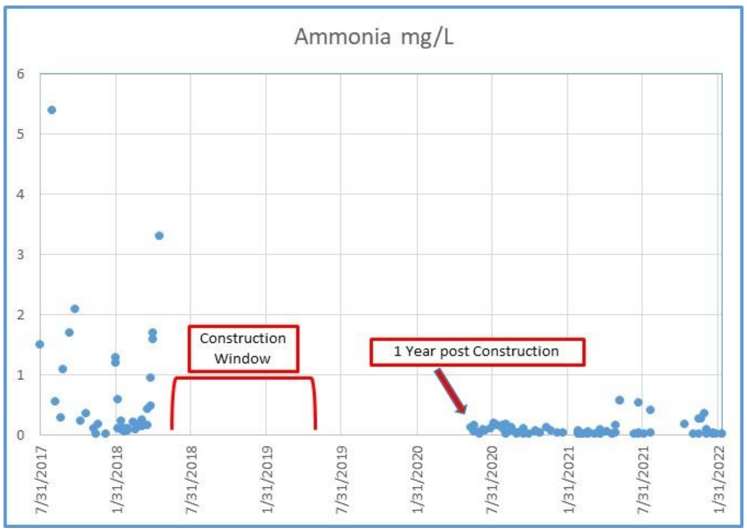
7/31/2021
1/31/2022


Ammonia mg/L
6
5
4
3
2
1
0
Construction Window
1 Year post Construction
7/31/2017
1/31/2018
7/31/2018
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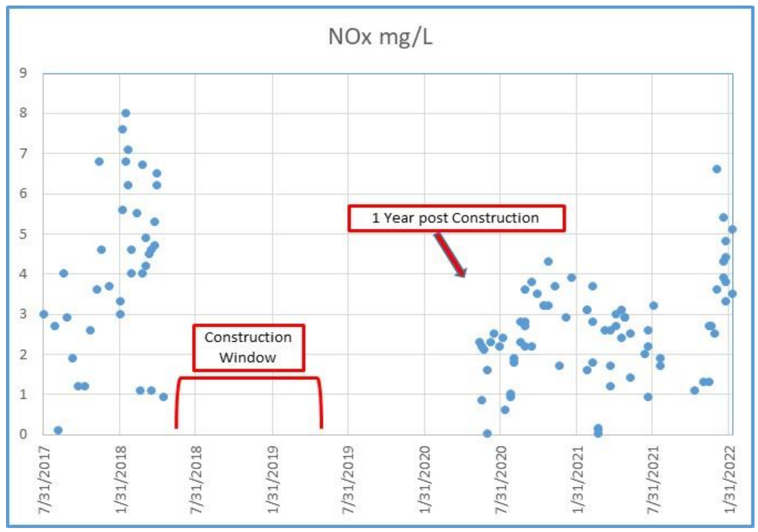
7/31/2021
1/31/2022


