RESEARCH & DEVELOPMENT

Reducing the Environmental Impact of Road Construction

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Reducing the Environmental Impact of Road Construction

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16. Abstract

Construction of roads exposes large areas of soil which can lead to high erosion rates. Current best management practices are good at keeping larger sized particles on-site, but smaller particles still remain a problem for construction site stormwater discharges. Turbid water leaving construction sites can have detrimental impacts for the surrounding environment, especially for aquatic organisms such as mussels. Polyacrylamide (PAM) has been shown to help reduce turbidity of construction site stromwater. Additionally, good vegetation cover can help reduce erosion from construction sites. Typically grass is planted, but there has been increased interest in using wildflowers as they provide food and habitat for a variety of pollinator insects. Our research evaluated the effectiveness of (1) I-540 sediment basins on Swift Creek water quality (turbidity and total suspended solids [TSS]) and (2) different wildflower mixes with and without compost and fertilizer as a stormwater control measure (SCM). The monitoring of sediment basins and Swift Creek investigated water quality being discharged from the sediment basins and water quality in Swift Creek on a storm event basis. The results from the sediment basin monitoring confirmed PAM application will reduce the turbidity and TSS of water in sediment basins. Without PAM application, turbidity levels being discharged were exceeding that of Swift Creek. However, Swift Creek often rose 6-7' during rain events, and the turbid discharge from the construction site was rarely evident in the Swift Creek monitoring. These results suggest that (1) PAM should be consistently applied to get the clearest construction site stromwater discharge and (2) the flashiness of Swift Creek might be diluting the turbid water from the construction site. Second, the field studies considered vegetation cover from grass, wildflowers, and grass-wildflower mixes with and without compost (30% by volume) and/or fertilizer. It was found in both field studies that compost can be used without fertilizer and get the same vegetation cover as compost plus fertilizer, and compost had increased infiltration rates compared to no compost. Grass-wildflowers mixes and wildflowers preformed the same as grass for vegetation cover up to one year after planting. Vegetation establishment was best when excelsior matting was used as the ground cover compared to hydromulch. Overall, the results suggest that wildflowers and grass-wildflower mixes can be used with compost and no fertilizer to get good vegetation cover. Compost is recommended on less steep slopes as it can increaser the infiltration rate of the soil, which is necessary for SCMs. It is unknown if these practices could be applied to steeper (>10%) slopes. Pollinator friendly vegetation appears to be a viable option for an alternative ground cover on less steep slopes.

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EXECUTIVE SUMMARY

Highway construction or widening of highways can generate significant amounts of sediment from exposed soil. This produces turbid runoff while construction is underway. All construction projects are required to have a sediment and erosion control plan that uses the best management practices (BMPs) such as sediment basins, wattles, and silt fences. The practices have been improved and refined to retain most of the larger particles generated on site. However, the smaller particles causes the water to be turbid and still remain a problem for construction stormwater. Polyacrylamide (PAM) can be introduced to construction stormwater and greatly reduce the turbidity of the water. Discharging clean water from construction sites is particularly important in sensitive watershed, such as the Swift Creek watershed, which is home to an endangered freshwater mussel. A progression of monitoring studies were conducted to determine the effect of construction on Swift Creek water quality (turbidity and total suspended solids (TSS)) and sediment basin performance. The first monitoring campaign investigated sediment basin performance on the active construction site of I-540 and tracked PAM application. The two other monitoring campaigns investigated Swift Creek water quality (1) on a daily basis, and (2) on a storm event basis. In general, as water moved from the first baffle to the skimmer, the turbidity and TSS of the water decreased. When PAM was consistently used, water being discharged from the basin had low turbidity (averaged 56 NTU). Sediment basins without consistent PAM application were discharging very turbid water (over 700 NTU). Swift Creek monitoring showed the creek was very flashy and the stream level changed a lot during storm events. However, water quality of the creek did not seem to be impacted by the construction of I-540 despite the sediment basins discharging turbid water. Swift Creek water quality appears to be more related to stream level. It is possible the turbid water from the construction site is diluted in the creek when the stream levels increases during storm events.

There is also interest in using wildflowers as a vegetation cover on highways. Wildflowers provide food and habitat for pollinator insects as well as many other environmental benefits. New construction areas are of particular interest as bare subsoil on exposed slopes need to be stabilized with vegetation to prevent erosion. Little is known about optimal condition to get wildflowers to grow on roadsides and what mixes work best. Two field experiments were designed to develop wildflower mixes for roadways and optimize soil amendments for wildflower growth. The first field experiment investigated wildflower, grass, and wildflower-grass mixes with and without compost and with and without fertilizer. Twelve month after plot establishment, all vegetation covers performed similarly when compost or fertilizer was used. It was additionally found that compost can be used without fertilizer to establish grass-wildflower mixes. Compost additionally increased the infiltration rate, which is imperative on roadways that receive higher volumes of runoff. The second field experiment was able to get grass-wildflower mixes established on a 3:1 slope. Excelsior matting worked better as a ground cover for wildflowers and grass-wildflower mixes. Overall, grass-wildflowers mixes with excelsior matting are a viable option for less steep slopes. Compost additionally can be used without fertilizer and still get strong vegetation cover with grass-wildflower mixes.

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INTRODUCTION

Soil erosion is a major problem at the global and local level. The United States Environmental Protection Agency estimates that soil loss rates from construction sites are 10 to 20 times those of agricultural lands (USEPA, 2003). Construction and widening of highways results in large areas of exposed soil which have high erosion rates. Best management practices (BMPs) are implemented on construction sites to slow the flow of runoff, so sediment can settle out and remain on the construction site. In North Carolina, BMPs have been optimized over the years to settle out larger sized particles, but finer sized particles remain a problem in construction site discharge.

Another way to reduce sediment loads is to have rapid and healthy vegetation establishment. Typical vegetation on construction sites include various grass seed mixes. In North Carolina, grass mixes are chosen based on the region in North Carolina and the season of planting. There has been increased interest in finding alternatives to grass such as wildflowers. Wildflowers can serve the purpose of erosion control, pollinator habitat, and be aesthetically pleasing to drivers. Wildflowers often have a deep rooting system, which can potentially help with infiltrating stormwater coming from roads.

Results of Literature Review

Construction sites are required to have a sediment and erosion control plan, which include a diversity of practices to intercept and treat runoff prior to being discharged. Practices can include wattles, check dams, and sediment basins. Current practices are good at settling out larger sized particles, but finer particles are often not captured in these practices. It is estimated that trapping efficiencies greater than 90% are needed to meet water quality standards, but this rate is rarely met (Ward et al., 1980). In fact, a recent study found even >90% retention will not substantially reduce turbidity from fine particles (McCaleb and McLaughlin, 2008)

Flocculants can be used to promote clumping of soil particles and are widely used in other industries such as water treatment. Specifically, polyacrylamide (PAM) has been found to be an effective soil flocculent to improve suspended sediment capture (Bhardwaj et al., 2008; Bhardwaj and McLaughlin, 2008; Kang et al., 2015; Kang and McLaughlin, 2016; McLaughlin et al., 2009a; McLaughlin et al., 2009b; McLaughlin and Bartholomew, 2007). The PAM can be placed in channels and pipes leading to sediment basin to dose the turbid runoff and promote clumping of suspended sediments.

Turbid discharge to natural water bodies can alter the aquatic environment and have negative effects on aquatic organisms. The use of PAM on construction sites can significantly reduce sediment loads going to natural water bodies. Testing on freshwater mussels (an organism sensitive to turbid water) in North Carolina found PAM not to be toxic to freshwater mussels (Buczek et al., 2017, 2018). Thus, the use of PAM to reduce sediment in discharges from construction sites is encouraged. However, *there have been no studies to quantifying how effective PAM is with the currently installed BMPs for North Carolina.*

The construction of roadways results in physically and hydraulically degraded soils that limit stormwater infiltration, increase runoff volume, and accelerate soil erosion (Crogger, 2005; Gregory et al., 2006; Kelling and Peterson, 1975; Mohammadshirazi et al., 2017; Violin et al., 2011). Vegetation is a crucial part of stormwater control measures (SCM). The rapid establishment of vegetation cover is the most widely used erosion control practice along roads and highways to reduce the impacts of stormwater runoff (Haynes et al., 2013). It is a relatively inexpensive, effective, and a long-term solution to soil stabilization and erosion control on roadsides.

The selection of appropriate vegetation is a vital factor for soil stabilization and erosion control in roadside soils because inappropriate vegetation species may provide poor vegetation cover and that may cause massive soil erosion. Vegetation types depend on factors such as climate, soil, slope, management practices, and growing time (Arnold et al., 1992).To maintain infiltration rates, and perennial species can be selected for permanent ground cover since deep-rooted perennials can provide additional structural support for the soil. Single-species plantings are more susceptible to disease, insects, and extreme weather than mixed stands of vegetation. Therefore, mixtures of quick growing annual, multiple perennial, and 1-2 legume species should always be considered for soil stabilization and erosion control.

Although various grass mixtures are most commonly used as vegetation covers in North Carolina, the NCDOT has been incorporating wildflower areas since 1985 as part of the highway beautification program (NCDOT, 2012). Compared to grass, wildflowers require less frequent mowing, with only one to two mowings per year. Wildflowers have been shown to provide ecosystem services to the local environment such as pollinator habitat, climate regulation, and improved soil and air quality (Aldrich, 2002; Norcini & Aldrich, 2004).

Pollinators are essential to our well-being, food supply, and the health of ecosystems. However, pollinators are experiencing declines due to a loss of habitat, the spread of disease, overuse of pesticides, and various other factors. Declines in pollinators threaten the viability of our agricultural productivity and put the health of natural ecosystems at risk. Planted wildflowers along highways, median strips, exit ramps, etc., can provide habitat for pollinators species. Roadsides also help pollinators to move through landscapes by linking fragmented habitats. The roadsides themselves give refuge to pollinators in otherwise inhospitable landscapes (Billeisen et al., 2022; Blackmore and Goulson, 2014; Hopwood, 2008). With the right conditions, roadsides can support a diversity of generalist pollinators, including bumble bees, honey bees, and butterflies, as well as rare or federally listed species.

Wildflowers are often outcompeted by weeds from the seed bank in the topsoil or from nearby stands. However, on construction sites, the topsoil is removed, so wildflowers have a better opportunity to get established (May et al., 2017). Previous research in North

Carolina has demonstrated that wildflowers improved soil infiltration rate compared to NCDOT grass mixes up to 2.5 years after planting (Alshraah, 2020). Wildflower plots also maintained their low bulk density and high infiltrations rates longer compared to grass plots since mowing occurred once a year in wildflower plots (Alshraah, 2020). However, this research was conducted at research stations. Having wildflower trials on construction sites is necessary to understand how they can provide erosion control. Optimal wildflower mixes and rates are necessary to get rapid and strong vegetation cover and to reduce costs associated with seeds. *There are no studies optimizing wildflower mixes for quick establishment and reducing erosion on newly graded sites.*

The NCDOT has recently updated their BMPs to include compost incorporation to roadside soils. Documented changes in soil physical properties in compost amended urban soils have included bulk density, infiltration rate, hydraulic conductivity, water content, aggregate stability, and porosity. These beneficial effects are interactive and are attributed to the compost materials applied and the amount of OM in the compost feedstock (Crogger, 2005; Kranz et al., 2020).

Previous research in North Carolina has found compost incorporation at 30% compost by volume to supported dense and vigorous vegetation, which can reduce erosion (Kranz et al., 2022). The study also found that 10-50% compost application also significantly increased the infiltration rate of the soil. Increased infiltration rates are necessary for roadway stormwater management. However, fertilizer was used alongside compost application as per NCDOT guidelines (2015). Compost is a source of nutrients and can provide enough nutrients to vegetation. Using compost without fertilizer could be even more cost saving for NCDOT. *There are no studies on the effects of compost on vegetation establishment either with or without added fertilizer or the response of wildflowers to compost incorporation.*

Report Organization

The main body of this report includes a summary of the methods and results for the experiments. There were three monitoring experiments related to the construction of I-540 and water quality. The first study included monitoring of sediment basin water quality (turbidity and TSS) on the active I-540 construction site. The second study involved PAM distributed on wattles leading to a sediment basin, and monitored the change in water quality in the sediment basin. The third study was monitoring Swift Creek water quality on a daily basis and storm event basis to see if construction actives from I-540 impacted water quality. Next, there were three experiments to explore grass and wildflower ground cover options on construction sites. The first was a field experiment at a research station looking at the effects of grass and wildflower mixes, compost with and without fertilizer, on ground cover and soil properties over several years. The next two were field experiments on construction sites focusing on ground cover (excelsior blanket vs. hydromulch) effects and grass or wildflowers alone or mixed as vegetative covers. Following the description of research activities, we include a summary of the main findings and associated recommendations.

In addition to these main sections of the report, we have included three appendices. The first appendix has additional turbidity, TSS, and changes over time for each sediment basin for each storm monitored. The second appendix has supplemental Swift Creek stream level, turbidity, and TSS for each storm event monitored. The third appendix summarizes germination studies on wildflower mixes and pollinator counts.

MONITORING SEDIMENT BASIN WATER QUALITY ON AN ACTIVE CONSTRUCTION SITE

One objective of this monitoring was to compare water quality being discharged from the basins on the I-540 construction site to water in Swift Creek, which cuts through the construction site. Swift Creek is home to an endangered mussel species, and excess sediment loads could potentially damage habitat for them. For this study, water quality refers only to turbidity and total suspended solids (TSS). In addition, the condition of the sediment and erosion control practices and activities in each watershed were noted relative to basin discharge water quality. The monitoring is summarized below.

Materials and Methods

The monitoring was conducted during the construction of I-540 near Raleigh, NC. Multiple basins were monitored from March 2020 to December 2022. The elevation and topography varied between basins and changed frequently as construction progressed. The size of the basin also varied between basins depending on the design watershed and potential runoff. Sediment basins were designed, constructed, and maintained by an NCDOT contractor.

Automatic samplers (ISCO 6712 Portable Sampler, ISCO, Lincoln, NE) were installed at each sediment basin to take samples from the first baffle and the skimmer (Figure 1). While sampling at the inlet of the basin would have been preferred, we avoided that location due to previous experience with sampler clogging due to high sediment concentrations. Samples were taken when the level of the basin increased by 0.5 ft. The sampler was programmed to take a sample every hour the basin water level was above the 0.5 ft increase. A level sensor (HOBO RX2100, Bourne, MA) connected to a remote monitoring station (HOBO RX3000 Remote Monitoring Station, Bourne, MA) was placed on the first baffle to monitor the change in water level in the basin. Rainfall data were collected from a tipping bucket rain gauge (HOBO, Bourne, MA). In most cases, two basins were monitored simultaneously where there was active grading.

Samples were collected after each qualifying storm event (>0.5 ft rise in basin) and analyzed for turbidity and TSS. TSS was determined by filtration (Clesceri et al. 1998) using 90 mm glass fiber filters (ProWeight, Environmental Express, Mt. Pleasant, SC). Turbidity was measured according to the USEPA standard method 180.1 (O'Dell 1993). Averages, minimums, and maximums for turbidity and TSS were calculated for each storm event per basin. For each sediment basin, a storm-weighted average was calculated (Equation 1).

$$Storm - weighted\ average = \frac{avg_1 \times n_1 \times\ avg_2 \times\ n_2 \times\ avg_n \times\ n_n}{n_1\ +\ n_2\ + n_n}$$

where avg is the average value for the storm event, and n is the number of storms monitored for the basin. This is a way to weight the data according to the number of storm events each basin received during the monitoring period.

Results and Discussion

Sediment Basin and Watershed Monitoring

Each sediment basin had a different watershed and different construction activities during the monitoring period. This section is a summary of the watershed activities around each basin as it relates to the water quality results discussed below. Basin numbers are given in order of construction progress (i.e., basin 1 was the first basin we monitored at the start of construction, and basin 7 was the last basin we monitored near the end of the project).

<u>Sediment Basin 1 and 2</u>

Basin 1 and 2 were the first sediment basins monitored during the start of construction on I-540. Monitoring started in March of 2020 and ended in August of 2020 (Figure 2 & 3). Basin 1 was located next to a privately owned home and off 10332 Jordan Road, Raleigh, NC. PAM was applied consistently to wattles in the ditch leading to basin 1 to see how PAM application alters turbidity and TSS loads. Basin 2 was located off a Ten Ten Road at the corner of Benson Road, Raleigh, NC next to privately owned homes. Ditches leading to basin 2 did not receive PAM applications from NCSU staff.

Much of the area around basin 1 and 2 was covered with grass or an erosion control fabric during the monitoring period. Ditches were generally lined with an erosion control fabric and well maintained. Very little earthwork or tree removal was occurring in these basin watersheds (Figure 4 & 5). Compared to all the basins monitored in this project, basin 1 had the lowest average turbidity (56 NTU) and TSS (58 mg/L) followed by basin 2 (244 NTU and 140 mg/L) (Table 1). It is likely that the minimal earthwork and good ground cover led to lower sediment loads entering the basins. Basin 1 received PAM applications which resulted in a reduction in turbidity and TSS compared to basin 2, which received no PAM applications from NCSU staff. The PAM application led to a 4X reduction in turbidity and a 2.5X reduction in TSS. However, the basin size and watersheds were not similar, so it is hard to directly compare these results.

<u>Sediment Basin 3 and 4</u>

Basin 3 and 4 were the second set of basins monitored. Monitoring started in July 2020 and ended in March 2021 (Figure 6 & 7). Basin 3 and 4 were located off of the Benson Road construction entrance on the opposite side of the construction trailer and parking lot. The basins were located next to each other and were of similar size (Figure 8). Neither ditches leading to the basin had consistent evidence of PAM application, but occasionally PAM was applied by NCSU.

More ground cover and trees were present at the start of monitoring compared to the end. Ditches were well maintained at the start of monitoring, but their condition deteriorated over time. This can be explained by the progression of construction and increased amount of earthwork happening in the basin watersheds. Due to the increased earthwork in the basin watershed, turbidity and TSS were higher compared to basin 1 and 2. As grading activities progressed, more runoff entered the basins without passing through the ditches where PAM treatment was possible. Average turbidity for basins 3 and 4 were 791 NTU and 768 NTU, respectively. Average TSS for basins 3 and 4 were 494 mg/L and 527 mg/L respectively (Table 1).

Sediment Basin 5

Basin 5 was the third basin set to be monitored. Monitoring started in June of 2021 and ended in June of 2022 (Figure 9). Basin 5 was located off of the Ten Ten Road construction entrance about halfway down the construction area next to a private barn. Ditches leading to the basin did not receive consistent PAM application, but evidence of PAM application was found occasionally. The basin was resized in February of 2022 to accommodate greater drainage area due to grading activities.

Little construction activity was happening when the monitoring of basin 5 started. Several months later major earthwork and grading activities started. Basin 5 started out as being level with the ground around it and having grass cover. By the end, it was at the bottom of a 2:1 slope with lots of soil eventually covered by excelsior blankets (Figure 10). The slope was left uncovered while the final slope grade was being constructed, which took several months. The average turbidity and TSS were 667 NTU and 1,550 mg/L, respectively (Table 1). The TSS was the highest average TSS recorded for the basins monitored in this project. The major earthwork and being at the bottom of a steep slope could be the reason why TSS was extremely high.

Sediment Basin 6 and 7

Basin 6 (Figure 11 & 12) and 7 (Figure 13) were the last set of basins monitored. Monitoring started July of 2021 and ended in March 2022 (basin 7) and December 2022 (basin 6). The basins were located off of the Benson Road construction entrance near the end of the construction site on either side of the construction road. Ditches leading to the basins did not receive PAM application by NCSU, and evidence of PAM was rarely seen in these basins. Standing water was rarely seen in the first chamber of basin 6 (Figure 12), suggesting there could have been high infiltration at that location. Basin 6 was a larger basin which was going to be converted to a stormwater detention basin, while basin 7 was a smaller temporary basin.

Substantial earthwork was happening during the duration of monitoring of these basins. The earthwork created a steep slope next to basin 6 that was covered with straw and grass seed several times during the monitoring. The land in front of basin 7 was cleared shortly after monitoring started, and few erosion control practices were implemented to control the sediment from the cleared land into basin 7 (Figure 14). A soil stockpile started to be piled next to the entrance of basin 7, and it continued to grow over the course of monitoring. The soil stockpile was not covered with straw and grass seed like the soil stockpile next to basin 6. Basin 7 was often in need of repairs when samples were collected.

Basin 6 had the second highest average turbidity at 868 NTU and an average TSS of 723 mg/L. Turbidity levels of basin 6 were comparable to basins 3 and 4. Basin 7 had the highest average turbidity at 1,822 NTU and second highest average TSS at 803 mg/L (Table 1). The soil stockpile next to the entrance of basin 7 likely overloaded the basin with sediment as the basin was often filled with sediment when samples were collected. Such a soil stockpile should be moved or covered to prevent mass sediment transport. Alternatively, the sediment basin could be resized to accommodate the sediment loads.

Turbidity

Basin 1 had the lowest average turbidity with an average of 56 NTU, while basin 7 had the highest average turbidity at 1,822 NTU (Table 1). NCDEQ has set turbidity standards for freshwater streams at 50 NTU and trout streams at 10 NTU (Standards Table 061020199, NCDEQ, 2019). The turbidity in basin 1 is just above the limit for freshwater streams and would be unsuitable for sensitive water bodies such as trout streams. All other sediment basins are well above the 50 NTU recommendation, even for the minimum values. Turbidity should be further reduced before discharged into Swift Creek, which is a sensitive waterbody.

Turbidity generally decreases as stormwater moves through the sediment basin (Figure 15). When comparing the sample at the first baffle to the sample at the skimmer, the samples at the first baffle generally had a higher turbidity than the sample at the skimmer. The negative change indicates that the first baffle had higher turbidity than the sample at the skimmer. Basin 5 had a positive change indicating that the turbidity got worse as it moved through the sediment basin. This trend of increasing turbidity started to happen after the basin size was increased to handle more sediment loads (Figure 9, Figure A9). We noticed that the middle chamber of the basin was lower than the chamber with the skimmer. It is possible the resizing and regrading of the basin allowed for improper movement of water in the basin and sample collection. See Appendix 1 for individual sediment basin turbidity loads. Overall, the sediment basins reduced the sediment loads in the stormwater within the basin, but not as much as expected (or needed) in a sensitive waterbody. Because we did not try to sample inflow until the first baffle to avoid clogged intake tubing, the reduction in turbidity is likely underestimated.

Total Suspended Solids

Basin 1 had the lowest average TSS at 58 mg/L, and basin 5 had the highest average TSS at 1,550 mg/L (Table 1). The average TSS of basin 5 is about double the average TSS of the second highest average TSS from basin 7 (803 mg/L). Similarly, the second lowest average TSS (basin 2, 140 mg/L) is about double the lowest average TSS (Table 1). Generally, basins that had higher turbidity had a higher TSS. See the appendix for individual storm event sediment basin TSS loads. As stated for turbidity, because we did not try to sample inflow until the first baffle to avoid clogged intake tubing, the reduction in TSS is likely greatly underestimated.

The TSS largely decreases from the first baffle to the skimmer, as can be seen in the negative change for basins (Figure 16). Basin 6 was the only basin to have a positive change, indicating the stormwater gained TSS as it moved through the basin (Figure A12). This basin was monitored for about 18 months. During this time, there were only two storm events that got samples from both the first baffle and skimmer. Basin 6 rarely had samples in the first chamber, indicating that the water was moving rapidly through the basin or infiltrating (Figure 12). Only very large storm events (hurricanes) allowed enough water to accumulate in the first chamber to get samples, which likely skewed the data in addition to the low number of comparisons.

Table 1. Sediment basin water quality.

		Turbidity Average (NTU)			TSS Average (mg/L)		
Basin	**Number of storms**	**Min.**	**Max.**	**Average**	**Min.**	**Max.**	**Average**
1	6	19.7	122.0	56.1	23.3	104.9	57.7
2	7	103.1	454.9	243.6	40.8	297.1	140.4
3	24	358.2	1251.9	790.9	249.3	774.2	494.1
4	16	182.3	1328.7	767.7	122.8	1420.5	527.4
5	11	215.6	1307.2	666.8	167.6	3662.3	1550.1
6	10	307.3	1556.5	867.8	387.6	1476.2	722.5
7	4	470.9	10850.3	1822.4	268.8	3674.3	803.3

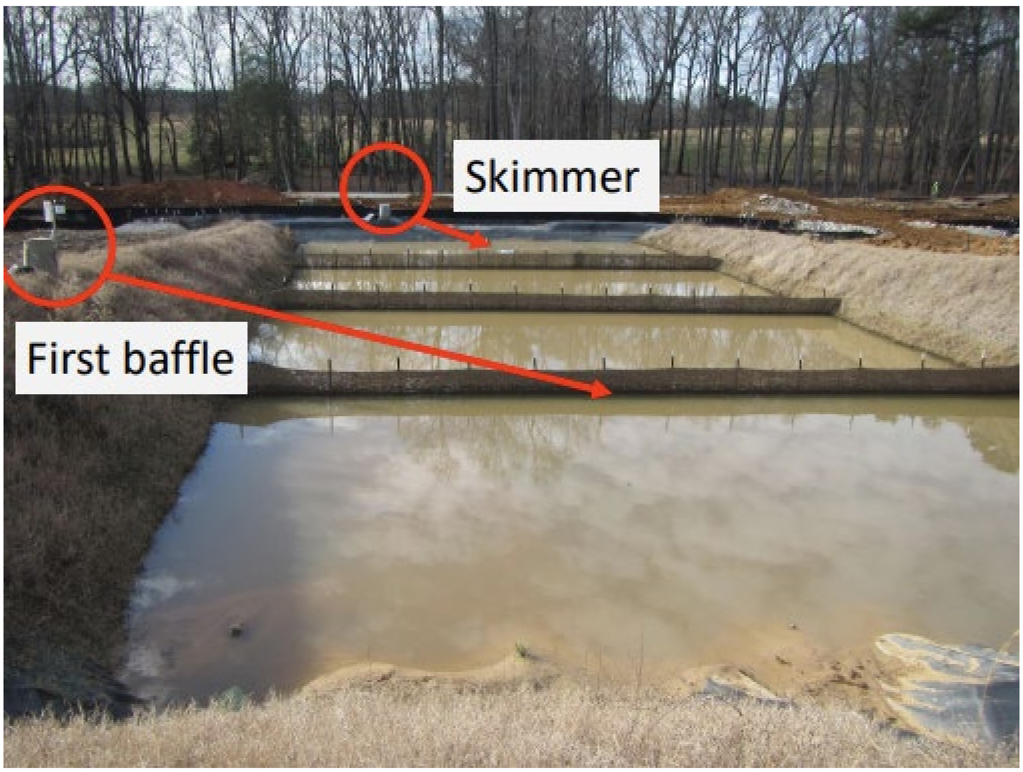

Figure 1. Sediment basin sampler setup.

Figure 2. Basin 1 at the start (March 2020) and end (July 2020) of sample collection.

Figure 3. Basin 2 at the start (March 2020) and end (July 2020) of sample collection.

Figure 4. Drone image of basin 1 in April of 2020.

Figure 5. Drone image of basin 2 in April of 2020.

Figure 6. Basin 3 at the start (July 2020) and end (March 2021) of sample collection.

Figure 7. Basin 4 at the start (July 2020) and end (March 2021) of sample collection.

Figure 8. Drone image of basin 3 and 4 in January 2021.

Figure 9. Basin 5 at the start (June 2021) and end (June 2022) of sample collection.

Figure10. Steep slope located next to basin 5.

Figure 11. Basin 6 at the start (July 2021) of sample collection. Note there is no soil stockpile located next to the basin at this time.

Figure 12. Basin 6 at the end (December 2022) of sample collection. (Left) Looking at the first baffle (first chamber), and (Right) looking at the skimmer (last chamber).

Figure 13. Basin 7 at the start (July 2021) and end (March 2022) of sample collection.

Figure 14. Basin 7 evolution of soil stockpile growing at the entrance of the basin.

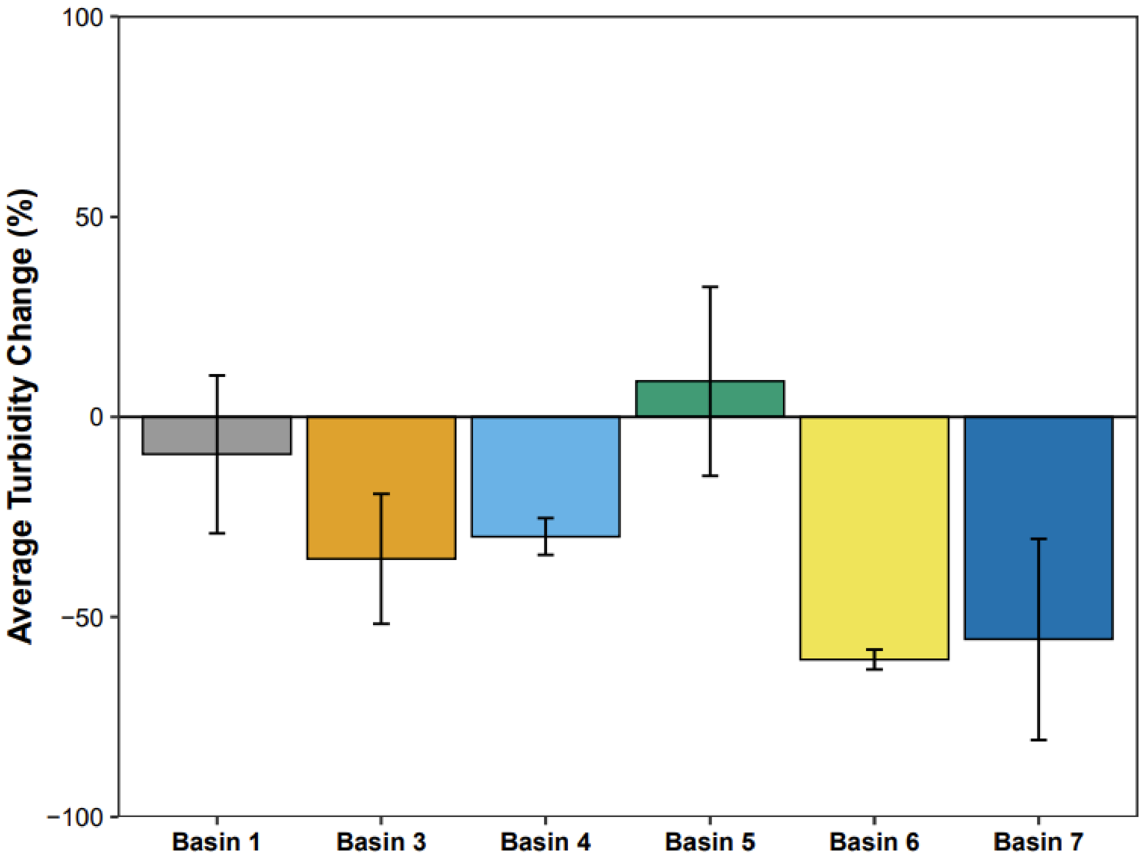

Figure 15. Average change in turbidity for the sediment basins. Negative change means the first baffle sample had higher turbidity than the skimmer sample. Error bars ± 1SE. n=number of storms from Table 1.

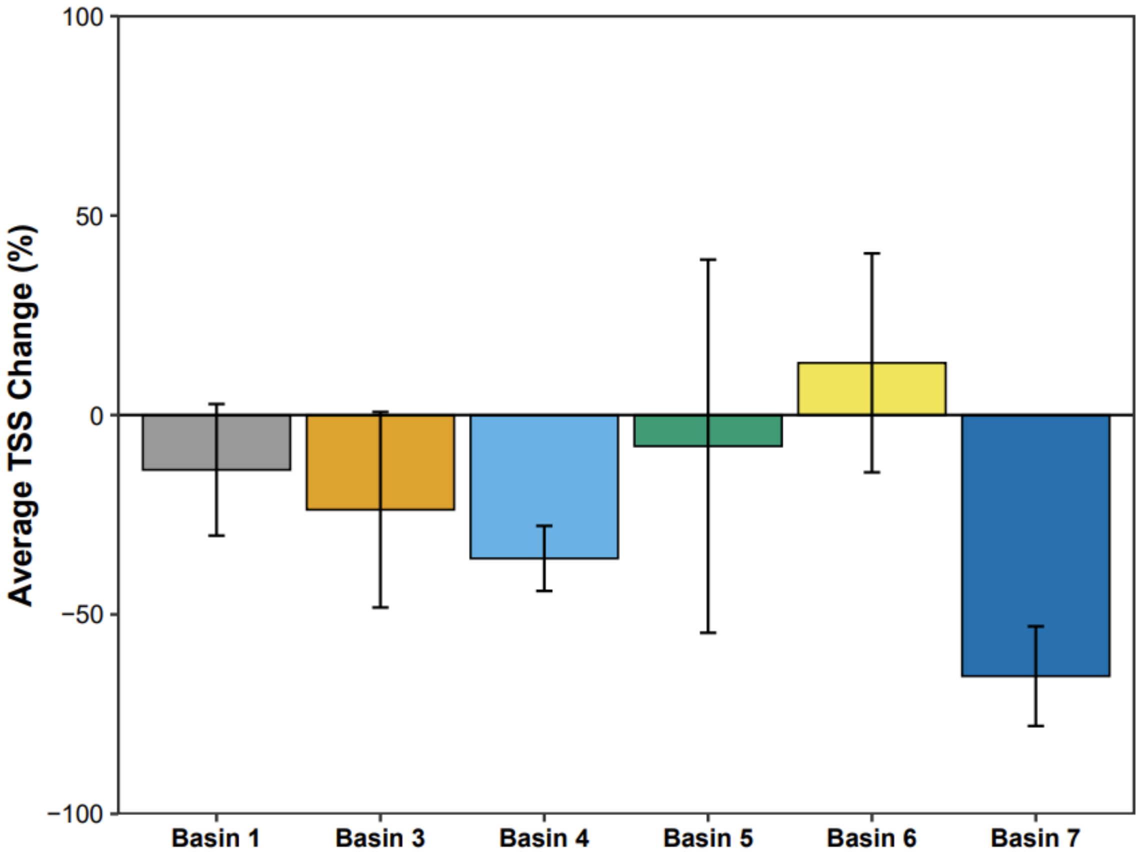

Figure 16. Average change in total suspended solids (TSS) for the sediment basins. Negative change means the first baffle sample was higher than the skimmer sample. Error bars ± 1SE. n=number of storms from Table 1.

PAM APPLICATION TO REDUCE TURBIDITY

The objective of this project was to put PAM out on wattles leading to sediment basins to maximize turbidity control in sediment basins. We did not see evidence of PAM being applied to the basin watersheds on this project, although it is possible it was just not visible where we looked.

Materials and Methods

Most of this part of the project was conducted during the construction I-540 near Raleigh, NC. Basin 1 was chosen as the chemical treatment basin (Figure 17). It was monitored from March 2020 to August 2020. The sediment basin was designed, constructed, and maintained by an NCDOT contractor.

Automatic samplers (ISCO 6712 Portable Sampler, ISCO, Lincoln, NE) were installed at the sediment basis to take samples from the first baffle and the skimmer. Samples were taken on a storm event basis when the level of the basin increased by 0.5 ft. The sampler was programmed to take a sample every hour the basis water level was above the 0.5 ft increase. A level sensor (HOBO RX2100, Bourne, MA) connected to a remote monitoring station (HOBO RX3000 Remote Monitoring Station, Bourne, MA) was placed on the first baffle to monitor the change in sediment basin level. Rainfall data were collected from a tipping bucket rain gauge (HOBO, Bourne, MA).

A second site was established late in this grant project to further explore PAM application to reduce turbidity. This NCDOT project was at the I40-NC86 interchange where the exit and entrance ramps were being moved. At this site, no automatic samplers were used but instead stage samplers were placed in three basins, one of which was a 3-cell tiered basin. The samplers were attached to fence posts placed after the last baffle so that the lower bottle collected the rising water after approximately 1" of rise and the upper bottle after approximately an 8" rise.

PAM 705 (Applied Polymer Systems, Woodstock, GA) was used as the flocculating agent. A granular form of PAM was applied in 4 oz increments to each wattle in the ditches leading to basin 1 (Figure 18). The ditch and wattles were checked after each qualifying storm event to see if more PAM needed to be applied. For the NC86 site, PAM was also applied inside slope drains and on inlets to each basin.

Water samples were collected after each qualifying storm event and analyzed for turbidity and TSS. Averages, minimums, and maximums for turbidity and TSS were calculated for each storm event for basin 1. For the NC86 basins, only turbidity was measured.

Results and Discussion

Turbidity and Total Suspended Solids: Basins 1 and 2 on I-540

As noted in the previous section, basin 1 had the lowest average turbidity. Samples collected at the first baffle averaged 74 NTU and 56 NTU at the skimmer (Figure A1). All storm events had a negative percent change, indicating the skimmer was discharging cleaner water than at the first baffle, except for 1 storm event (08/2020) (Figure A15). These turbidity values were much lower than the other basins monitored in the previous section and compared to most other basins monitored on NCDOT construction sites.

The TSS of the basin averaged 72 mg/L at the first baffle and 58 mg/L at the skimmer (Figure A2). Similar to turbidity, the TSS of basin 1 had a negative percent change meaning there was less TSS in the samples at the skimmer compared to the first baffle. There was one positive change in TSS (08/2020), which was the same date where there was a positive change in turbidity (Figure A16). The TSS loads measured were well below the amount of sediment from other sediment basins monitored in the previous section and from other NCDOT monitoring projects.

The low turbidity values can be attributed to the PAM applied in the ditch leading to the sediment basin. The PAM reacted with the sediment in the ditch, and once in the sediment basin, the flocs of soil could settle out. As the water moved though the sediment basin, there was additional sediment trapping. Additionally, there was very little earth work going on next to basin 1 during the monitoring period (Figure 4 & 17). It is possible there was just less sediment loads going into the sediment basin due to lack of exposed soil. The combination of PAM and little earth work allowed this basin to have a low turbidity and TSS load.

As mentioned in the section above, basin 1 and 2 were monitored at the same time, but they were located in different areas, had different watershed sizes, and the basis were different sizes. The PAM application led to a 4X reduction in turbidity and a 2.5X reduction in TSS on average (Table 1). There was no sediment basin of a similar size in the area that we could have compared these results to. Ideally, we would have two sediment basins of similar size, receiving similar amount of sediment, where we could put PAM on one. This would have allowed for direct comparison of turbidity and TSS reduction with the use of PAM, although differences in watershed activities might have also complicated comparisons.

Turbidity: I-40/NC86 Interchange

In general, this site was very well managed and the sediment control devices constructed properly (Figure 19). The first samples were obtained several days after a rain event on March 1, 2023 and the turbidity levels were similar to those found in the basins a week earlier (Table 2). NCSU staff applied PAM after that storm to check dams, basin inlets, and pipes, and turbidity levels dropped considerably over the subsequent storms even with the addition of stockpiles and other disturbances (Figure 20). This suggests that the combination of a well-managed site, good sediment control device construction, and distributed flocculent applications can reduce turbidity substantially.

Table 2. Turbidity at the I40/NC86 project site basins. Basins 3-1 – 3-3 are cells in a 3-tiered basin, from upper to lower respectively. Rainfall for each sample collection period is shown in parentheses.

Basin	Bottle	2/24/23 (Grab)	3/1/23 (0.89")	3/12-27/23 (1.83")	4/7-9/23 (4.68")
		Turbidity (NTU)			
A	Lower	130	163	43	86
A	Upper	--	153	--	109
B	Lower	200	229	22	108
B	Upper	--	228	--	168
C-1	Lower	370	338	46	26
C-1	Upper	--	330	--	--
C-2	Lower	360	316	93	36
C-2	Upper	--	275	--	--
C-3	Lower	--	42	110	120
C-3	Upper	--	--	176	159

Figure 17. (Left) The ditch leading to basin 1, and (Right) basin 1.

Figure 18. Polyacrylamide (PAM) application on wattles leading to basin 1.

Figure 19. Basin A and Basin C-3 (tiered) at the I-40/NC86 site.

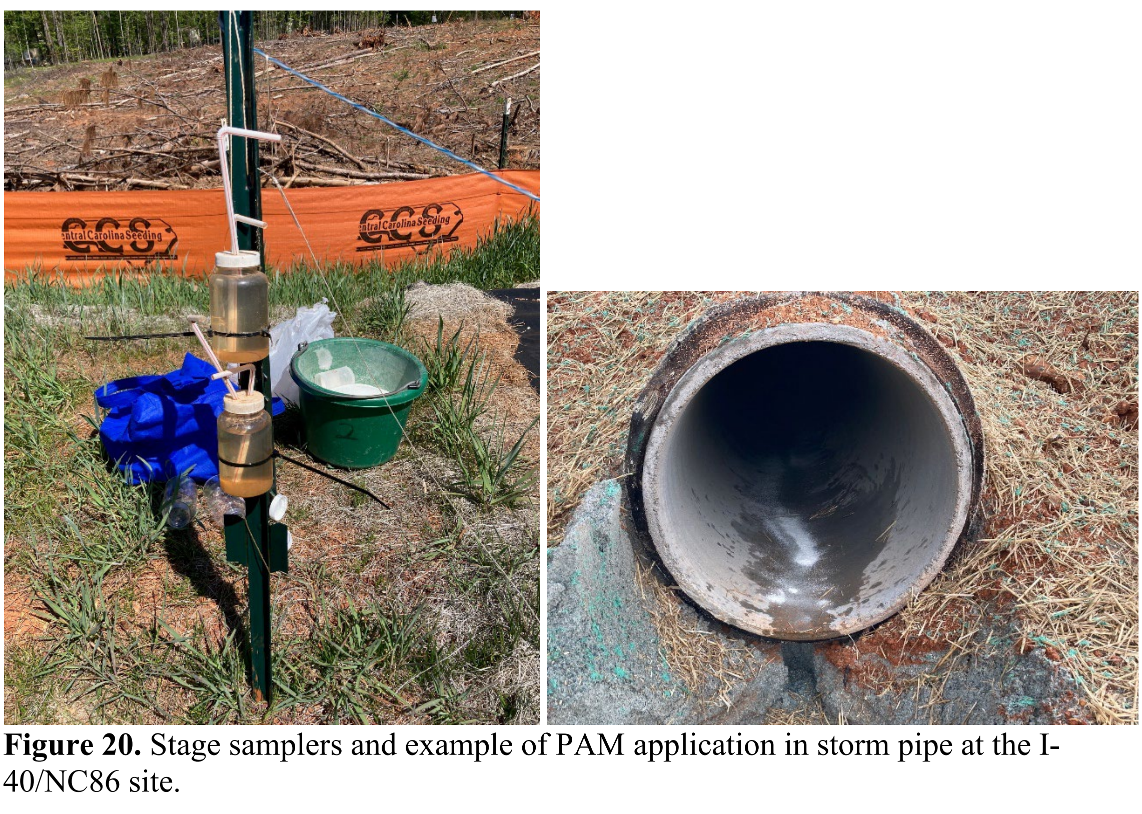

Figure 20. Stage samplers and example of PAM application in storm pipe at the I-40/NC86 site.

MONITORING SWIFT CREEK WATER QUALITY DURING HIGHWAY CONSTRUCTION

The objective of this monitoring was to see if construction of I-540 impacted the water quality of Swift Creek, since there was going to be a highway bridge built over Swift Creek. Swift Creek is home to an endangered freshwater muscle and additionally sediment loads could further threaten their existence.

Materials and Methods

The portion of Swift Creek we were interested in was where I-540 is being constructed, which is near southeast Raleigh, NC (Figure 21). Monitoring upstream and downstream of the construction area started in December of 2018 and ended in December of 2022.

Automatic samplers (ISCO 6712 Portable Sampler, ISCO, Lincoln, NE) were installed at three locations along the creek: (1) upstream of the construction –"upstream", (2) downstream of the construction – "downstream 1", and (3) downstream of the construction – "downstream 2" (Figure 22). Downstream 2 sampler was placed further downstream than downstream 1 to see if water quality parameters changed with distance from the construction site.

Two automatic samplers were installed at upstream and downstream 1 to take samples: (1) every day at the same time and (2) on a storm event basis. One sampler was installed at downstream 2 to take a sample every day at the same time. Samples in the event basis sampler were taken when the level of the creek increased by 1 ft. The sampler was programmed to take a sample every hour the creek water level was above the 1 ft increase. A bubbler tube was installed on the sampler to take stream level measurements. Samples were collected after each qualifying storm event or every 24 days and analyzed for turbidity and TSS as in the previous sections.

Results and Discussion

Daily Monitoring

The purpose of the daily monitoring was to give a baseline of how Swift Creek water quality and stream level changes on a daily basis. On average, all locations had a similar average daily turbidity of 30 to 35 NTU (Table 3, Figure 23). The maximum turbidity was 1,653 NTU (upstream), 656 NTU (downstream 1), and 588 NTU (downstream 2) (Table 3). Upstream of the construction site had nearly 2.5 times the maximum turbidity of the downstream samples. This indicates that there is a wide range of turbidity in Swift Creek regardless of construction activities. Construction activities did not seem to impact the turbidity of the creek.

All locations had a similar average daily TSS of 32 to 45 mg/L (Table 3, Figure 23). Maximum TSS values were 506 mg/L (upstream), 2,302 mg/L (downstream 1), and 549 mg/L (downstream 2). The downstream 1 had a significantly higher maximum TSS value (4.5 times). However, the sediment in Swift Creek seems to be diluted back to upstream levels by the time water gets to the downstream 2 sampler. Construction activities might have been impacting the TSS levels of Swift Creek for a short distance after being discharged from the construction site.

The daily average Swift Creek level was similar between upstream (1.8 ft) and downstream 1 (2.1 ft) (Table 3). Downstream 2 was slightly lower averaging 1.4 ft. This was primarily due to the placement of the bubbler tube in the stream. The maximum daily stream values were 8.5 ft (upstream), 8.9 ft (downstream 1), and 7.8 ft (downstream 2). Again, upstream and downstream 1 have similar stream levels, but downstream 2 is about a foot lower than the locations above it. The minimum daily stream levels were 0 ft (upstream), 0.3 ft (downstream 1), and 0.1 ft (downstream 2). Upstream of the construction site, the creek dipped below the bubbler tube during dry periods over the monitoring period.

Daily monitoring showed that generally sediment concentrations did not increase as construction progressed closer to Swift Creek and as the bridge was being built over the creek (Figure 24). Construction activities did not seem to alter the level of Swift Creek and the level of the creek varied widely during the monitoring period.

Storm Event Monitoring

Storm event monitoring occurred at upstream and downstream 1. During the monitoring period, there were several tropical storms and hurricanes that passed in the Swift Creek watershed. There were Tropical Storm Arthur (5/20/20), Hurricane Sally (9/17/20), Hurricane Delta (10/11/20), Hurricane Lota (11/11/20), Hurricane Elsa (7/03/21), and Hurricane Ian (9/30/22).

<u>Turbidity</u>

The average storm event turbidity was 79 NTU (upstream) and 90 NTU (downstream 1) (Table 4). The minimum turbidity values were 0.3 NTU (upstream, storm date 6/10/22) and 1.8 NTU (downstream, storm date 4/18/22). The maximum turbidity values were 704 NTU (upstream, storm date 7/27/21) and 1,845 NTU (downstream, storm date 10/09/21). Downstream had 2.6 times the maximum turbidity level as upstream. Turbid discharge from the construction site could have been causing higher turbidity levels below the construction area. Neither of these maximum values came from a tropical storm or hurricane. This indicates that Swift Creek turbidity can fluctuate substantially during a storm event and it does not have to be an extreme storm event.

For example, the storm on 7/27/21 was a standard North Carolina summer rain. Upstream turbidity started at 48 NTU and peaked at 704 NTU (Table 5, Figure A50). Downstream 1 started at 71 NTU and peaked at 495 NTU. Upstream actually had substantially higher turbidity compared to downstream 1. The stream level increased by about 1 ft during this storm. Conversely, the storm on 10/09/21 had the opposite trend from above. Upstream turbidity started at 256 NTU and peaked at 587 NTU before declining to 59 NTU at the end of sample collection (Table 5, Figure A51). Downstream 1 started at 223 NTU and peaked at 1,845 NTU. The sample collected 1 hour after this peak turbidity was 259 NTU, and the turbidity at the end of sample collection was 71 NTU. The stream level increased by about 5.5 ft at both sample locations. Overall, there was no trend of upstream or downstream 1 having a higher turbidity compared to one another.

Total Suspended Solids

The average storm event TSS was 103 mg/L (upstream) and 115 mg/L (downstream 1) (Table 4). The minimum TSS values were 1.2 mg/L (upstream, strom date 11/20/21 and 11/23/21) and 16.5 mg/L (downstream 1, storm date 4/18/22). The maximum TSS values were 1,397 mg/L (upstream, storm date 10/09/21) and 917 mg/L (downstream 1, storm date 8/31/20). Maximum TSS values did not overlap with maximum turbidity storm dates or hurricane events. Again, this demonstrates that Swift Creek water quality can vary a lot within a regular rain storm.

The maximum upstream TSS storm started at its peak value of 1,397 mg/L before declining to 133 mg/L at the end of sample collection (Table 5, Figure A51). The downstream 1 TSS ranged between 207 and 214 mg/L for this storm. The stream level increased by about 5.5 ft at both sample locations. For the maximum downstream 1 TSS, it started at 191 mg/L and peaked at 917 mg/L three hours into the sample collection. By the end of sample collection, the TSS was 94 mg/L. For the upstream TSS during the 8/31/20 storm event, it started at 453 mg/L, peaked at 678 mg/L, and then declined to 90 m/gL at the end (Table 5, Figure A37). The stream level increased by about 7 ft at both locations. Again, there was no clear trend of upstream or downstream 1 having higher TSS compared to each other. In most cases, values flipped back and forth in the storm as to which one was higher, but the values were generally comparable to each other.

Swift Creek Stream Level

The average upstream and downstream 1 level was 4.5 ft and 4.7 ft, respectively (Table 4). For the upstream location, the minimum level was 0.3 ft and the maximum level was 9.5 ft. For the downstream 1 location, the minimum stream level was 1.4 ft and the maximum level was 9.1 ft. During the monitoring of Swift Creek, the stream level fluctuated a lot during many storm events, up to 8 ft. Swift Creek was flashier than other streams monitored in North Carolina (McLaughlin and Jennings, 2005). It was found that turbidity and TSS levels increased and decreased with the stream level, indicating stream levels play an important role in determining the amount of sediment in the stream (Figure A31, Figure A39, Figure A51). Despite being a flashy creek, turbidity and TSS levels were generally lower than other streams monitored in North Carolina (McLaughlin and Jennings, 2005). Swift Creek is in a highly suburban watershed. It is possible that the construction of suburbs has led to more water flowing into the creek and the highly variable stream levels observed. Updating the equations for estimating peak flow in Swift Creek is necessary as more development happens in the watershed.

Other Environmental Pressures

During the monitoring of Swift Creek, other environmental pressures were found on the creek besides potential sediment loads from constructions. First, Swift Creek level changed a lot during storm events. This caused stream bank erosion to happen at all locations monitored. In particular, the upstream site had the most stream bank erosion during the monitoring period (Figure 25). Over the course of one year, several feet were eroded and the samplers needed to be moved so they didn't fall into the creek.

