Sediment Monitoring and Management Tool for Improved Stream Health Below Lake Merriweather

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December 13, 2022

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Introduction

Under the Federal Clean Water Act (1972), states are required to assess the quality of their waterbodies and develop clean-up plans for waters that do not meet water quality standards. In 1996, the Little Calfpasture River was listed as not meeting the general water quality standard for aquatic life. The reason for the impairment was determined to be excess sediment, and in 2010, the Virginia Department of Environmental Quality (VDEQ) developed a Total Maximum Daily Load (TMDL) for sediment in the Little Calfpasture River (VDEQ, 2010). This TMDL called for an overall 56% reduction in sediment from the watershed and a 34% reduction in sediment from the management of Lake Merriweather.

Lake Merriweather is highly influenced by both the land area around it as well as the ecological conditions of upstream environments. The lake receives sediment loads from upstream and much of that sediment settles within the lake. During the winter, however, current lake management practice is to lower the level of the lake for seasonal maintenance and the removal of debris. During this time period of lake drawdown, exposed mudflats erode during storm events and transport excess sediment downstream below the lake, impacting benthic aquatic life.

In 2018, VDEQ developed a Water Quality Improvement Plan (VDEQ, 2018) designed to implement the 2010 TMDL. This plan recommended actions that could be taken to meet the required reductions in sediment. These actions included agricultural control measures, such as livestock exclusion, riparian buffers, and improved management for pastures, cropland, and timber harvesting. The plan also recommended lake management control measures to reduce the load of sediment coming from Lake Merriweather. These control measures included reducing the depth or the amount of time that the lake is drawn down in the winter, revegetating exposed mudflats, excavating sediment from mudflats, and stabilizing the emergency spillway.

This project has been designed to deliver the outcomes of giving an improved understanding of the impact of lake management decisions on turbidity levels and provide lake management recommendations that decrease downstream sediment loads. This report serves as an update on the findings of this project as the midway point of JMU's one year of equipment and data monitoring passes.

Location and History

The section of the Little Calfpasture River that was found to be impaired is located near the town of Goshen, Virginia. This river section runs out of Lake Merriweather, via Goshen Dam, before joining with the Calfpasture River to form the Maury River, a tributary of the Chesapeake Bay watershed to be emptied through the bay into the Atlantic Ocean. The Little Calfpasture River watershed itself covers around 83 square miles and stretches across both Rockbridge and Augusta Counties (VDEQ, 2010). Lake Merriweather is a manmade waterbody located on the Little Calfpasture River and typically has an area of 444 acres. This lake is the primary distributer of water downstream into the impaired section of the Little Calfpasture. Figure 1 below shows the location of the lake in relation to the counties and streams around them. In the Figure 1 depiction, the red stream represents the section of the Little Calfpasture that the VDEQ recognized as impaired due to excess sediments (VDEQ, 2010).

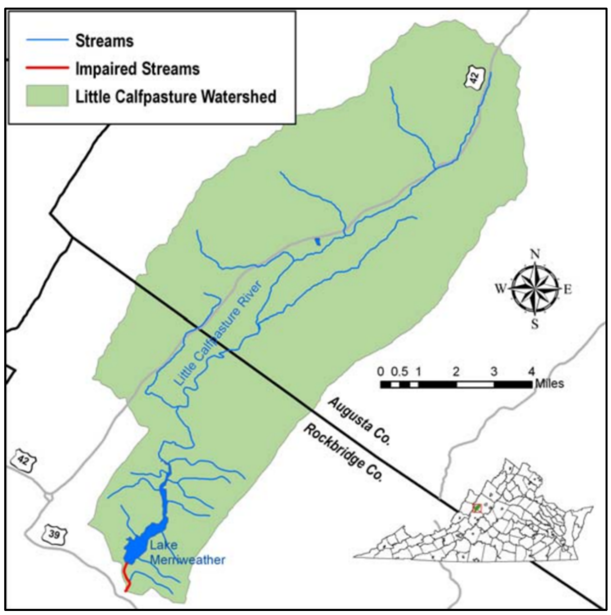

Figure 1: Depiction of the Little Calfpasture watershed showing both Lake Merriweather and the impaired section of the Little Calfpasture River (VDEQ, 2010)

Long Term History and Regulations

Goshen Dam and Lake Merriweather opened fully opened in 1967 as a Boy Scout reservation in Rockbridge County. Between the first five years of the lake's life, issues of excess sediment presence had already begun to be seen. The Department of Game and Inland Fisheries (DGIF) went on to report nine unauthorized sediment discharges from Lake Merriweather between 1967 and 1992. In 1992 a fish kill took place just below the dam which also caught the attention of the DGIF (Rockbridge Conservation, 2015).

Benthic sampling by the Department of Environmental Quality (DEQ) between the years 1993 and 1999 found further issues with the environmental impact of the dam. More specifically, the DEQ's investigation on this issue outlined that there was significant impairment of the Little Calfpasture River below the dam due to increased sediment presence. The year 1993 brought about many revelations and movements on the environmental health of the aquatic ecosystems of Lake Merriweather and the Little Calfpasture River. Most notably, in the year 1993, the DEQ issued a notice of violation for the lake's sediment discharge and the USACE found the lake to violate the Environmental Protection Agency's Clean Water Act. Moreover, in this year the DGIF and the State Water Control Board (SWCB) found that excess sediments in the Little Calfpasture would undoubtedly have negative effects on the future benthic communities; this caused the Boy Scouts of America (BSA) to report an implementation plan for changing dam management due to an SWCB consent order. Throughout 1994, the ecosystems showed no improvement, even with the changes made by the BSA, and in 1995, the DEQ concluded that there would be no improvement unless the practice of lowering the lake in the winter was stopped (Rockbridge Conservation, 2015).