NOx mg/L
9
8
7
6
5
4
3
2
1
0
1 Year post Construction
Construction Window
7/31/2017
1/31/2018
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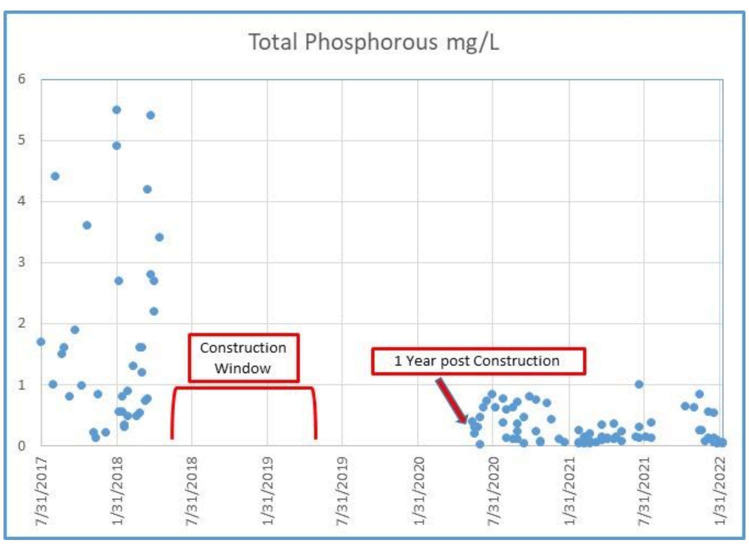
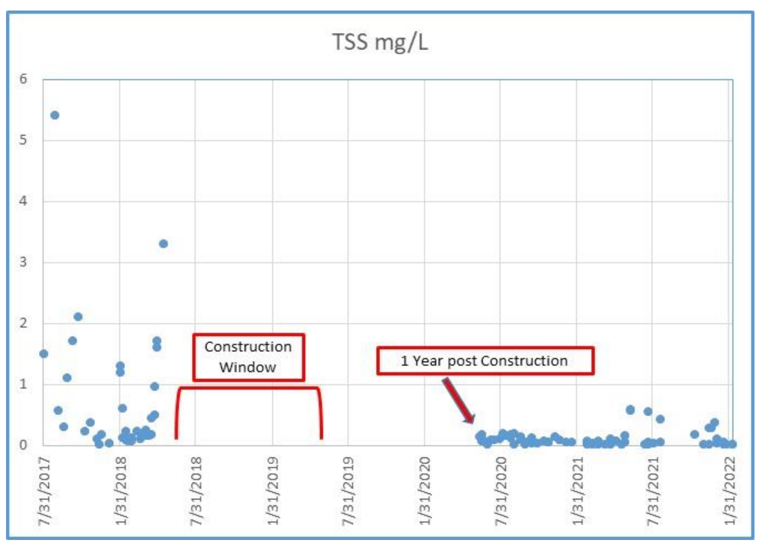
7/31/2021
1/31/2022


Total Phosphorous mg/L
6
5
4
3
2
1
0
Construction Window
1 Year post Construction
7/31/2017
1/31/2018
7/31/2018
1/31/2019
7/31/2019
1/31/2020
7/31/2020
1/31/2021
7/31/2021
1/31/2022


TSS mg/L
6
5
4
3
2
1
0
Construction Window
1 Year post Construction
7/31/2017
1/31/2018
7/31/2018
1/31/2019
7/31/2019
1/31/2020
7/31/2020
1/31/2021
7/31/2021
1/31/2022

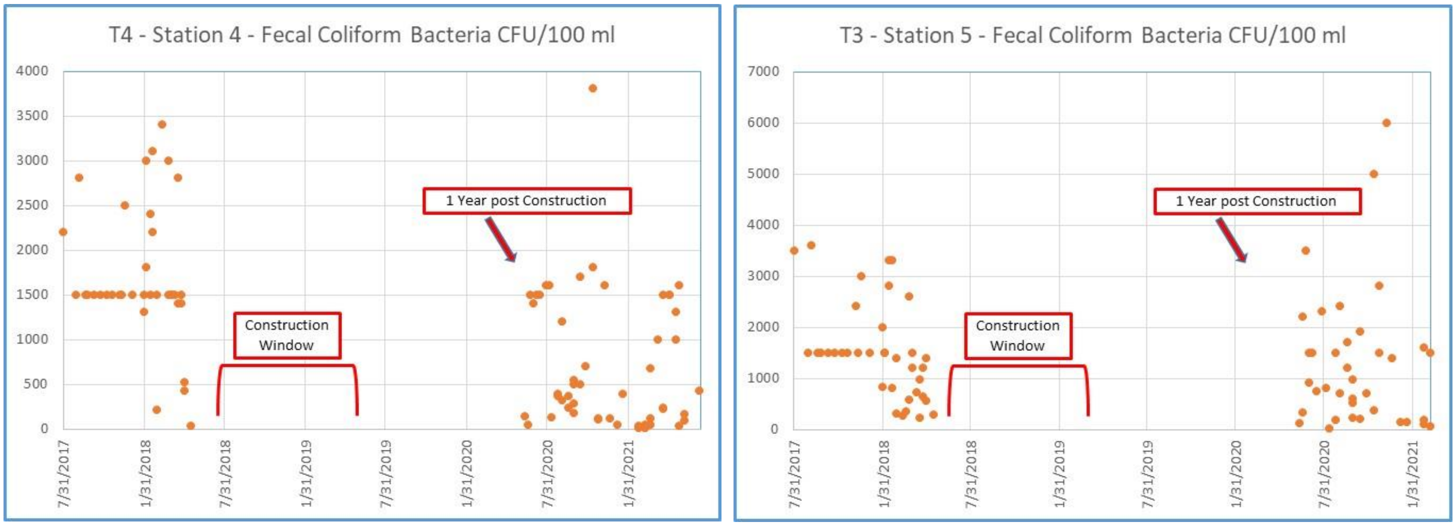


Figure 4. Time series for water quality parameters at treatment station 4 on T4 and station 5 on T3