Second, it was observed that the endangered freshwater mussels were being consumed, most likely by raccoons. Construction activities can eliminate habitat for various animals. While raccoons are well adapted to suburban and urban habitats, the effects of both highway construction and the development that follows on mussel predation should be considered.

Table 3. Swift Creek water quality and stream level from daily monitoring. Samples were taken every day at 8 AM from December 2018 to November 2019 (downstream 2) and December2022 (upstream and downstream 1).

	Turbidity (NTU)			**TSS (mg/L)**			**Level (ft)**		
Location	Min.	Max.	Average	Min.	Max.	Average	Min.	Max.	Average
Upstream	1.4	1652.9	32.4	1.4	505.9	31.9	0.0	8.5	1.8
Downstream 1	1.4	656.1	35.2	1.4	2302.5	44.9	0.3	8.9	2.1
Downstream 2	5.3	588.5	30.2	1.6	549.4	39.9	0.1	7.8	1.4

Table 4. Swift Creek daily water quality and stream level averaged by sample location.

		Turbidity (NTU)			**TSS (mg/L)**			**Level (ft)**		
Location	**Storm Events**	**Min.**	**Max.**	**Average**	**Min.**	**Max.**	**Average**	**Min.**	**Max.**	**Average**
Upstream	39	0.3	703.6	79.2	1.2	1397.0	103.3	0.6	9.5	4.5
Downstream 1	35	1.8	1845.4	90.5	16.5	917.1	115.3	1.4	9.1	4.7

Table 5. Swift Creek water quality and stream level by storm date. Storm on 5/20/20, 9/17/20, 10/11/20, 11/11/20, 7/03/21, and 9/30/22 were rainfall from Tropical storm Arthur, Hurricane Sally, Hurricane Delta, Hurricane Lota, Hurricane Elsa, and Hurricane Ian, respectively.

		Turbidity (NTU)			TSS (mg/L)			Level (ft)		
Storm Date	**Location**	**Min.**	**Max.**	**Average**	**Min.**	**Max.**	**Average**	**Min.**	**Max.**	**Average**
11/23/2019	Upstream	19.9	70.5	40.6	19.7	46.4	30.8	0.8	1.4	1.1
12/13/2019	Upstream	26.7	173.7	85.4	35.3	302.3	166.7	1.2	6.5	5.0
	Downstream	26.9	169.7	96.8	37.7	306.1	183.8	2.2	7.7	6.1
1/13/2020	Upstream	36.1	319.4	112.1	45.3	347.9	148.3	2.8	6.1	5.6
	Downstream	35.2	287.6	106.3	56.1	369.4	158.2	4.1	7.3	6.8
3/25/2020	Downstream	26.3	186.1	80.1	48.6	251.5	119.4	3.5	5.5	5.2
4/20/2020	Upstream	28.7	101.2	55.7	23.3	91.0	55.8	1.1	2.7	2.3
	Downstream	4.7	6.4	6.0	37.9	99.8	62.6	1.9	3.6	3.2
5/20/2020	Upstream	19.8	112.0	60.9	34.1	140.2	75.6	0.6	4.8	2.4
	Downstream	20.6	107.3	56.6	33.8	175.1	90.8	1.4	5.5	3.1
6/15/2020	Upstream	24.6	97.8	55.4	45.2	88.2	73.7	1.3	3.6	2.8
	Downstream	32.5	286.9	71.1	55.5	269.2	94.9	2.1	4.4	3.7
7/12/2020	Upstream	15.8	50.5	28.0	32.2	53.7	38.7	1.1	1.2	1.1
	Downstream	16.1	293.9	95.0	64.2	394.4	149.4	1.9	2.9	2.4
7/23/2020	Upstream	22.3	126.6	46.1	32.7	199.6	74.5	1.4	3.1	2.7
	Downstream	22.8	91.7	43.6	44.7	165.1	70.4	1.8	3.5	3.1
8/18/2020	Upstream	17.1	111.0	34.4	22.4	110.0	44.6	3.6	4.7	4.3
	Downstream	12.0	60.7	28.4	36.6	113.3	58.4	4.4	5.3	4.9
8/31/2020	Upstream	71.7	465.4	179.6	90.4	774.5	271.9	1.3	8.6	6.9
	Downstream	70.1	937.8	216.6	88.1	917.1	260.2	1.9	8.9	7.4
9/17/2020	Upstream	22.9	78.7	51.1	53.9	1030.4	587.3	2.1	5.4	3.9
	Downstream	21.7	72.5	47.3	61.3	108.6	77.9	2.5	6.0	4.3
10/11/2020	Upstream	9.7	184.8	58.8	33.3	234.0	81.3	1.6	4.2	3.6

	Downstream	23.6	227.4	63.4	32.9	248.0	83.6	2.2	4.8	4.1
11/11/2020	Upstream	24.5	285.0	127.2	55.2	343.7	156.9	2.1	8.7	5.1
	Downstream	30.2	297.0	134.4	86.0	352.1	211.1	2.6	9.1	5.6
11/30/2020	Upstream	24.4	154.2	60.3	36.3	155.7	72.0	2.9	6.3	5.5
	Downstream	24.0	149.8	61.8	44.7	189.4	97.8	1.6	2.1	1.7
12/14/2020	Upstream	16.3	81.4	43.4	19.4	60.2	36.9	3.4	4.6	4.3
	Downstream	24.0	101.7	48.6	23.9	77.8	48.2	3.0	4.4	4.1
1/9/2021	Upstream	19.1	52.2	34.8	21.3	27.7	23.4	4.9	5.1	5.0
	Downstream	10.4	70.0	41.5	37.4	117.8	66.4	4.7	5.0	4.8
1/28/2021	Upstream	63.6	120.4	88.4	37.1	92.1	64.6	4.9	5.2	5.1
1/31/2021	Upstream	34.0	201.1	77.6	39.4	157.3	81.3	6.0	7.5	7.2
	Downstream	35.6	213.1	85.3	42.2	251.3	112.6	5.8	7.6	7.2
2/27/2021	Upstream	18.7	52.7	34.1	25.2	44.8	32.3	4.8	5.2	5.1
	Downstream	26.9	88.2	48.8	77.7	165.1	116.7	4.5	5.1	4.9
3/28/2021	Upstream	19.8	90.0	43.1	34.6	83.7	53.0	3.6	6.1	5.0
	Downstream	33.9	121.4	63.2	74.3	106.0	88.0	3.3	6.0	4.6
6/5/2021	Upstream	10.5	31.5	20.3	22.0	38.3	29.3	2.4	2.4	2.4
6/11/2021	Downstream	14.1	87.3	49.5	64.0	114.0	92.3	2.2	4.6	4.0
7/3/2021	Upstream	18.0	75.3	40.1	30.2	57.1	46.9	2.8	4.0	3.6
	Downstream	18.0	60.2	38.7	50.4	74.3	62.3	2.7	3.7	3.4
7/27/2021	Upstream	48.0	703.6	251.2	91.7	127.3	109.5	1.9	9.1	4.3
	Downstream	70.9	495.5	186.2	115.4	124.1	119.9	2.2	3.0	2.5
10/9/2021	Upstream	58.9	587.2	215.3	133.6	1397.0	598.9	2.4	8.1	4.5
	Downstream	26.8	1845.4	278.0	207.3	214.3	210.8	2.0	7.6	3.9
11/20/2021	Upstream	5.7	62.2	16.7	1.2	3.3	2.1	3.9	4.0	4.0
11/23/2021	Upstream	6.0	26.6	12.1	1.2	3.3	2.1	5.5	6.5	6.2
1/3/2022	Upstream	17.5	327.2	93.7	16.1	110.9	59.0	--	--	--
	Downstream	16.1	110.9	59.0	36.3	144.7	83.4	2.4	8.1	6.2

1/16/2022	Upstream	26.5	234.8	81.6	28.2	178.5	87.5	5.6	7.9	7.3
	Downstream	39.0	177.3	91.3	59.6	243.0	139.7	4.5	7.0	6.4
2/7/2022	Upstream	48.8	455.7	125.6	16.2	34.9	26.8	4.4	4.7	4.6
	Downstream	55.8	481.9	205.2	27.4	63.7	45.1	3.3	3.6	3.5
3/12/2022	Upstream	39.4	295.7	130.6	42.9	249.0	108.5	3.5	6.8	6.2
	Downstream	46.7	192.9	114.8	50.9	311.1	124.6	2.7	6.0	5.4
4/1/2022	Upstream	56.8	192.9	114.8	24.2	71.3	38.2	6.1	9.5	6.6
	Downstream	49.3	167.4	93.7	43.1	93.5	62.9	5.5	6.1	5.7
4/18/2022	Upstream	39.2	318.7	117.5	26.1	241.7	85.4	3.7	5.7	5.1
	Downstream	1.8	222.6	112.3	16.5	162.6	73.9	2.9	4.9	4.2
5/8/2022	Upstream	21.3	243.0	88.1	13.6	26.5	20.1	2.9	3.9	3.7
	Downstream	17.1	185.1	99.2	22.7	39.5	29.7	2.6	3.7	2.7
5/24/2022	Downstream	24.1	215.0	65.1	49.6	254.5	123.6	5.3	8.3	7.1
6/10/2022	Upstream	0.3	41.1	8.8	6.6	28.0	15.6	4.2	4.4	4.3
	Downstream	12.7	311.1	119.2	31.4	203.1	103.0	--	--	--
8/12/2022	Upstream	15.1	142.4	105.3	52.8	389.6	168.0	--	--	--
8/21/2022*	Upstream	46.8	77.0	8.5	53.3	53.3	53.3	--	--	--
9/11/2022	Upstream	45.2	181.7	102.6	35.6	169.2	100.1	--	--	--
	Downstream	20.1	321.5	143.4	36.8	185.3	145.4	--	--	--
9/30/2022	Upstream	38.6	325.8	157.5	50.2	470.4	188.9	4.3	8.3	7.3
	Downstream	5.9	266.6	98.1	56.6	441.8	186.0	2.7	6.6	5.7
11/1/2022	Upstream	48.6	354.0	145.7	47.8	123.6	78.2	--	--	--
	Downstream	5.1	256.8	83.7	71.0	118.0	86.2	2.7	3.9	3.2

*There was 1 sample analyzed for TSS.

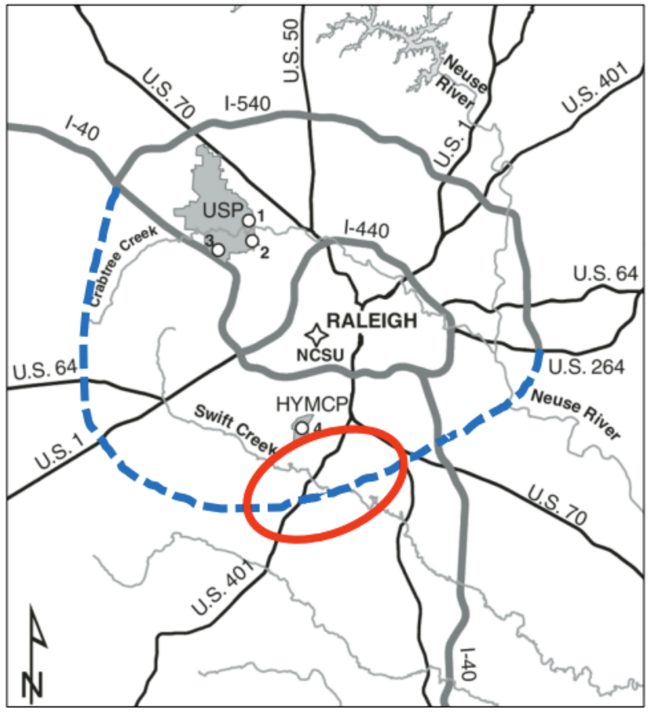

Figure 21. Map of interstate highways (thick grey lines) and streams (thin grey lines) in the Raleigh area. The dashed blue line is the intended construction of I-540. The red circle indicates where the construction site intersects with Swift Creek, and where the creek monitoring occurred.

Figure 22. Swift Creek sample collection sites.

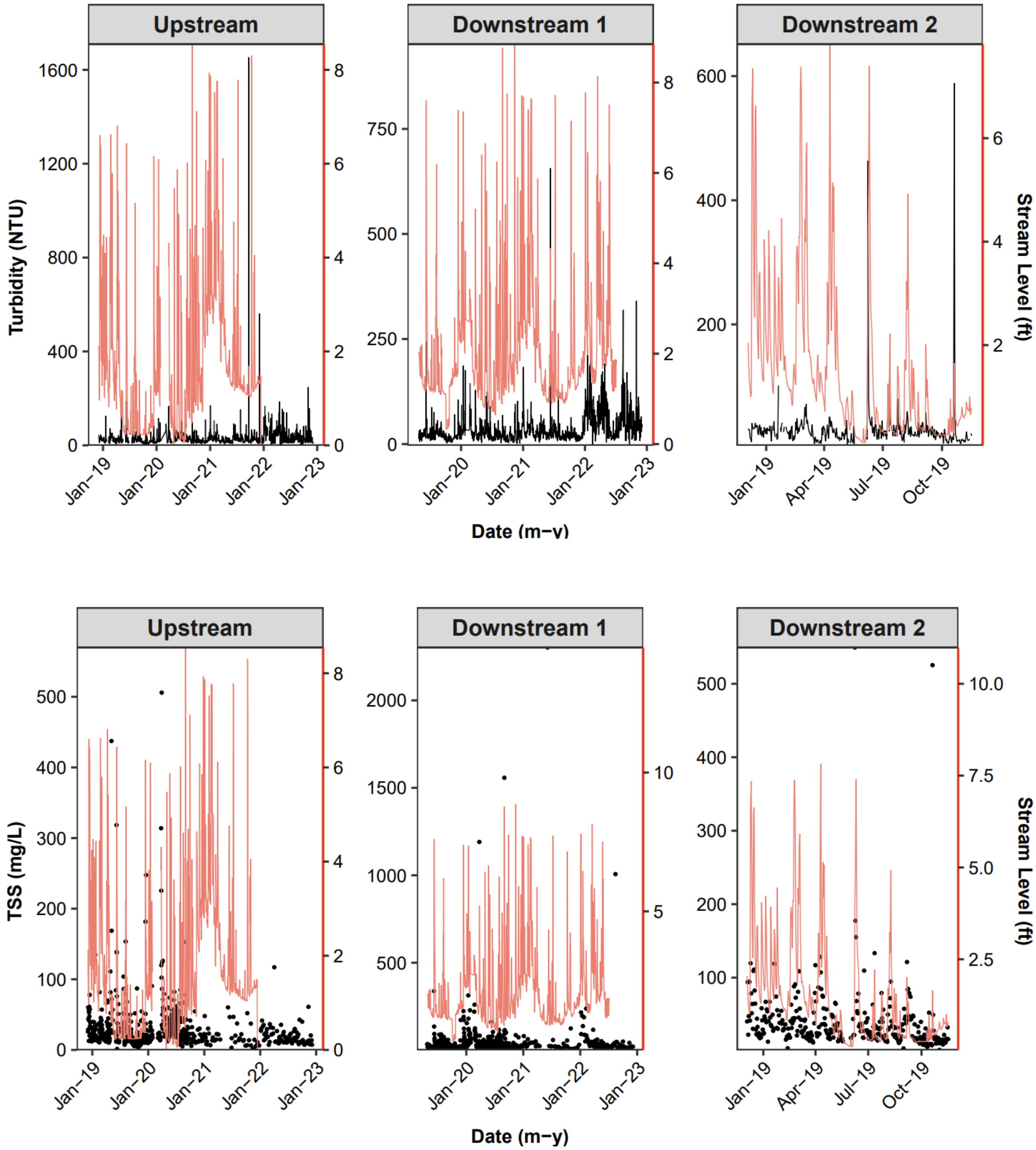

Figure 23. Swift Creek daily turbidity and TSS. The red line is Swift Creek level as noted by the red right-hand y-axis. Black line and black dots represent the turbidity and TSS respectively.

Figure 24. Construction progression of the bridge over Swift Creek.

Figure 25. Stream bank erosion on Swift Creek upstream of the construction site.

COMPOST INCORPORATION AND WILDFLOWERS TESTING FOR VEGETATION ESTABLISHMENT AND STORMWATER INFILTRATION

The objectives of this experiment were to (1) assess the impacts of compost incorporation on vegetation growth and stromwater infiltration, (2) evaluate the effectiveness of wildflowers as a vegetation cover, and (3) assess the interaction compost plus fertilizer on vegetation establishment.

Materials and Methods

The experiment was conducted at the Lake Wheeler Field Laboratory, Raleigh, NC. Plots were established in September 2021. The topsoil and vegetation were removed to expose the subsoil. Particle size analysis, bulk density, and moisture content samples were taken from the exposed subsoil (0-6 inch). Plots were tilled to 6 inches and graded to have a uniform 10% slope. All plots received lime at 4000 lbs/ac.

Half of the plots received compost at 30% by volume (1.8 inches), and the compost was tilled into the top 6 inches of the soil (Figure 26). The compost was collected from North Carolina State University Compost Facility and Research Cooperative and analyzed for nutrients and heavy metals.

There were three types of vegetation treatments: (1) grass, (2) wildflowers, and (3) grass-wildflower mixture. Grass plots were seeded with NCDOT seeding mix including tall fescue (*Festuca arundinacea*) at 50 lbs/ac, unhulled bermudagrass (*Cynodon dactylon*) at 35 lbs/ac, and centipede (*Eremochloa ophiuroides*) at 10 lbs/ac (NCDOT, 2015). Wildflower plots were seed with lance-leaf *Coreopsis* (4.5 lbs/ac), *Cosmos* (11 lbs/ac), California poppy (10 lbs/ac), and blanket flower (10 lbs/ac). Grass-wildflower plots received a 60:40 ratio of grass to wildflower seed by weight (Figure 24). Plots that received fertilizer got a 10-20-20 fertilizer (500 lbs/ac) (NCDOT, 2015).

Plots were covered with either hydromulch or excelsior blankets anchored with metal sod staples. Profile® Erosion Control Hydromulch Blend at a rate of 3000 lbs/ac was used for hydromulch cover. It was mixed with water at a 70:30 ratio before spraying by NCSU staff. Vegetation cover was monitored monthly using drone images process using ArcGIS. Infiltration rate, nutrients content, moisture content, and bulk density were measured on a spring, summer, and fall season basis. Plots were mowed to 4 inches in early March 2022 to control weed pressure. This experiment will continue until October of 2023.

Results and Discussion

Vegetation Cover

The compost-fertilizer treatment had significantly higher cover than fertilizer only plots after 3 months of growth for all three vegetation treatments, but not higher than compost only. Compost only treatments and fertilizer only treatments resulted in vegetative cover that was similar. All three treatments had significantly higher vegetation cover than the control of no fertilizer, no compost (Figure 27, Figure 28).

However, differences disappeared over time, and compost, fertilizer, and compost-fertilizer treatments had similar vegetation cover at 12 months (Figure 29). Vegetation cover reached 90-95 % at 12 months except for the control (no compost, no fertilizer). There were no significant differences between the vegetation types at the studied time periods. This suggests that wildflowers are a viable option as a vegetation cover where grass is currently being planted.

There is a common belief that compost addition promotes weed infestation, but there were not any significant differences or specific trends between the treatments (Figure 30). The good vegetation initially after seeding may have reduced weeds infestation, but more studies are needed to determine these effects. Any vegetation cover will provide erosion control even if it are not the species planted.

Soil Physical Properties and Infiltration Rate

The 30 % compost incorporation significantly decreased soil bulk density and increased moisture content (Figure 31). There was an 18-25% decrease in bulk density and a 48-83% increase in moisture content. There were no statistical differences between vegetation types for bulk density or moisture content. Compost amendment seems to be the factor changing soil physical properties verses vegetation type in the short-term (< 1 year).

Incorporated compost increased infiltration rate 3.5 to 6 times compared to treatments without compost (Figure 32). There were no significant differences between vegetation types for infiltration rates.

A 30% compost incorporation rate can be a good management practice for increasing stormwater infiltration, and vegetation establishment. Wildflower performance was similar to grass regarding vegetation cover and infiltration; thus, wildflowers can be an alternative to current grass seeding mixes. Future research should focus on the long-term effects of single compost incorporation on stormwater management, vegetation cover, and soil organic carbon dynamics.

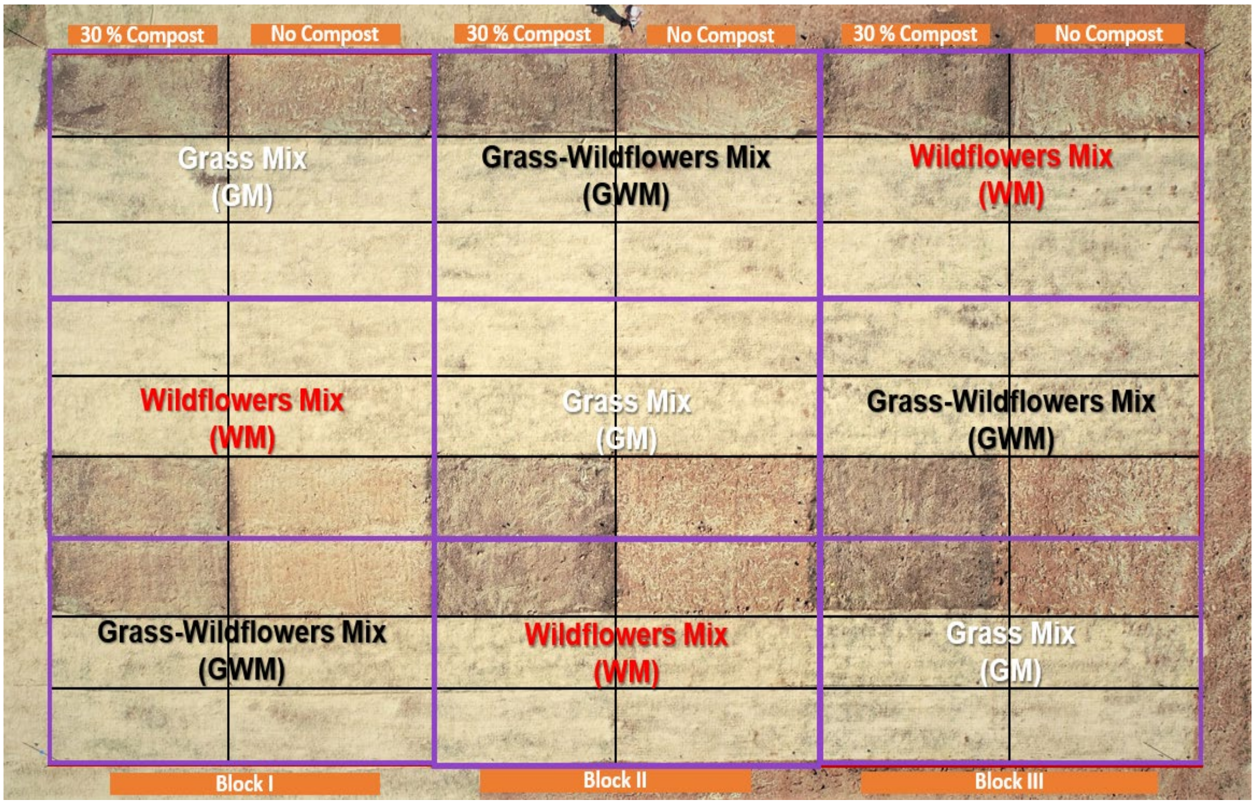

Figure 26. Drone image of plot layout at the establishment (size: 116 ft × 72ft).

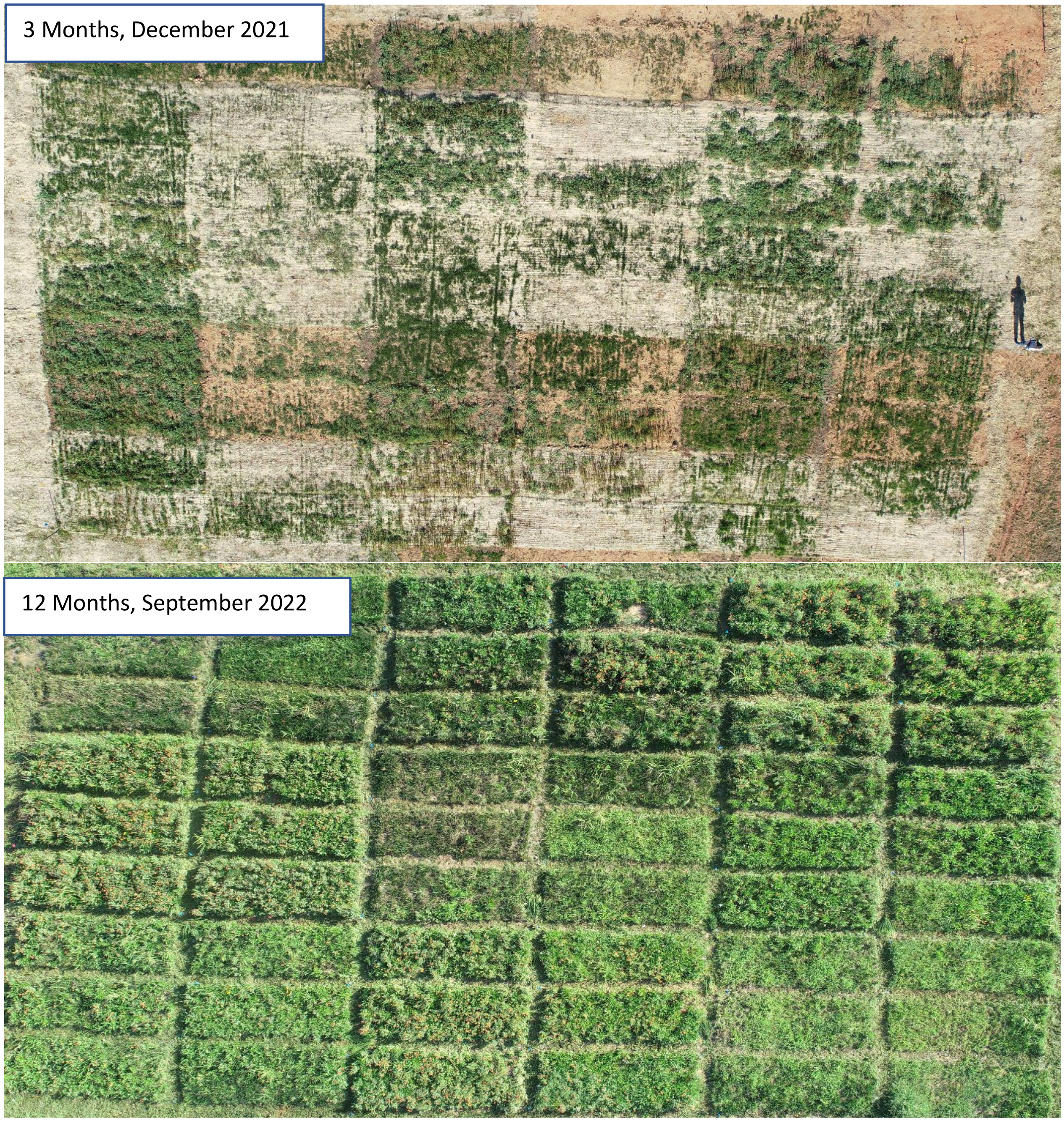

Figure 27. Vegetation cover at the established plot at 3 Months (December 2021) and 12 Months (September 2022).

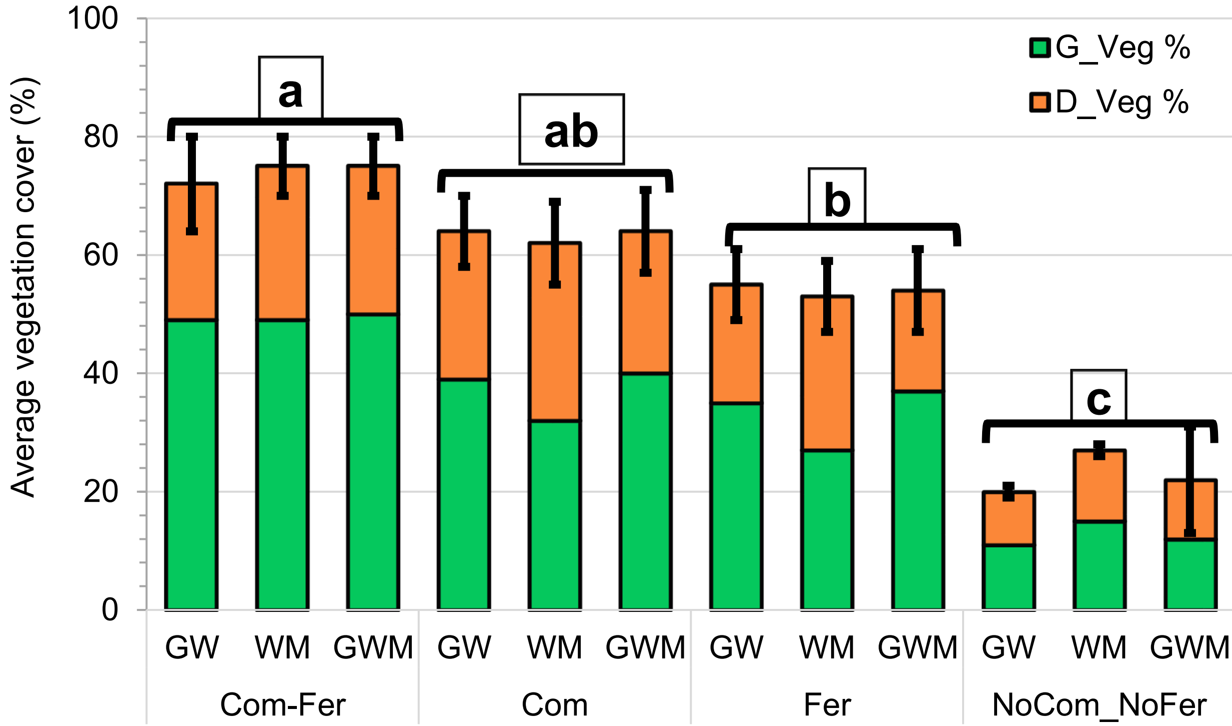

Figure 28. Vegetation cover at 3 Months; Com is compost and Fer is fertilizers; GM, WM and GWM are grass, wildflowers and grass-wildflowers treatments, respectively. G_Veg is green vegetation and D_Veg is dormant/dead vegetation.

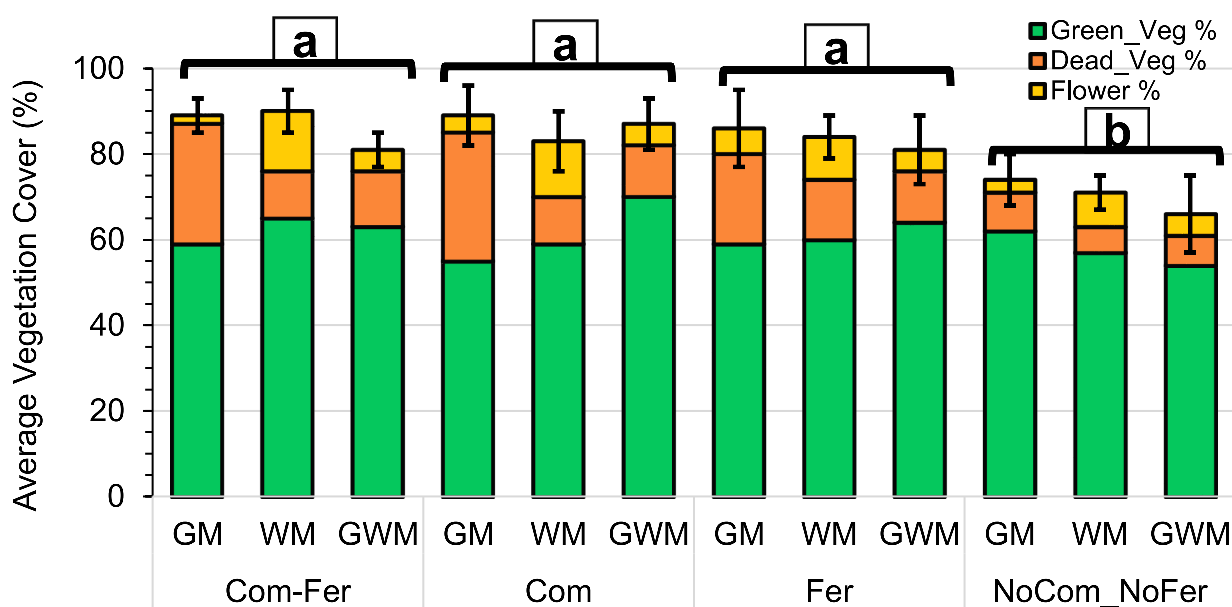

Figure 29. Vegetation cover at 12 Months; Com is compost and Fer is fertilizers.

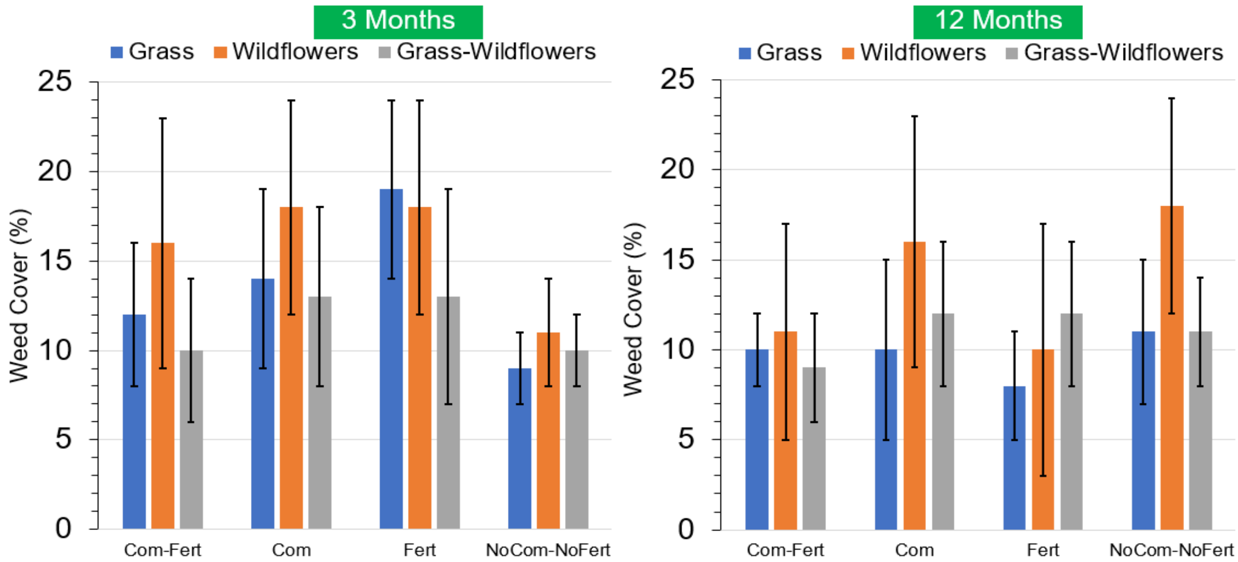

Figure 30. Weed covers at 3 and 12 Months events.

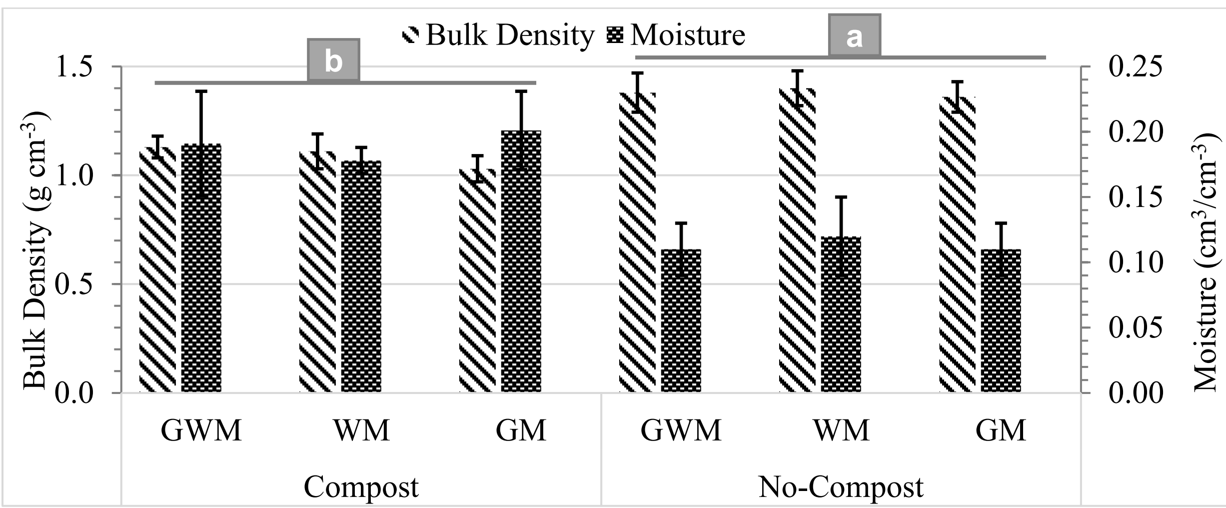

Figure 31. Soil bulk density and moisture content after 12 Months.

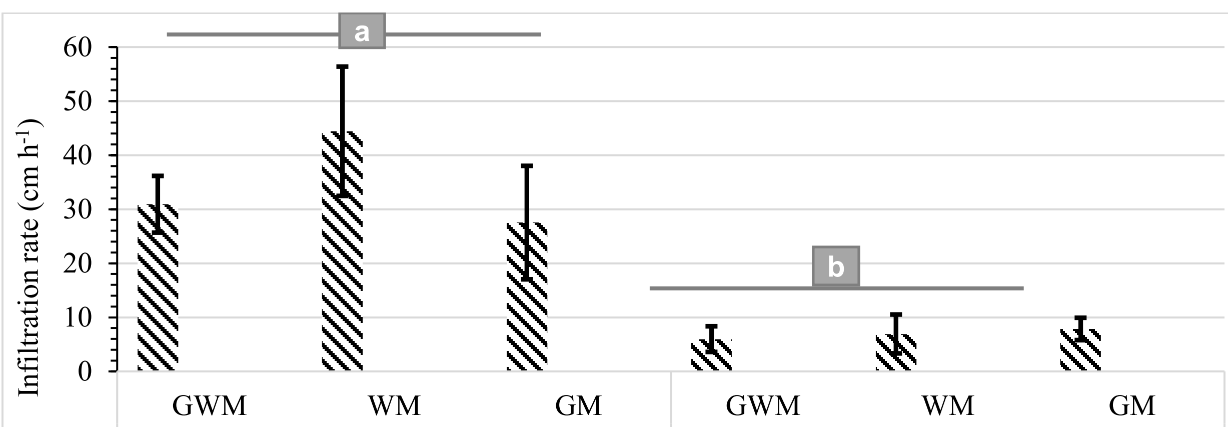

Figure 32. Infiltration rate after 12 Months.

EROSION CONTROL VEGETATION COVER ESTABLISHMENT IN 2:1 TYPE CUT SLOPE AT I-540 ACTIVE CONSTRUCTION SITE

The objectives of this experiment were to (1) assess the potential of wildflowers and grass-wildflower mixes as an alternative to grass cover on 2:1 roadside cut slopes, and (2) evaluate the effects ground cover (hydro-mulch and excelsior matting) on vegetation cover.

Materials and Methods

Site Description and Preparation

This study site was in Garner, North Carolina, USA (35°37'57" N 78°34'42.3" W**)**, where the expansion of I-540 was being constructed (Figure 33). This site was established in April 2022. The previously hilly forest was cut, topsoil was removed and the exposed subsoils were compacted severely by heavy construction traffic. The cut slopes had saprolite and micas in the bottom part. The 2:1 cut slopes were first smoothed and then tracked by a bulldozer from the bottom to top of the slope for providing ridges and depressions to slow runoff and in which seeding materials can lodge.

In this experiment, treatments consisted of two temporary ground covers (excelsior blankets and hydromulch) and three vegetation types (grass, wildflowers and grass-wildflowers mixtures).The treatment plots were as follows: (1) grass with excelsior matting (GE), (2) grass with hydro-mulch (GH), (3) wildflowers with excelsior matting (WE), (4) wildflowers with hydro-mulch (WH), (5) grass-wildflower mix with excelsior matting (GWE), and (6) grass-wildflower mix with hydro-mulch (GWH). The plot size was 20 ft by 8ft. Plots were set up in a completely randomized block design, where each treatment was replicated in the three blocks (Figure 34).

Three composite soil samples from the top, middle, and bottom parts of each block were collected that represent each individual plot of the block. Collected soils were analyzed for particle size, moisture content, and available and total nutrients.

Amendments Application and Seeding

Lime at a rate of 4000 lbs/ac and 10-20-20 grade fertilizer at a rate of 500 lbs/ac were applied on the plot surface homogenously using a hand spreader following NCDOT recommendation (NCDOT, 2015). No fertilizer was applied to wildflower-only plots. All plots were seeded on 21 April 2022 following the NCDOT seeding mix recommendation based on the location and time of planting (Table 6) (NCDOT, 2015).

The plots were temporarily covered with two different erosion control blankets (excelsior and hydro-mulch) following the treatment randomization. The excelsior blankets were anchored to the ground with metal sod staples. The hydro-mulch was mixed with water (2:1 ratio) in a hydroseeder and sprayed over the plots at approximately 3000 lbs/acre by a NCDOT contractor (visually determined).

Vegetation Cover

The green vegetation cover in each plot was monitored using Canopeo mobile apps on iPhone 13 Pro (4.5 ft above soil surface and 90° angle) following the developer's recommendation, capturing feasibility and area coverage. Drone survey at 82 ft height (25 m), and manual drone images were captured from 26 ft height (8 m) and analyzed in ArcGIS Pro.

Results and Discussion

The plots were established following standard NCDOT protocols. However, heavy rainfall within 1.5 months of plot establishment washed away seeds and created rill erosion (Figure 35, Figure 36). There was some evidence that the grass established better on this steep slope than wildflowers, but all the treatments resulted in insufficient vegetation for a good evaluation. It is likely that similar results on a slope would have resulted in the need to redo the vegetation establishment operation.

Table 6. Location and plantation time-based seeding mix recommended by NCDOT.

Vegetation Type	Vegetation Species	Application Rate
Grass mix	Tall Fescue (*Festuca arundinacea*) Hulled Bermuda (*Cynodon dactylon*) Centipede (*Eremochloa ophiuroides*)	50 lbs/acre 25 lbs/acre 10 lb /acre
Wildflowers mix	Lance-leaf Coreopsis (*Coreopsis lanceolata*) Cosmos (*Cosmos bipinnatus*) California Poppy (*Eschscholzia californica*) Blanket flower (*Gaillardia aristata*)	4.5 lbs/acre 11 lbs/acre 10 lbs/acre 10 lbs/acre
Grass-Wildflowers mix	Same as grass and wildflowers above	60 grass : 40 wildflowers

Figure 33. Location of plot in the I-540 Interstate highway. Taken from Google Maps.

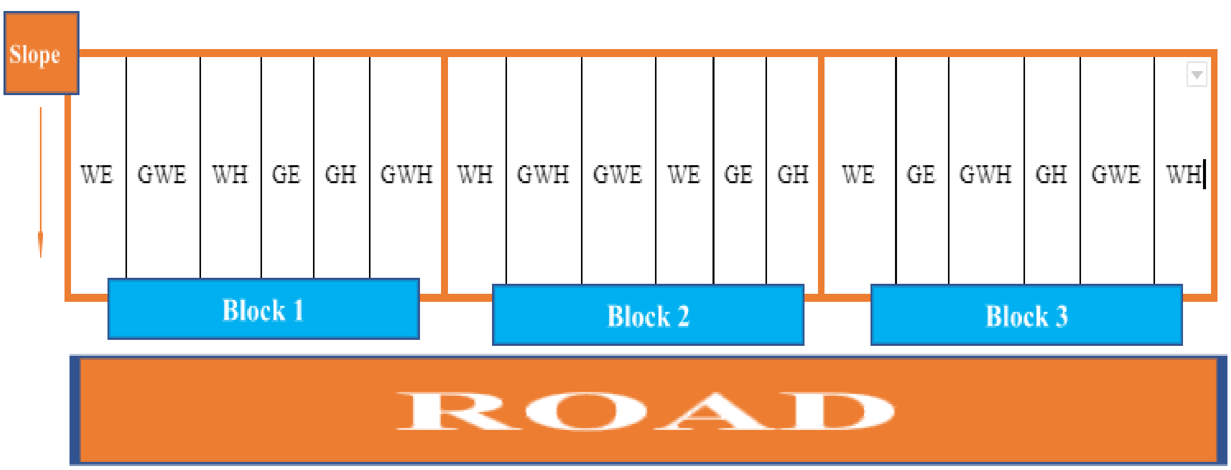

Figure 34. Experimental design of the experiment.

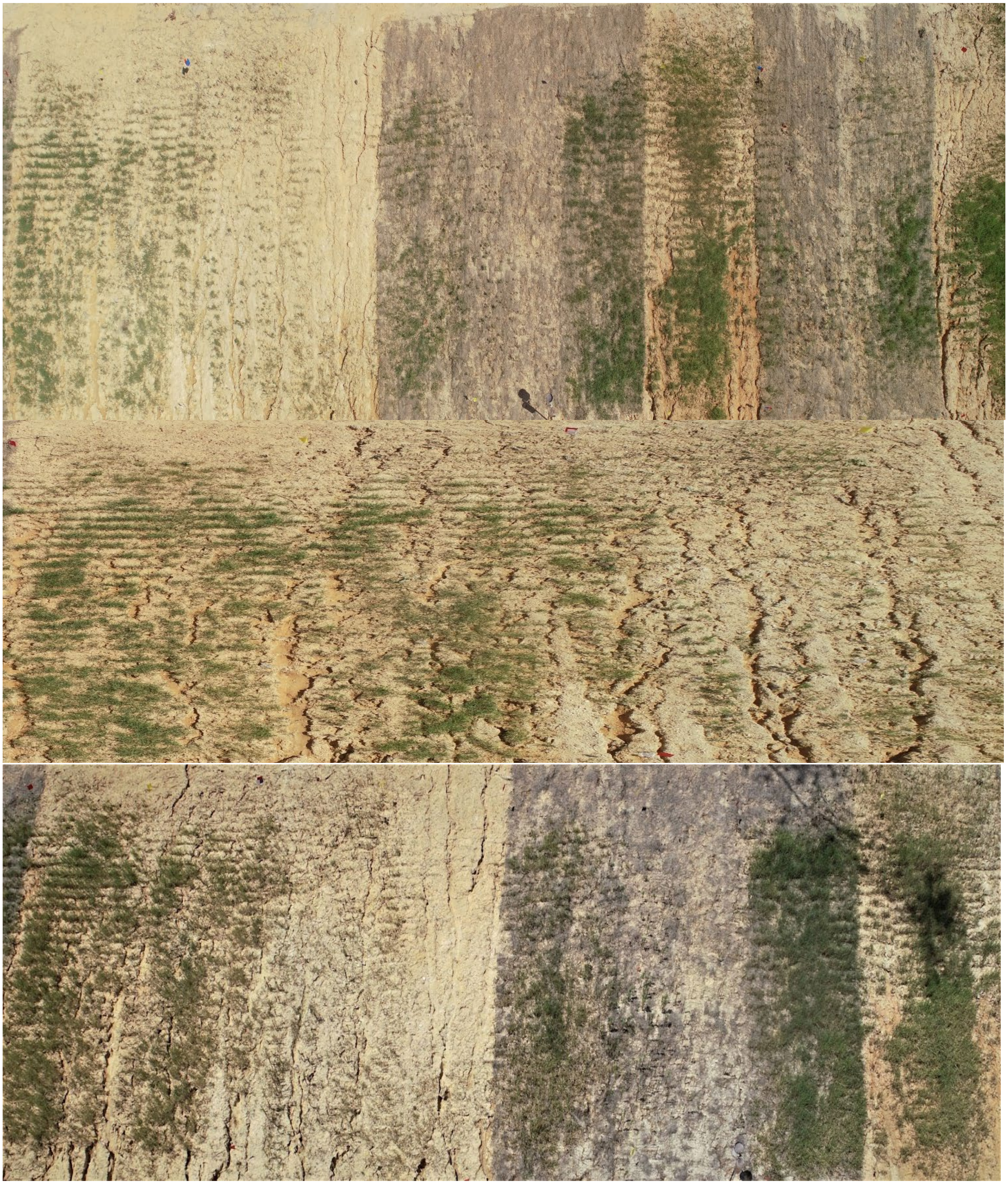

Figure 35. Heavy rill erosion at the established plot area.

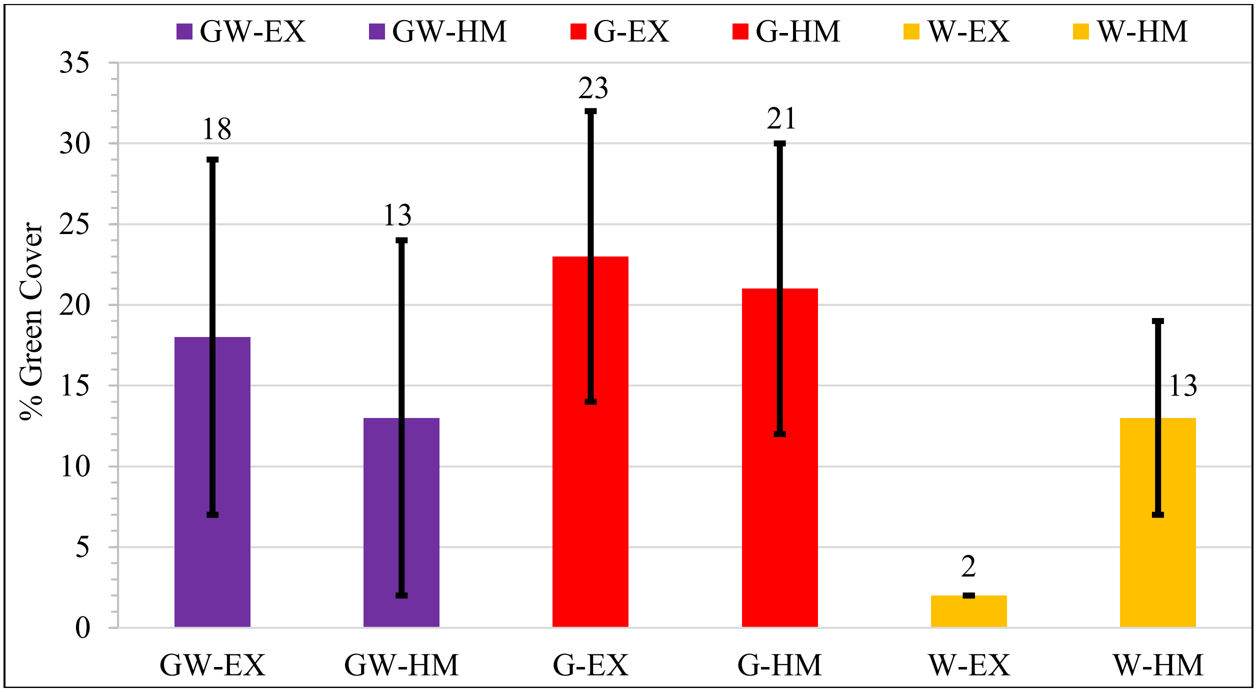

Figure 36. Green vegetation cover (%) after 1.5 months of plot establishment. Here, Ex is excelsior, and HM is hydro mulch covers.

EROSION CONTROL VEGETATION COVER ESTABLISHMENT IN 3:1 TYPE FILL SLOPE AT KINGSBORO CONSTRUCTION SITE

The objectives of this experiment were to (1) assess the potential of wildflowers and grass-wildflower mixes as an alternative to grass cover on 3:1 roadside fill slope, and (2) evaluate the effects ground cover (hydro-mulch and excelsior matting) on vegetation cover.

Materials and Methods

Site Description and Preparation

This study site was in Tarboro, North Carolina, USA (35.930163, -77.650839**)**, where a new industrial park was being established. The plots were established in April 2021 on a fill slope that was made as an entry road in that area (Figure 37). The plots areas were scraped to bare earth with an excavator before planting.

In this experiment, treatments consisted of two ground covers (excelsior and hydro-mulch) and three vegetation types (grass, wildflowers and grass-wildflowers mixtures).The treatment plots were as follows: (1) grass with excelsior matting (G-EX), (2) grass with hydro-mulch (G-HM), (3) wildflowers with excelsior matting (W-EX), (4) wildflowers with hydro-mulch (W-HM), (5) grass-wildflower mix with excelsior matting (GW-EX), and (6) grass-wildflower mix with hydro-mulch (GW-HM). The plot size was 20 ft by 8ft. Plots were set up in a completely randomized block design, where each treatment was replicated in the three blocks.

Three composite soil samples from the top, middle, and bottom parts of each block were collected that represent each individual plot of the block. Collected soils were analyzed for particle size, moisture content, and available and total nutrients.

Amendments Application and Seeding

Lime at a rate of 4000 lbs/ac and 10-20-20 grade fertilizer at a rate of 500 lbs/ac were applied on the plot surface homogenously using a hand seed spreader following NCDOT recommendation (NCDOT, 2015). No fertilizer was applied to wildflower-only plots. All plots were seeded on 16 April 2021 following the NCDOT seeding mix recommendation based on the location and time of planting (Table 7) (NCDOT, 2015). American Meadows Southeast Wildflowers mix was used as wildflower vegetation. This mixture contains 26 wildflowers, 15 annuals for first-year color, and 11 perennials or biennials for second and successive years' bloom.

The plots were temporarily covered with two different erosion control products (excelsior and hydro-mulch) following the treatment randomization (Figure 38). The excelsior blankets were anchored to the ground with metal sod staples. The hydromulch was mixed with water (2:1 ratio) in a hydroseeder and sprayed over the plots at a rate of 3000 lbs/acre by NCSU staff.

Vegetation Cover

The green vegetation cover in each plot was monitored monthly using Canopeo mobile apps on iPhone 12 (4.5 ft above soil surface and 90° angle) following the developer's recommendation, capturing feasibility and area coverage. Drone images at 82 ft height (25 m) and manual drone images were captured from 16.5 ft height (5 m) and analyzed in ArcGIS Pro.

Results and Discussion

In this experiment, green vegetation cover was estimated in each plot using Canopeo Mobile Application and aerial photos from drone flights. Initially, excelsior plots with grass or grass-wildflower vegetation had more vegetation cover compared to wildflower vegetation, primarily due to the low cover in the W-HM treatment (Figures 39, 40). Green vegetation cover decreased with time due to dormancy and annuals but regrew in the following year (Figure 41). A year after seeding, the wildflower and wildflower-grass mix seeding appeared to have more ground cover (40-50%) than the grass seeding (20-30%). The Canopeo application only evaluates the green in a photo, so dead or dormant vegetation cover would have not have been included. Therefore, ArcGIS, remote sensing, or other techniques should be used to determine the total coverage on the plots. Although the American Meadows Southeast Wildflowers mix contained 26 wildflowers species, only 4-5 species were evident in the plots.

Table 7. Location and plantation time-based seeding mix recommended by NCDOT.

Vegetation Type	Vegetation Species	Application Rate
Grass mix	Tall Fescue (*Festuca arundinacea*) Hulled Bermuda (*Cynodon dactylon*)	50 lbs/acre 35 lbs/acre
Wildflowers mix	American Meadows Southeast Wildflower mix	40 lbs/acre
Grass-Wildflowers mix	Same as grass and wildflowers above	60 grass : 40 wildflowers

Figure 37. Location of plot in the Kingsboro Industrial Area. The existing vegetation was scraped off before installing the treatments.

Figure 38. Drone image at plot establishment (16 April, 2021). The green strips are the hydromulch plots (actual color of the hydromulch).

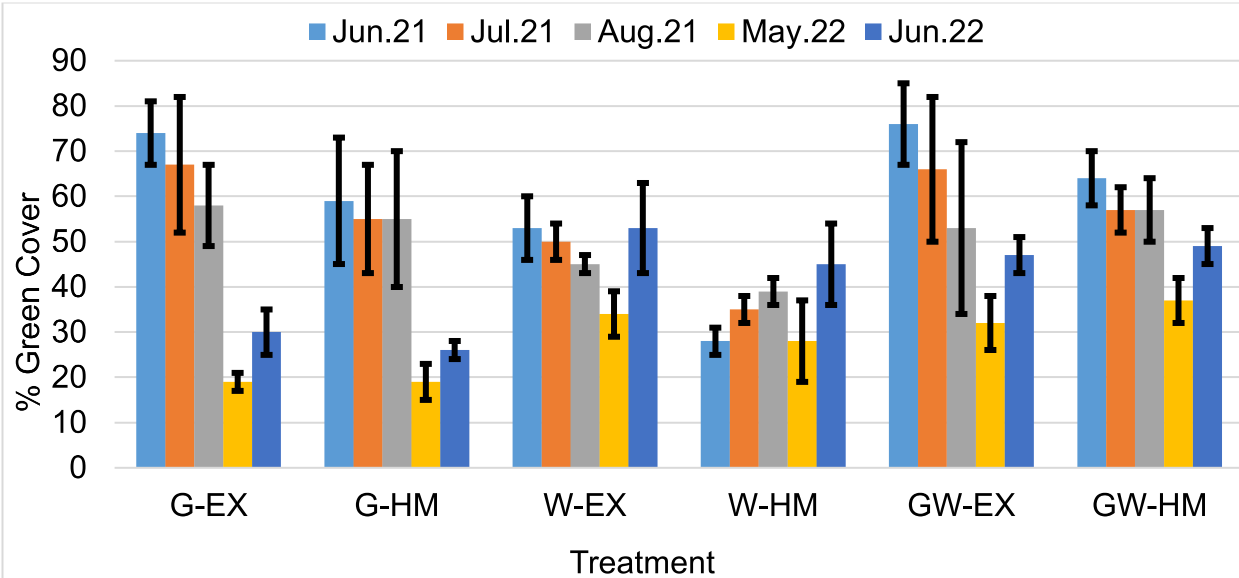

Figure 39. Green vegetation cover at Kingsboro; G: grass, W: wildflowers, EX: excelsior & HM: hydro-mulch.

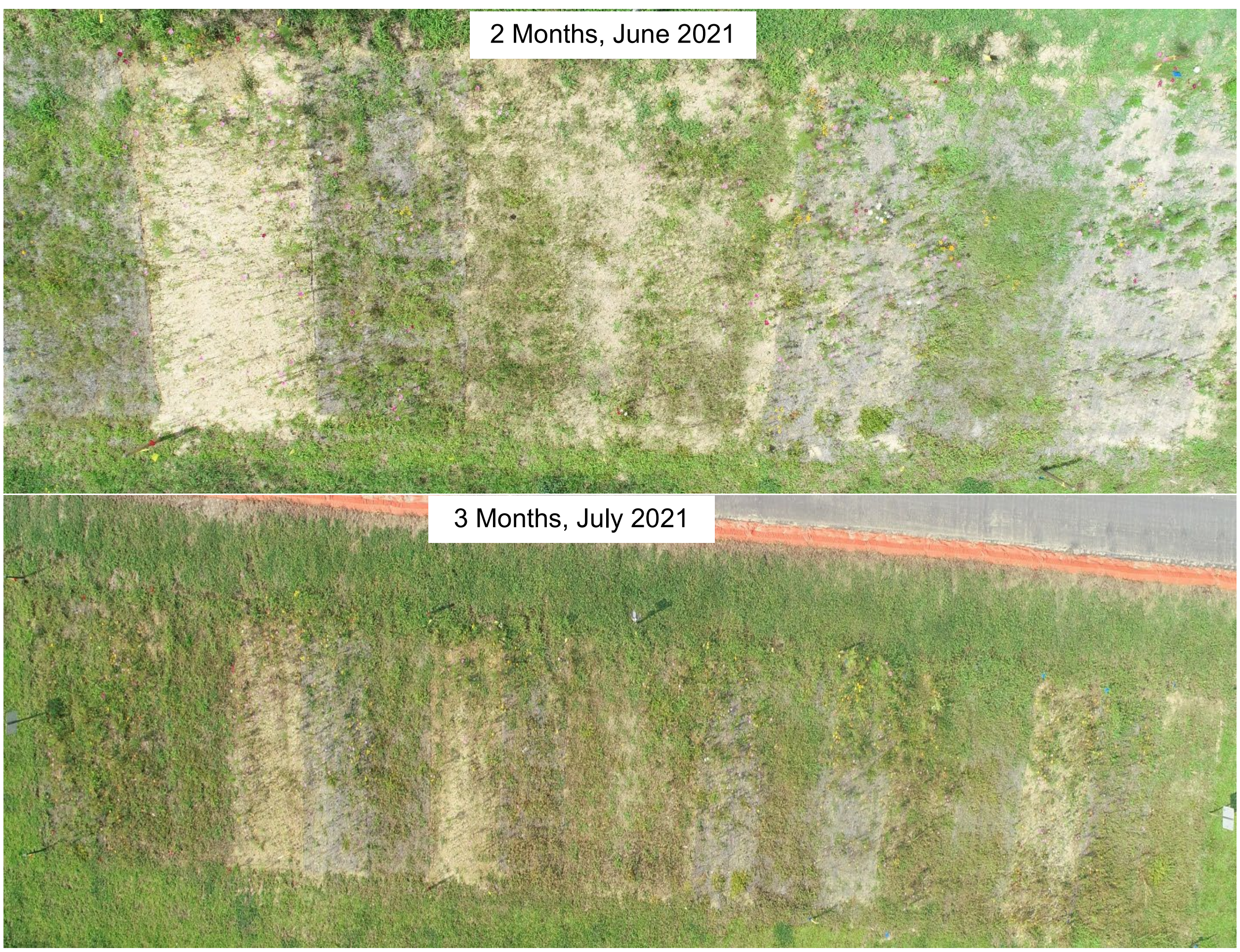

Figure 40. Green vegetation cover at Kingsboro 2 and 3 months after seeding.

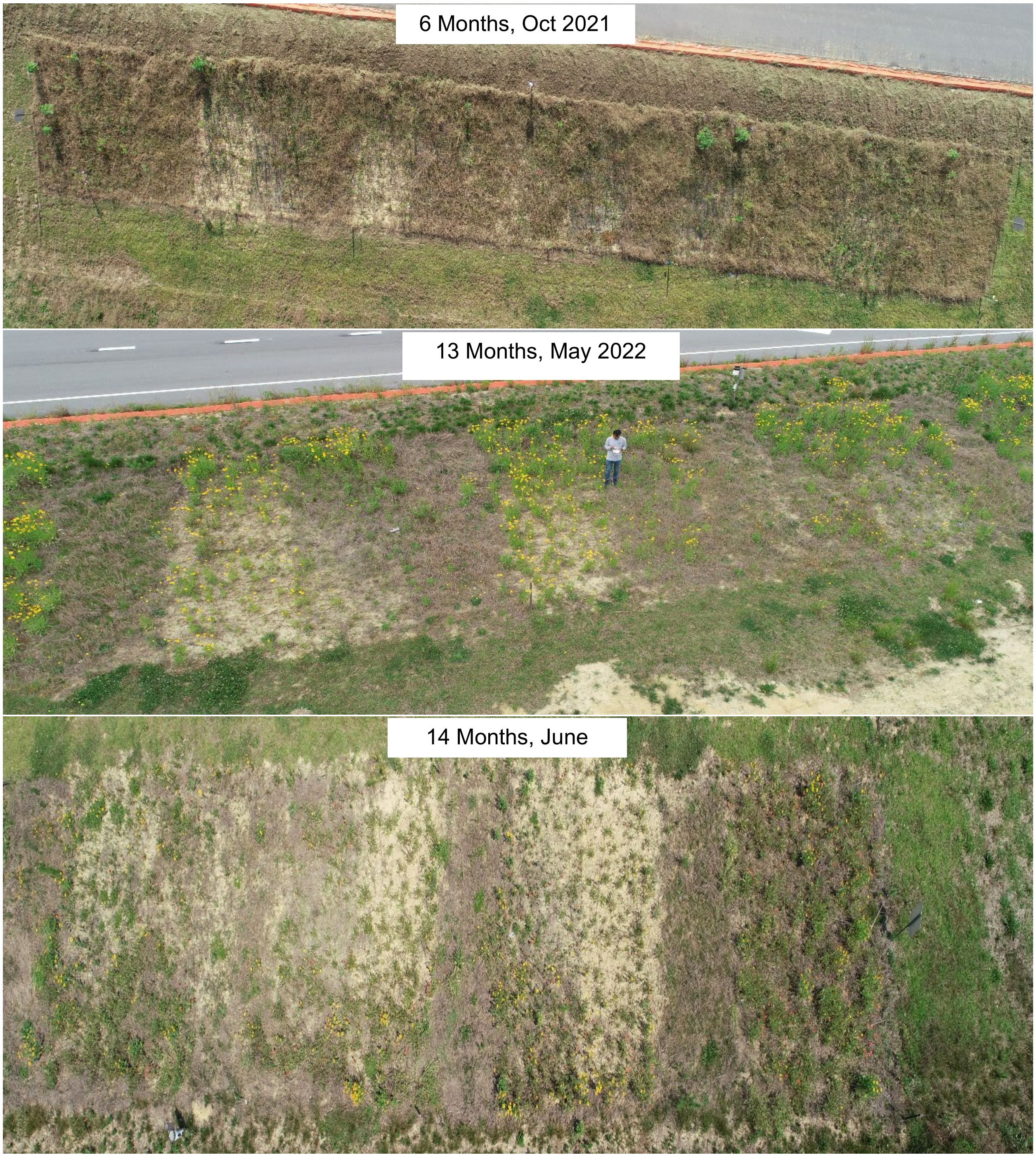

Figure 41. Green and brown vegetation cover at Kingsboro 6, 13, and 14 months after seeding.

FINDINGS AND CONCLUSIONS

Construction generates a lot of turbid runoff which can degrade water quality of the receiving streams. Prior research in North Carolina has shown PAM to be an effective flocculent to reduce turbidity in construction stormwater. The PAM binds the small clay particles together, which makes them drop out of the water faster. One of the easiest methods is to apply PAM in the ditch leading to the sediment basin on the wattles and check dams to passively dose the water.

In this study, consistent PAM application was found to reduce turbidity and TSS in sediment basins (first baffle and skimmer locations) compared to basins that did not receive consistent PAM application. In general, as water moved from the first baffle to the skimmer, water quality improved for all monitored sediment basins. When examining the effectiveness of sediment basins to reduce turbidity and TSS as water moved though the basin, the amount or surrounding earthwork played an important role. There was a clear connection between the amount and type of grading activities and the ability of PAM treatments to be effective. Often the large amount of sediment passing through diversion ditches where there was high disturbance levels and little or no ground cover would overwhelm the practices in the diversion ditches and even the sediment basins. In this environment, it is very difficult to use PAM to reduce turbidity and TSS. When comparing the first baffle to the skimmer sample, a greater reduction in turbidity and TSS from the first baffle to the skimmer in watersheds with greater disturbance. However, theses basins were still discharging higher sediment loads (turbidity over 500 NTU and TSS over 400 mg/L). It is important to consistently apply PAM and manage diversion ditches when there is lots of earthwork happening in the basin watershed to minimize impacts on surrounding streams and other water bodies. As shown in the brief study on the I-40/NC86 interchange, a well-managed site with distributed PAM dosing can produce much better discharge water quality.

Much of the water being discharged from the sediment basins had a high turbidity (over 500 NTU), which was higher than the water in Swift Creek. However, the elevated sediment loads were rarely detected by the Swift Creek water quality monitoring. Swift Creek turbidity averaged around 30-35 NTU depending on the sample location. Even during hurricane storm events, elevated turbidity seemed to be diluted in Swift Creek. When monitoring Swift Creek, the stream was found to be flashy and have its level drastically change when it rained (up to 8 ft in some storms). The flashiness of Swift Creek could be helping to dilute the sediment loads from the construction site. There was also no trend of water quality upstream or downstream of the construction site being better or worse than one another. Creek water quality was more dependent on the storm itself rather than location. Even within a single storm event, water quality would flip flop between upstream and downstream as to which location had higher turbidity and TSS.

It was found that as stream level increased, so did the turbidity and TSS. Stream level seems to be a controlling factor in Swift Creek water quality. During the Swift Creek monitoring, natural stream bank erosion was observed. This may be from the flashiness of the creek. Swift Creek is located in an urban, suburban watershed. Updating the equations for estimating peak flow in Swift Creek is necessary as more development happens in the watershed.

Having good vegetation cover is necessary for long-term sediment and erosion control. Previous research in North Carolina show that wildflowers as a promising alternative to traditional grass cover and that wildflower can serve as a pollinator habitat. Wildflowers require less maintenance compared to grass as they need to be mowed only once or twice a year. Additional research has determined compost can be used to increases vegetation establishment along roadsides.

This study investigated compost and wildflowers with different ground covers (excelsior and hydromulch) to find optimal guidance to wildflowers. Treatments with compost plus fertilizer had more vegetation cover compared to fertilizer treatments three months after plot establishment. But compost plus fertilizer had the same vegetation cover as compost only treatments at the three month mark. This indicates that compost can be used without fertilizer and still maintain strong vegetation cover. The use of compost did not alter the weed cover, and weeds were observed in all treatment plots. Any vegetation that is covering bare soil will be helping with erosion control.

The addition of compost also increased the infiltration rate of the soil, which is beneficial for stormwater management. Since compost can improve infiltration rate (and other soil physical properties) and still get the same vegetation cover results as compost plus fertilizer and fertilizer only (12 months after plots establishment), then compost can be used alone to amend roadsides. Overall, the results from these experiment suggest, that a one-time application of compost at 30% without fertilizer can provide sufficient nutrients to get good vegetation cover, whether it is grass or wildflowers or grass-wildflower mix, and improve soil physical and hydrological properties.

When comparing grass to wildflowers, grass and grass-wildflower mixes with excelsior matting had more vegetation cover compared to wildflowers initially, but a year later grass had the lowest cover. There appeared to a negative impact of hydromulch on wildflower establishment initially, but this was not evident a year after planting. Grass-wildflower mixes can be used on steeper (3:1) slopes and still maintain good ground cover. On less steep slopes (<10%), wildflowers only might be a viable option, but more research is needed.

RECOMMENDATIONS

- Consistent application of PAM is the most reliable way to reduce turbidity and TSS loads in construction stormwater using sediment basins. The PAM should be applied to check dams in the ditches leading to the sediment basins to passively dose the stormwater. Reapply the PAM as needed to meet water quality standards.

- The amount of earthwork clearly affects the sediment loads entering a sediment basin. Contractors need to place soil piles out of the path of sediment basins or have the piles of soil covered during rainfall. Contractors and NCDOT officials should work together to find optimal soil storage locations.

- Stream level is a determining factor in Swift Creek water quality. Peak flow estimates in Swift Creek should be updated to reflect the development that has happened in the watershed over the past ten years.

- Compost can be used without fertilizer application and still achieve strong vegetation cover with grass, wildflowers, and grass-wildflower mixes. Compost application was also shown to improve infiltration rates, which is necessary along roadsides as a stormwater management practices. A one-time application of a yard-waste based compost at 30% by volume can provide nutrients for vegetation cover, while improving the soil infiltration rates.

- When establishing vegetation cover on steep slopes, grass or grass-wildflower mixes with excelsior matting worked best. Since wildflowers provide pollinator habitat and other environmental benefits, a grass-wildflower mix with excelsior matting is recommended for areas identified as a potential spot for wildflowers.

- The grass-wildflower mix should be 60% grass seed as recommended by NCDOT guidelines and 40% wildflowers. Wildflower mix should consist of the following: lance-leaf coreopsis (4.5 lbs/ac), cosmos (11 lbs/ac), California poppy (10 lbs/ac), and blanket flower (10 lbs/ac).

- It is important to use a high-quality compost that is STA certified or meets the U.S. Composting Councils guidelines for STA certification.

IMPLEMENTATIONS

Our sediment basin monitoring results can optimize water quality performance on construction sites. We anticipate the NCDOT will be able to immediately implement our recommendations for PAM application in ditches leading to sediment basins and work with contractors to find optimal locations to store soil. PAM application is already in the planning and budgeting of construction projects. But contractors need to be consistent with their application of PAM. Inspectors can identify piles of soil that may be of concern, and work with NCDOT and the contractor to relocate the soil, cover it, or redesign the sediment basin.

Our research results and recommendations can optimize soil improvement specifications to ensure a low-cost effective solution to the current BMPs for highway stormwater management. The NCDOT can additionally implement our recommendation for the use of compost without fertilizer for vegetation establishment. Compost incorporation was recently added to the NCDOT BMP toolbox. We can further improve this recommendation and the cost effectiveness of compost if we do not add fertilizer when tilling compost into the soil. Implementation of compost incorporation without fertilizer is relatively low cost compared to building other stormwater management practices.

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APPENDIX 1: SUPPLEMENTAL TURBIDITY AND TSS LOADS FOR SEDIMENT BASINS

This appendix includes average water quality measurements (± standard error) taken after each qualifying storm event in the monitored sediment basins and average percent change (± standard error) between first baffle and skimmer samples.

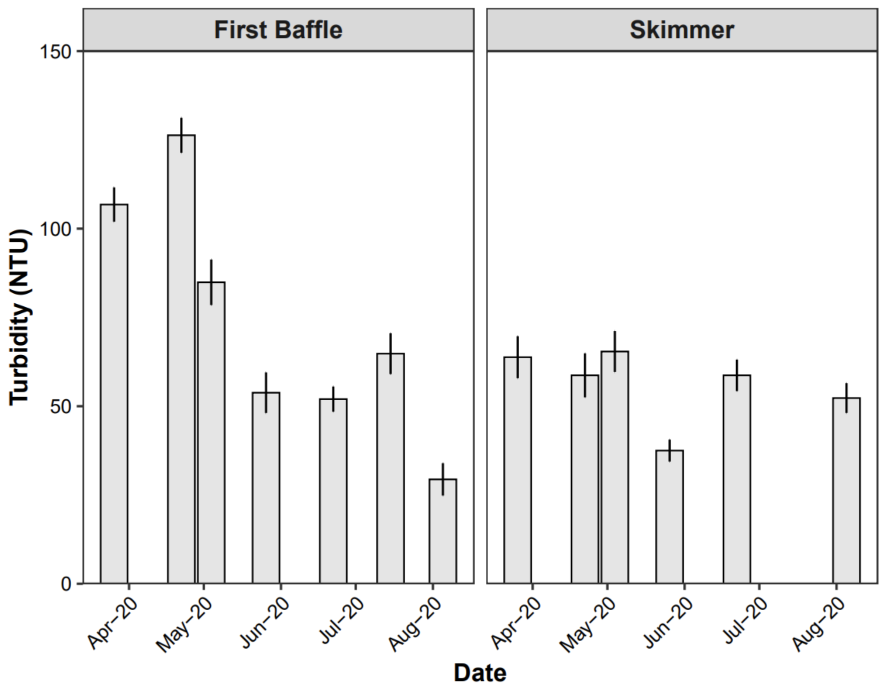


Figure A1. Average turbidity for basin 1 per storm event.

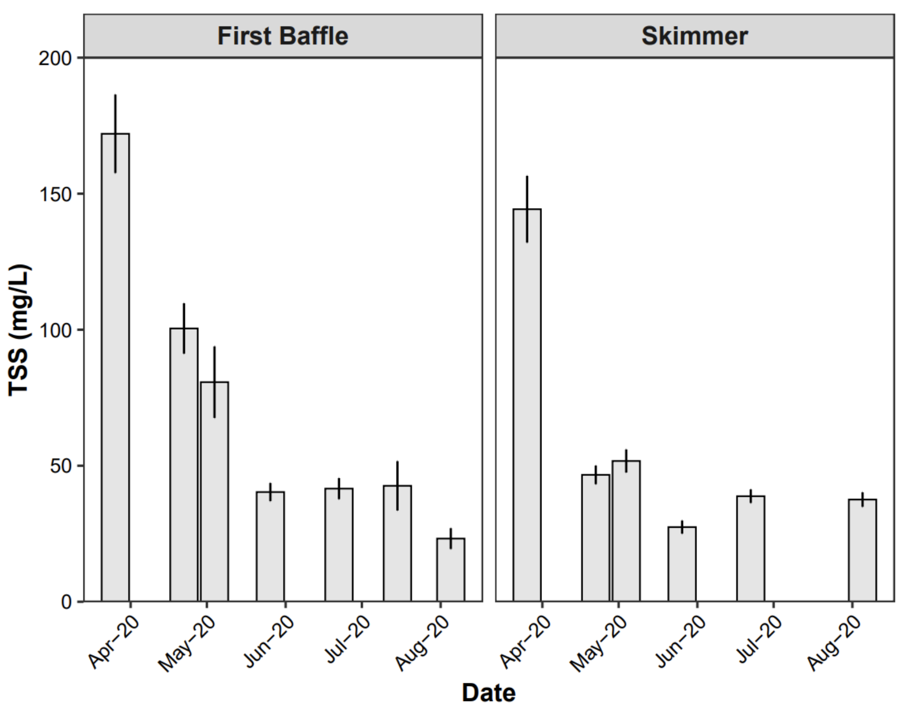


Figure A2. Average TSS for basin 1 per storm event.

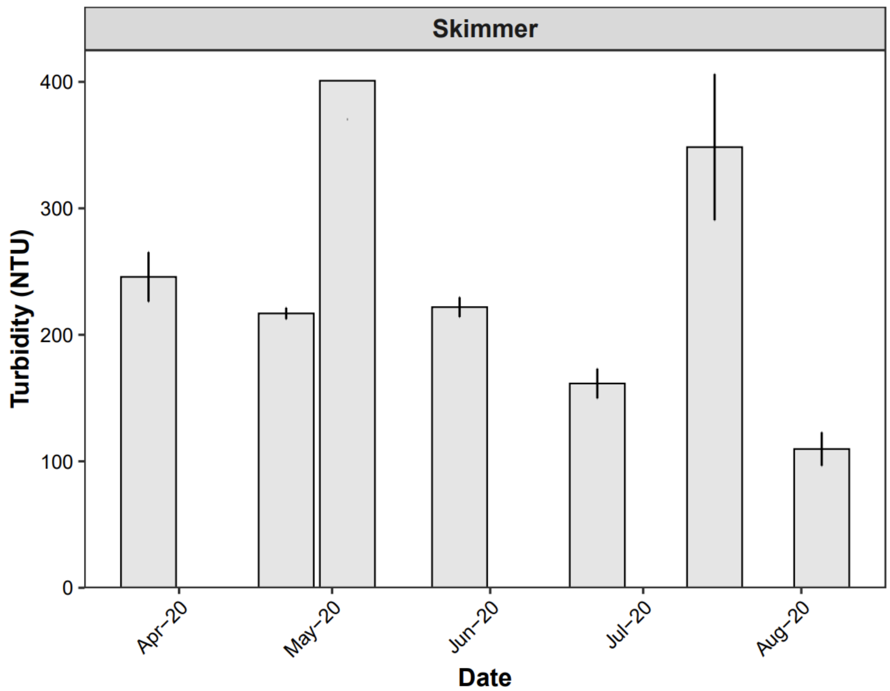


Figure A3. Average turbidity for basin 2 per storm event.

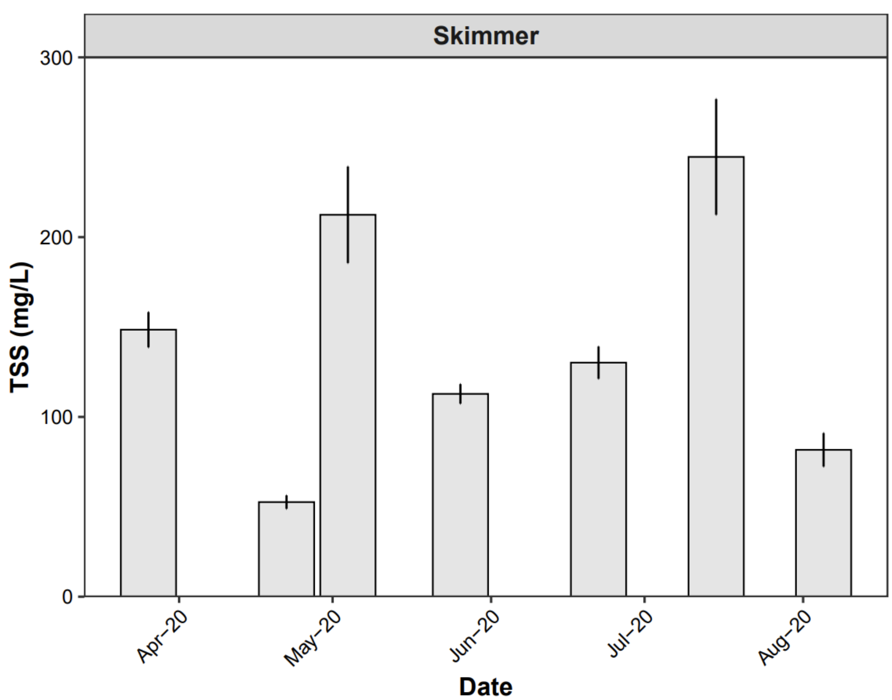


Figure A4. Average TSS for basin 2 per storm event.

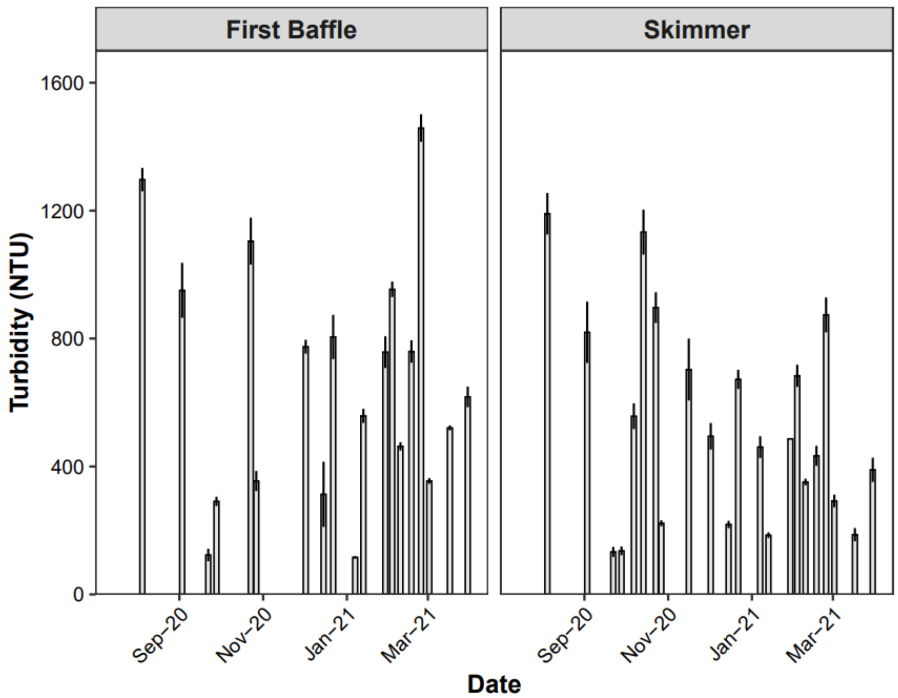


Figure A5. Average turbidity for basin 3 per storm event.

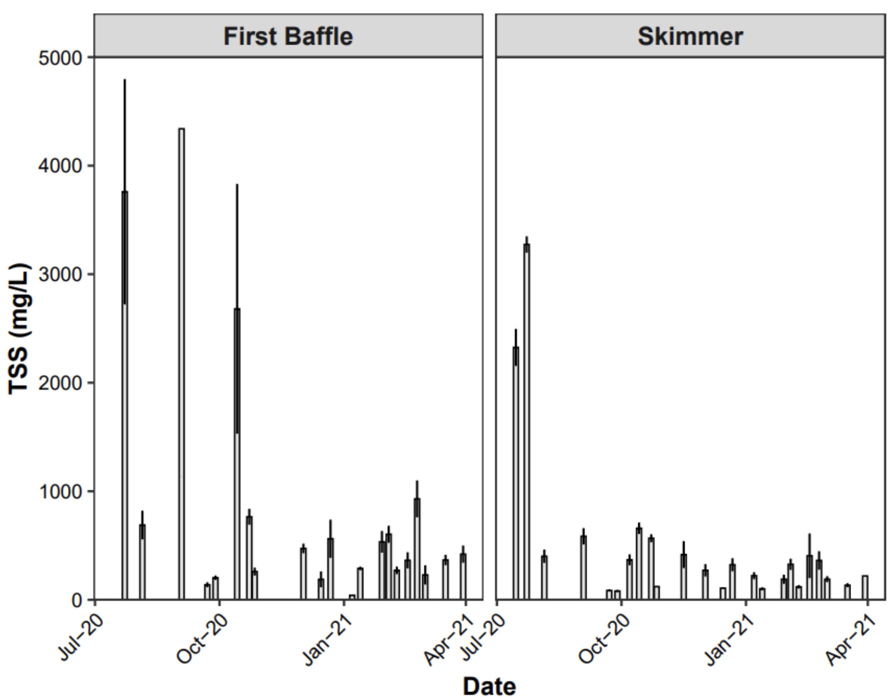


Figure A6. Average TSS for basin 3 per storm event.

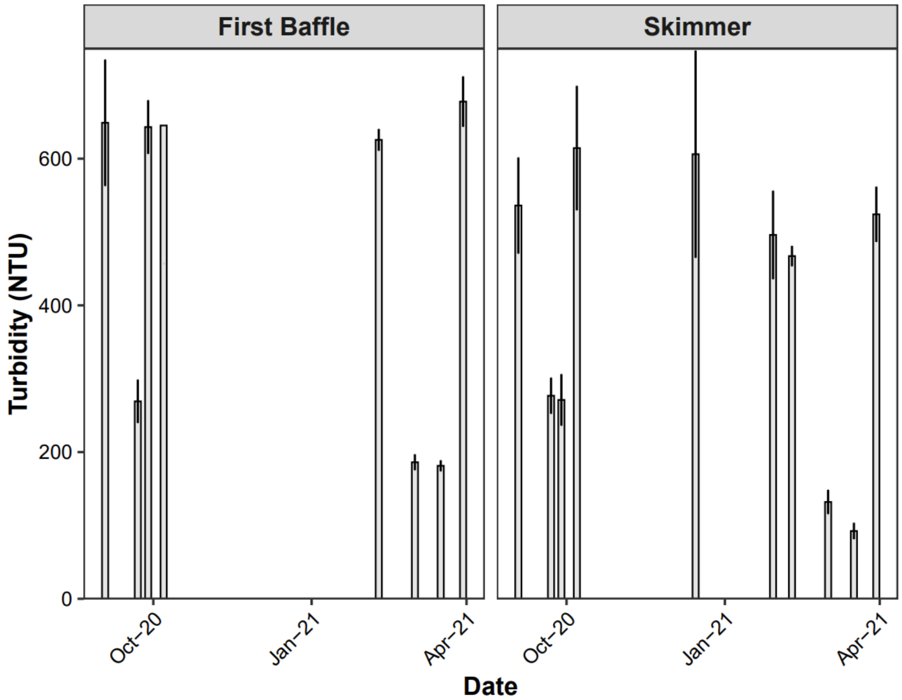


Figure A7. Average turbidity for basin 4 per storm event.

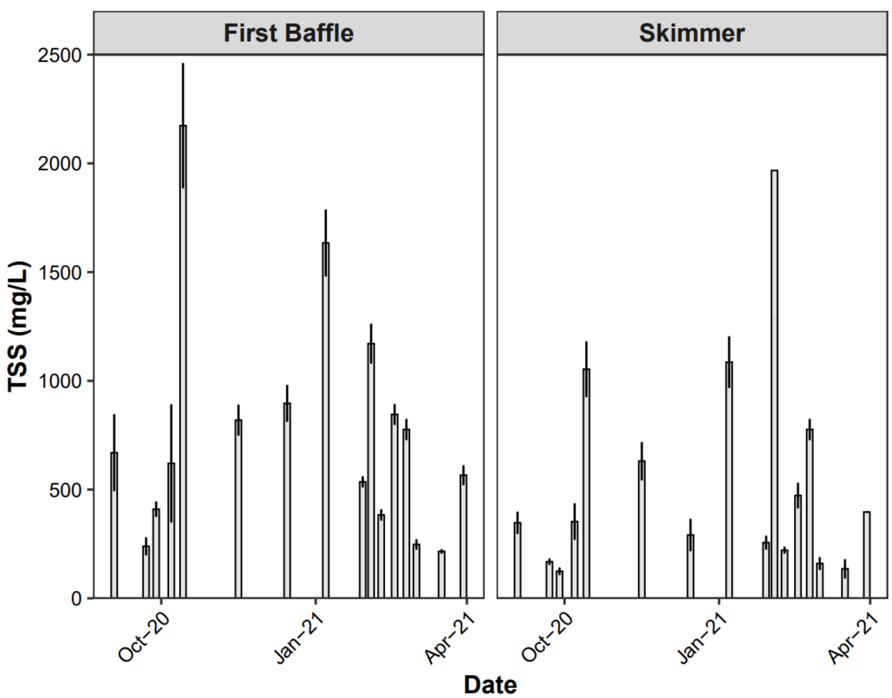


Figure A8. Average TSS for basin 4 per storm event.

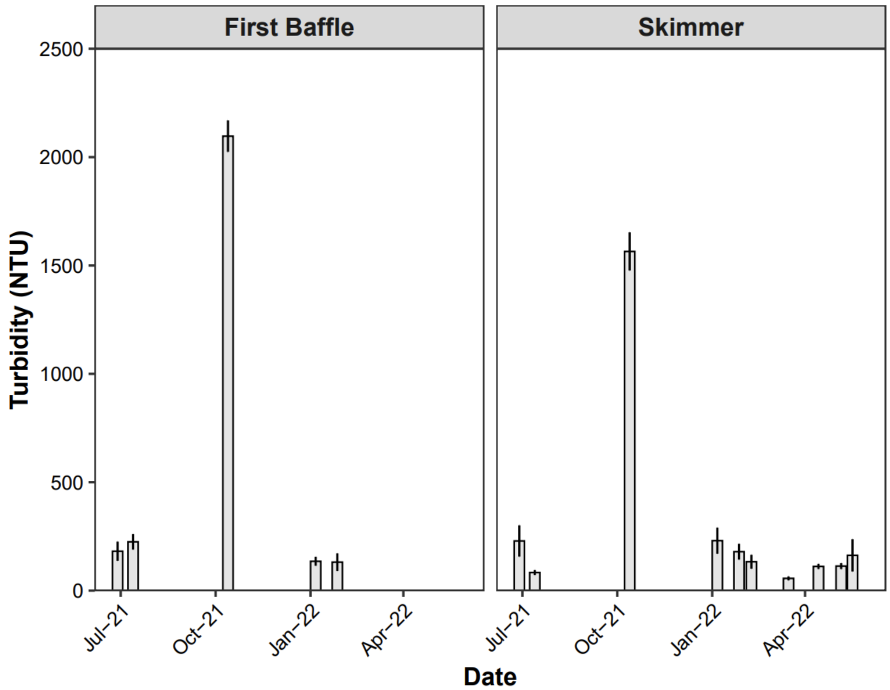


Figure A9. Average turbidity for basin 5 per storm event.

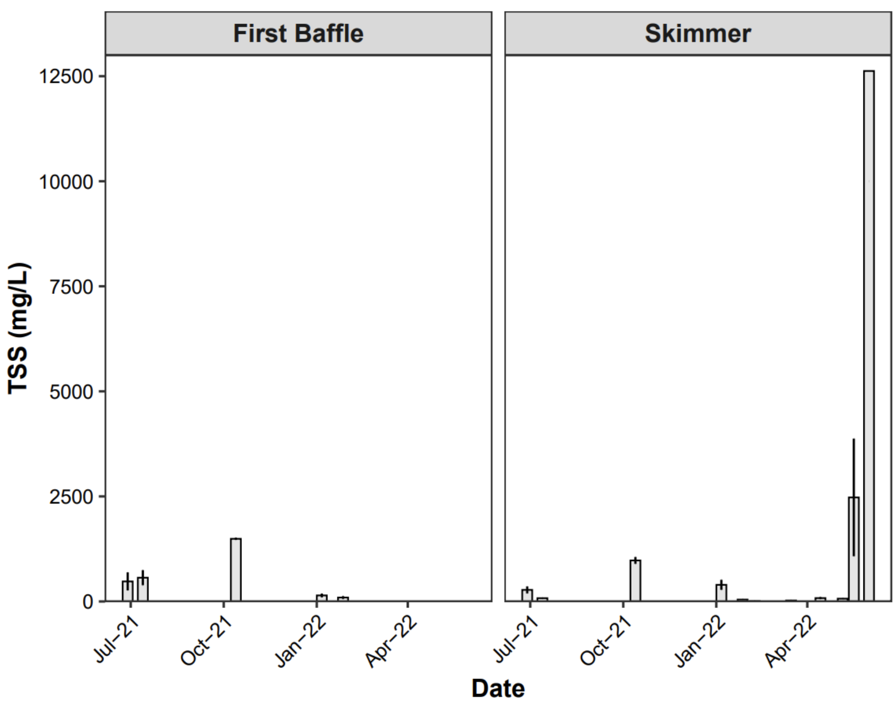


Figure A10. Average TSS for basin 5 per storm event.

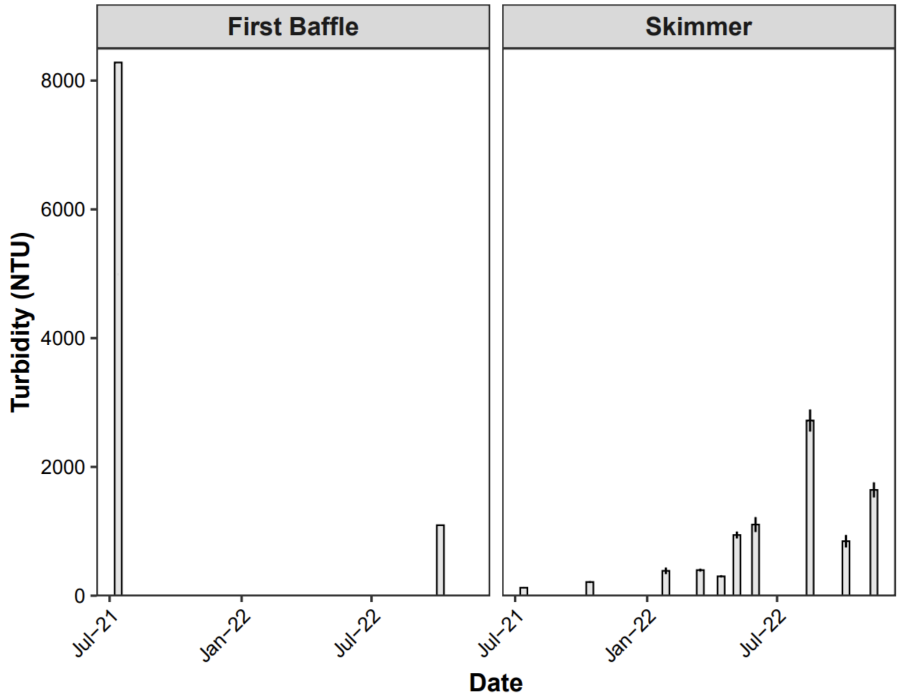


Figure A11. Average turbidity for basin 6 per storm event.

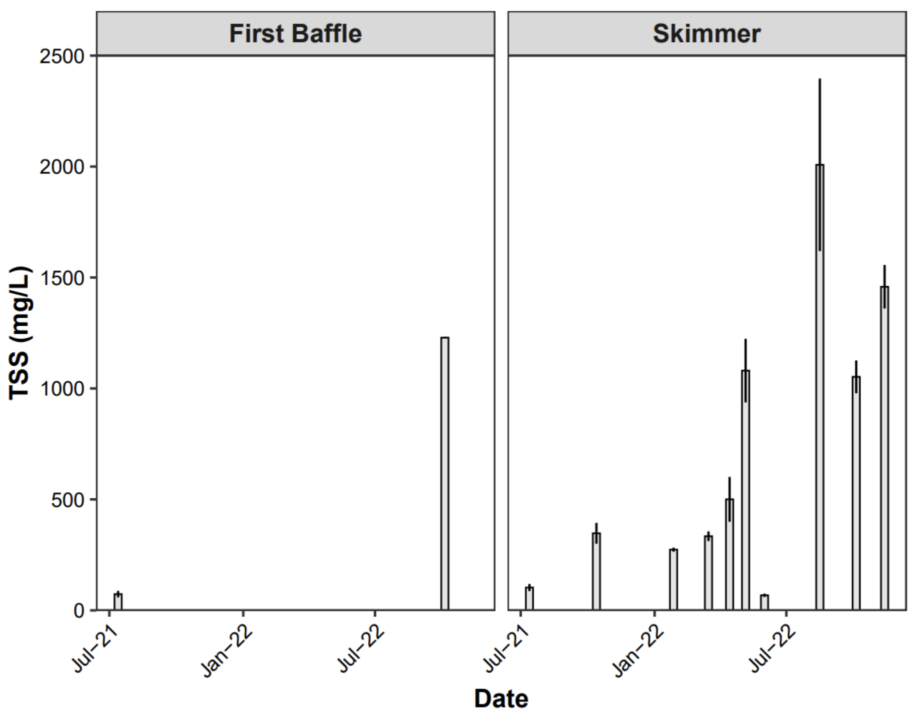


Figure A12. Average TSS for basin 6 per storm event.

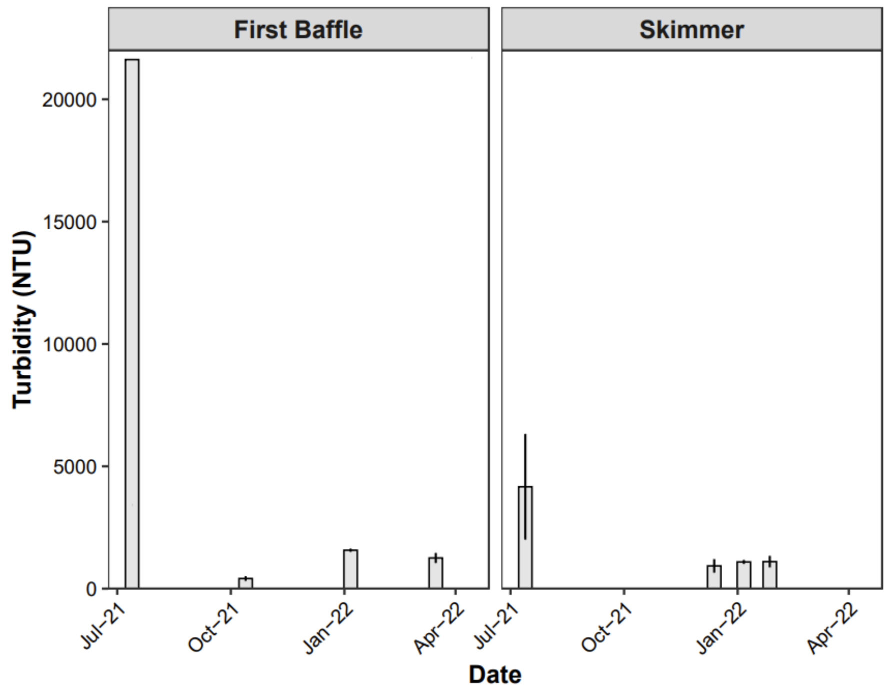


Figure A13. Average turbidity for basin 7 per storm event.

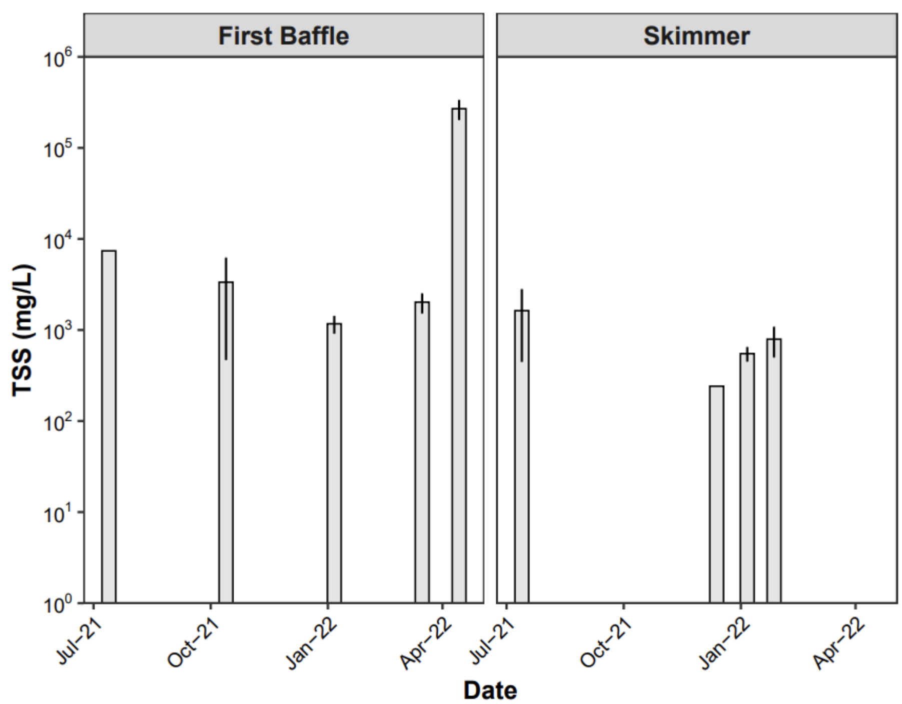


Figure A14. Average TSS for basin 7 per storm event.