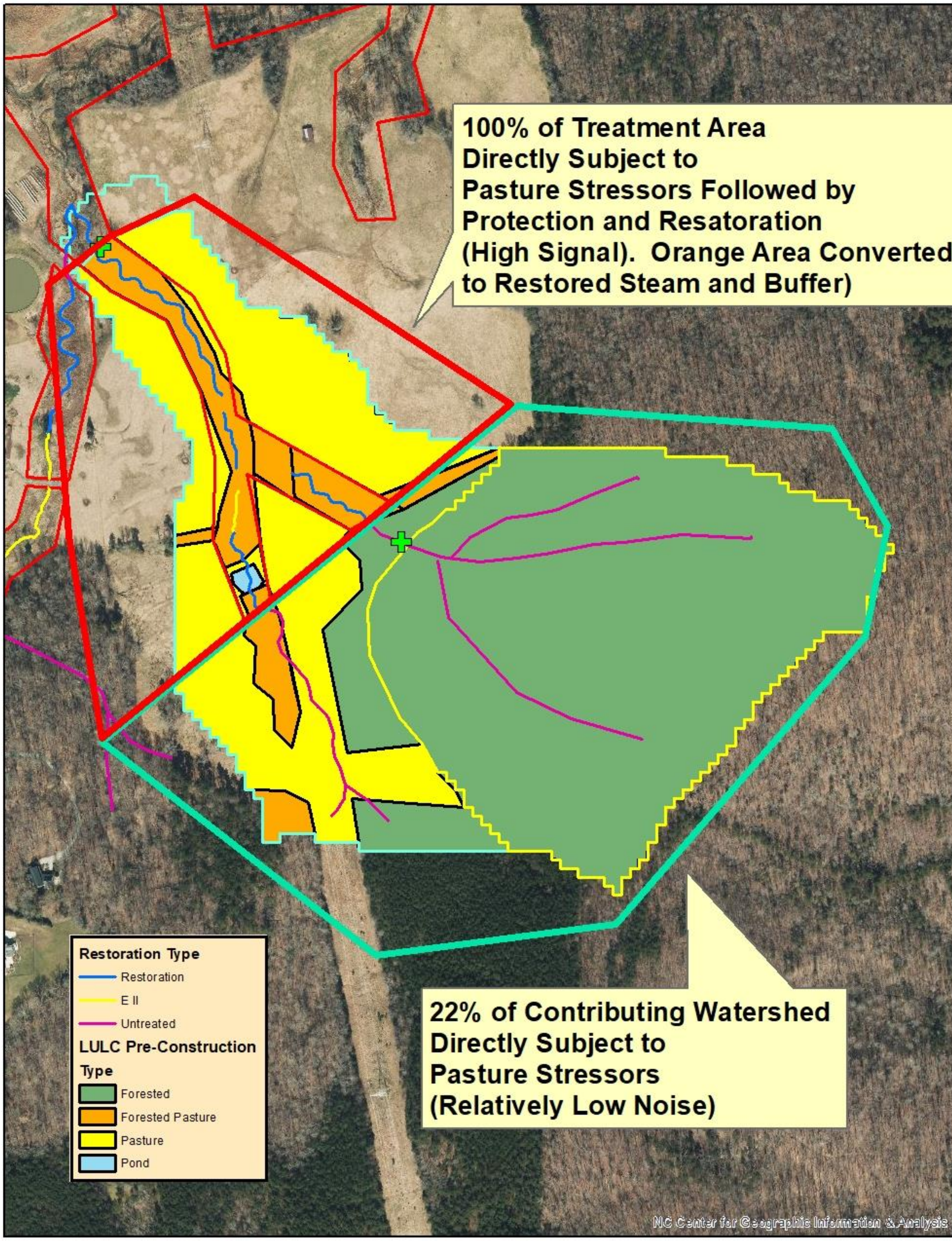


Figure 5. Map view of Pre-Construction Stressors and Restoration Treatments in T4 drainage

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