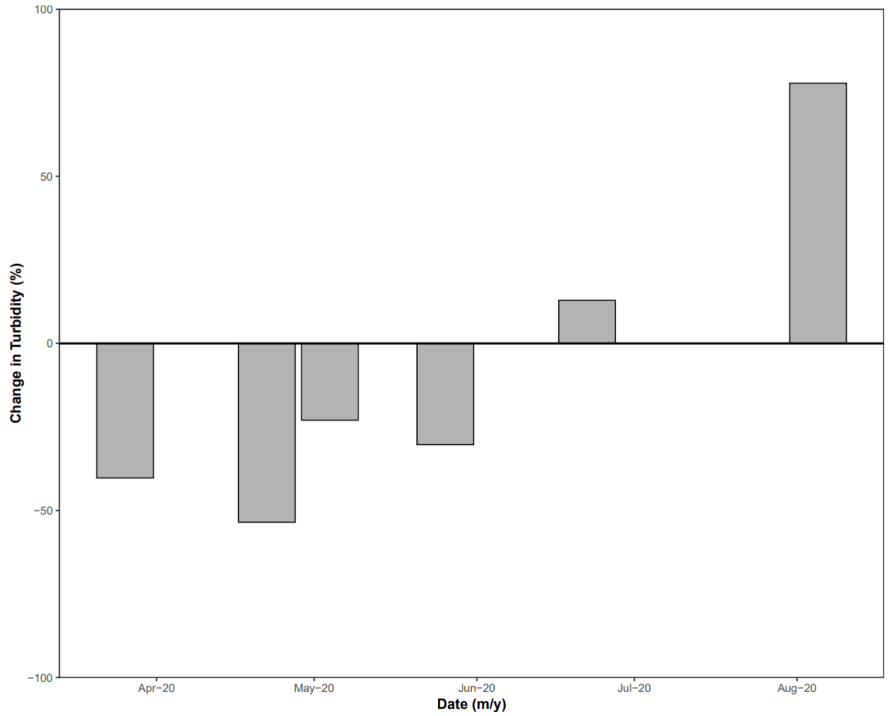


Figure A15. Average turbidity change for basin 1 per storm event.

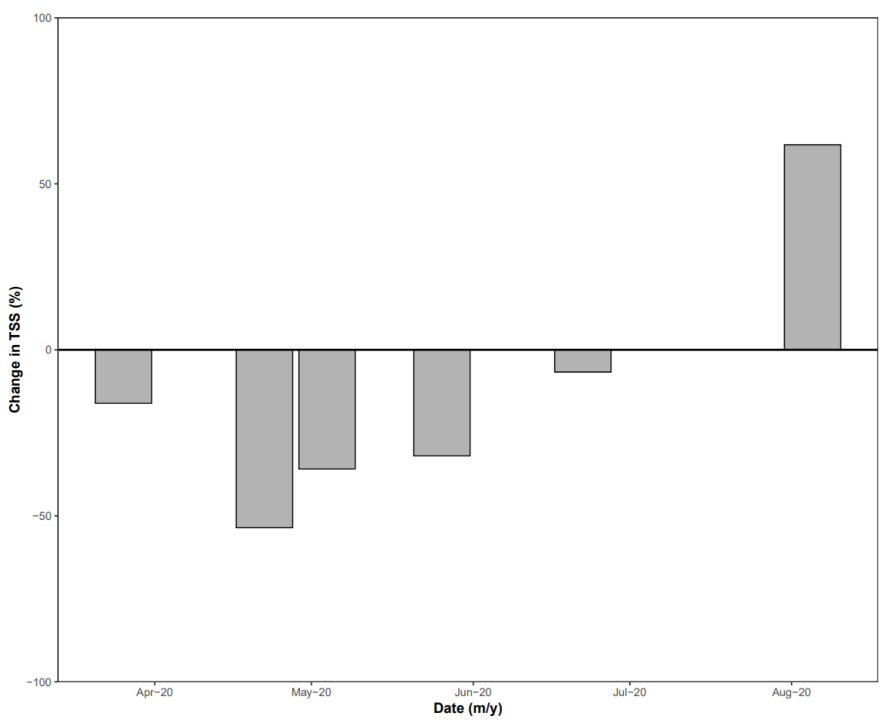


Figure A16. Average TSS change for basin 1 per storm event.

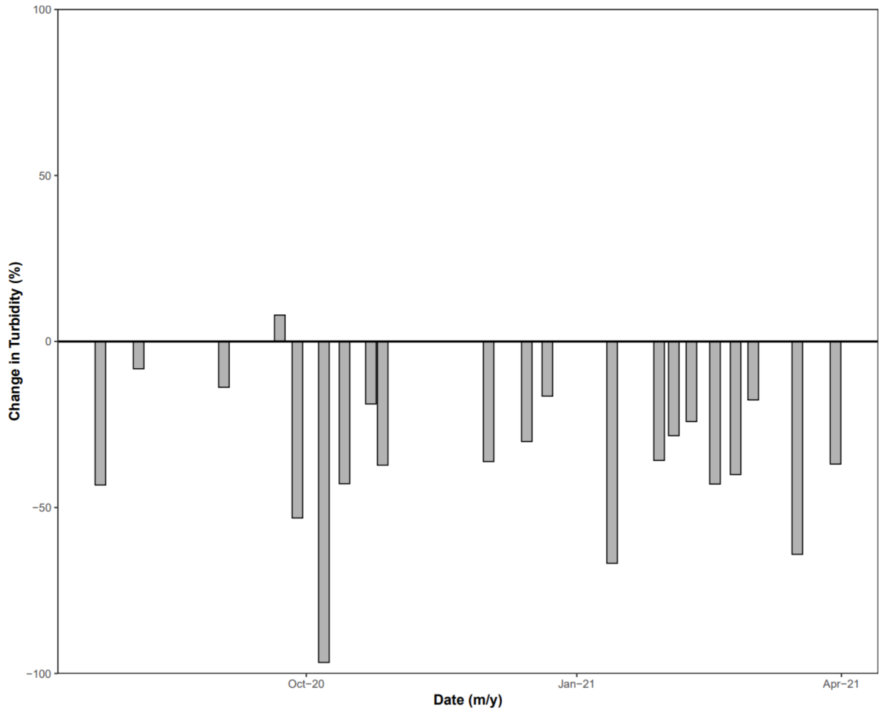


Figure A17. Average turbidity change for basin 3 per storm event.

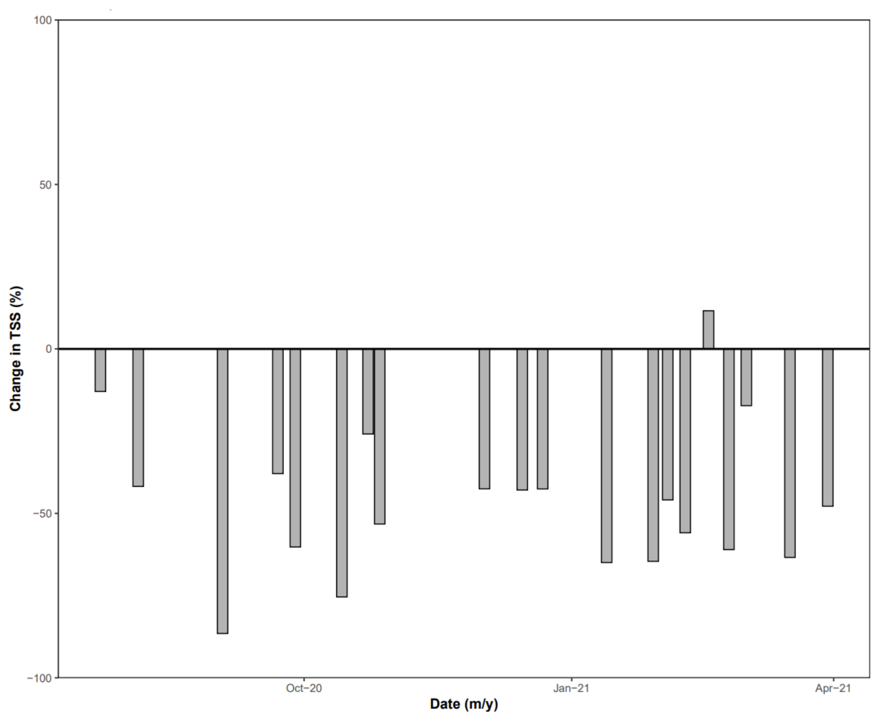


Figure A18. Average TSS change for basin 3 per storm event.

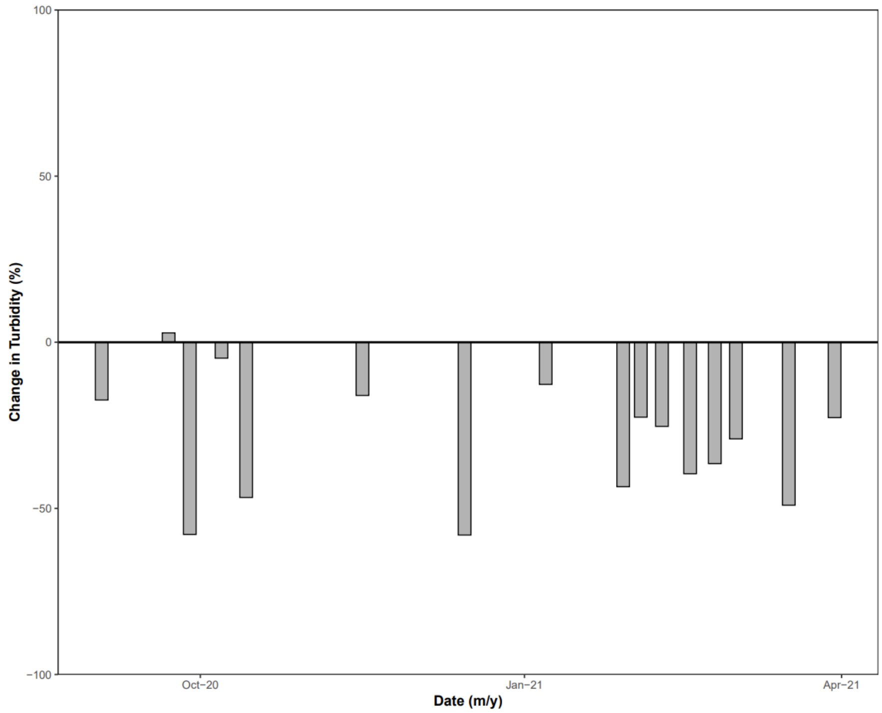


Figure A19. Average turbidity change for basin 4 per storm event.

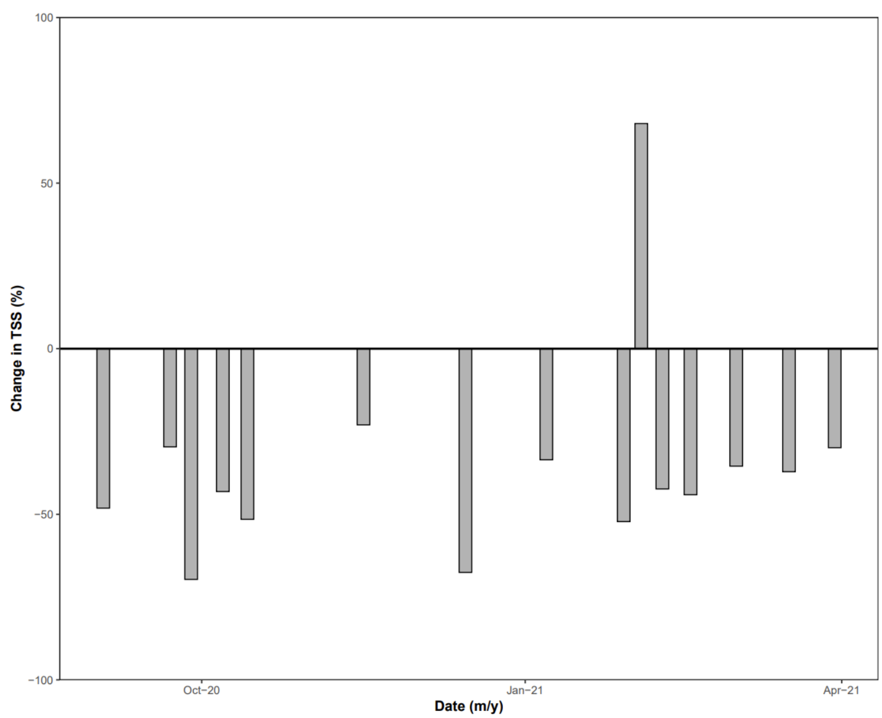


Figure A20. Average TSS change for basin 4 per storm event.

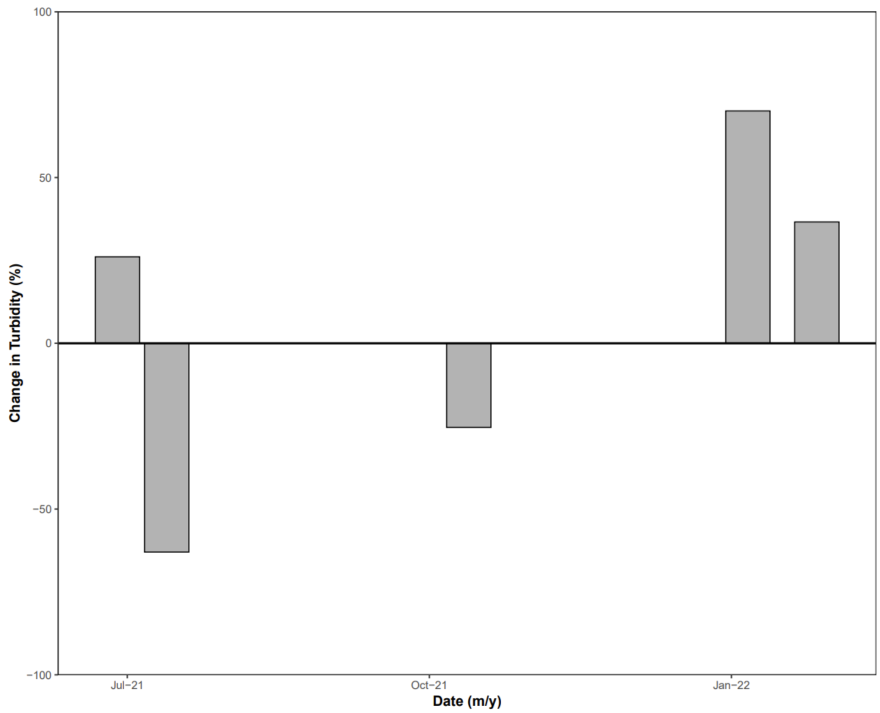


Figure A21. Average turbidity change for basin 5 per storm event.

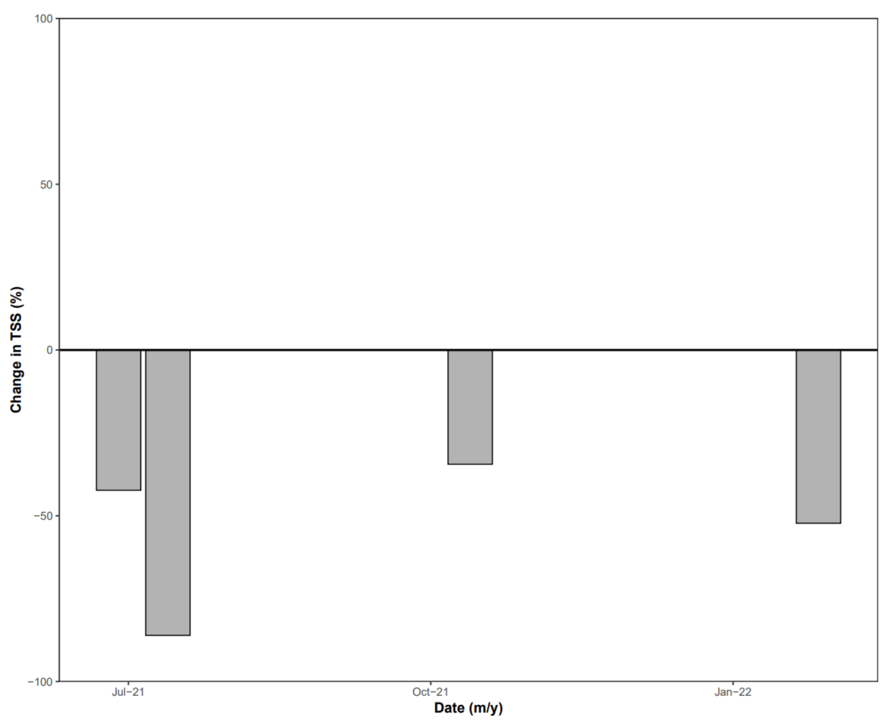


Figure A22. Average TSS change for basin 5 per storm event.

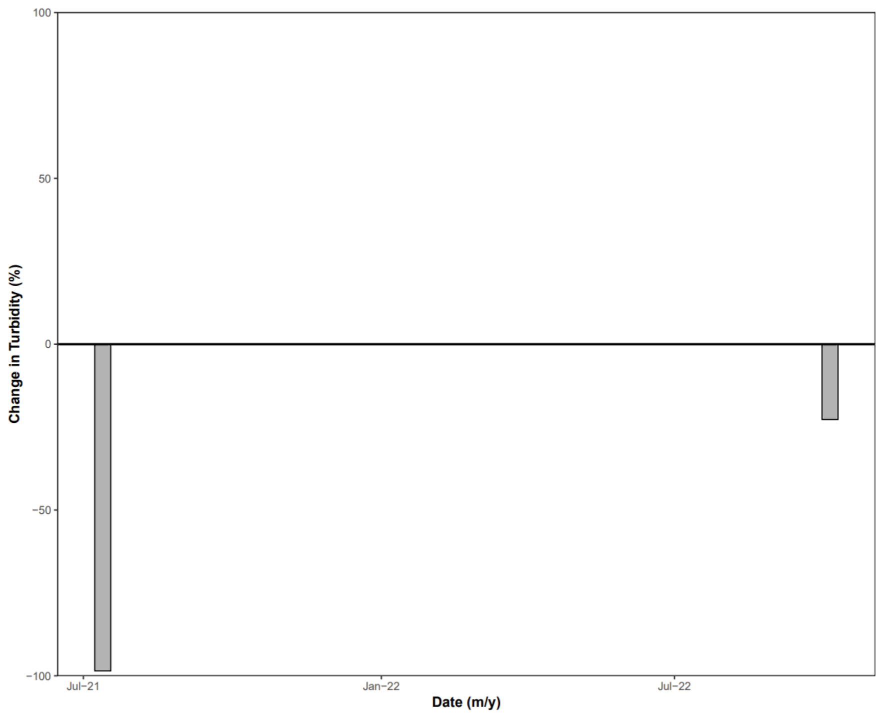


Figure A23. Average turbidity change for basin 6 per storm event.

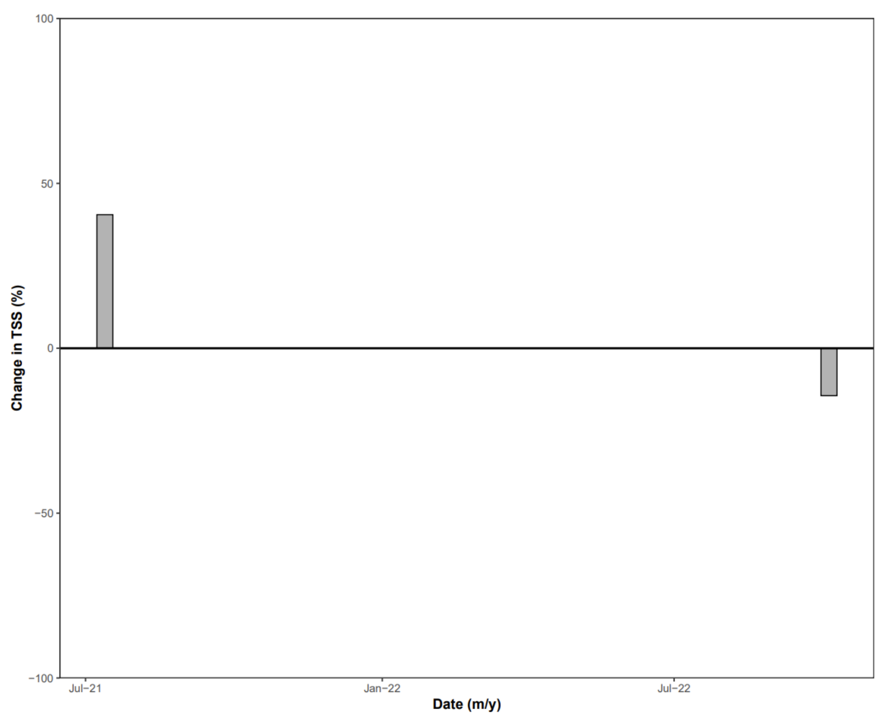


Figure A24. Average TSS change for basin 6 per storm event.

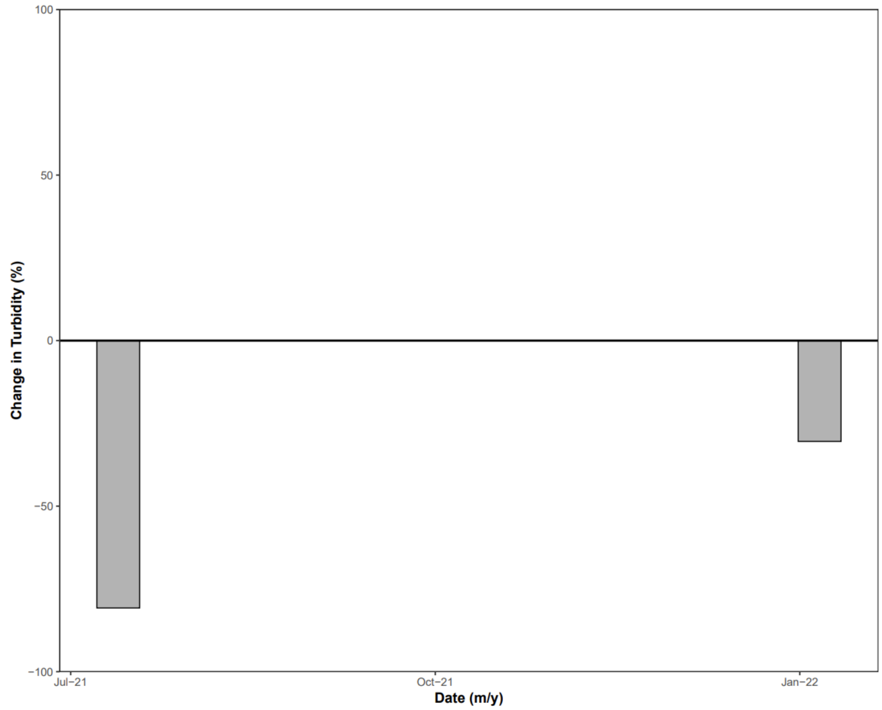


Figure A25. Average turbidity change for basin 7 per storm event.

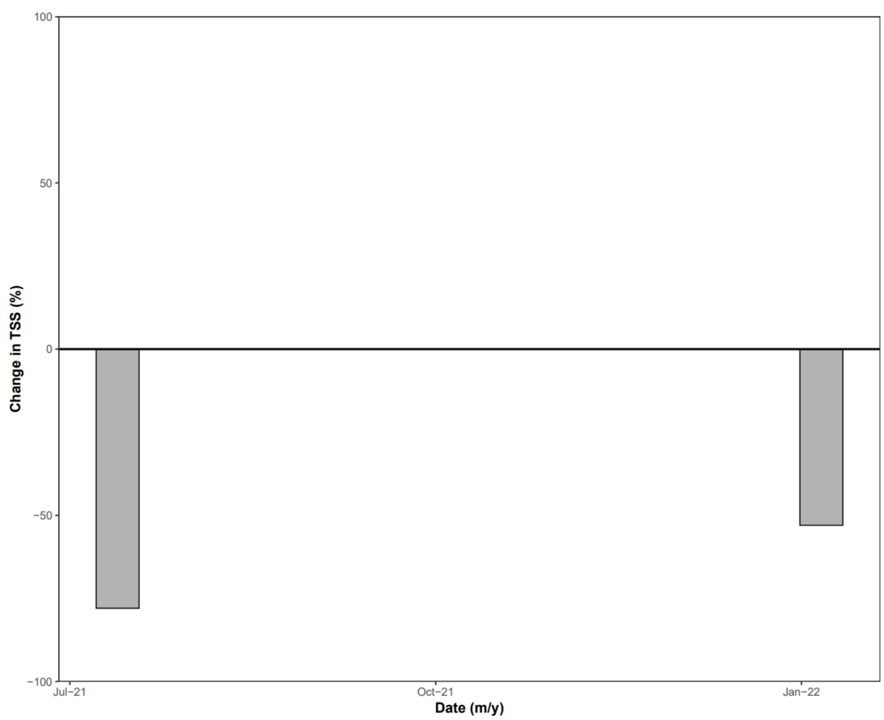
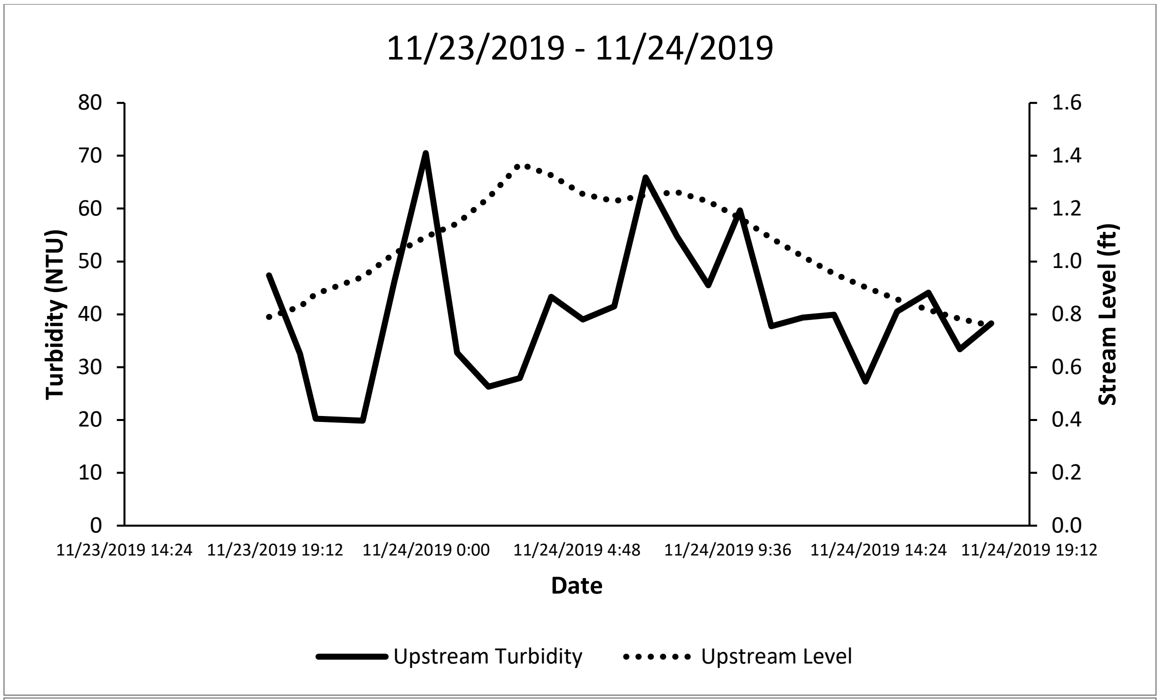


Figure A26. Average TSS change for basin 7 per storm event.

APPENDIX 2: SUPPLEMENTAL TURBIDITY AND TSS LOADS FOR SWIFT CREEK

This appendix includes hydrographs for Swift Creek comparing the stream level to the measure turbidity and TSS (upstream and downstream 1). Graph title is the date that the samples were taken from Swift Creek.



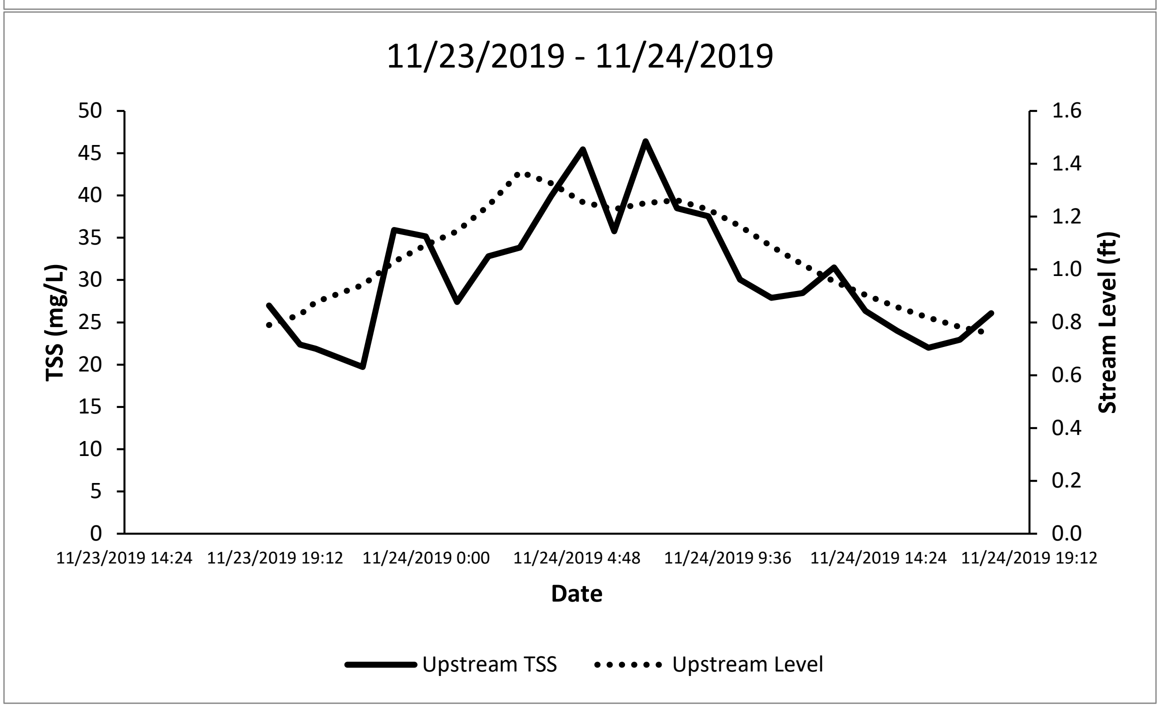


Figure A27. Turbidity (top) and TSS (bottom) in Swift Creek.

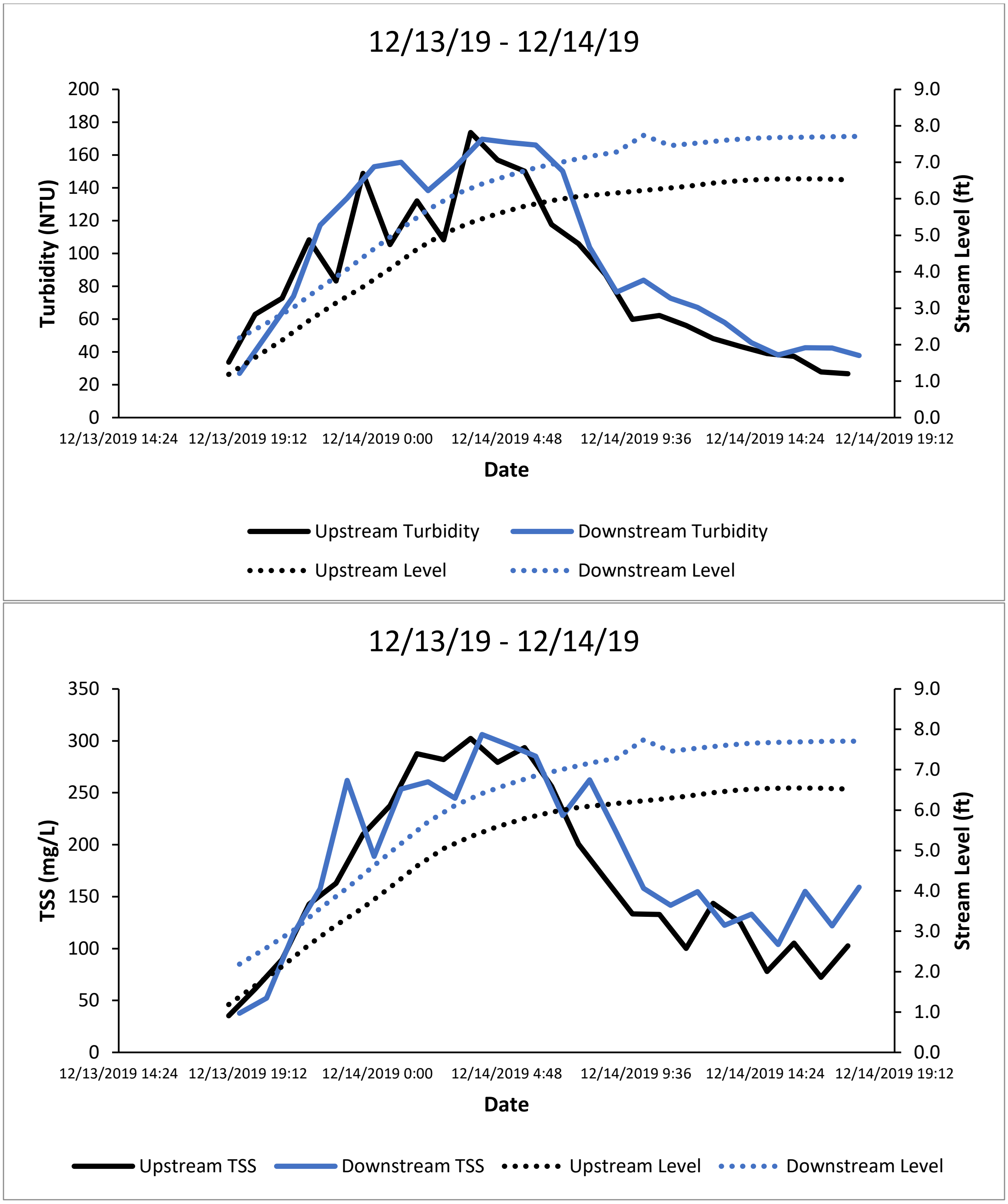
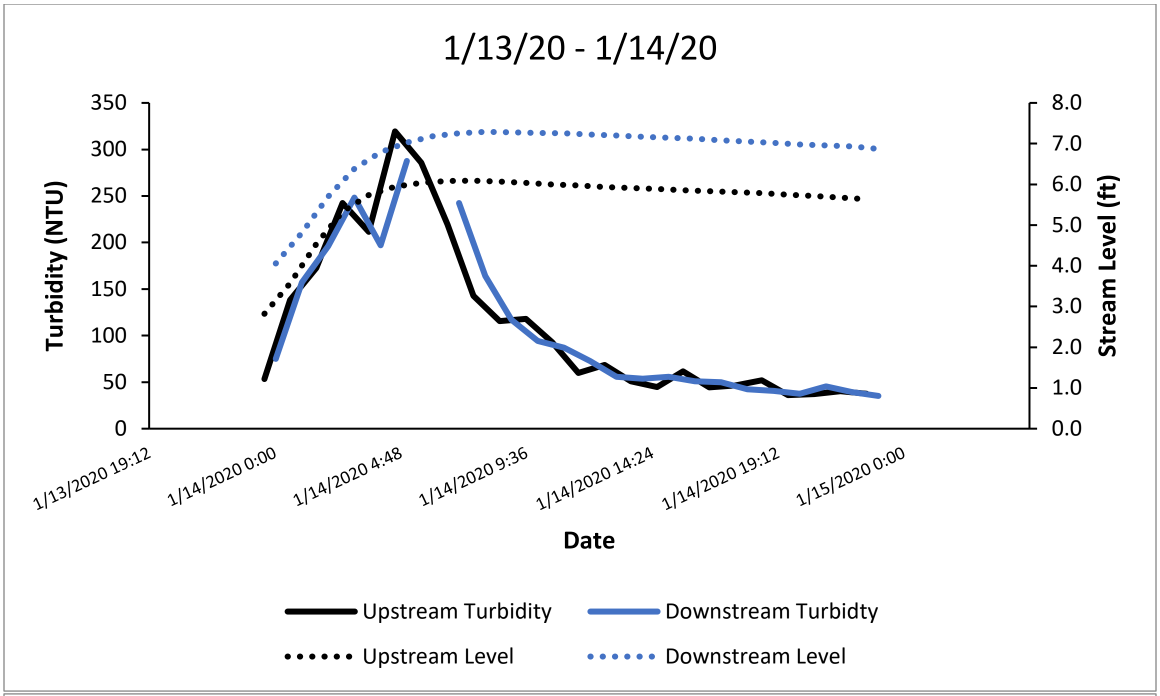


Figure A28. Turbidity (top) and TSS (bottom) in Swift Creek.



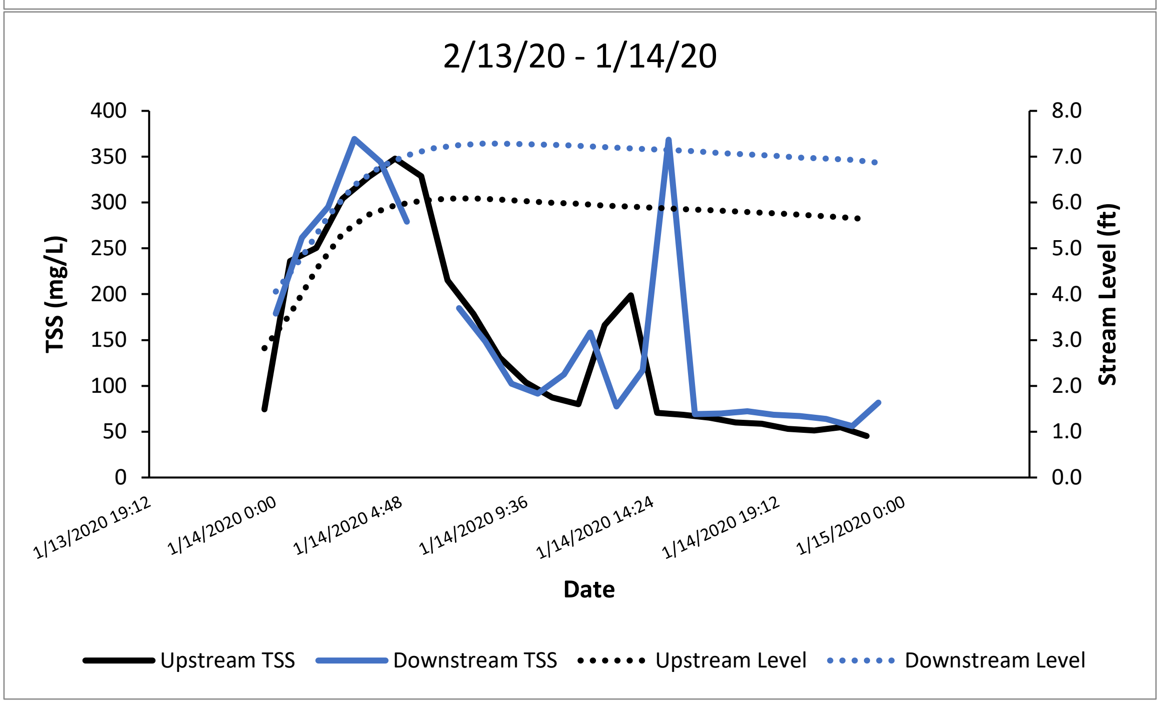
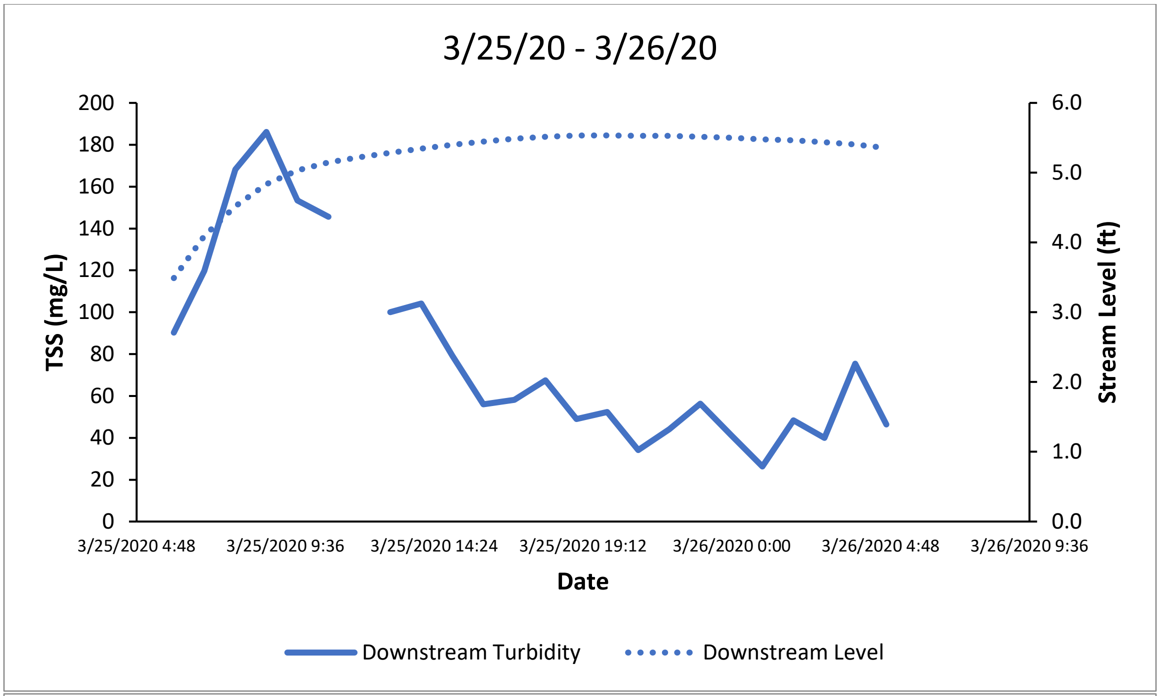


Figure A29. Turbidity (top) and TSS (bottom) in Swift Creek.



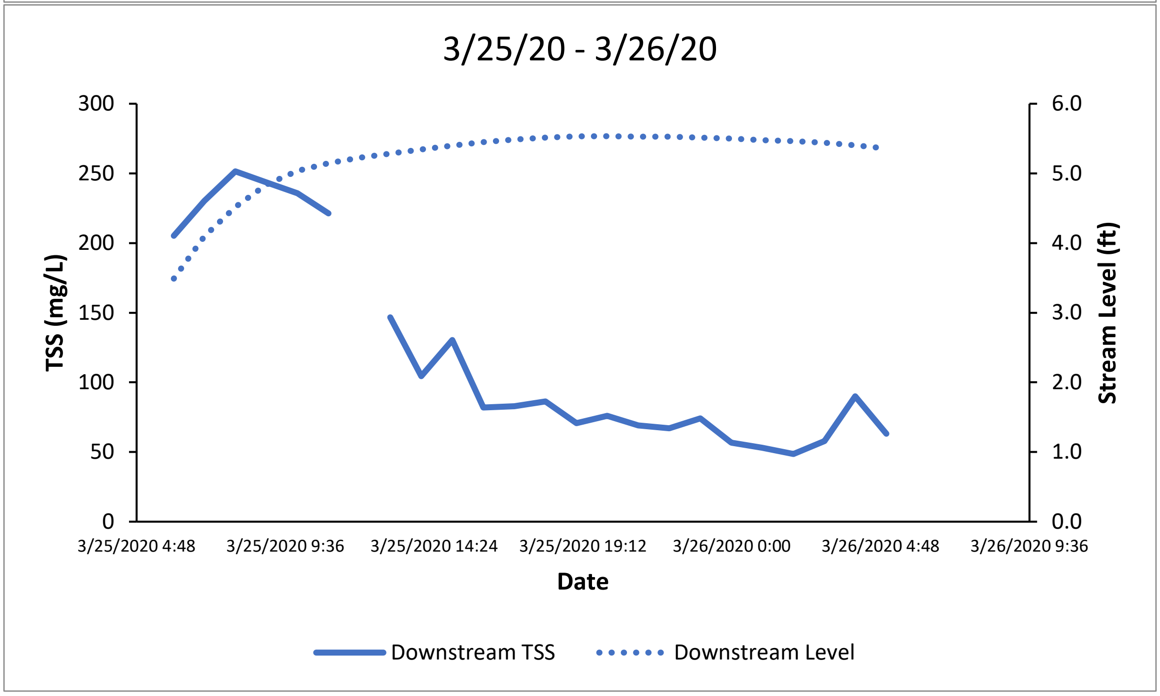
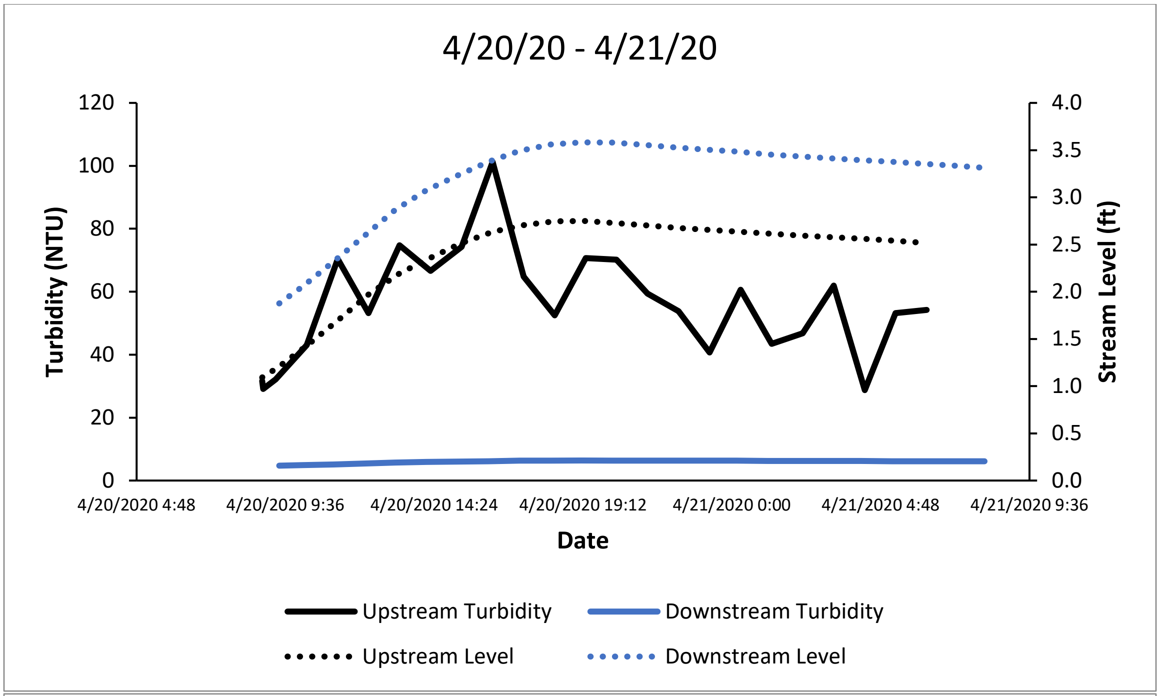


Figure A30. Turbidity (top) and TSS (bottom) in Swift Creek.



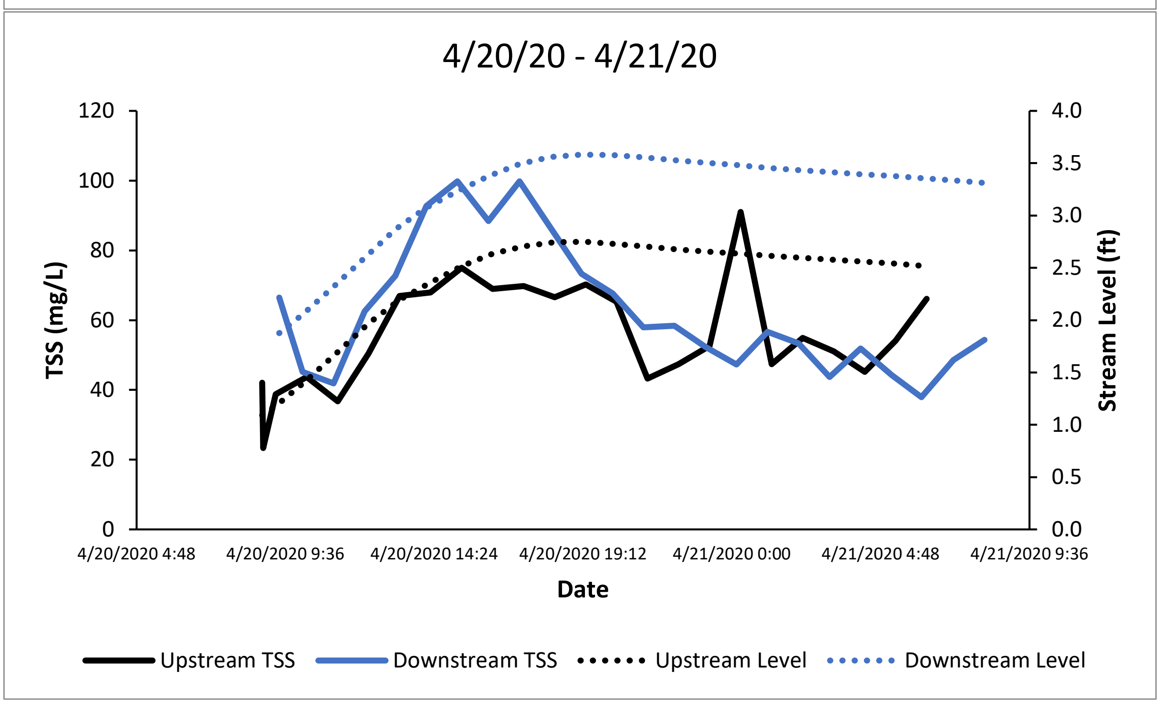
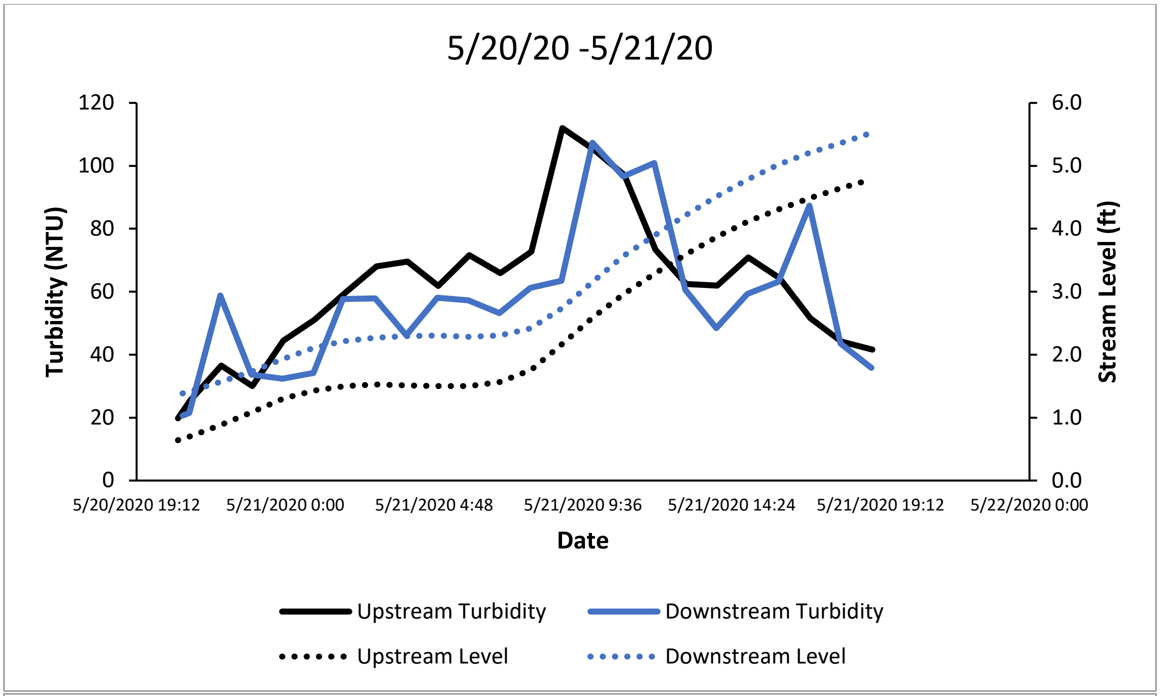


Figure A31. Turbidity (top) and TSS (bottom) in Swift Creek.



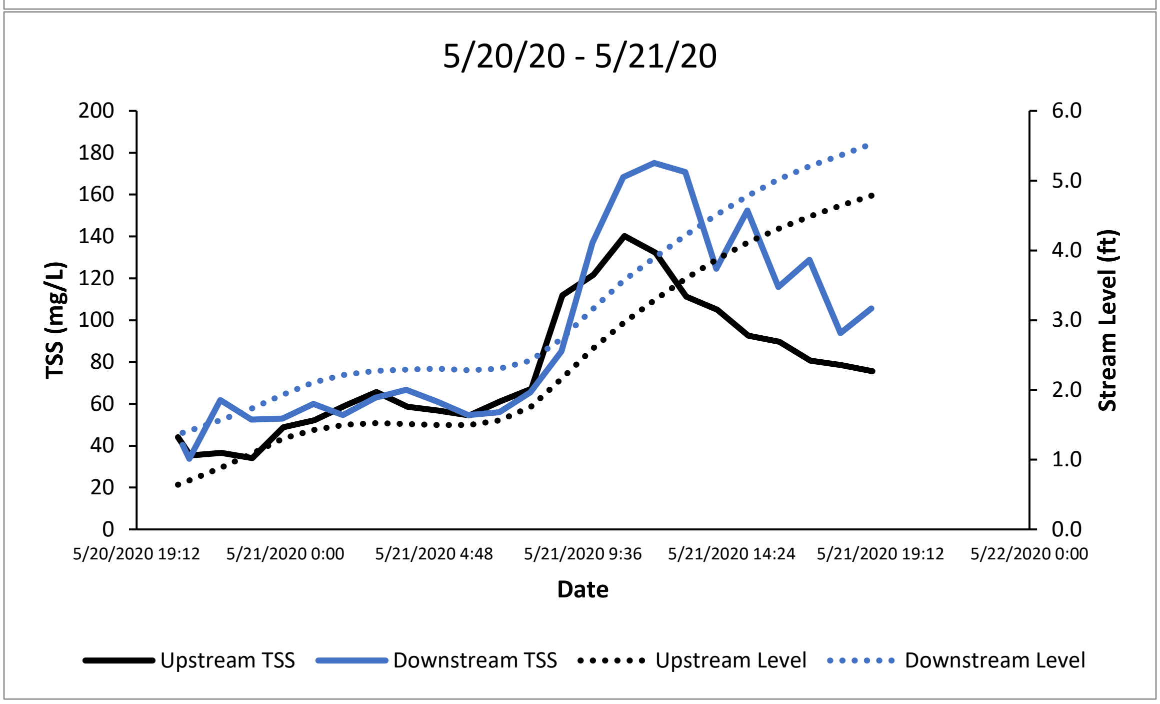
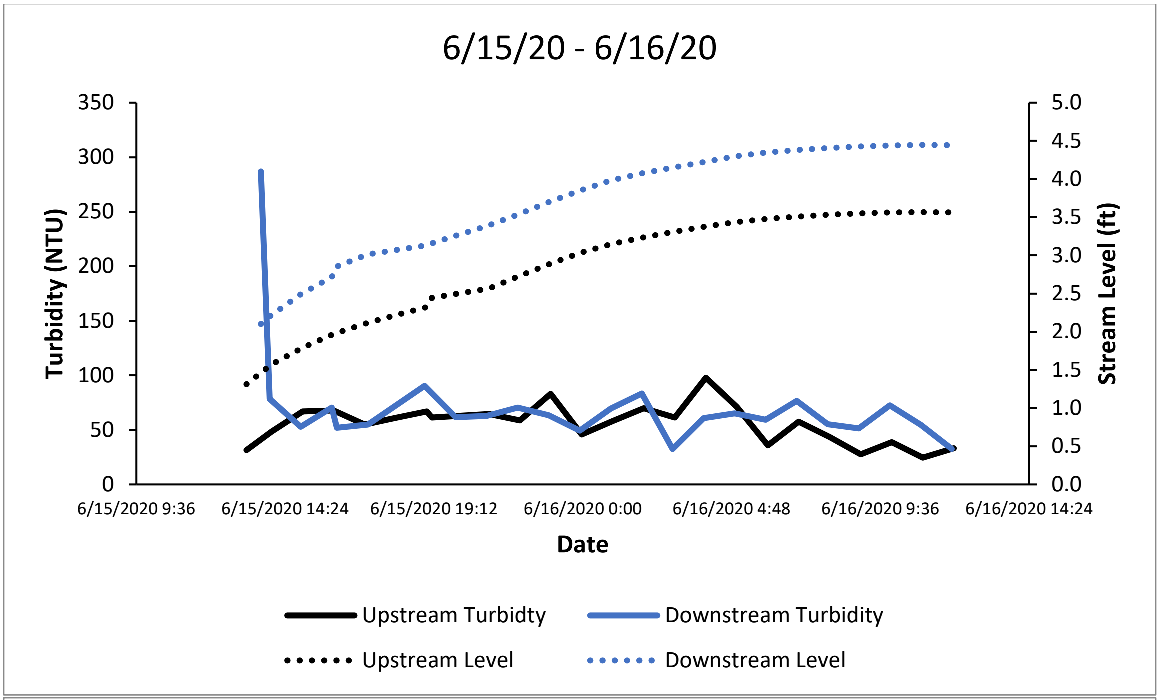


Figure A32. Turbidity (top) and TSS (bottom) in Swift Creek.



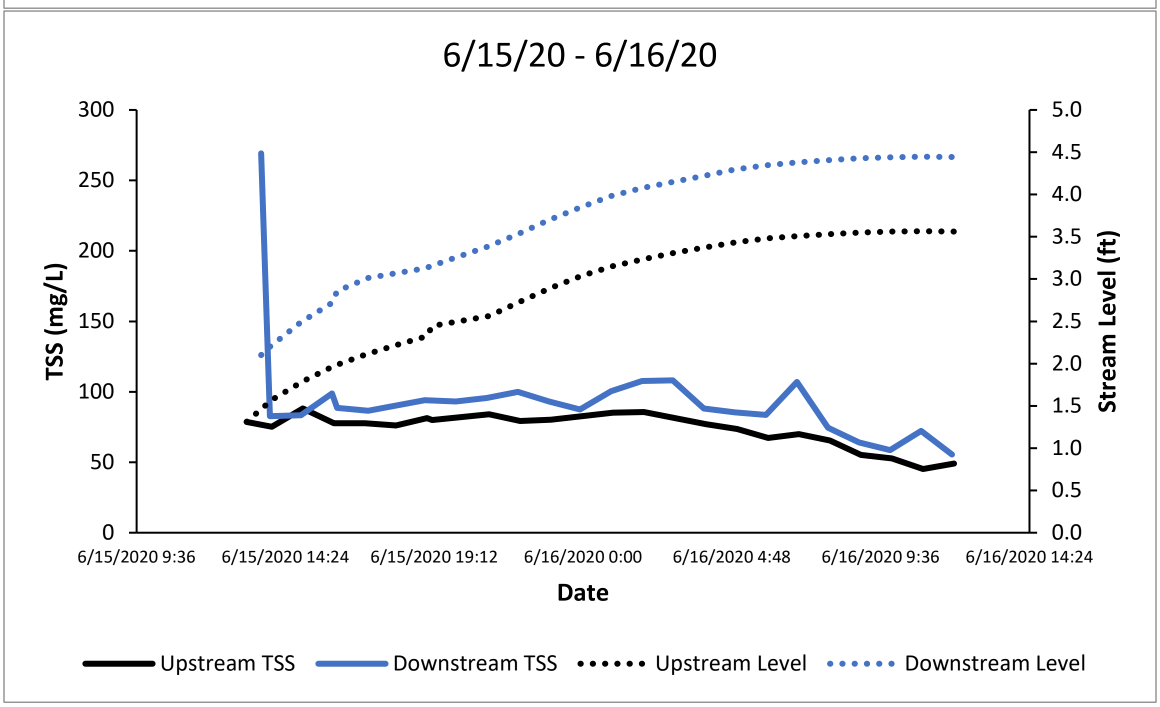
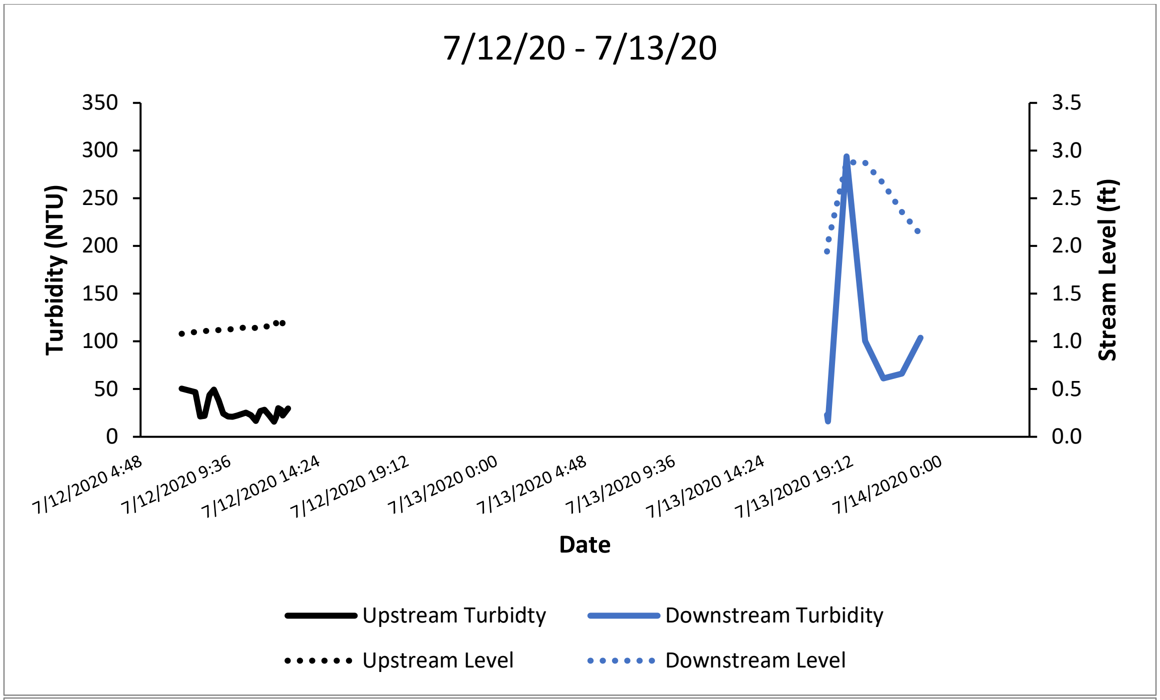


Figure A33. Turbidity (top) and TSS (bottom) in Swift Creek.



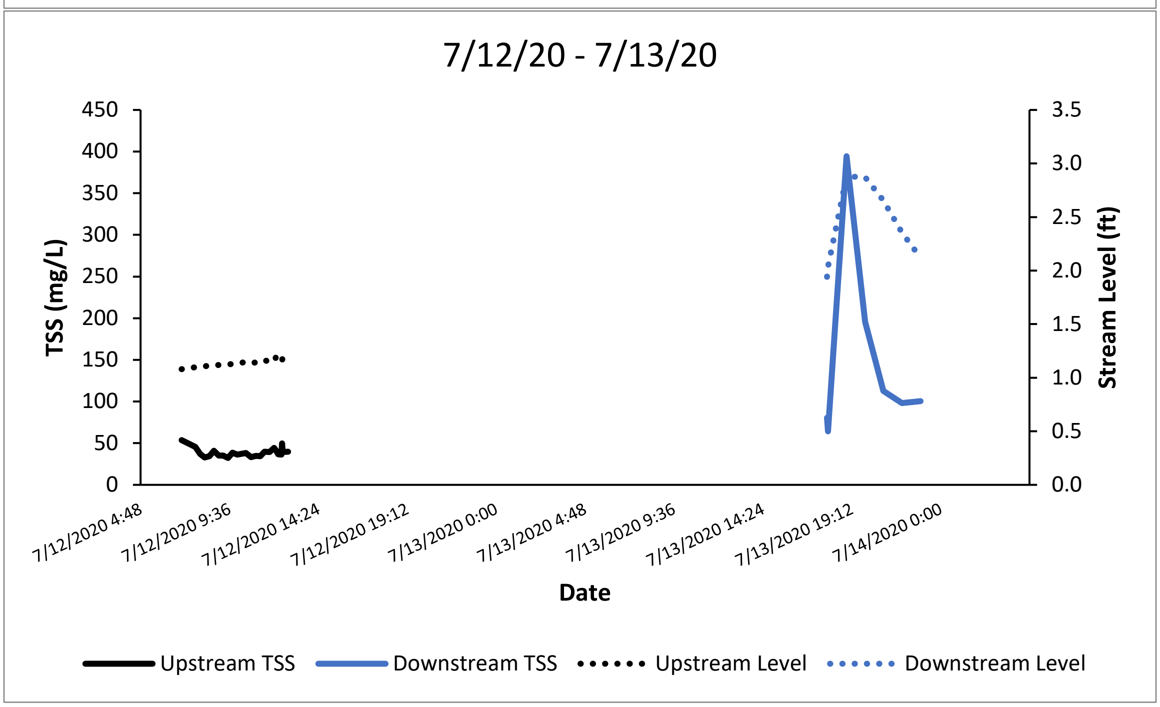
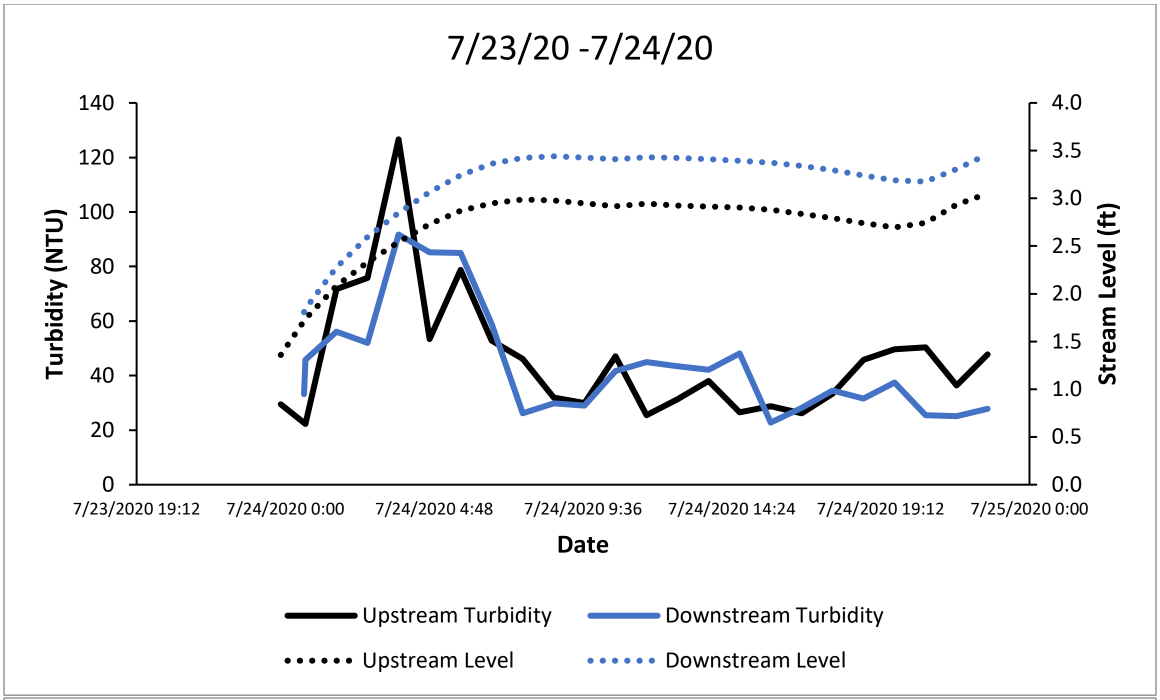


Figure A34. Turbidity (top) and TSS (bottom) in Swift Creek.



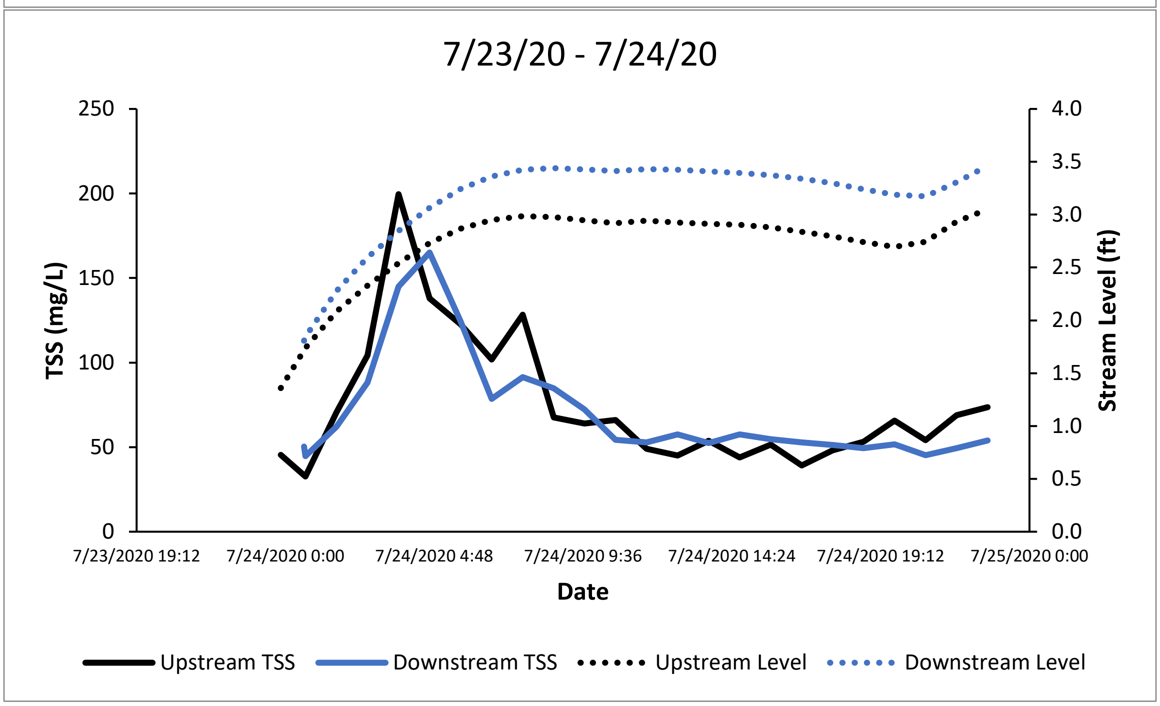
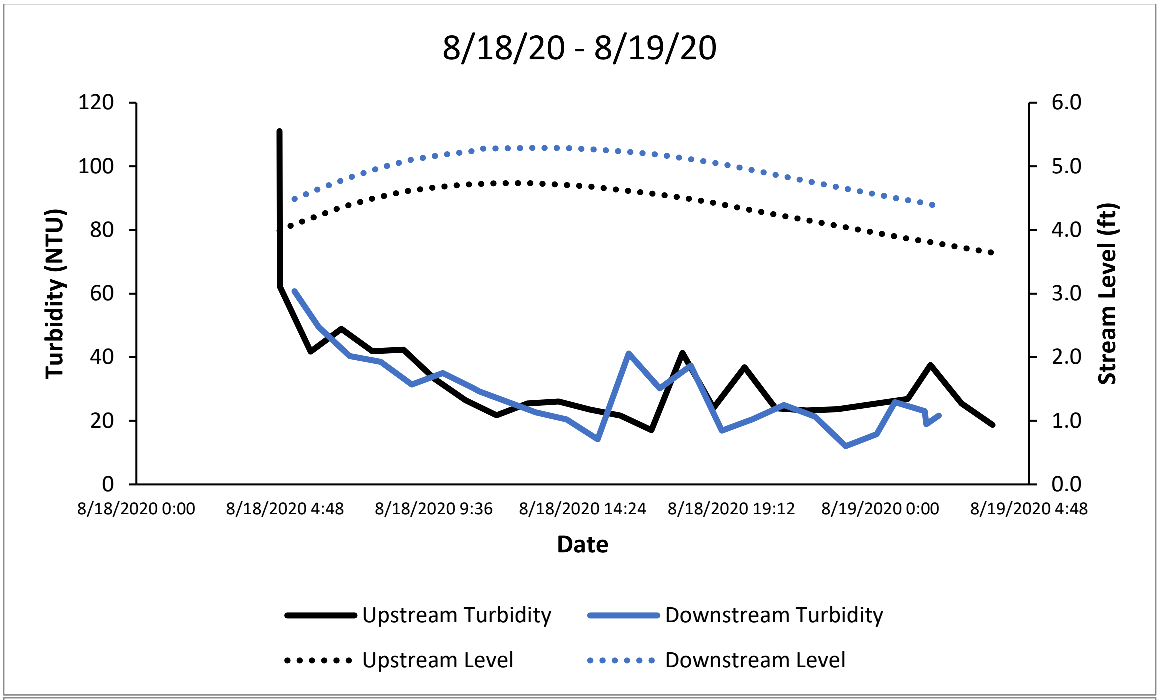


Figure A35. Turbidity (top) and TSS (bottom) in Swift Creek.



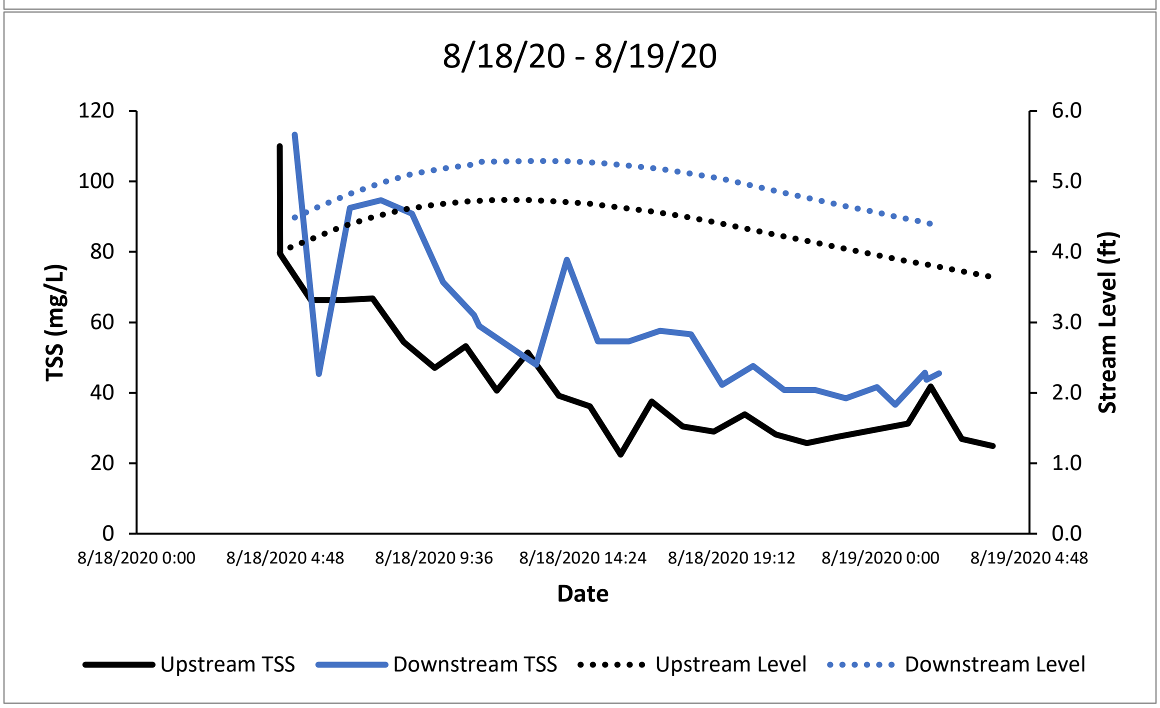
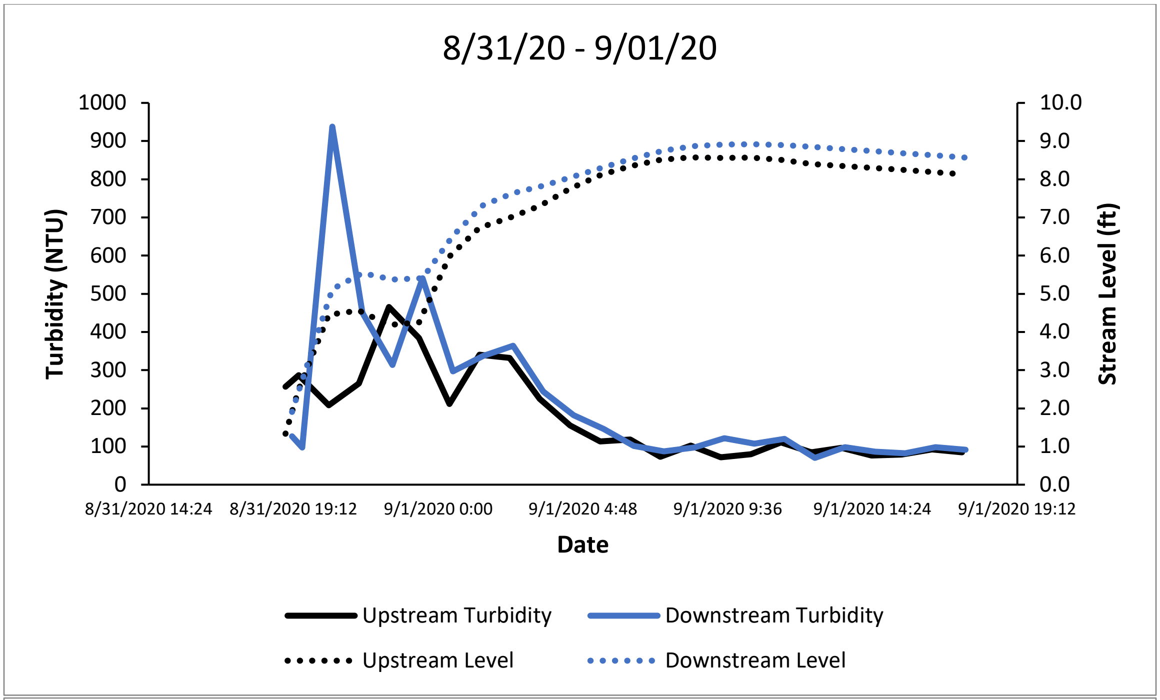


Figure A36. Turbidity (top) and TSS (bottom) in Swift Creek.



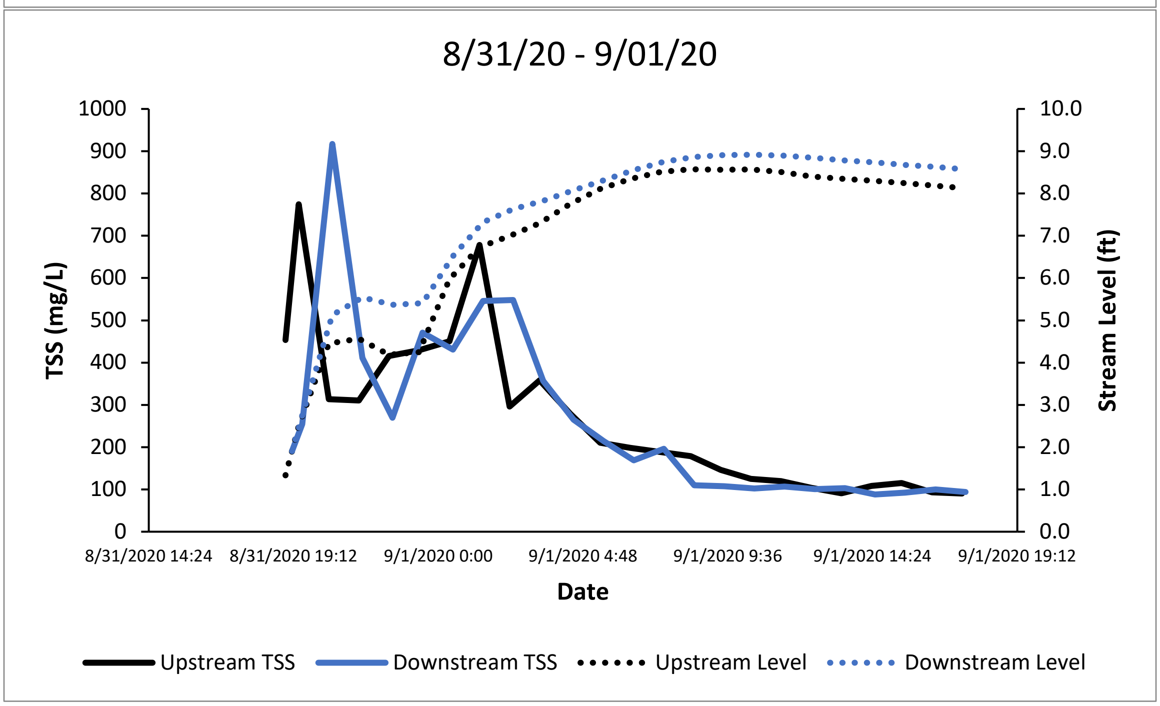
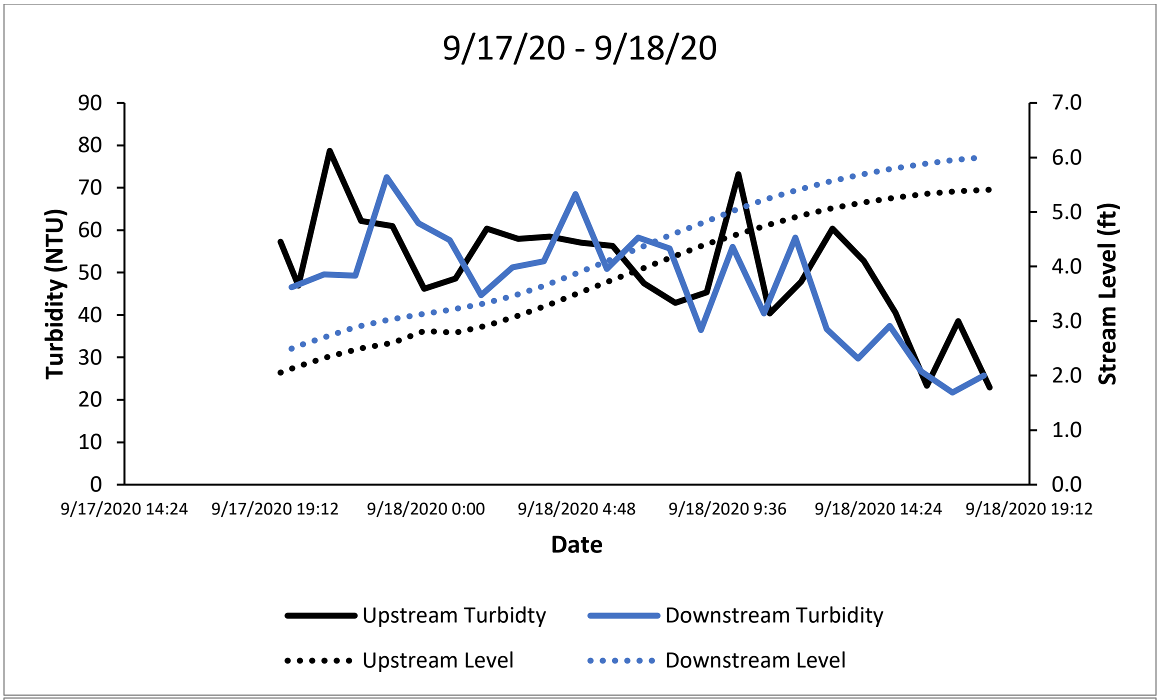


Figure A37. Turbidity (top) and TSS (bottom) in Swift Creek.



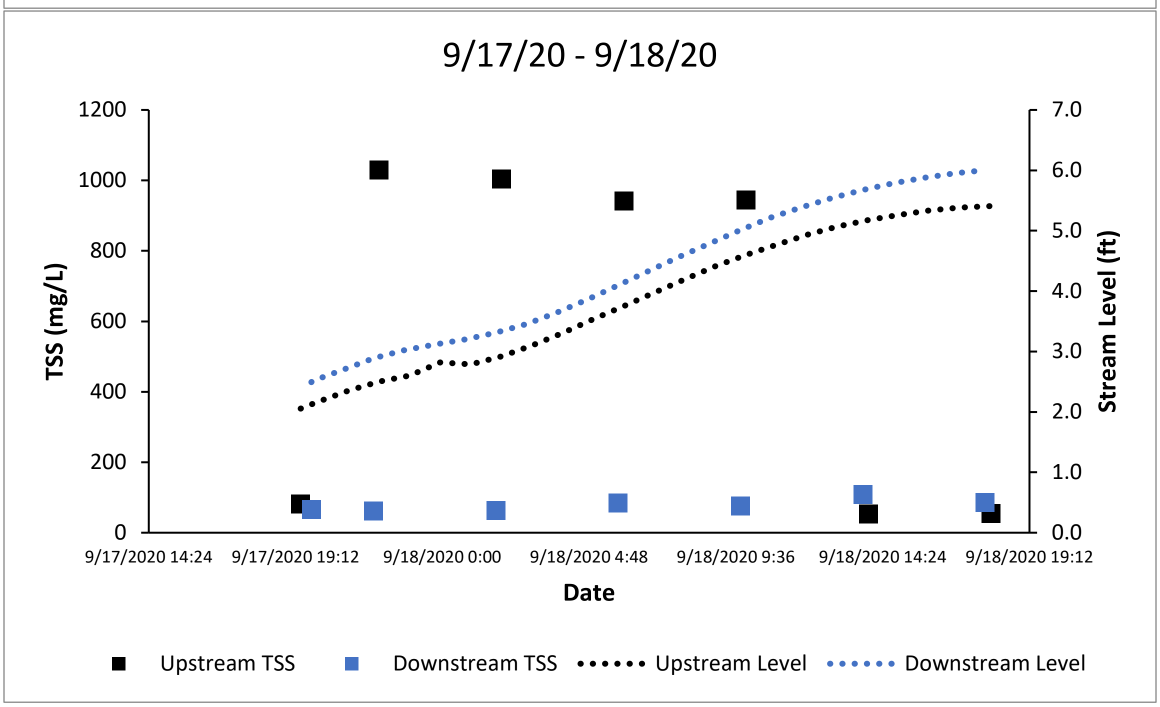
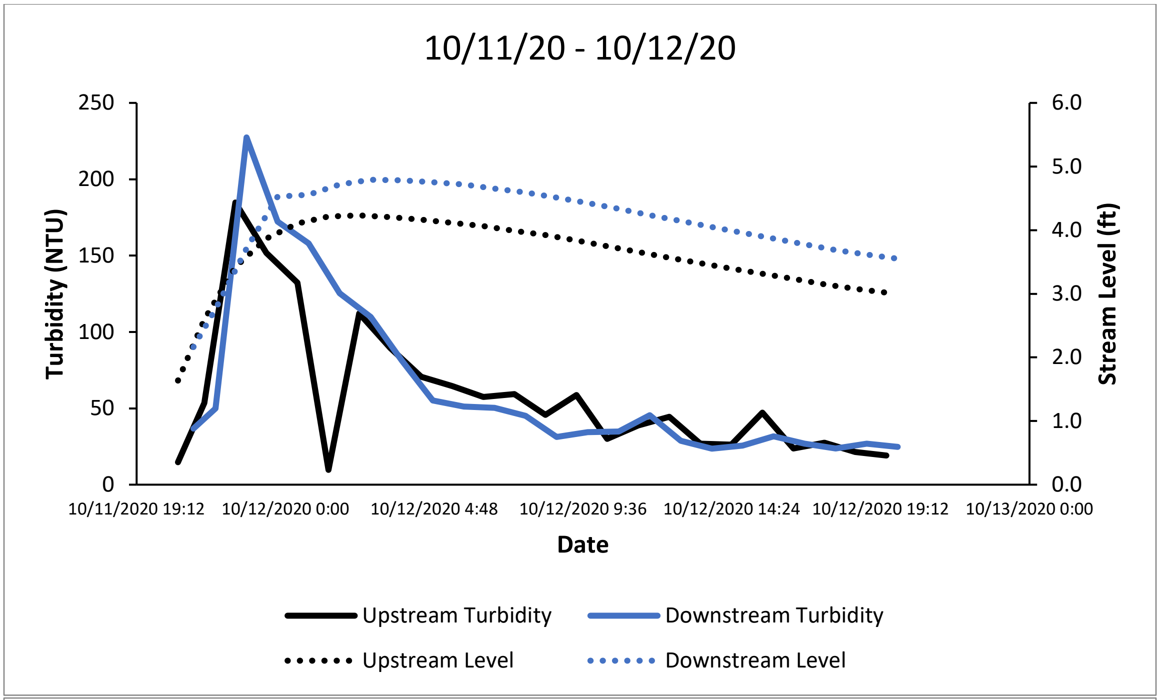


Figure A38. Turbidity (top) and TSS (bottom) in Swift Creek.



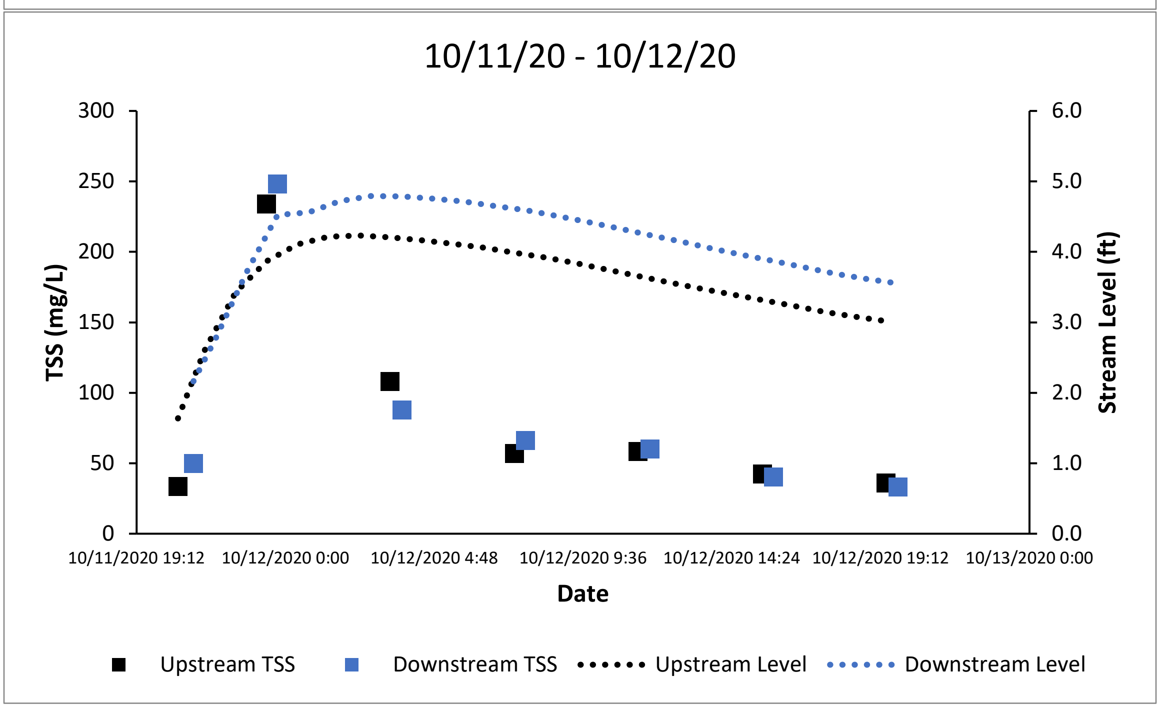
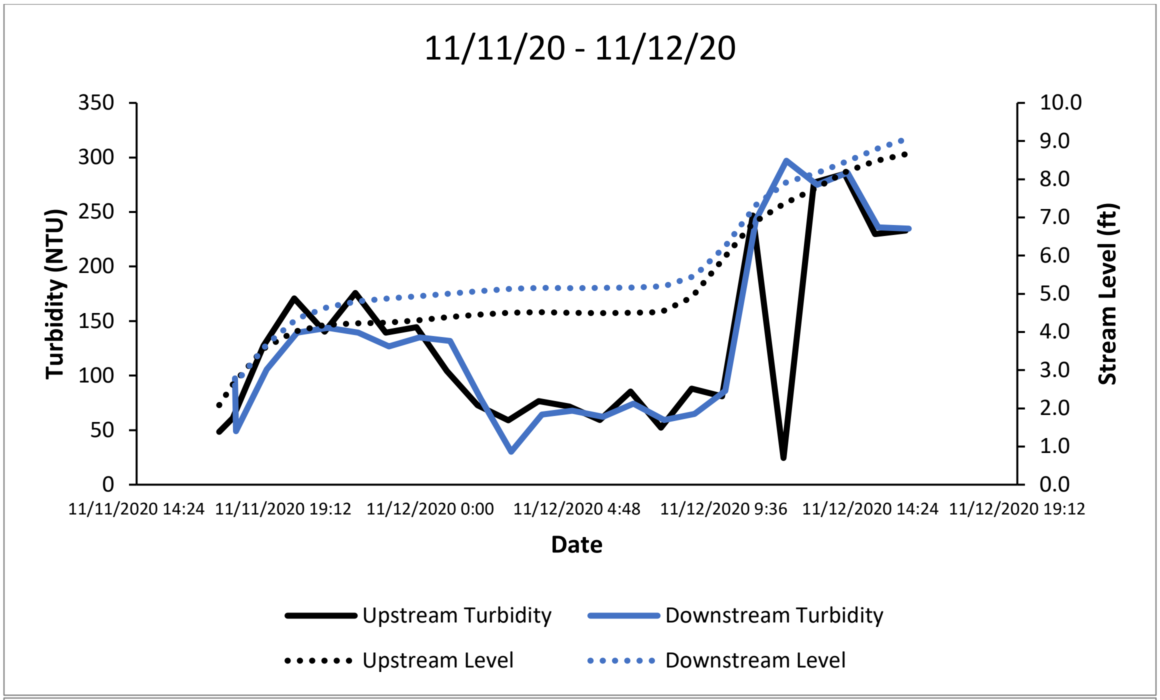


Figure A39. Turbidity (top) and TSS (bottom) in Swift Creek.



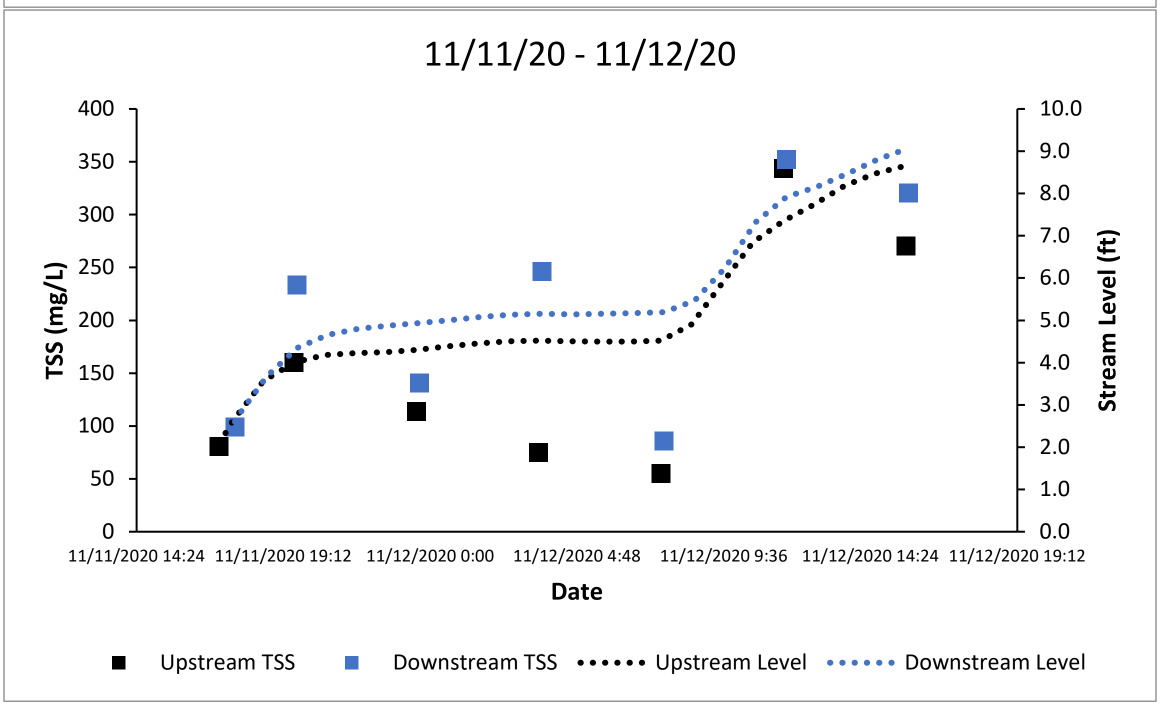
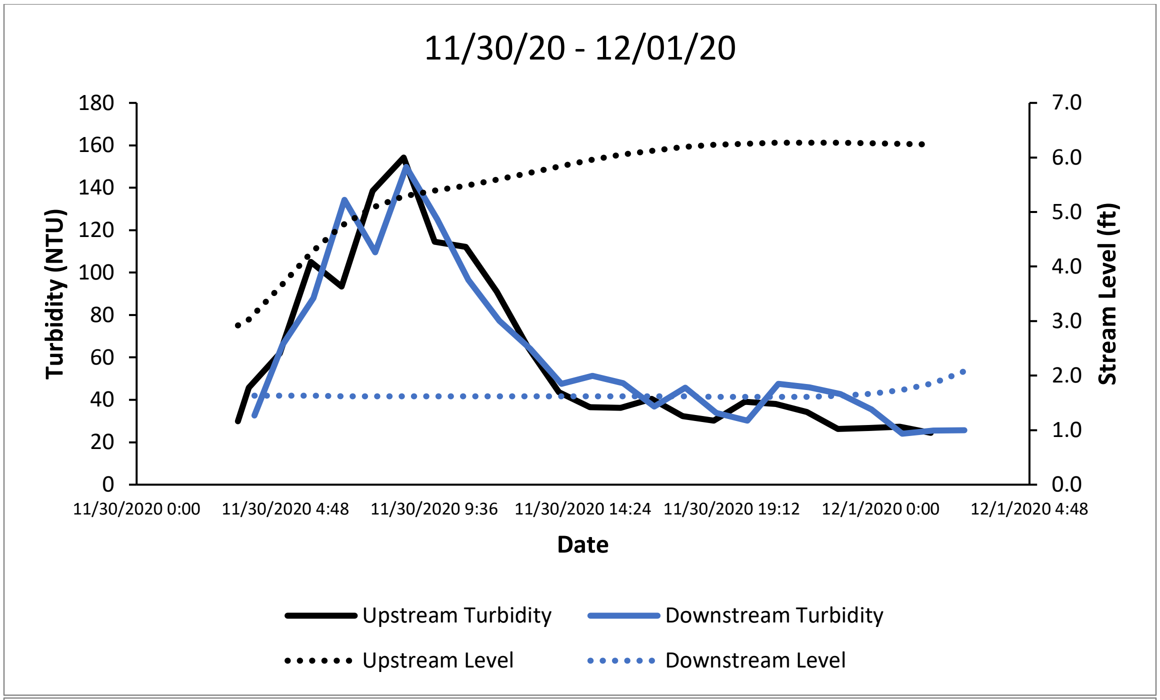


Figure A40. Turbidity (top) and TSS (bottom) in Swift Creek.



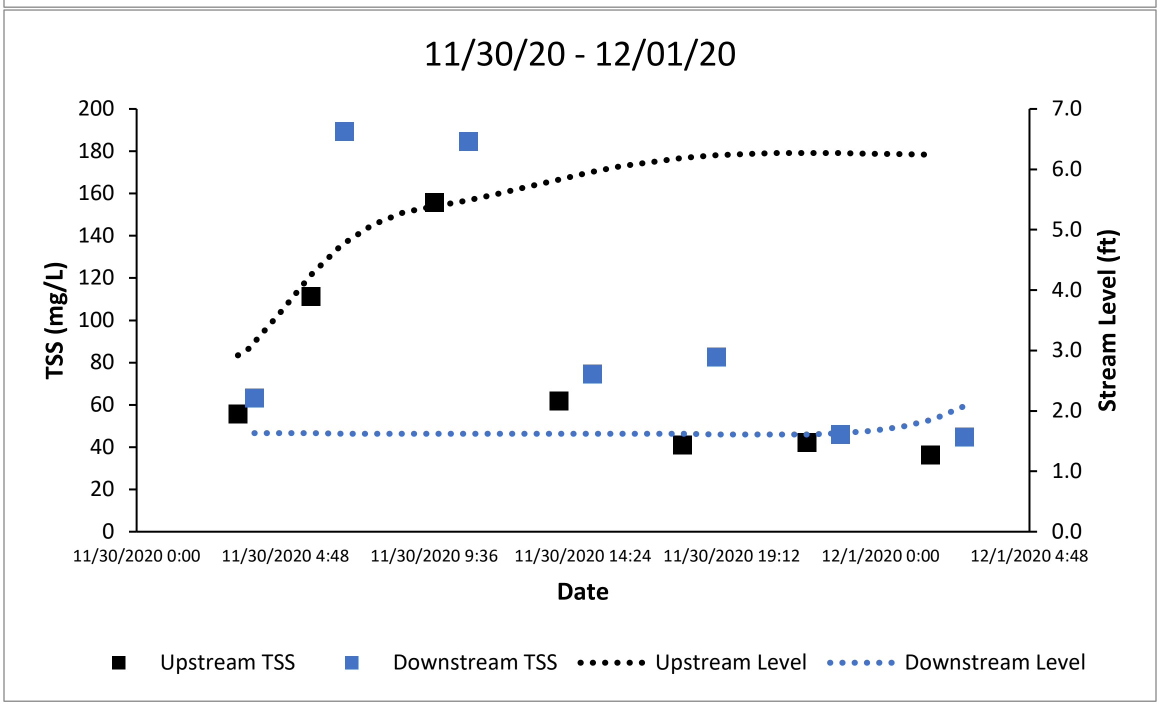
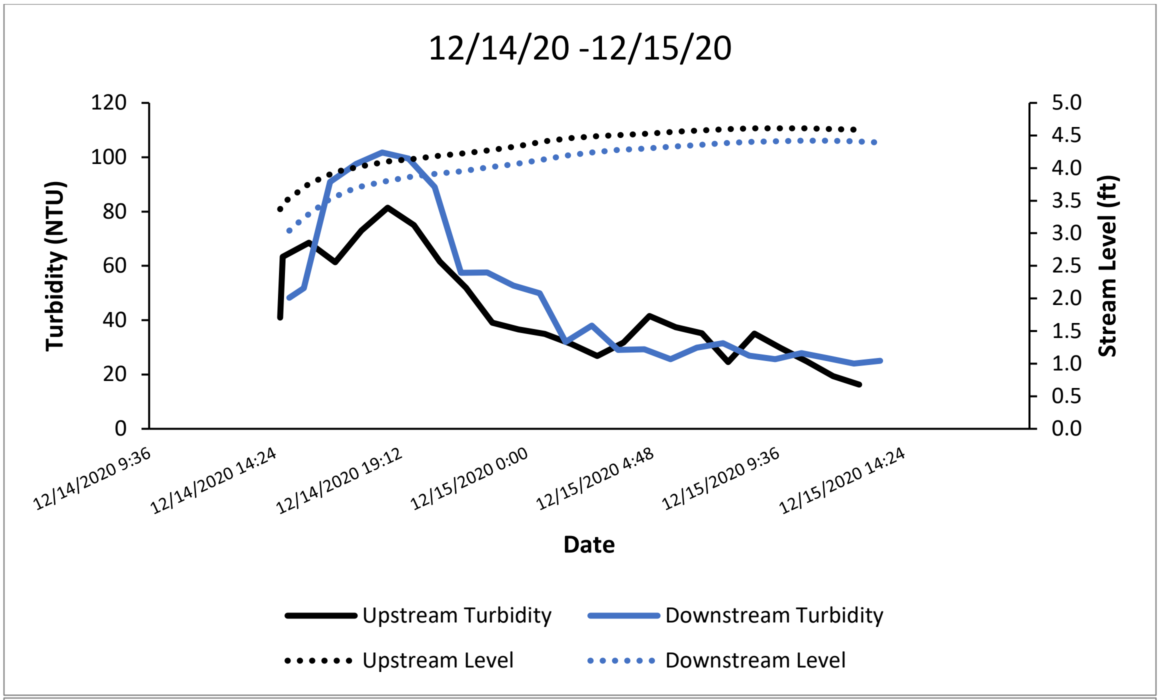


Figure A41. Turbidity (top) and TSS (bottom) in Swift Creek.



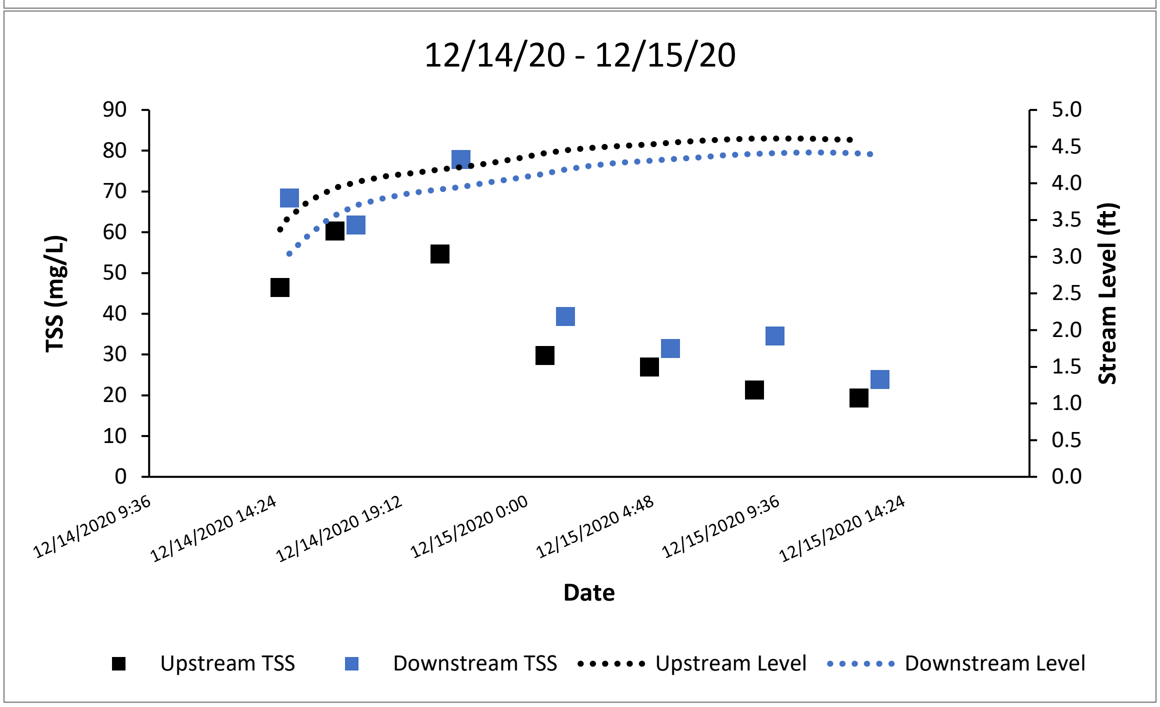
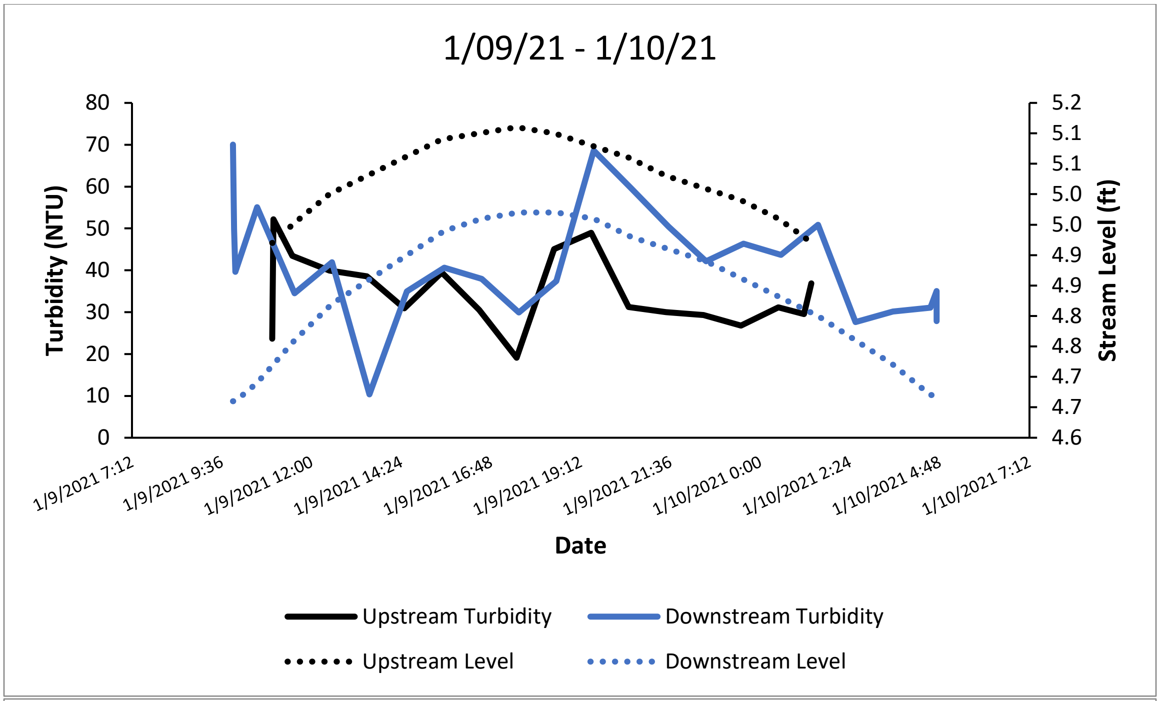


Figure A42. Turbidity (top) and TSS (bottom) in Swift Creek.



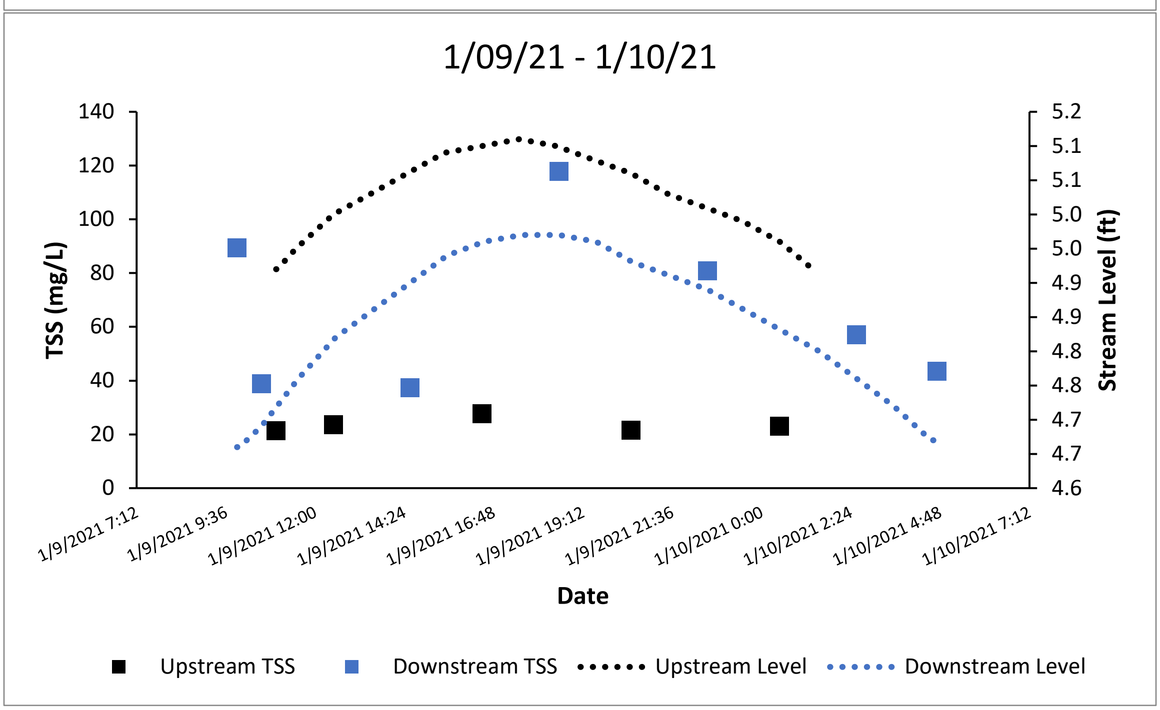


Figure A43. Turbidity (top) and TSS (bottom) in Swift Creek.

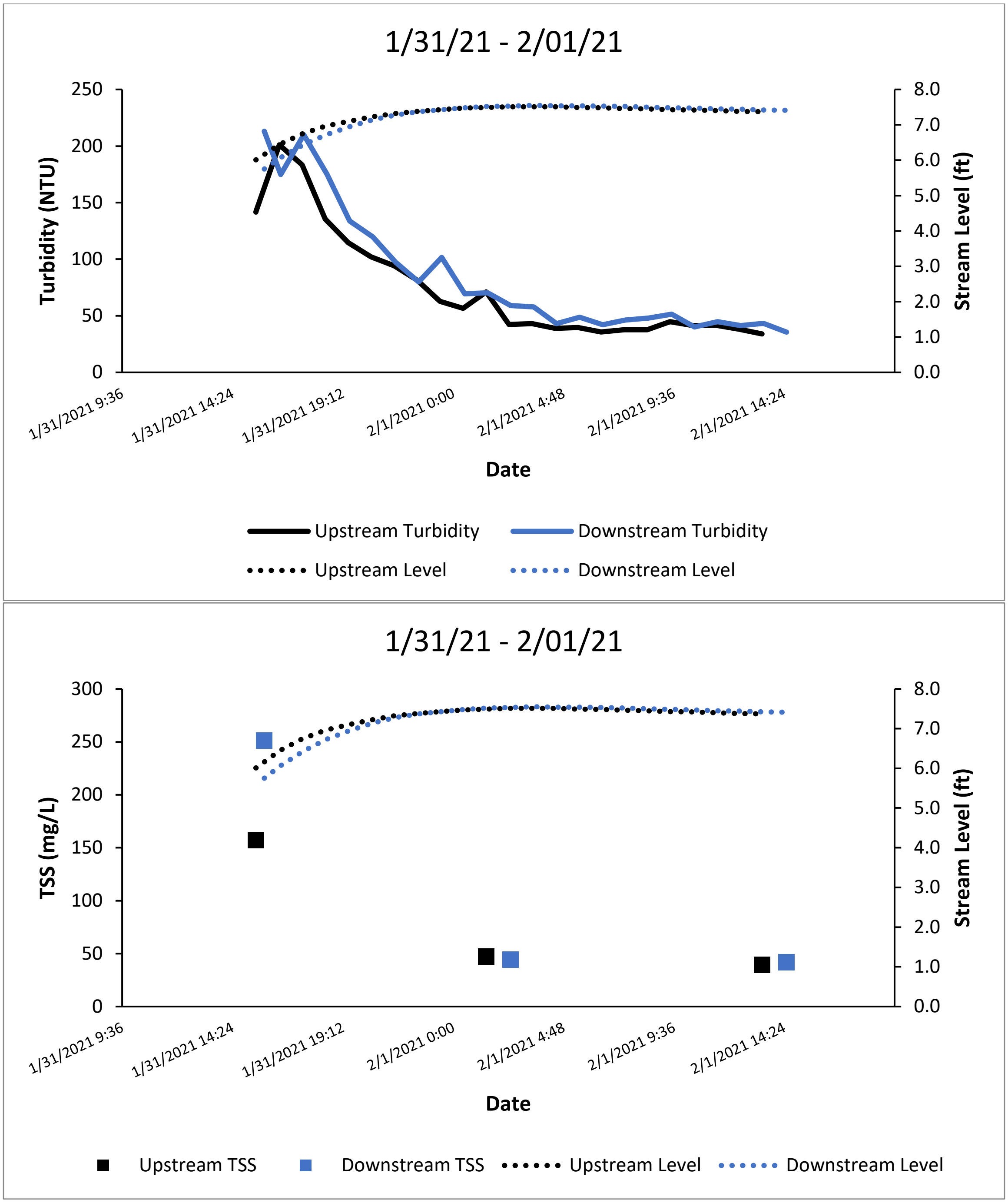
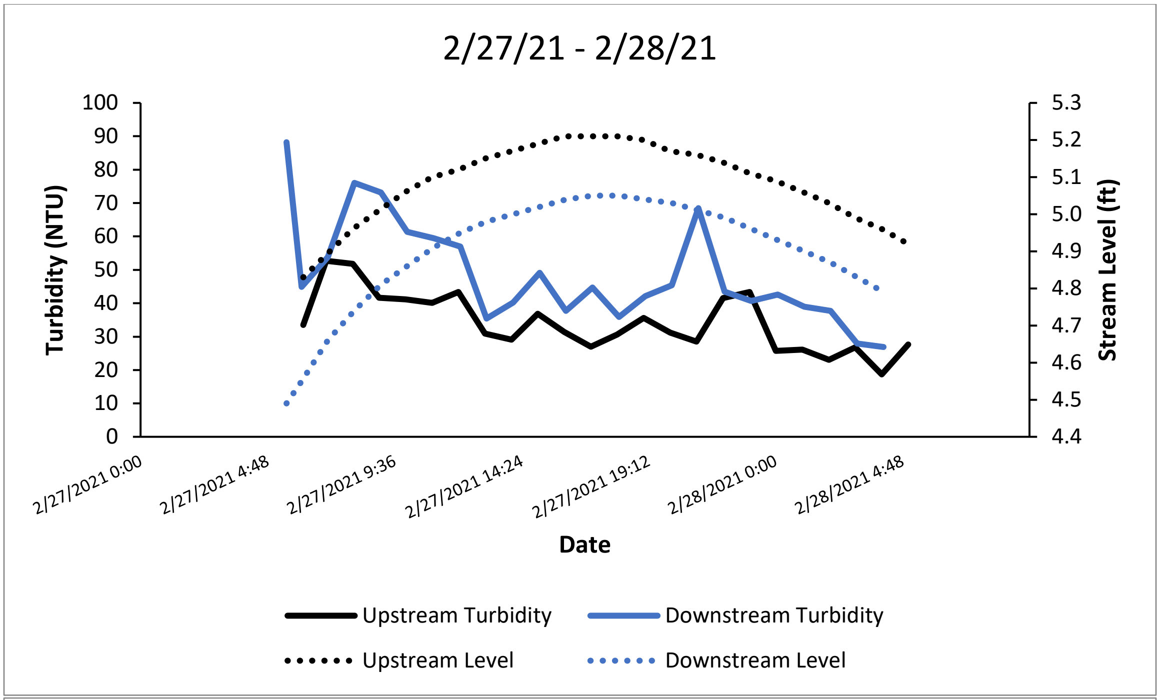


Figure A44. Turbidity (top) and TSS (bottom) in Swift Creek.



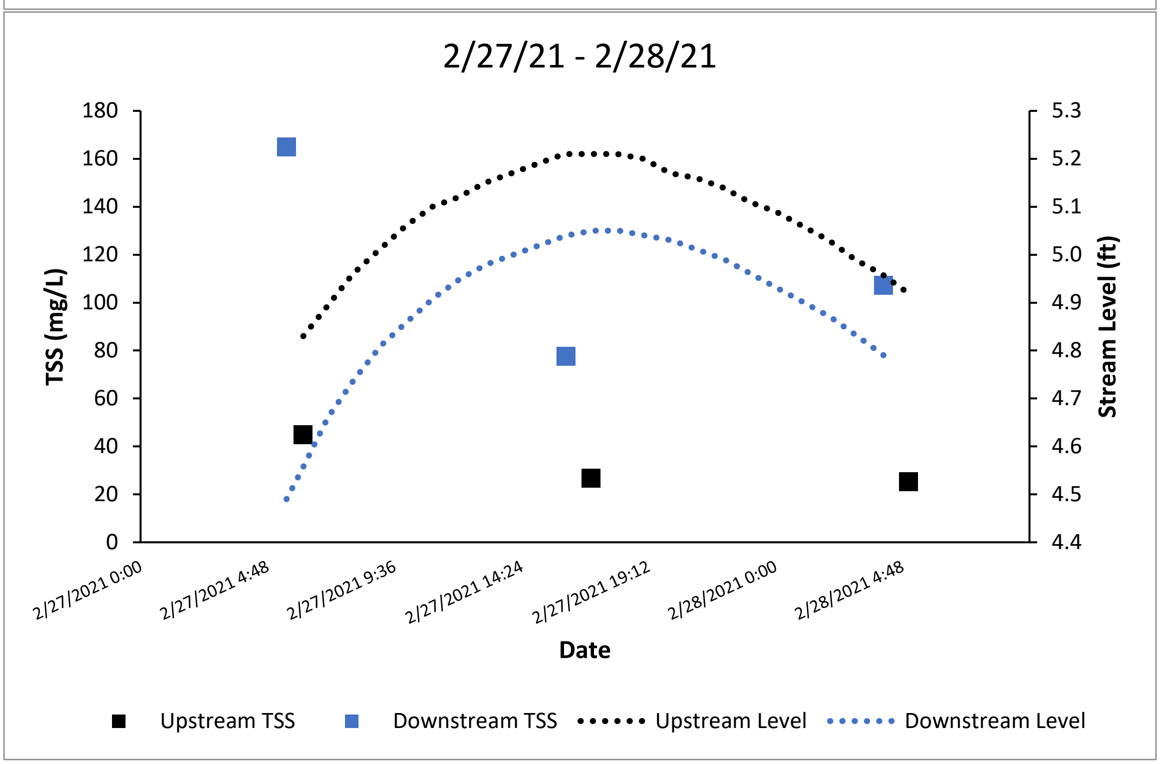
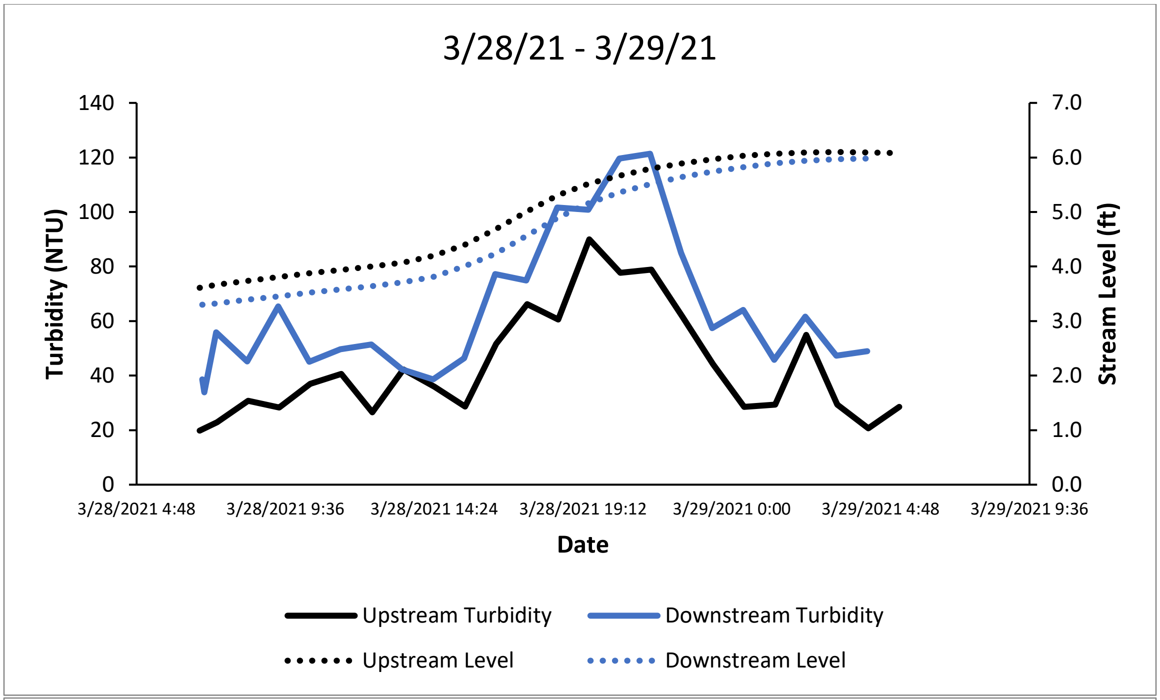


Figure A45. Turbidity (top) and TSS (bottom) in Swift Creek.



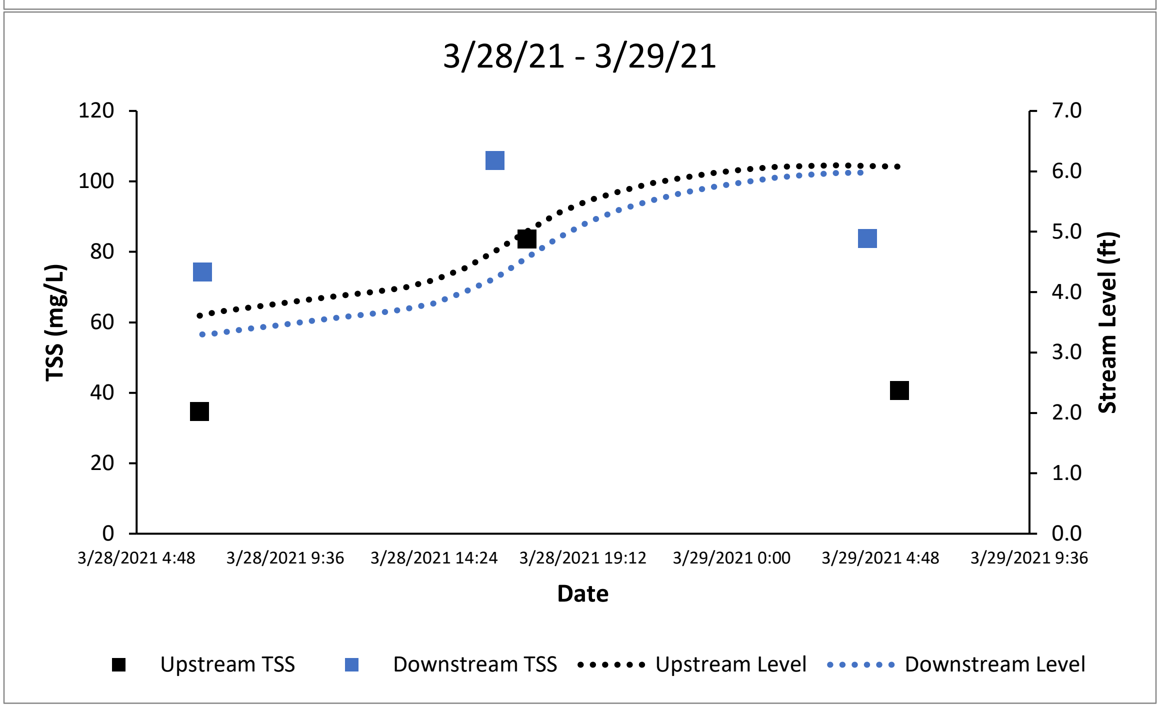
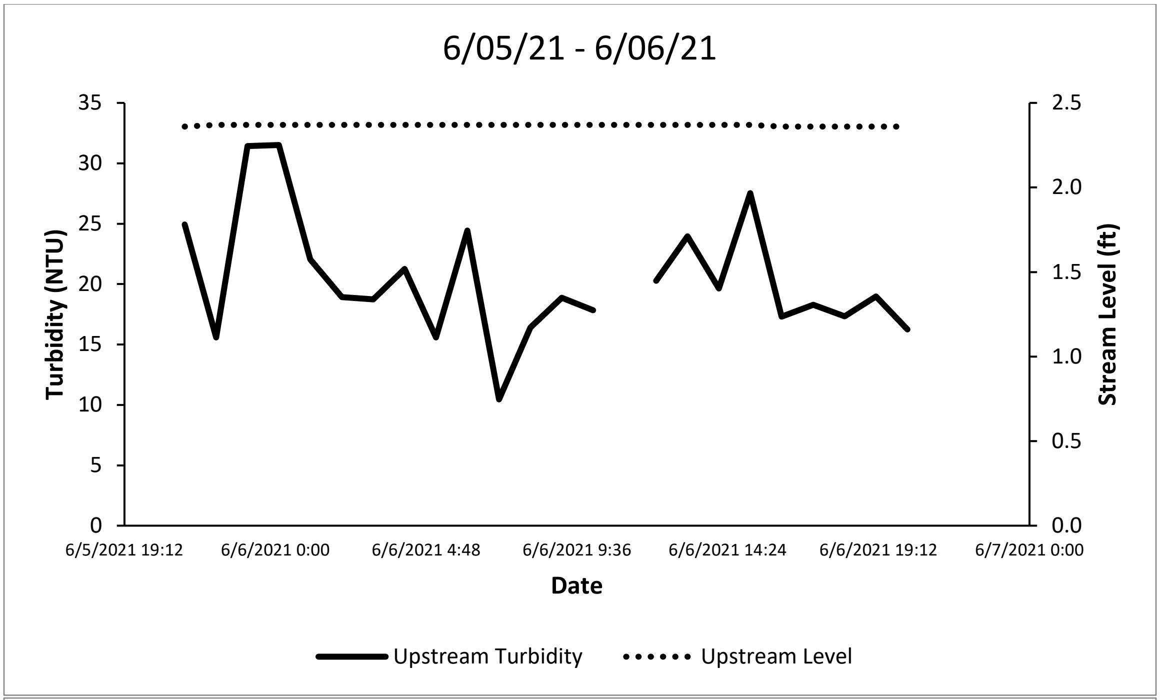


Figure A46. Turbidity (top) and TSS (bottom) in Swift Creek.



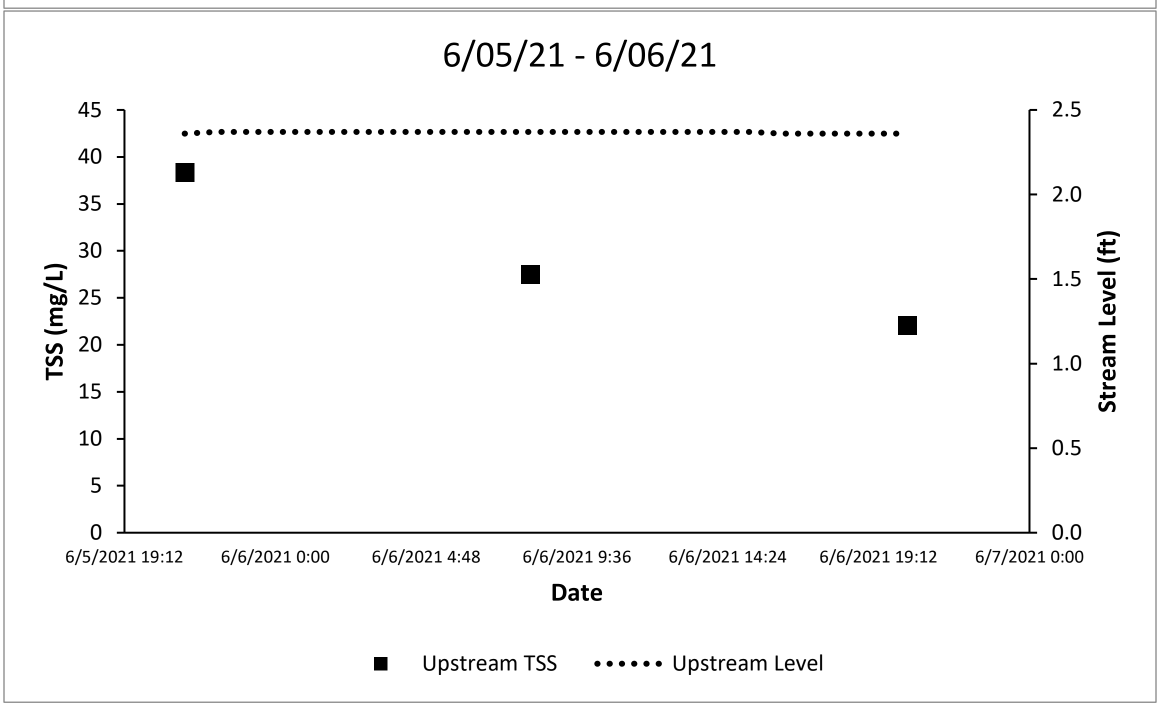
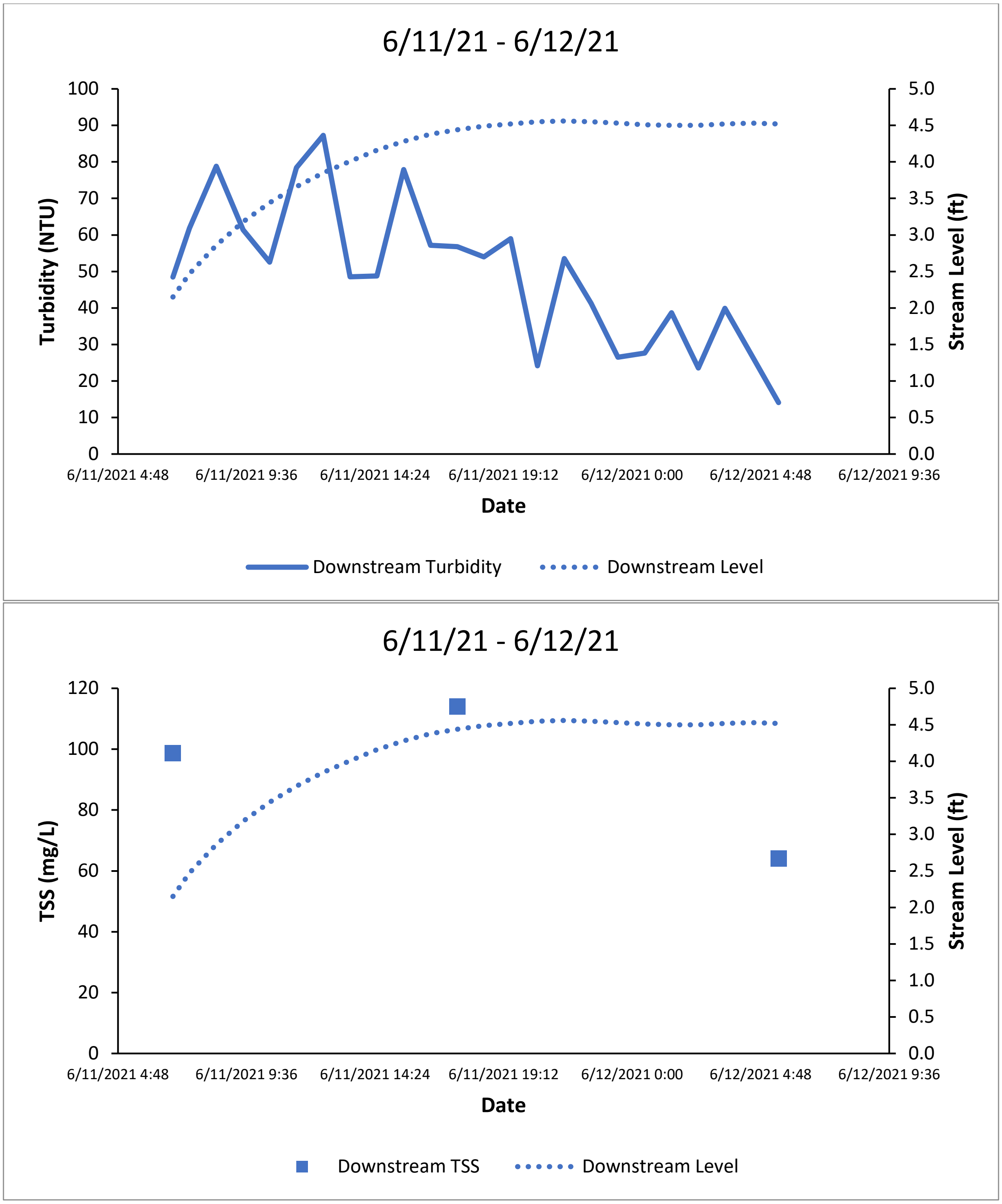


Figure A47. Turbidity (top) and TSS (bottom) in Swift Creek.



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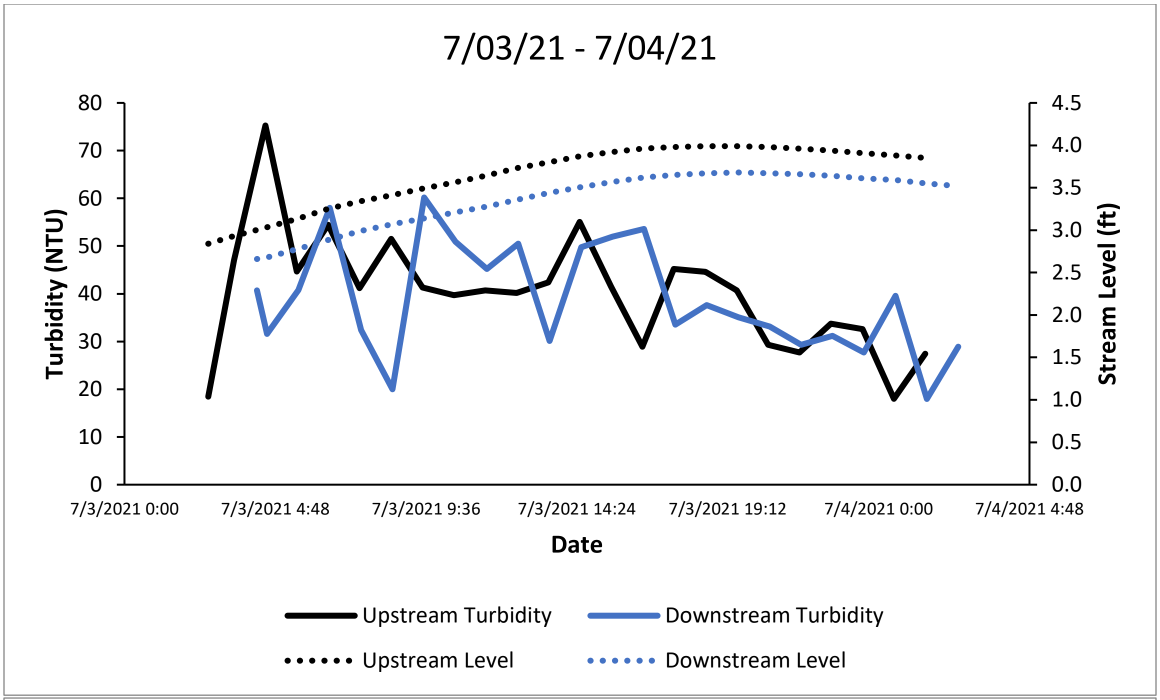

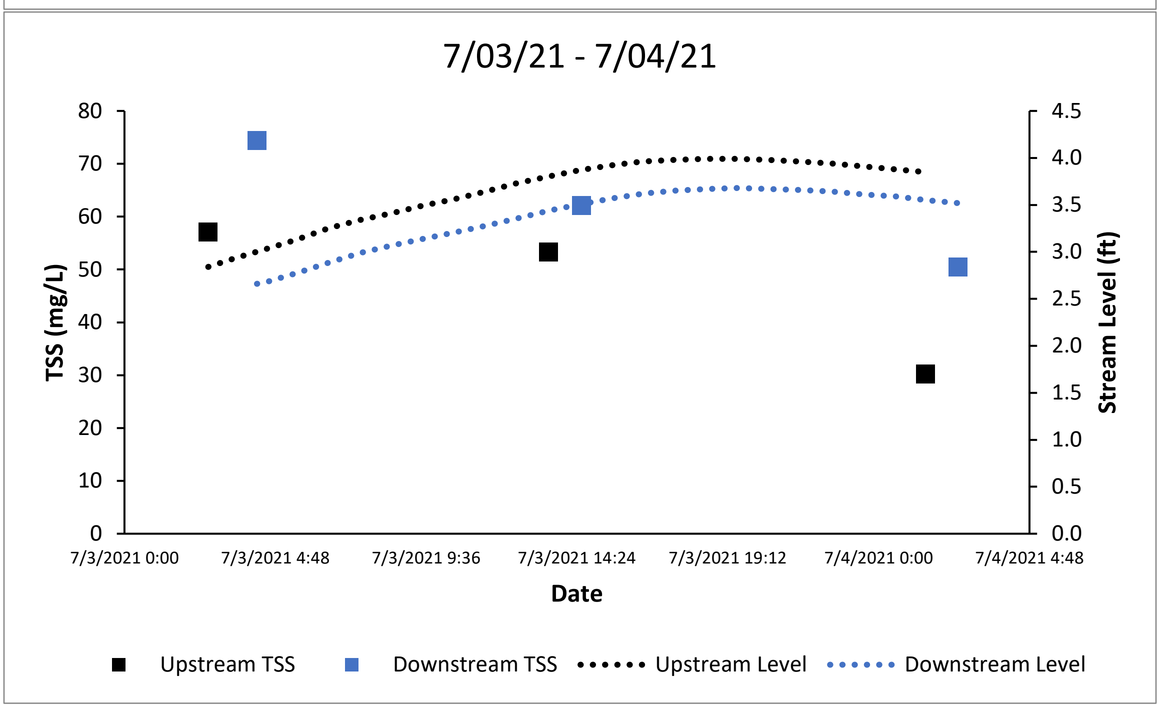

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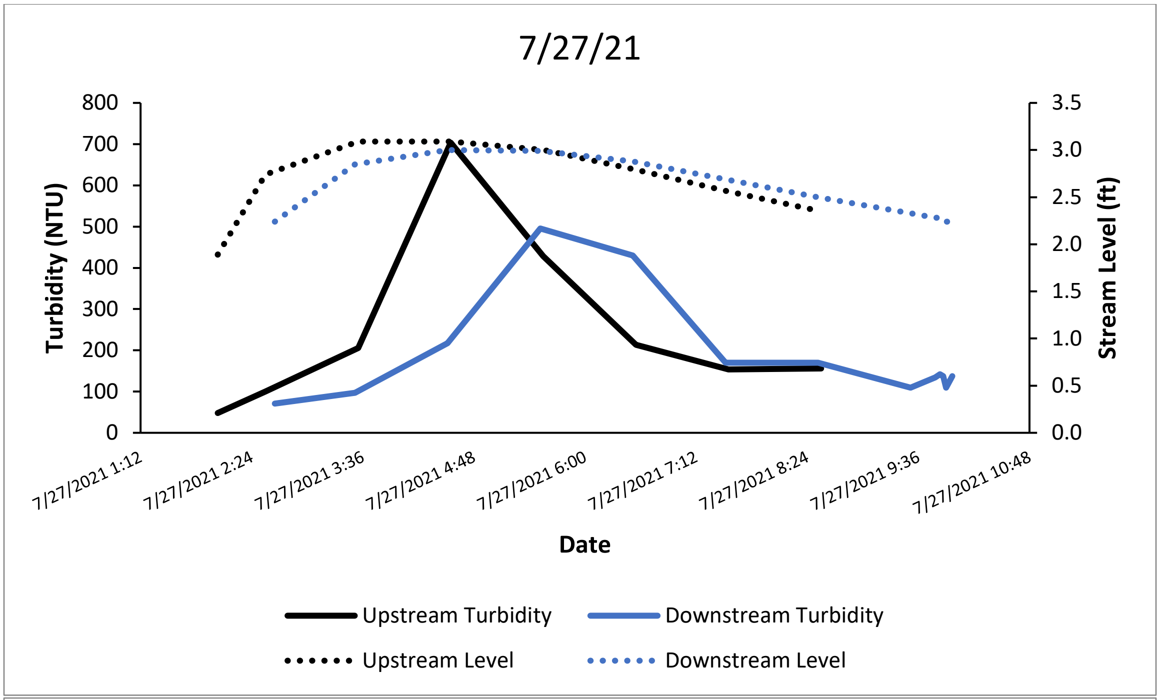


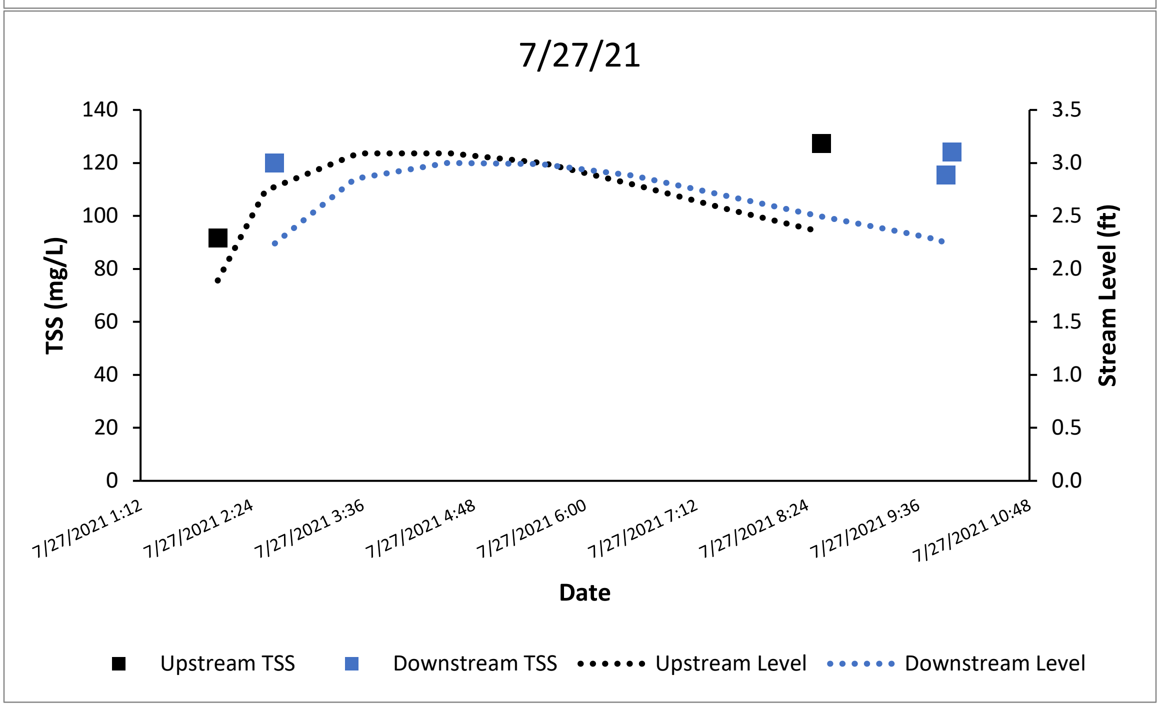
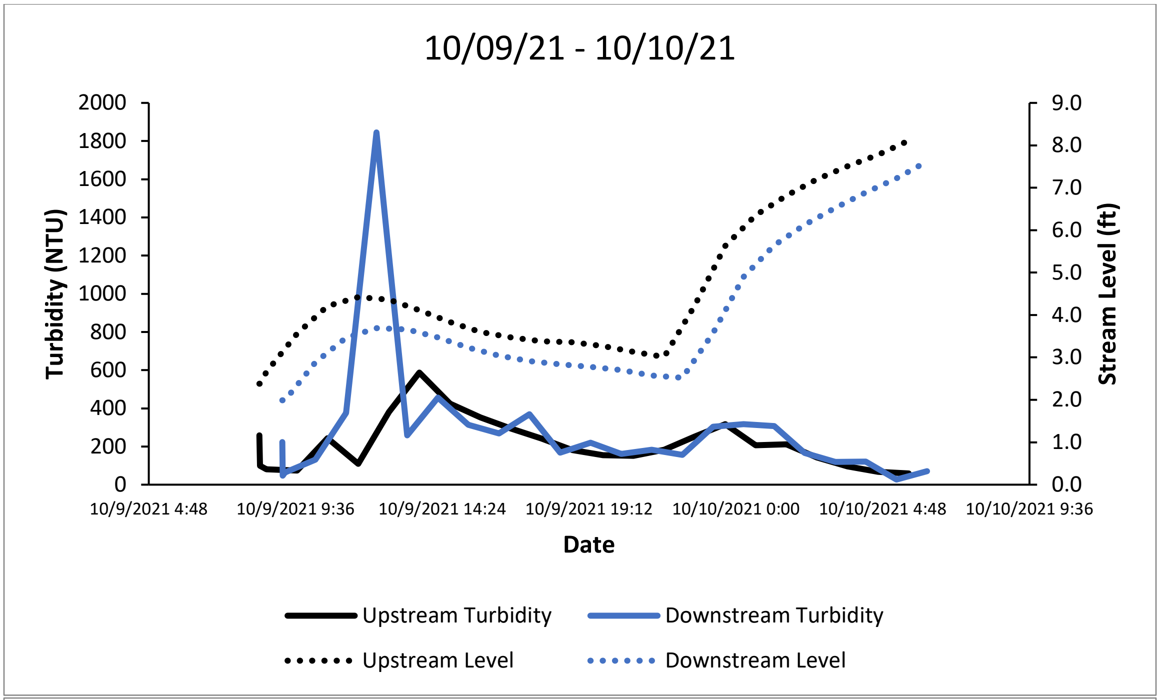


Figure A50. Turbidity (top) and TSS (bottom) in Swift Creek.



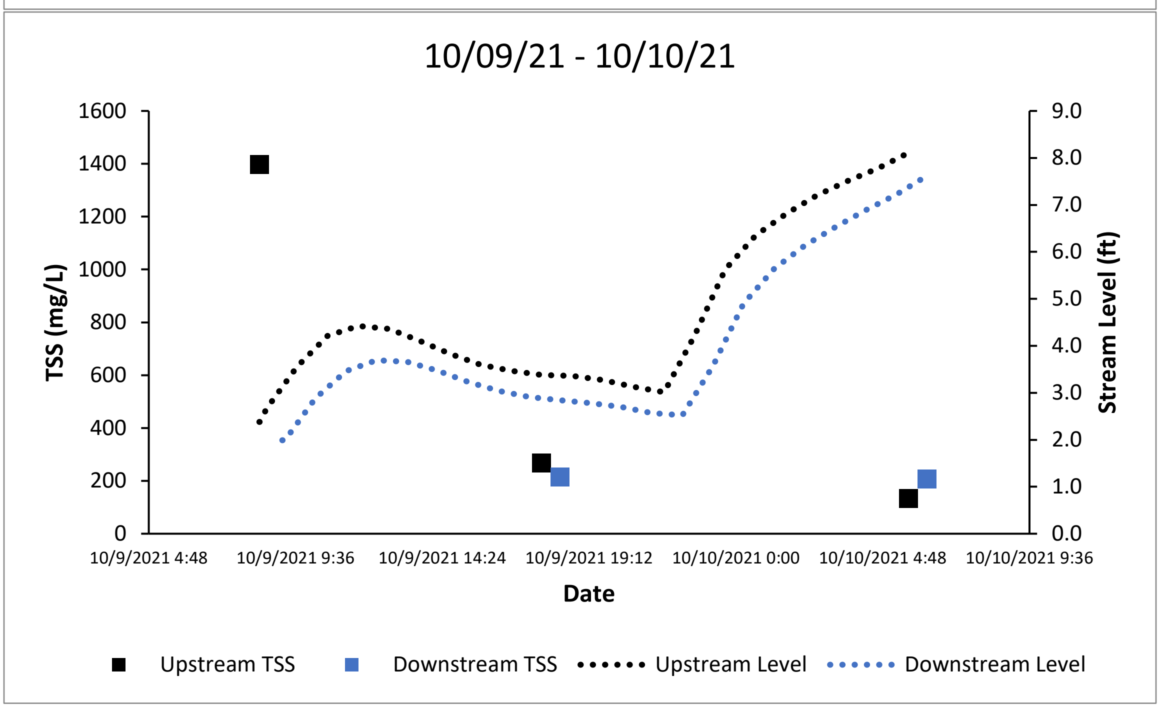
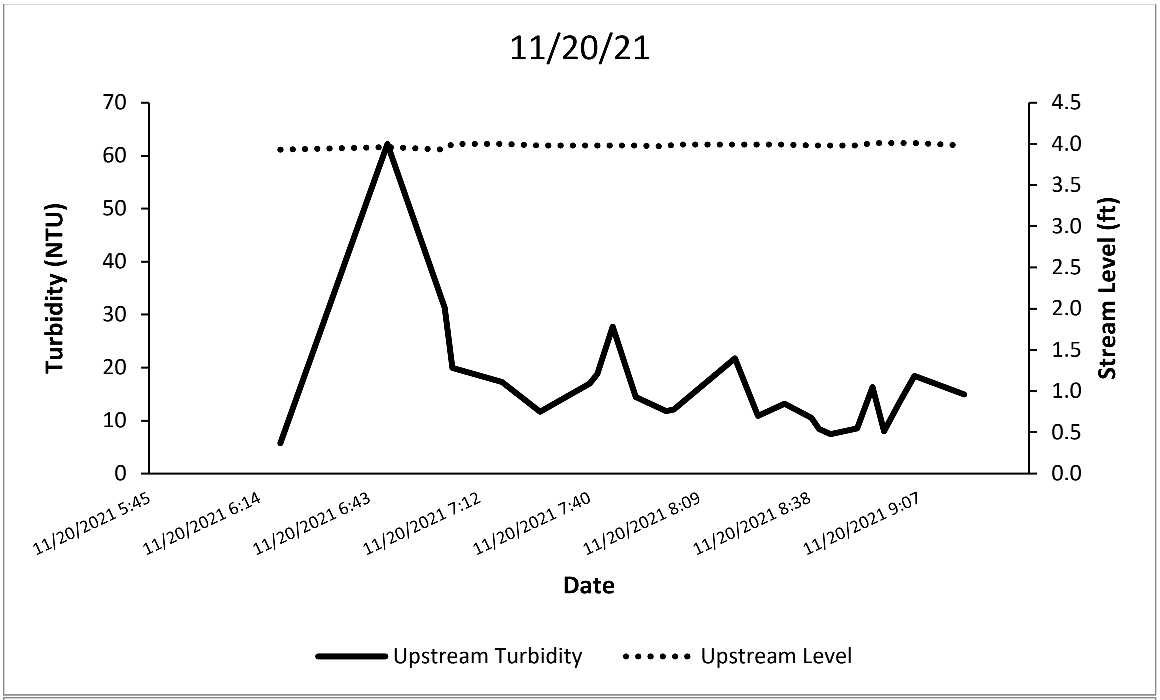


Figure A51. Turbidity (top) and TSS (bottom) in Swift Creek.



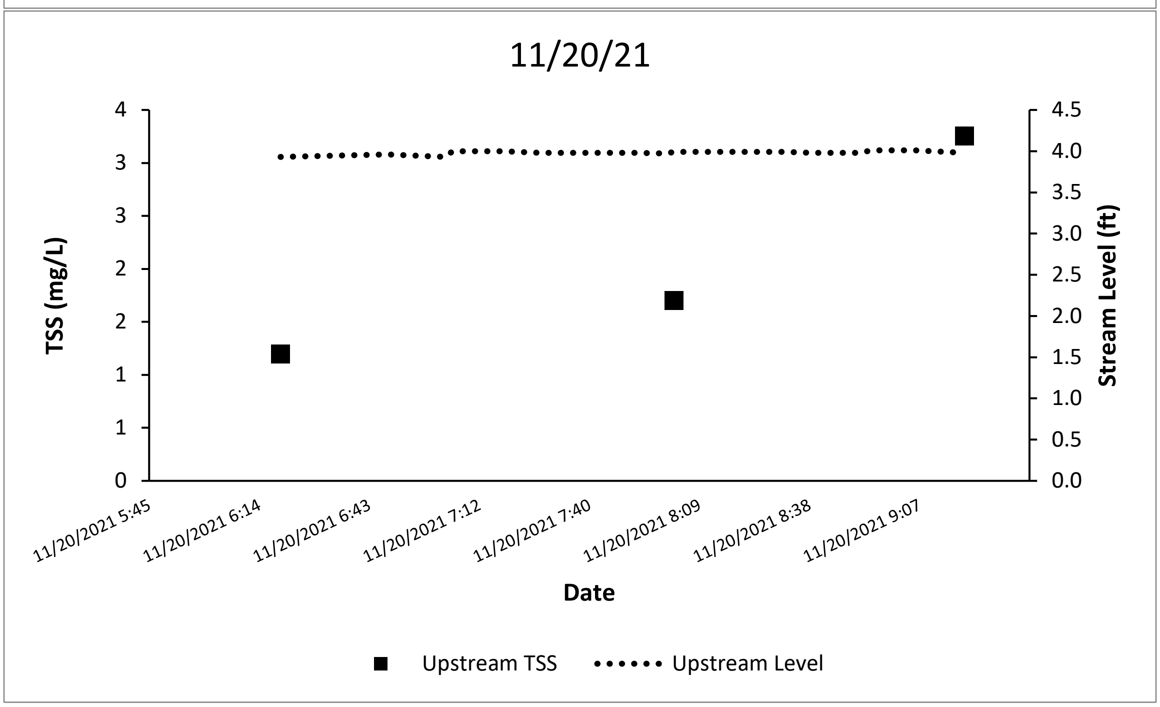
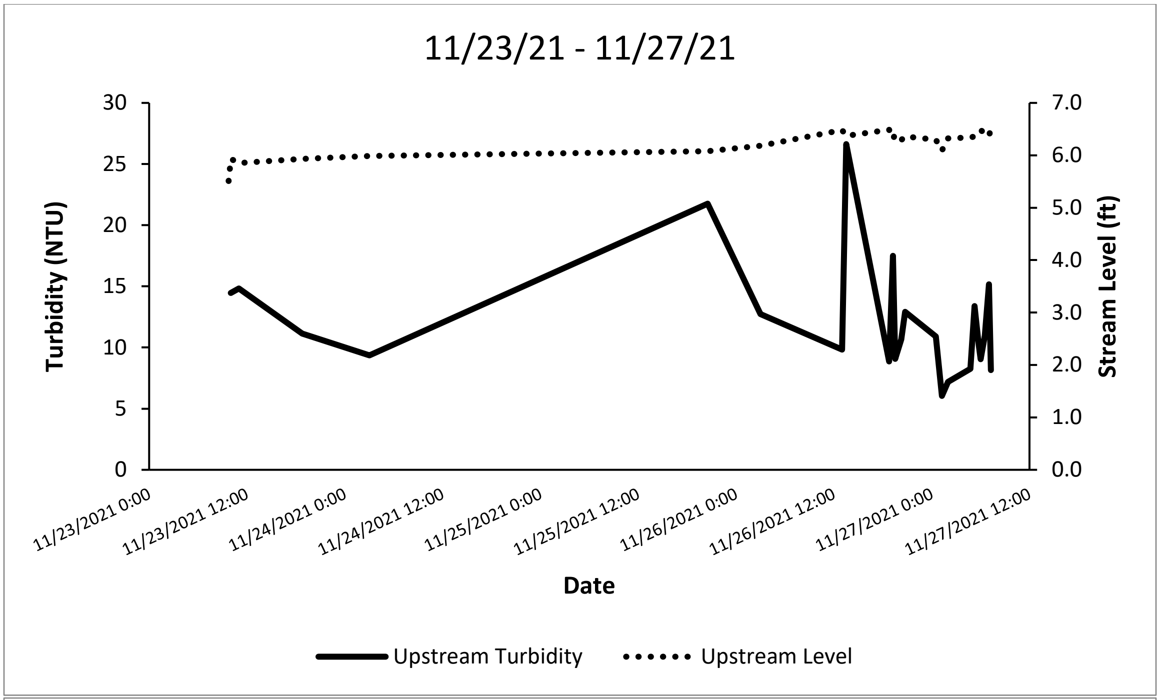


Figure A52. Turbidity (top) and TSS (bottom) in Swift Creek.



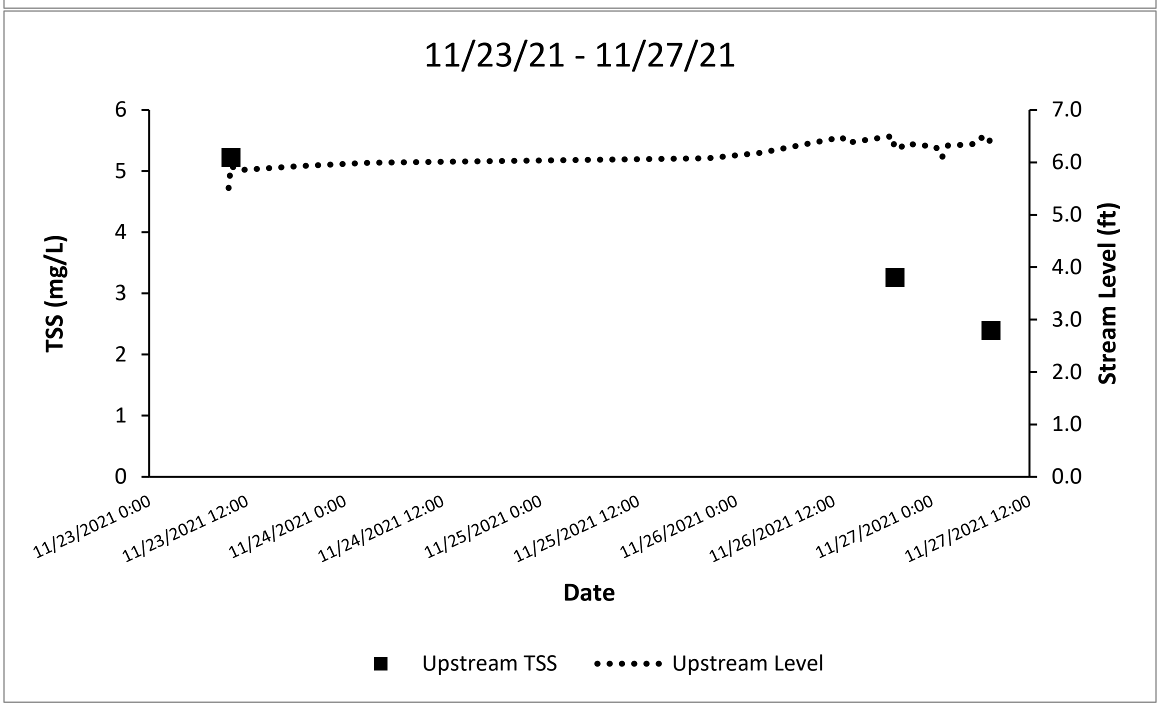
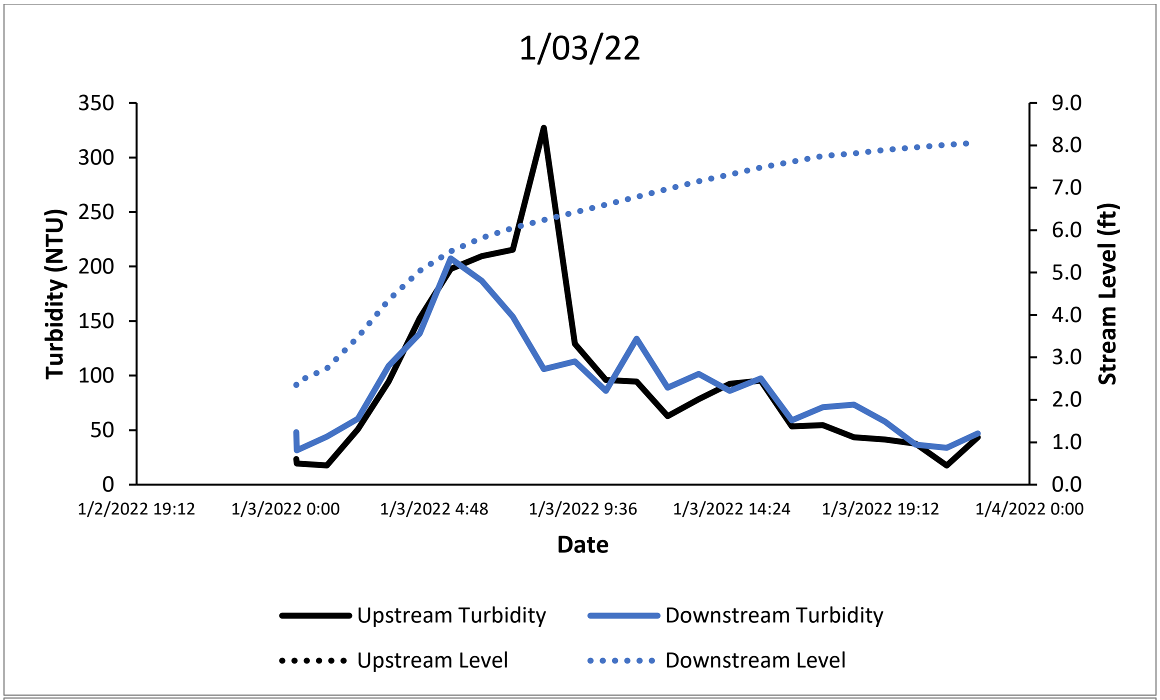


Figure A53. Turbidity (top) and TSS (bottom) in Swift Creek.



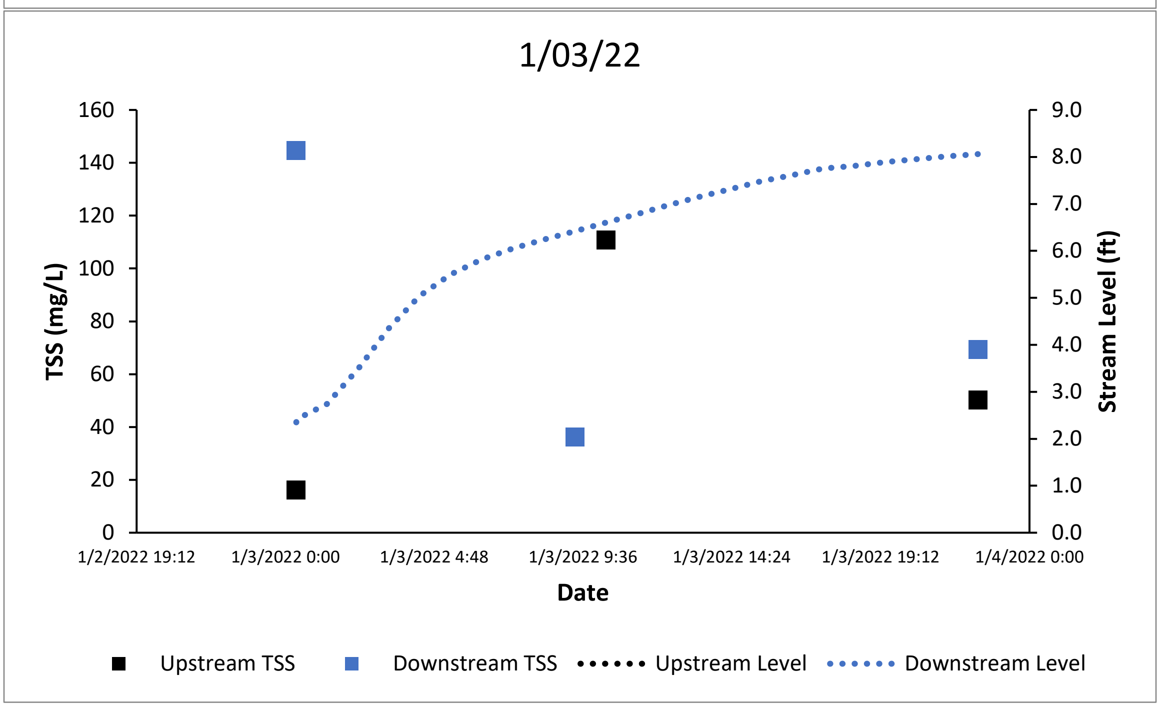
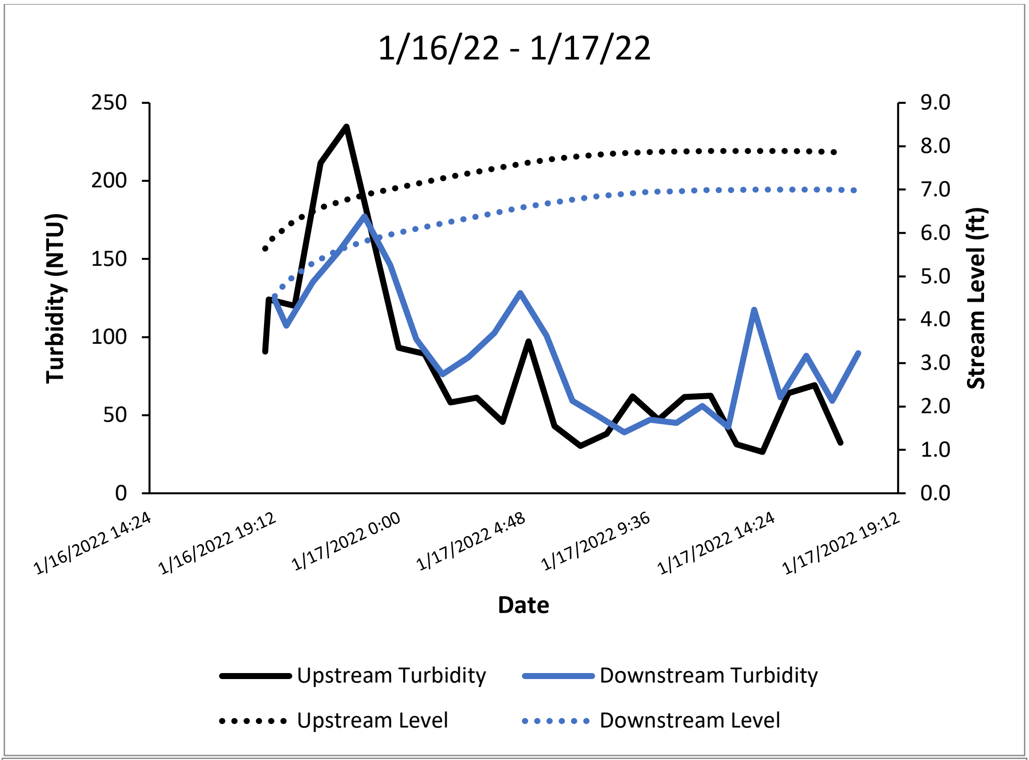


Figure A54. Turbidity (top) and TSS (bottom) in Swift Creek.



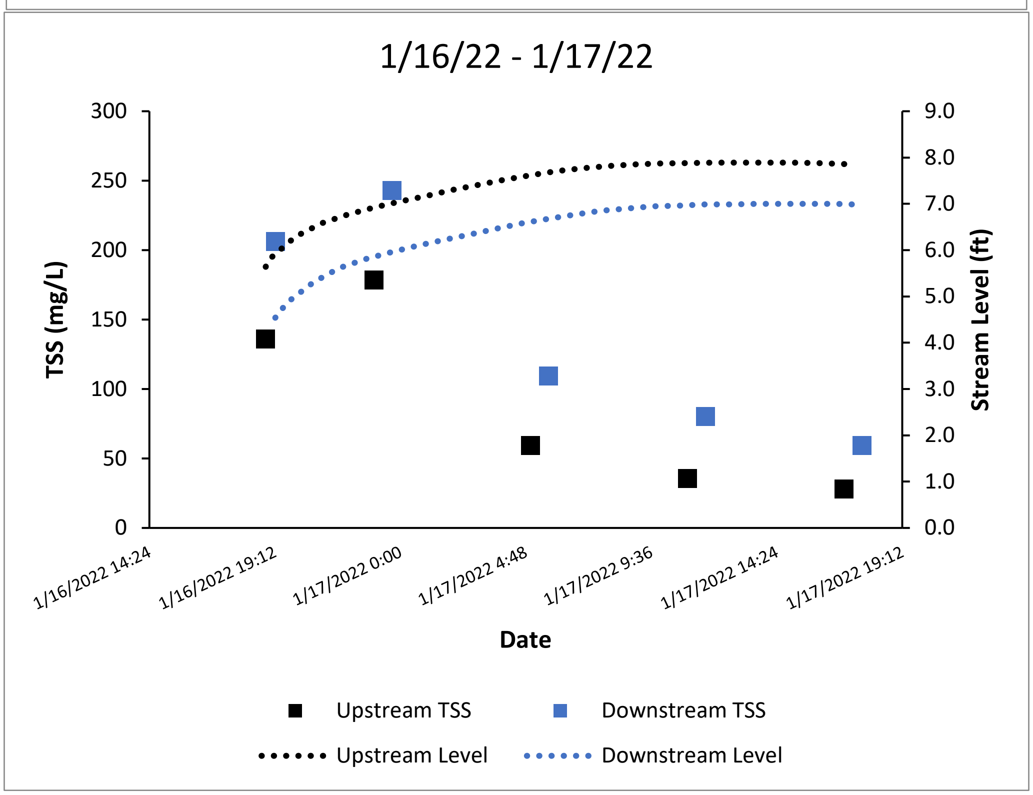
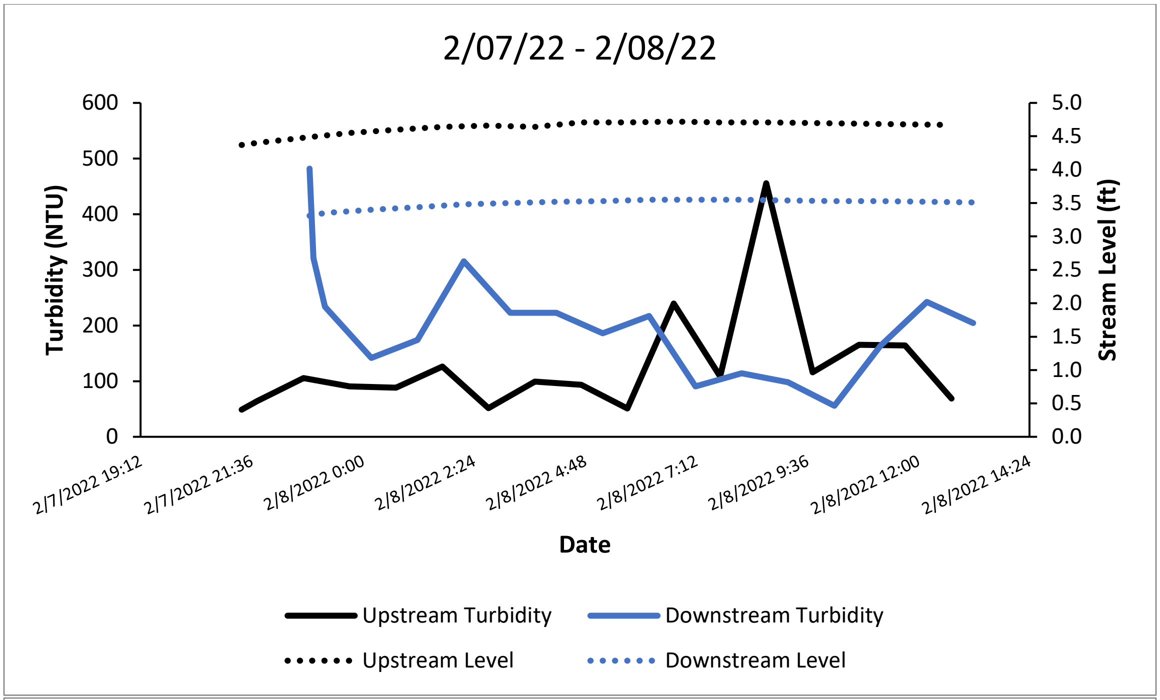


Figure A55. Turbidity (top) and TSS (bottom) in Swift Creek.



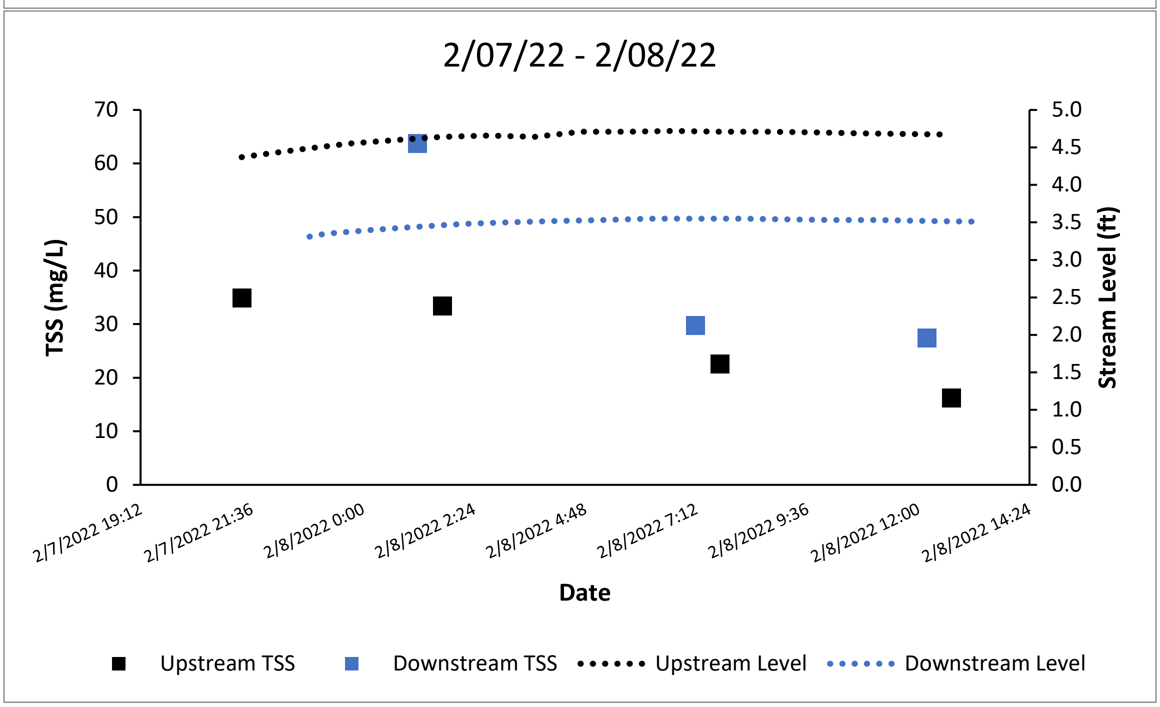
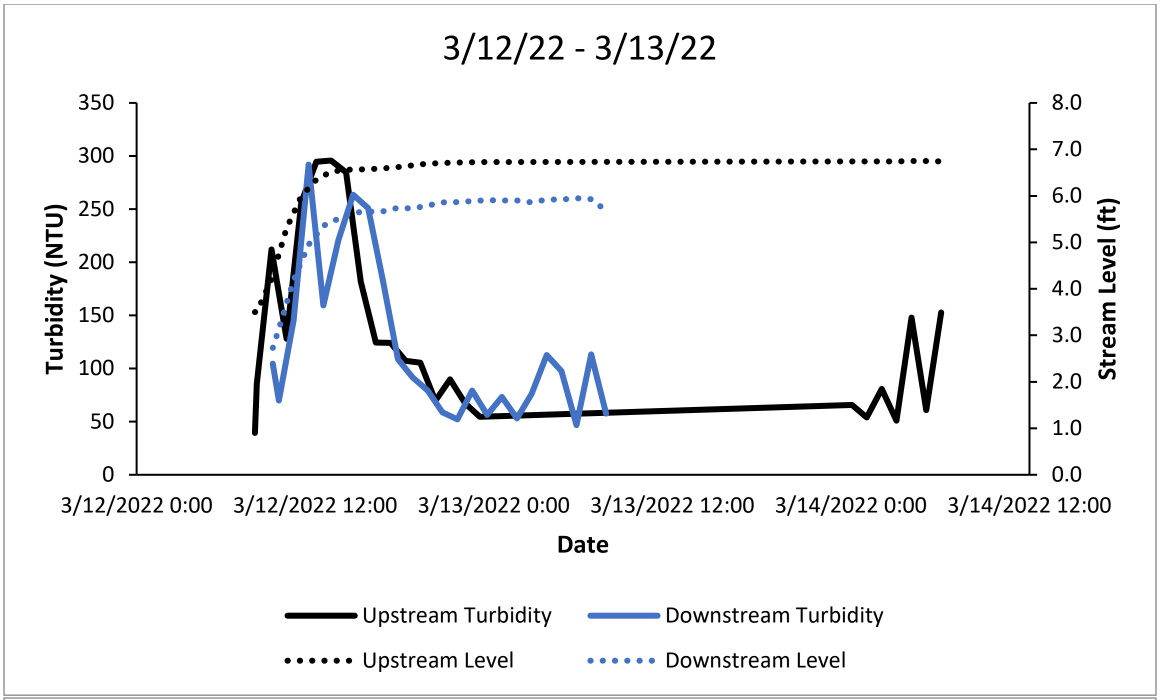


Figure A56. Turbidity (top) and TSS (bottom) in Swift Creek.



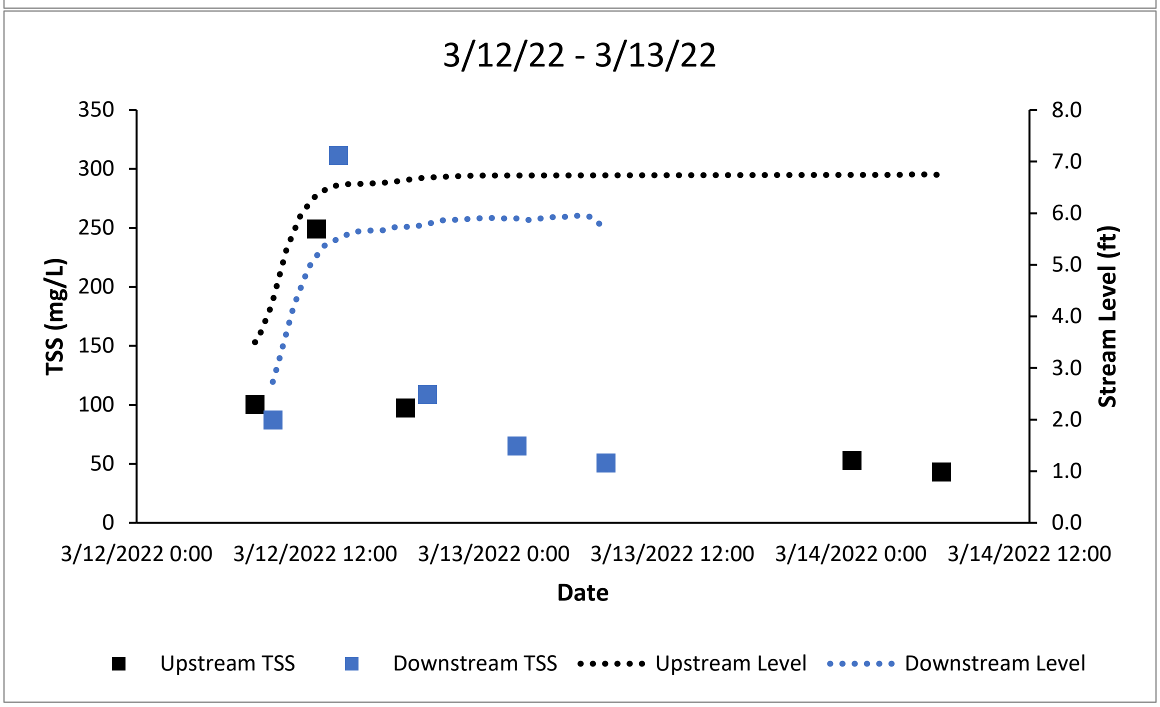
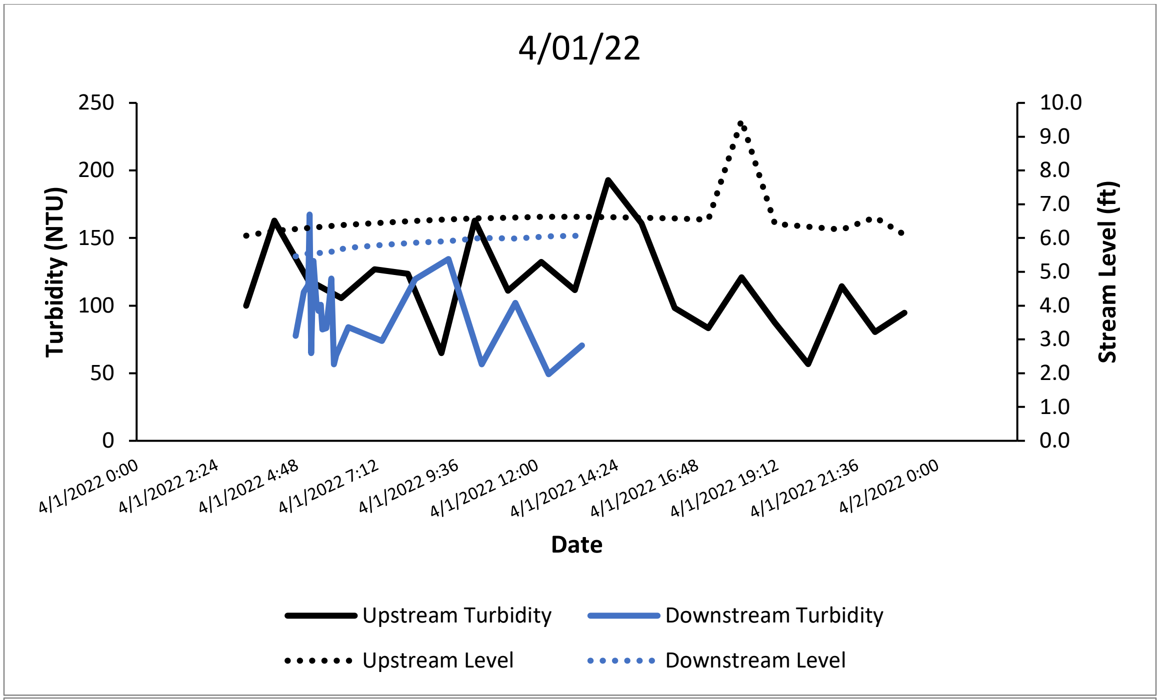


Figure A57. Turbidity (top) and TSS (bottom) in Swift Creek.



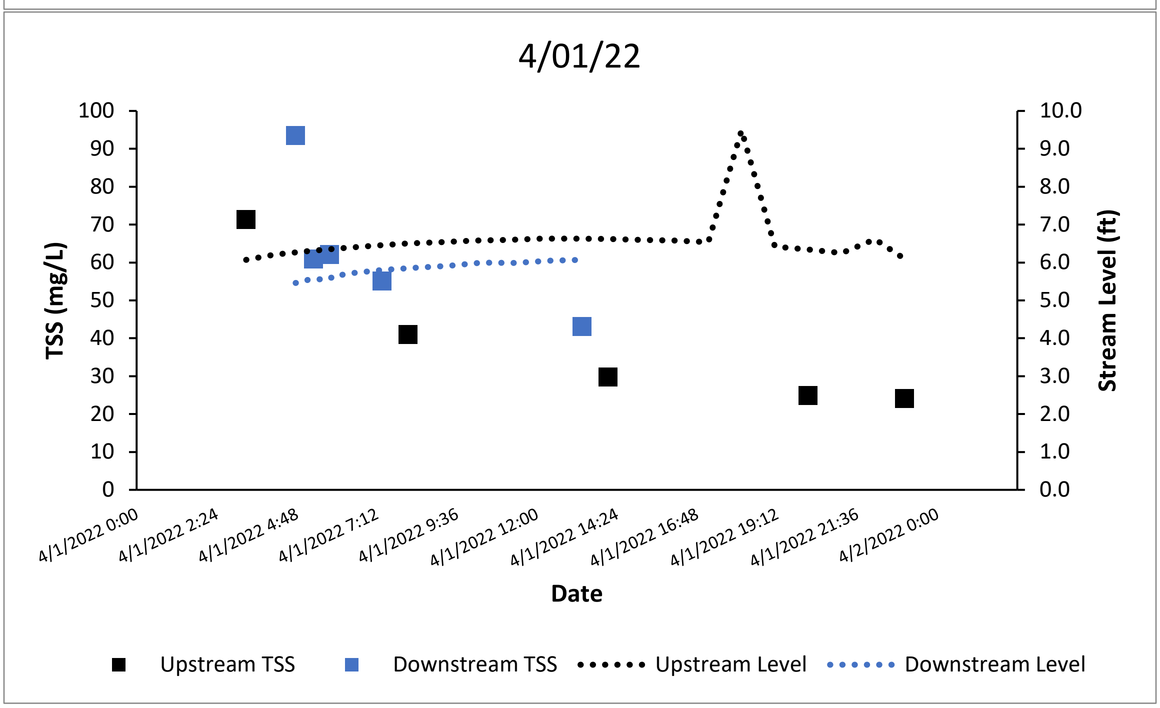
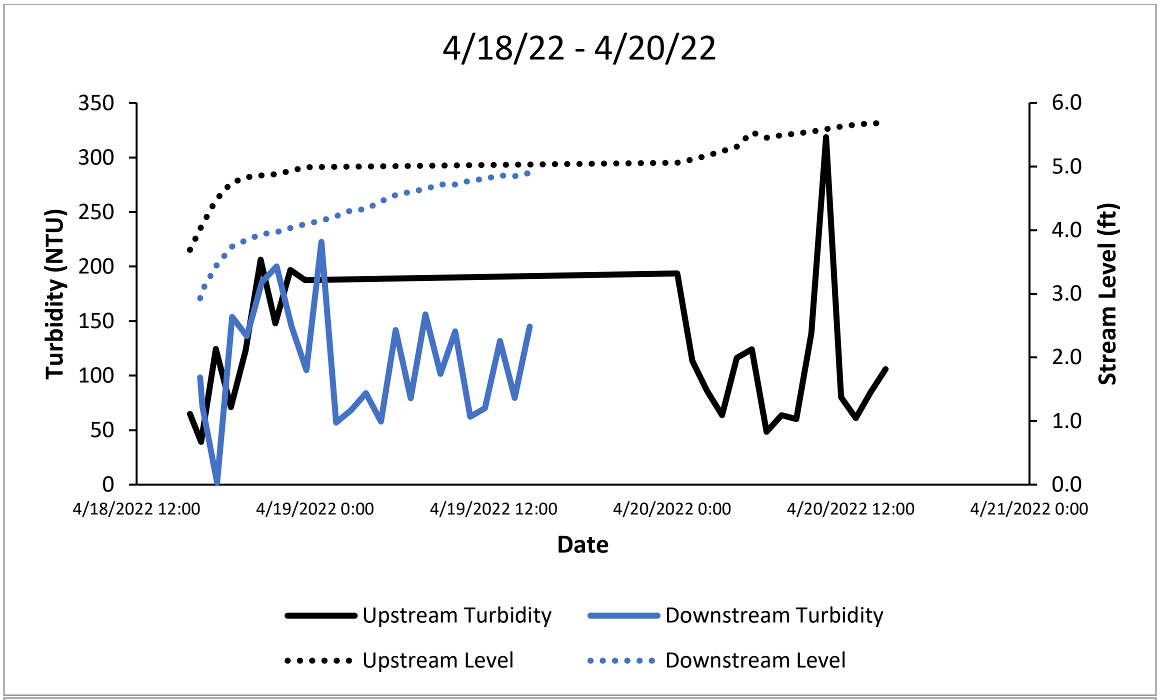


Figure A58. Turbidity (top) and TSS (bottom) in Swift Creek.



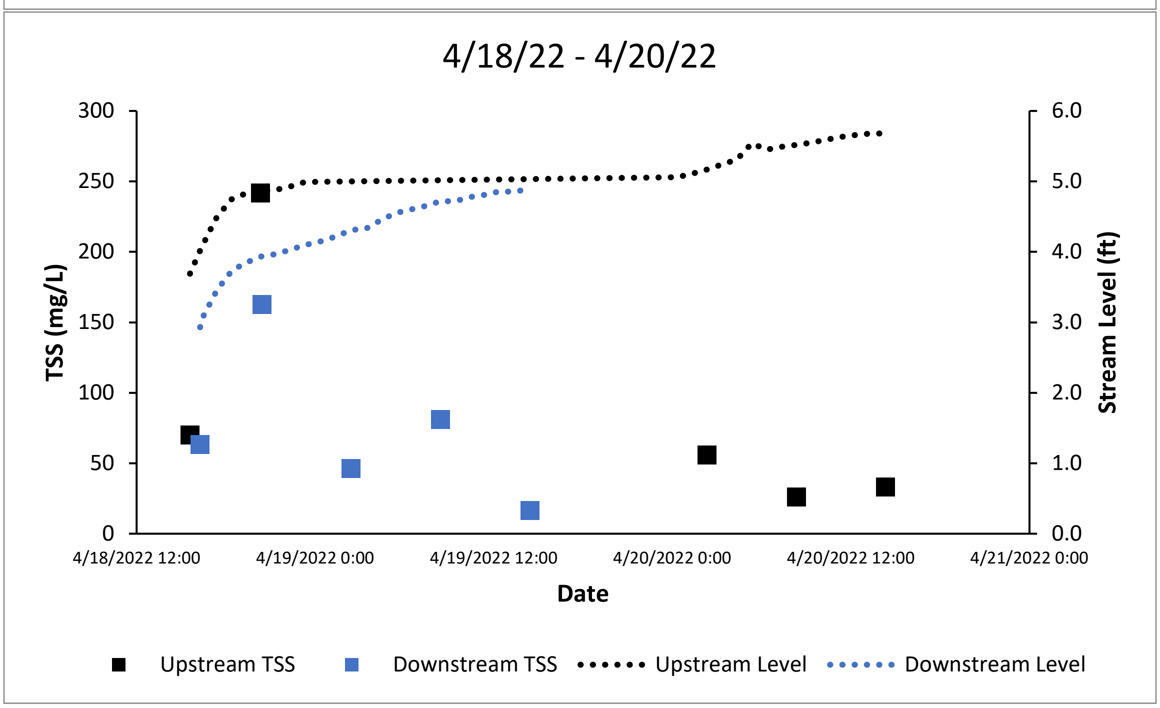
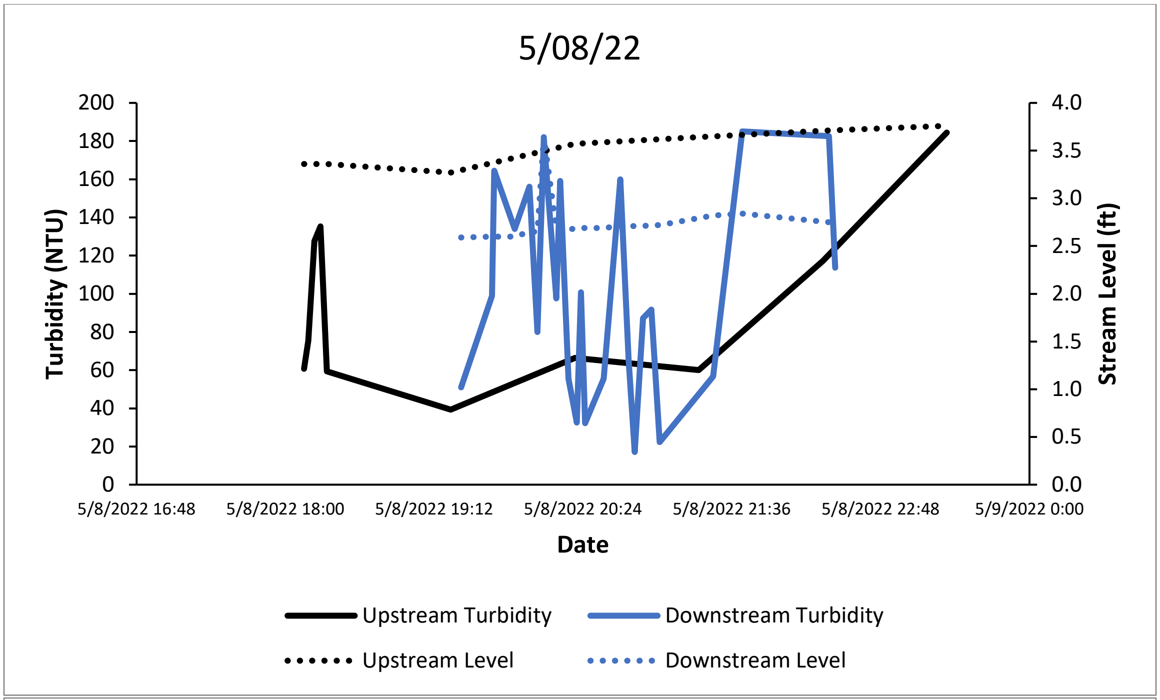


Figure A59. Turbidity (top) and TSS (bottom) in Swift Creek.



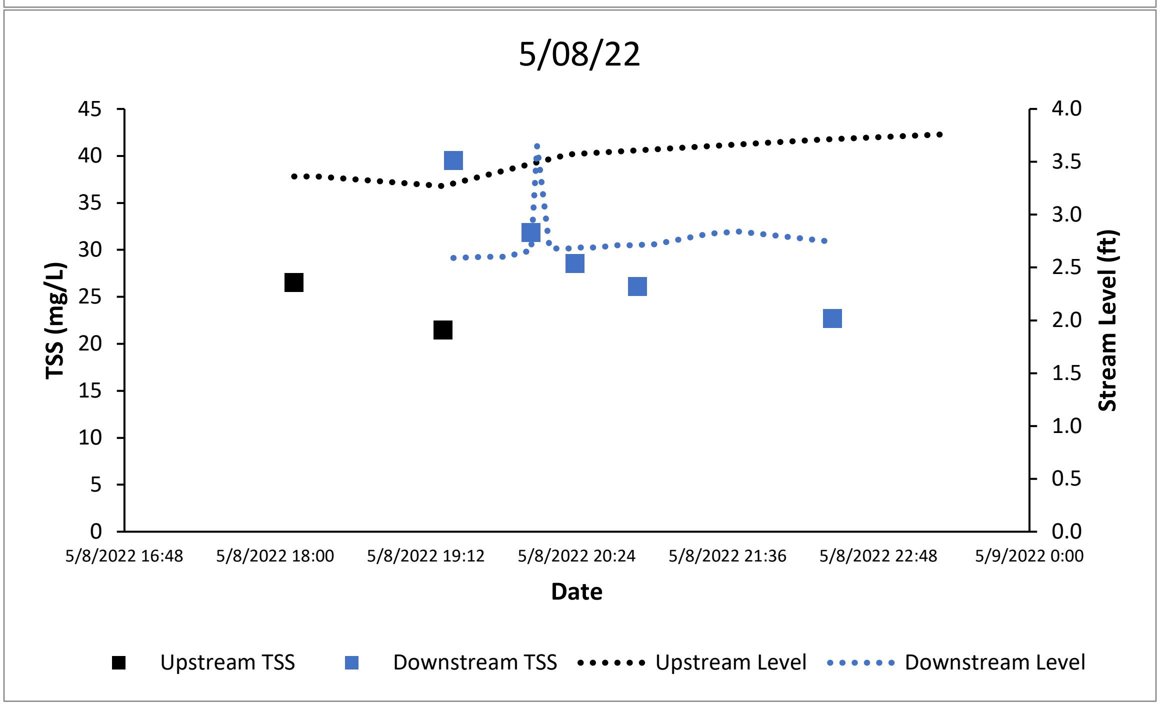


Figure A60. Turbidity (top) and TSS (bottom) in Swift Creek**.**

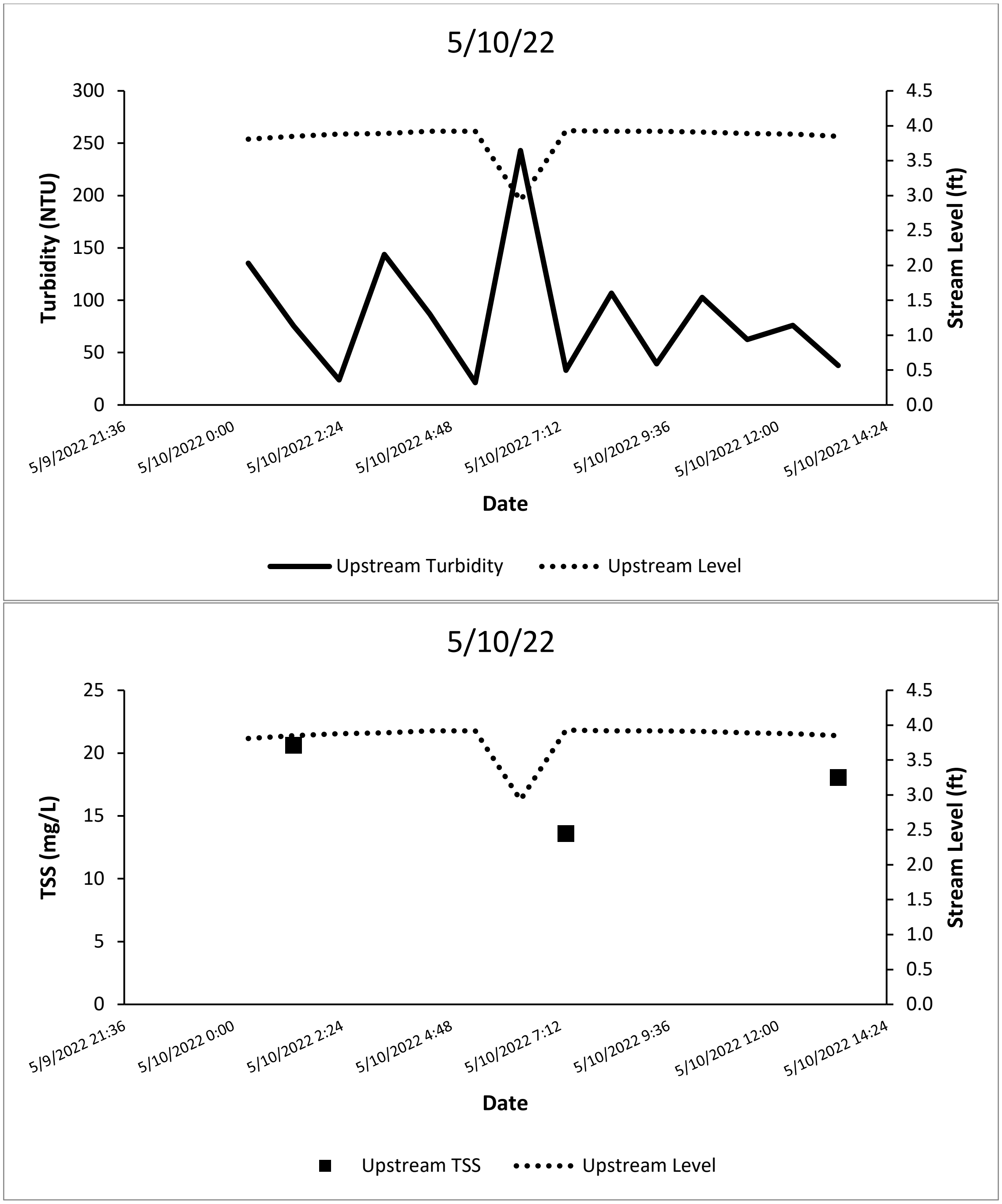
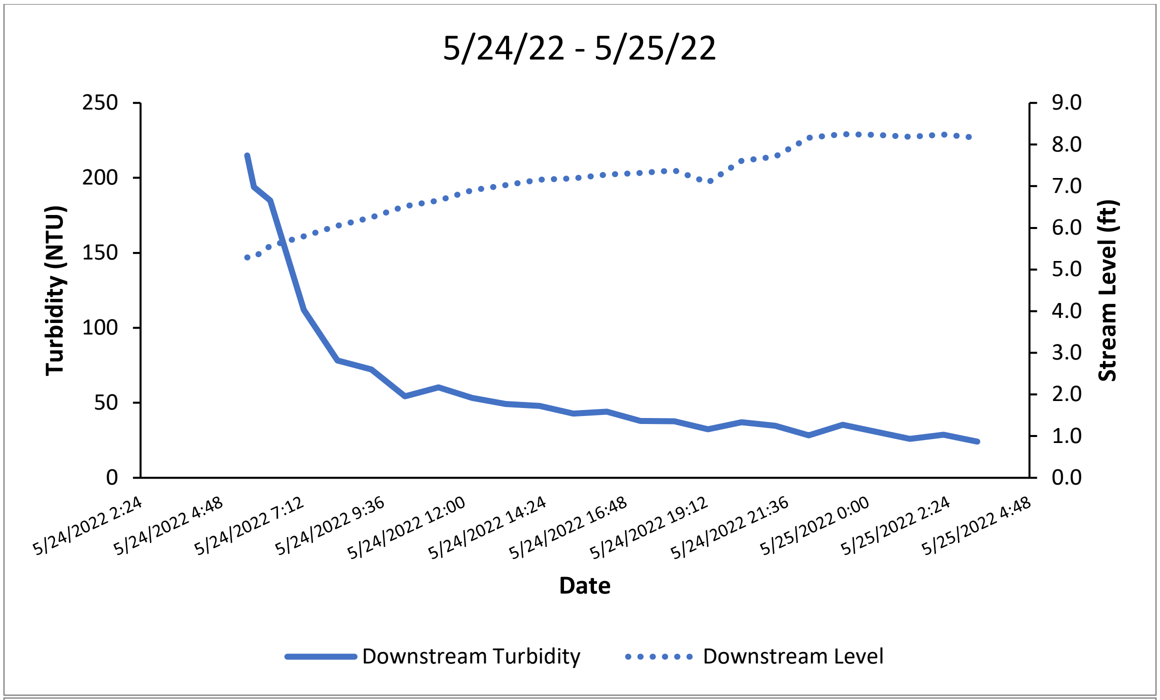


Figure A61. Turbidity (top) and TSS (bottom) in Swift Creek**.**



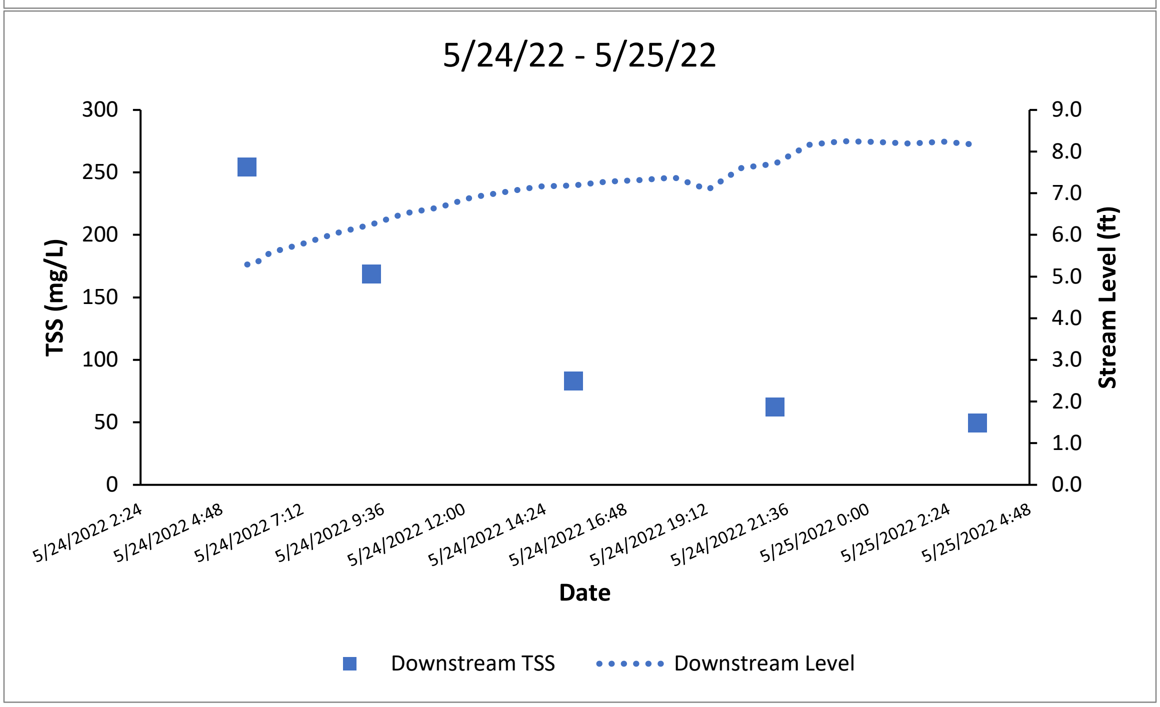
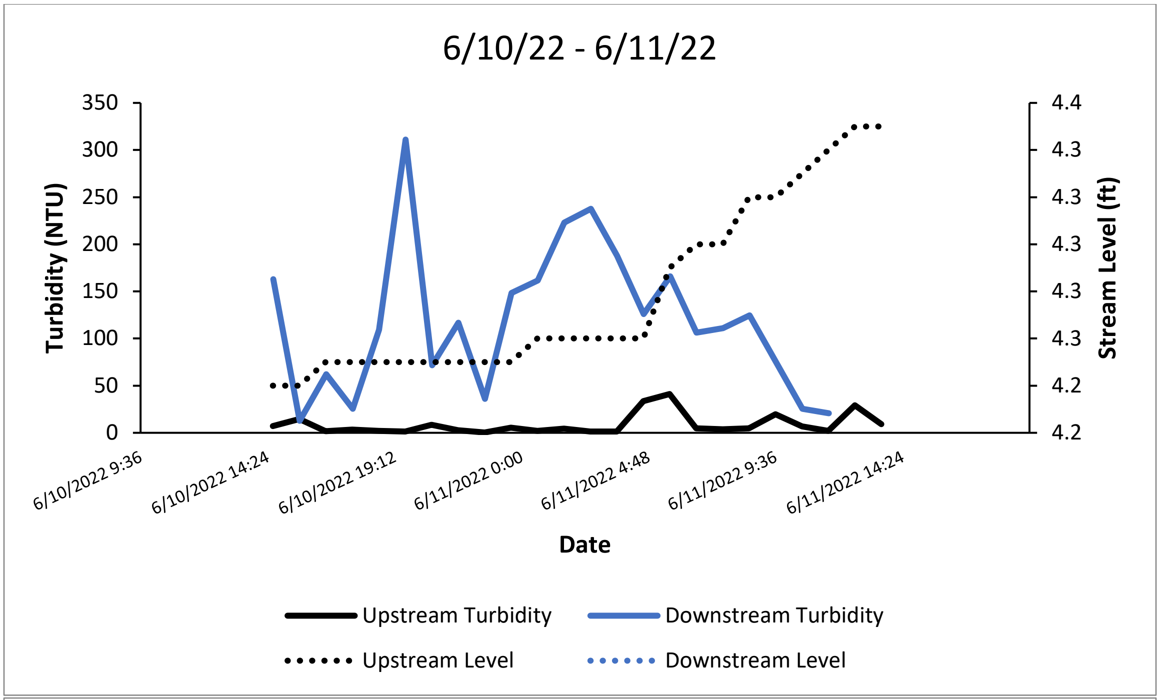


Figure A62. Turbidity (top) and TSS (bottom) in Swift Creek**.**



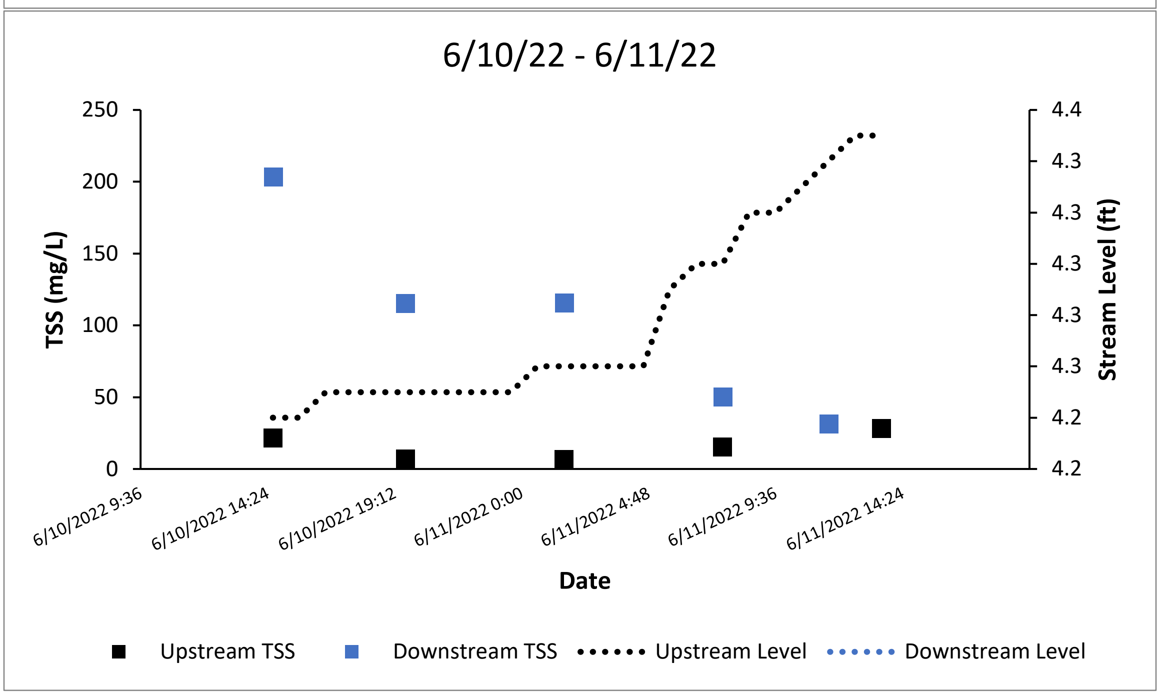
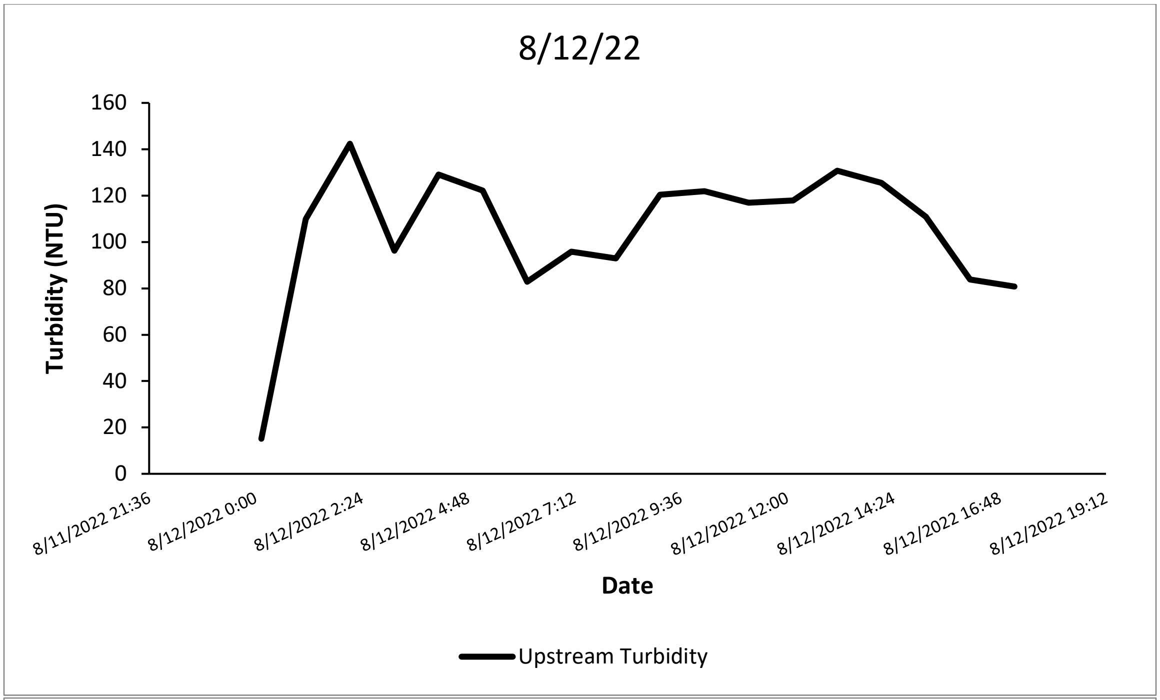


Figure A63. Turbidity (top) and TSS (bottom) in Swift Creek.



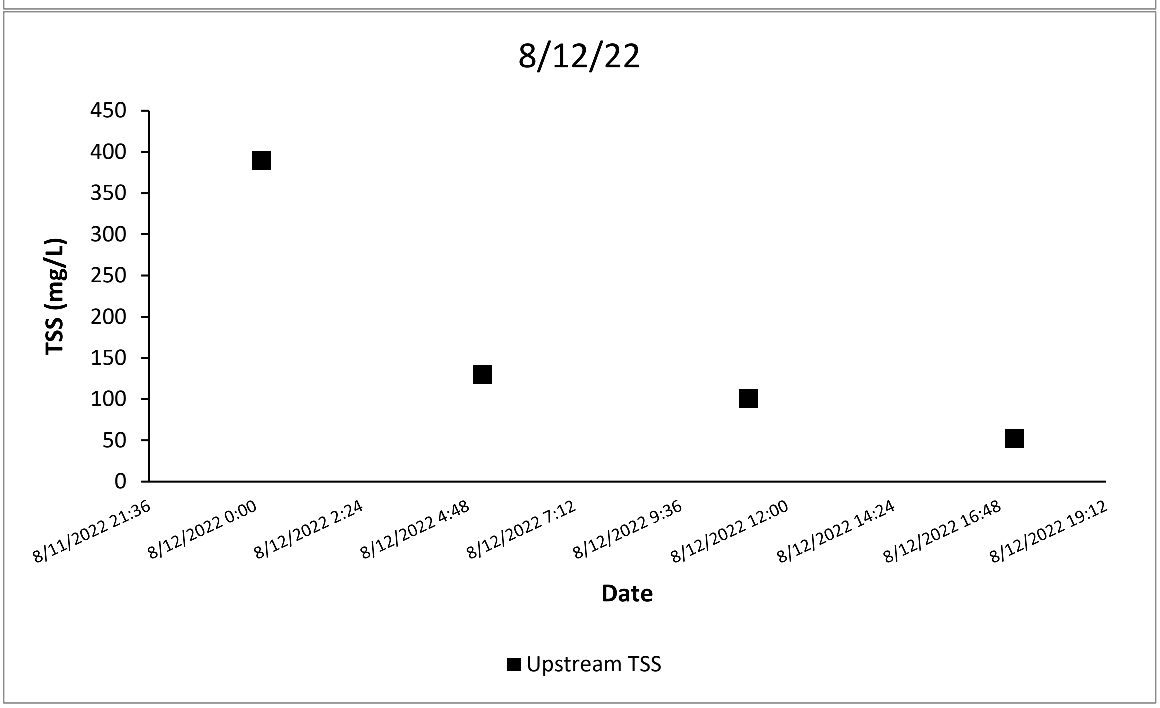
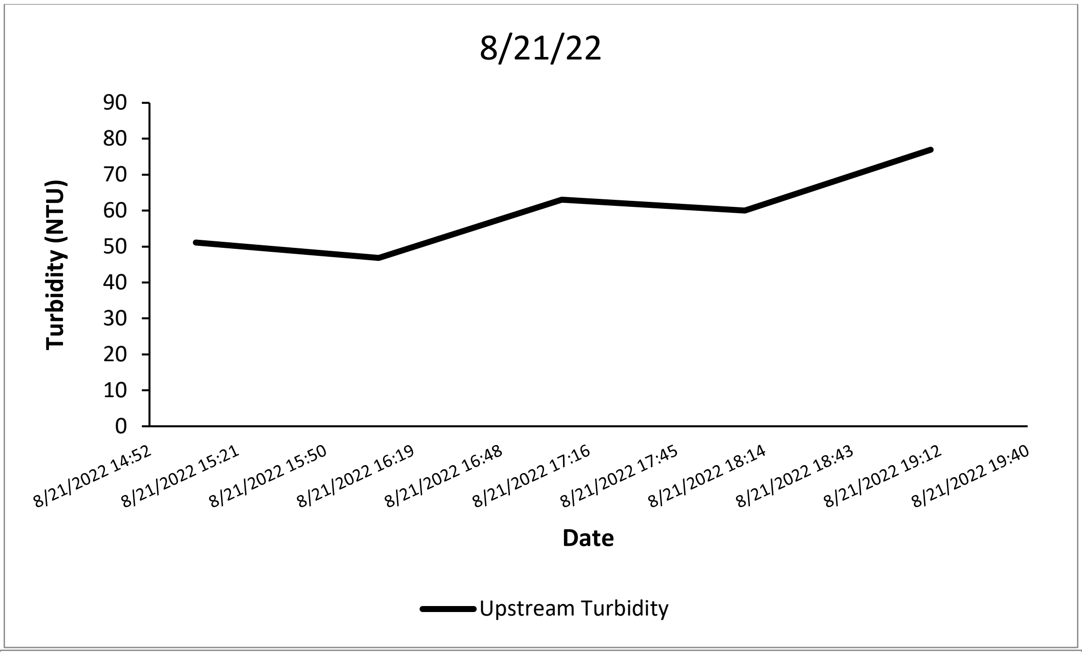


Figure A64. Turbidity (top) and TSS (bottom) in Swift Creek**.**



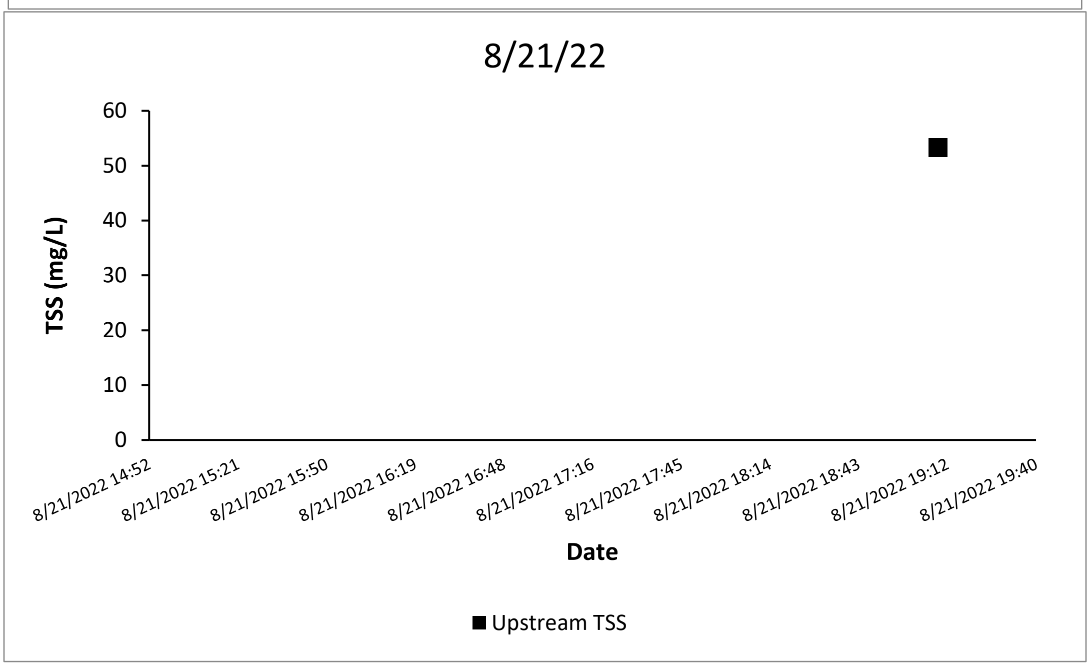
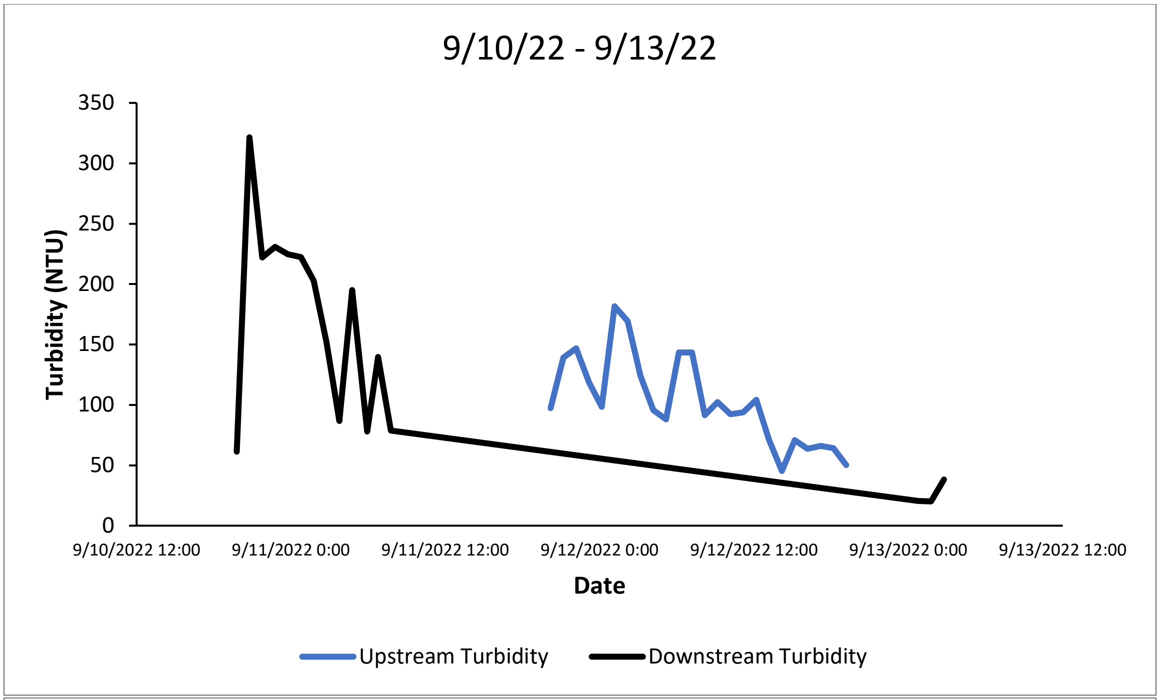


Figure A65. Turbidity (top) and TSS (bottom) in Swift Creek**.**



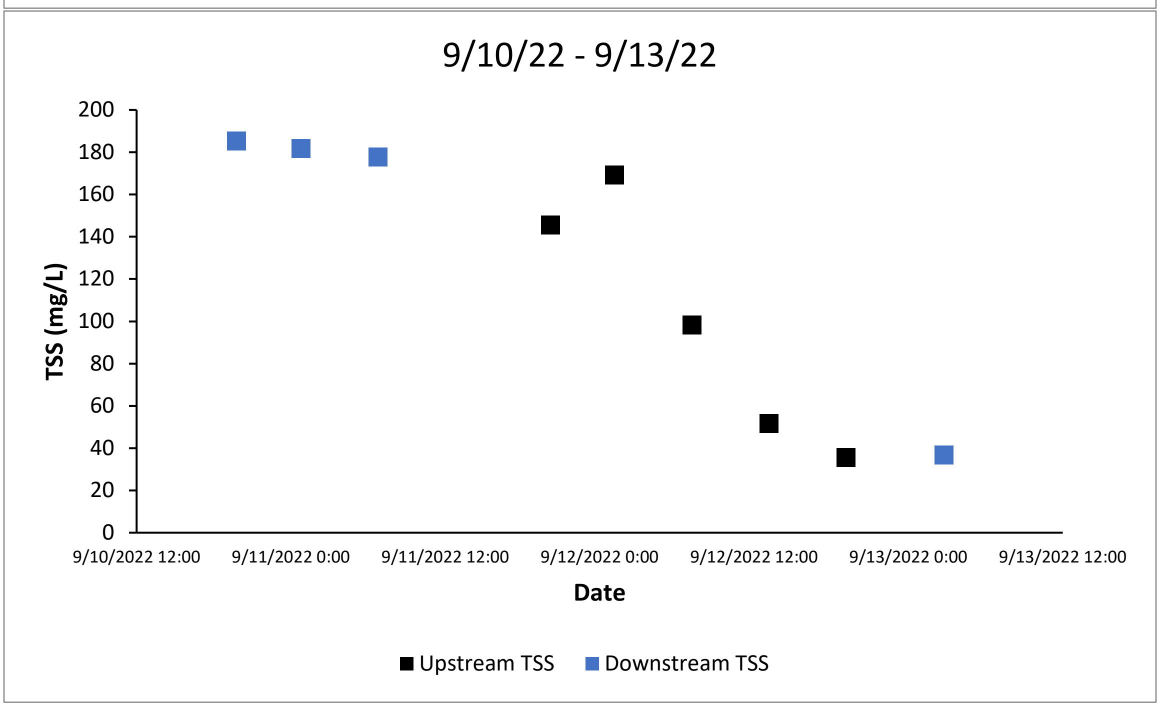


Figure A66. Turbidity (top) and TSS (bottom) in Swift Creek**.**

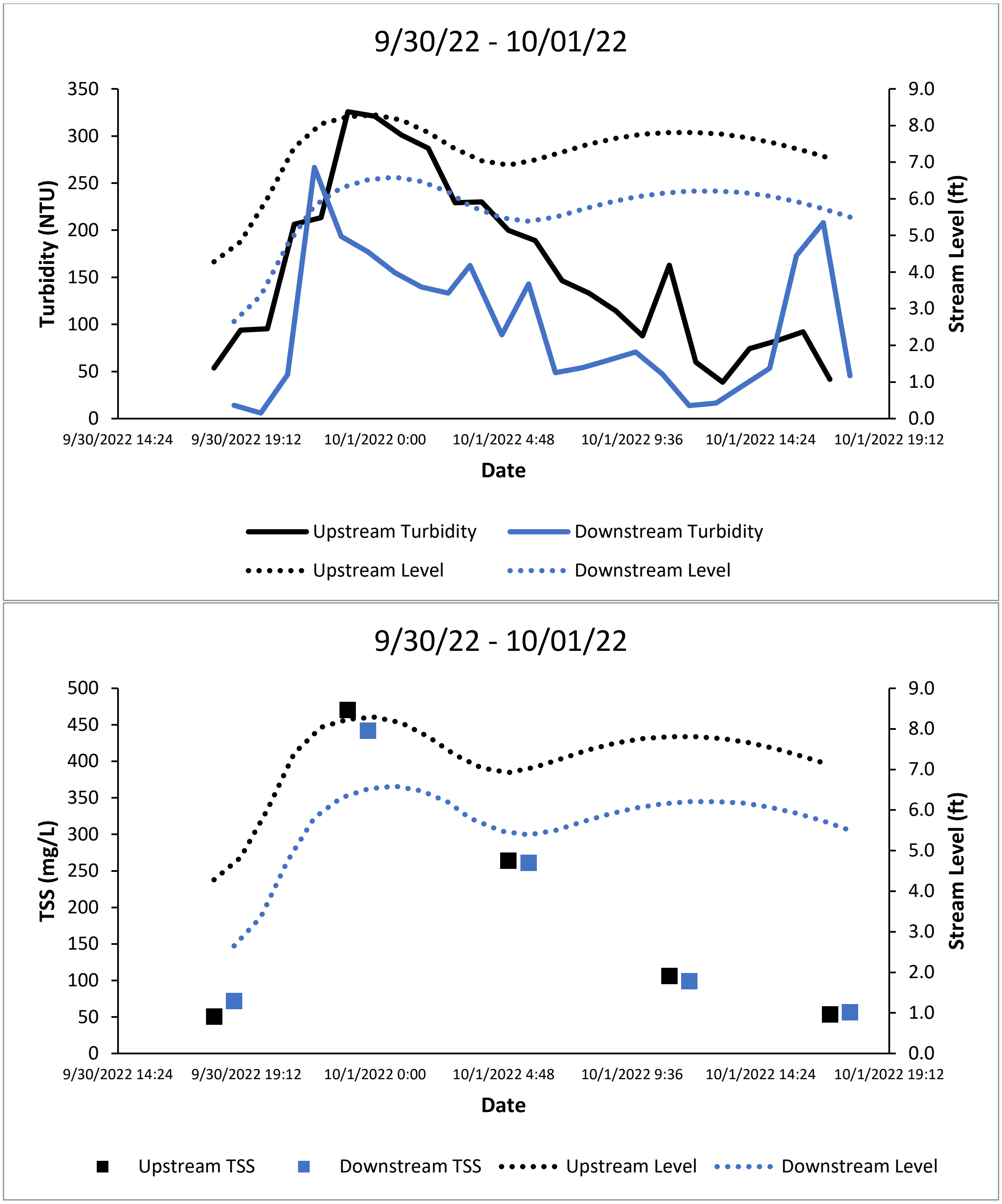
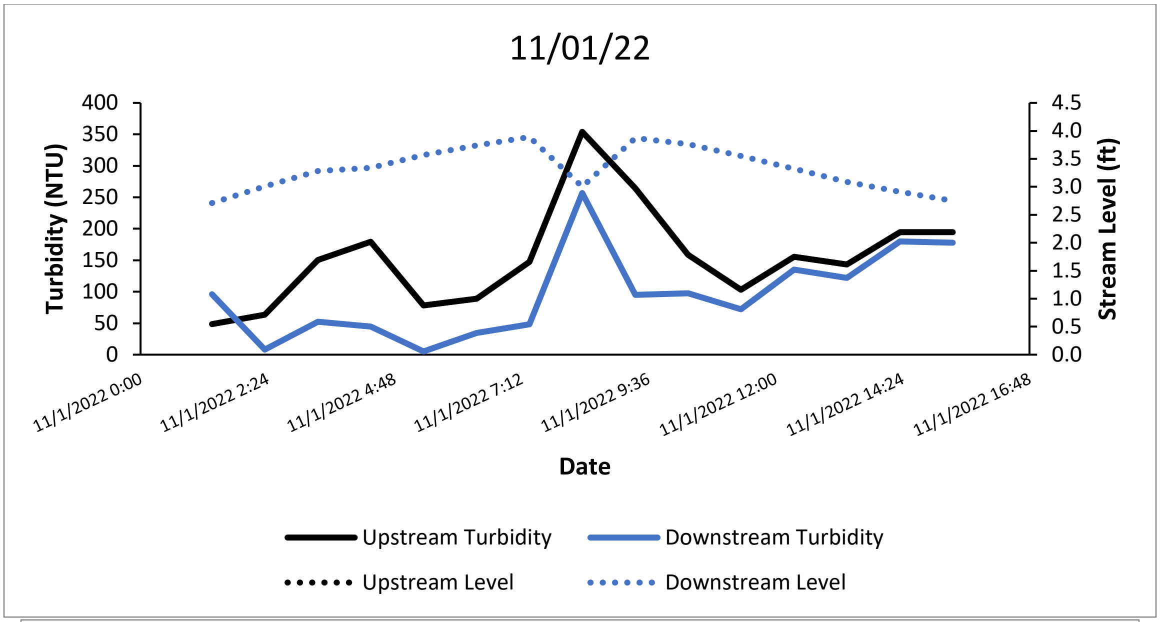


Figure A67. Turbidity (top) and TSS (bottom) in Swift Creek.



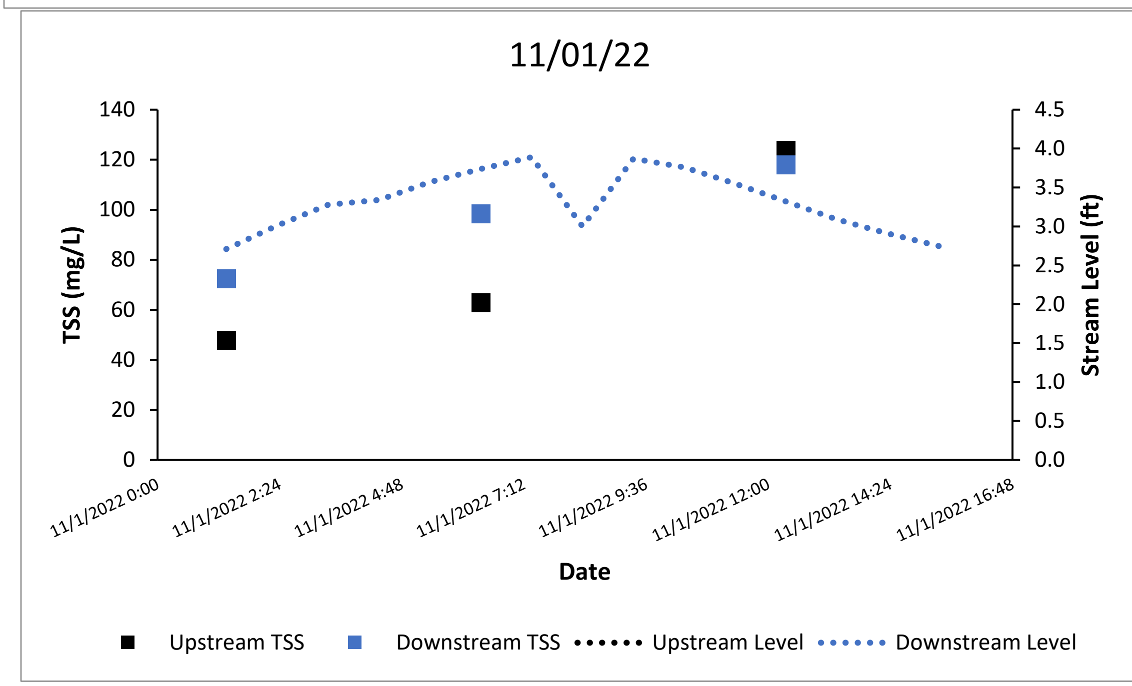
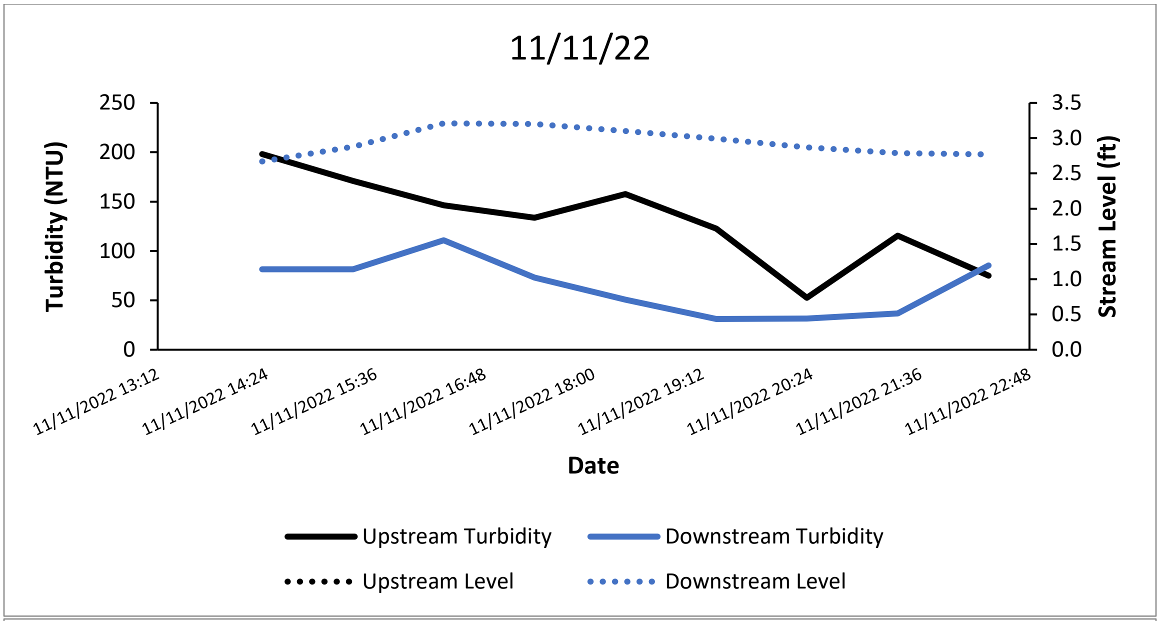


Figure A68. Turbidity (top) and TSS (bottom) in Swift Creek**.**



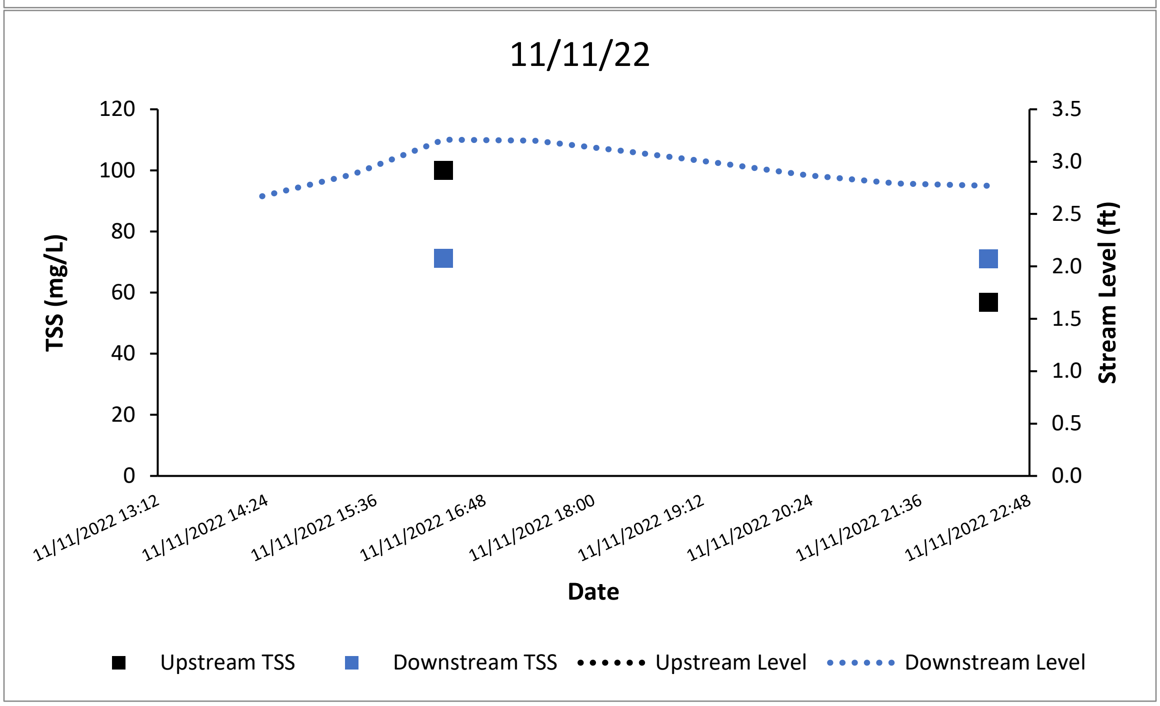


Figure A69. Turbidity (top) and TSS (bottom) in Swift Creek**.**

APPENDIX 3: SUPPLEMENTAL WILDFLOWER AND POLLINATOR STUDIES

This appendix includes additional wildflower and pollinator studies conducted in the phytotron and in the field.

Materials and Methods

Phytotron Study

Short-term germination studies were conducted in the Phytotron at North Carolina State University, Raleigh, NC, on both the American Meadows Southeast Pollinator Wildflower® seed mix (Shelburne, VT) and the Urban Farmer North Carolina Blend® seed mix (Westfield, IN) to compare their germination performance at both 26°C and 18°C.

Three seeds of each of the 17-wildflower species from the American Meadows Southeast Pollinator Wildflower® seed mix were counted separately and then recombined to create a total of 51 seeds, three seeds of each species, in each tested wildflower mix. This was done to control the number of seeds in each pot and ensure that all of the wildflower species in the mix were tested. There were eight replicates of the created 51-seed wildflower mix that were sown into eight, six-inch pots, filled with sandy loam soil mixed with 15mL of Osmacote fertilizer. After planting, each pot was watered thoroughly and then covered with plastic wrap. The same method was carried out for the 15 wildflower species (45 seeds total per pot) in the Urban Farmer North Carolina Blend® seed mix. Four pots of the recombined American Meadows Southeast Pollinator Wildflower® mix and four pots of the recombined Urban Farmer North Carolina Blend® seed mix were placed in a chamber set to 26°C with a 10-hour photoperiod. The remaining four pots of the American Meadows Southeast Pollinator Wildflower® mix and four pots of the Urban Farmer North Carolina Blend® seed mix were placed in a chamber set to 18°C with a 10-hour photoperiod.

Pots were watered when needed and germination counts were taken daily for 14 days. The saran wrap was removed from all of the pots in the 26°C chamber on day four of the experiment, when the seedlings had germinated and were tall enough to touch the saran wrap. The saran wrap was removed on day 7 from all of the 18 °C chamber. This experiment was conducted twice following the same protocol.
Germination rates for both seed mixes were analyzed using SAS (SAS Institute, 2001, Cary, NC) and Duncan's multiple range test ($\alpha = 0.05$). Duncan's multiple range test was selected to account for the varying number of seeds between the two seed mixes used in the experiment.

Field Study

Twelve turfgrass sites were selected based on location, site suitability for habitat establishment, and management intensity. Initial insect sampling was conducted beginning in the summer of 2018 in order to record a baseline for pollinators found at each site. Formal sampling for pollinators and floral resources was carried out between May-October, 2019.

Results

Phytotron Study

The Urban Farmer North Carolina Blend® and American Meadows Southeast Pollinator Wildflower® seed mixes in the 26°C chamber initiated germination on day two (Table A1). Germination for both the Urban Farmer North Carolina Blend® and American Meadows Southeast Pollinator Wildflower® seed mixes in the 18°C occurred on day four (Table A1).

In the first replication, the American Meadows Southeast Pollinator Wildflower® seed mixes average germination rate was slightly higher each day than the Urban Farmer North Carolina Blend® (Figure A70). However, in the second replication, Urban Farmer North Carolina Blend® germination rate was slightly higher each day than the American Meadows Southeast Pollinator Wildflower® (Figure A71).

Field Study

In 2018, a total of 129 pollinators were collected, and in 2019, 675 pollinators were collected. The bees collected in 2018 and 2019 represented four common bee families: *Andrenidae*, *Apidae*, *Halictidae*, and *Megachilidae*. The most commonly-collected bee family in both years was *Halictidae*, with 52 species collected in 2018, and 336 species collected in 2019.

Discussion

Phytotron Study

The results of the germination experiments can be used to evaluate the recommended planting time for the seed mixes. A significant finding was that overall, there was very little difference between the average germination rate of the two seed mixes at the different temperatures (Table A1). It also took a similar amount of time for the seed mixes to begin to germinate in both temperatures (Table A1).

After reviewing Milstein (2005), Pill et. al. (2000), Samfield, Zajicek, and Cobb (1991) and Wees (2002), we concluded that standard industry practice was to scarify and prime seeds to overcome dormancy as well as increase both germination rate and germination uniformity. Since temperature had no significant effect on germination rates, it could be that the seeds within the seed mixes we tested had been scarified or otherwise primed to aid in seedling germination. Another possibility of why temperature had no significant effect is that since each wildflower seed mix contains 15 to 17 different plant species; given that fewer than 50% of the seeds germinated in each replication (Table A1), it is possible that those species needing cold stratification did not germinate due to the short timing of this study.

Urban Farmer (2020) states that the seeds can be planted all year, except for "in the dead of summer" in places that have little to no frost. If an area is likely to have a "hard, killing frost" in the winter, they suggest planting in the spring, summer, or fall (Urban Farmer, 2020). American Meadows suggests planting seeds in early spring in both North Carolina and the Southeast region in general (American Meadows, 2020). Even though germination in the 18°C chamber occurred two days after that in the 26°C chamber, there was only a slight difference in overall the average germination. This indicates that if the wildflower seeds are sown in the autumn, per some of the existing planting recommendations, then there is potential for early germination during the winter season. If the seeds germinated during autumn, they could potentially die during a winter freeze, resulting in lower wildflower coverage in the spring.

This study provided some insight on when it would be most appropriate to plant wildflower seeds for optimal germination rates and establishment. However, more research is needed in this area. Specifically, future studies over longer time periods and in field-based contexts would allow bloom periods, species dominance, and the diversity of species to be evaluated. This would further increase our understanding of wildflower seed mix quality and appropriate use.

Field Study
Our findings support the hypothesis that it is possible to reestablish native areas on roadsides and other marginal areas. These habitats support pollinator communities found in association with managed turfgrass systems by increasing food and habitat availability.

Table. A1. Treatment (Trt), temperature (Temp), number of days the seedlings began to germinate after sowing (Days to Germ), and average germination rate shown in percent (AGP) of two wildflower seed mixes.

[z]**Urban Farmer North Carolina Blend®**	[y]Trt	[x]Temp	[v]Days to Germ	[u]AGP
UF	1	26°C	2	0.50ab[t]
UF	2	26°C	2	0.53a*
UF	1	18°C	4	0.39b*
UF	2	18°C	4	0.52a*
[z]**American Meadows Southeast Pollinator Wildflower®**				
AM	1	26°C	2	0.52a*
AM	2	26°C	2	0.46ab
AM	1	18°C	4	0.40b*
AM	2	18°C	4	0.43ab

*indicates significant difference. *Superscripts (a, b, c).* For a particular variable, mode means with same superscripts are not significantly (P>0.05) different. Means with the same letter are not significantly different.

[z]Seed mixes used in study
[y]Trt= Signifying first and second experiment
[x]Temp= Temperature of NCSU Phytotron Chamber in Celsius.
[v]Days to Germ= Number of days the seedlings began to germinate after sowing.
[u]AGP= Average germination rate shown in percent across all of four replications in the experiment.
[t]Statistics using Duncan's multiple range test with an alpha= 0.05 are given down.

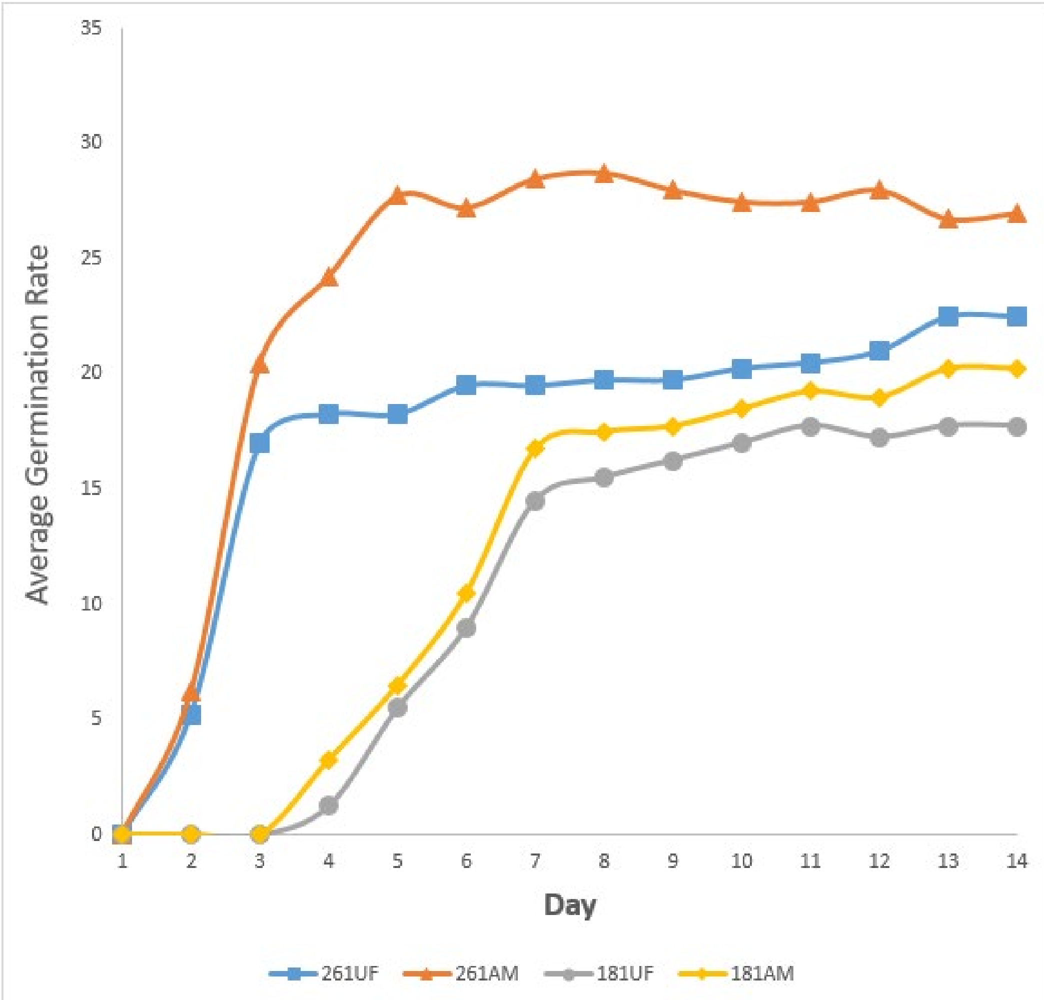


Figure A70. Replication 1 of 2 for the germination studies. Comparing Urban Farmer North Carolina Blend® and American Meadows Southeast Pollinator Wildflower® seed mixes average germination rate in days after planting at 26°C and 18°C. 261UF = 26°C with Urban Farmer North Carolina Blend®. 261AM = 26°C with American Meadows Southeast Pollinator Wildflower®. 181UF = 18°C with Urban Farmer North Carolina Blend®. 181AM = 18°C with American Meadows Southeast Pollinator Wildflower®.

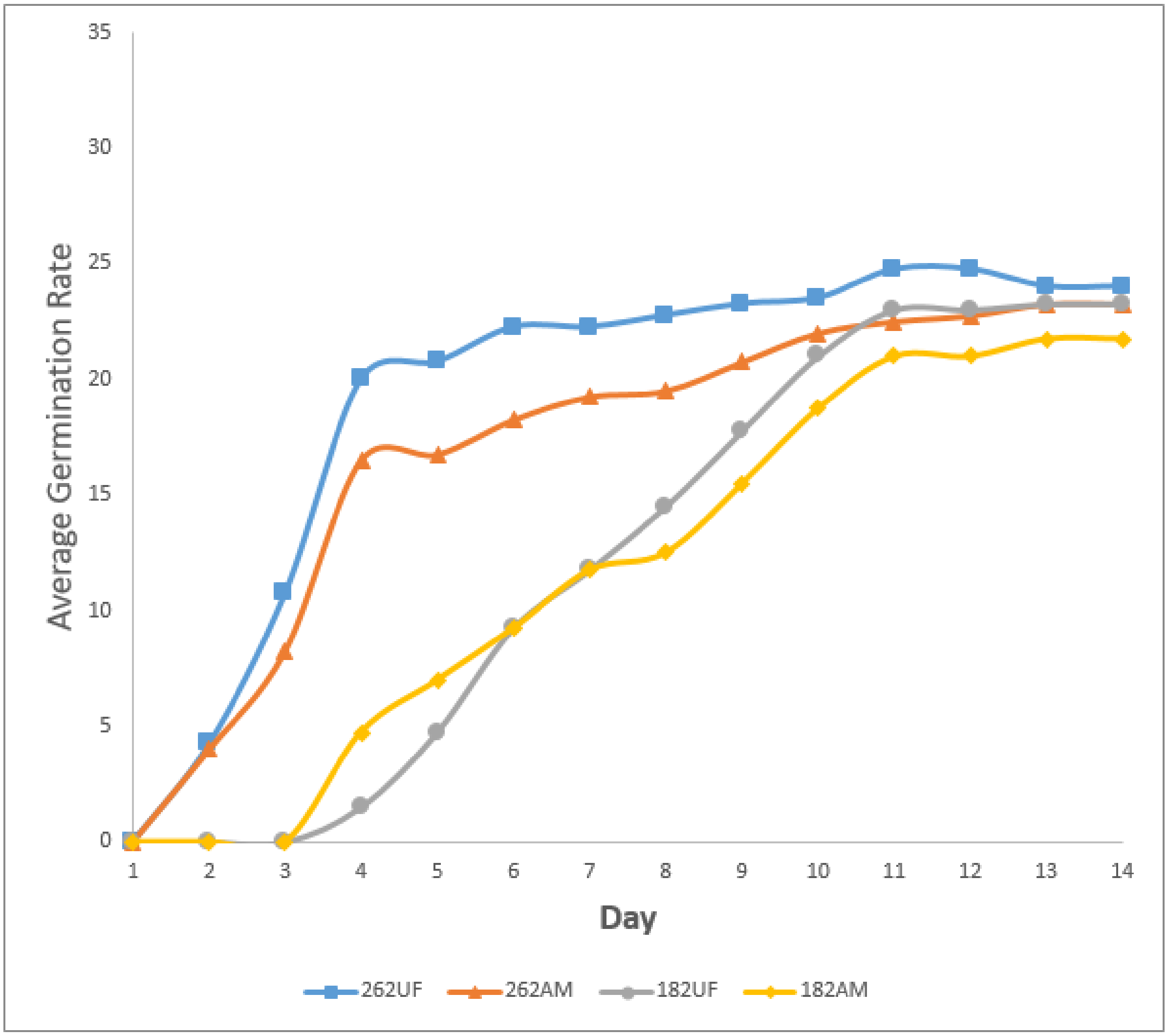


Figure A71. Replication 2 of 2 for the germination studies. Comparing Urban Farmer North Carolina Blend® and American Meadows Southeast Pollinator Wildflower® seed mixes average germination rate in days after planting at 26°C and 18°C. 261UF = 26°C with Urban Farmer North Carolina Blend®. 261AM = 26°C with American Meadows Southeast Pollinator Wildflower®. 181UF = 18°C with Urban Farmer North Carolina Blend®. 181AM = 18°C with American Meadows Southeast Pollinator Wildflower®.

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