Winter drawdown of dammed lakes is a common practice that takes place in the dam community. There are several reasons that dam owners and operators may prefer to keep lower water levels in the winter months. One of these reasons is to reduce any possible damage that ice may cause to dam structures along the water's shoreline. Additionally, it is also common practice to provide room for extra flood storage in the case of snowmelt and spring rain. Some less common, but still viable reasons for lower water levels in the winter are to perform repairs and maintenance on the dam or to discourage habitation of undesired animals along the shorelines (ASDM, n.d.).

In 1996, the DEQ issued a follow up to previous findings which stated that when sediment is exposed along the banks of the lake, it erodes and is deposited into the Little Calfpasture which leads to environmental damage to the river and its aquatic life which cannot be permitted to continue. Additionally, the DEQ also stated that the actions of the BSA seemed to suggest resistance to cooperation or to find alternative solutions. Furthermore, in 1996 Congress appropriated $6 million to upgrade the Goshen Dam, however, in 1998 the DGIF further found that the degree of turbidity in the Little Calfpasture is directly tied to the dam operation. On top of this, the SWCB required the BSA to keep the lake at full pool unless in the case of an emergency and to submit logs of daily dam practices (Rockbridge Conservation, 2015).

Between 1998 and 2005, findings continued to report impairment in the Little Calfpasture due to sediment but also began to include the Maury River as an influenced area. Between these years, despite the SWCB requirements of the BSA, the lake was continually lowered during the winter seasons on top of the authorized times during necessary weather events. This issue of a lack of compliance has been discussed many times between government parties and the BSA dam operators, however, lack of compliance continued to be seen (Rockbridge Conservation, 2015).

In 2009, parties within the VDEQ identified three stressors that came as a result of the Goshen Dam, these being changes in organisms that make up food chain bases, decreases in dissolved oxygen, and lake sediment that fills in river bottom spaces and smothers benthic life. To address the issue of dissolved oxygen, the BSA installed a cold water intake that helped reduce dissolved oxygen violations, however, the Little Calfpasture remained on the impairment list through 2014. Between 2012 and 2013, improvements were made to the dam in the form of a spillway for general safety requirements, however, still no real improvements were made to address sediment issues or dissolved oxygen any further (Rockbridge Conservation, 2015).

Point and Non-Point Source Pollutants

Sediment inputs into a body of water come from one of two sources: direct point sources and non-point sources. Point source pollutants are typical distinguishable and discrete single sources of input, such as sewage that comes from a treatment plant or a straight pipe from outdated plumbing in a house. Non-point sources, on the other hand, are typically pollutants that come from surrounding land, usually in the form of runoff or erosion. In Lake Merriweather, the main source of sediment has been found to be a result of non-point sources from the Little Calfpasture River watershed. Within this watershed, there are a variety of different land types including pasture, cropland, residential, forest areas, and impervious lands (VDEQ, 2010). Runoff from these different land types carries sediments throughout the watershed and incorporates them into the river system. Department of Environmental Quality models have found that around 3395 tonnes of sediment are deposited into Lake Merriweather each year, with most of it coming from degraded banks of pasture areas. Additionally, around 94% of the sediment present in Lake Merriweather has been found to be sourced from the upstream reaches of the Little Calfpasture while only around 5% of the sediments come from shorelines and lakesides. Of this sediment, it was found that around 76% of it is discharged below the dam and into the lower stretch of the Little Calfpasture (VDEQ, 2010).

Problem Statement

Current management practices of Lake Merriweather and Goshen Dam are contributing to increased levels of suspended sediment within downstream aquatic ecosystems. Excess sediment is the primary stressor causing the Little Calfpasture River to fail to meet aquatic life standards set by the Virginia Department of Environmental Quality. This project aims to install, operate, and instruct others in the use of remote monitoring equipment at the outlet of Lake Merriweather to optimize lake management practices for sediment reduction.

Project Goals

This specific project was carried out in hopes of developing a tool to help optimize lake management control measures and ensure that sediment reduction goals are met. As stated in the problem statement section of this report, there are three specific goals outlined for this project. First in these goals is the installation of real-time turbidity and depth monitoring equipment for data collection on Lake Merriweather. This goal was specifically implemented in the form of a permanent monitoring station that was installed along one of the Goshen Dam sidewalls adjacent to the exit of Lake Merriweather into the Little Calfpasture River. This station was designed for the collection of turbidity and depth data as well as the remote transmission of data via cellular transmitters. The second objective of this project is the operation of this equipment; this includes preforming maintenance, calibration, data analysis, and evaluations on management practices. Proper operation of this project's equipment primarily consisted of ensuring that reliable data was being collected and using this data to make calculations, view trends, and draw assumptions. Lastly, this project aims carry out the training of project partners on the maintenance and use of this system while providing recommendations on how to use data for future lake management. James Madison University was only meant to be involved in the preliminary stages of this project before passing control of equipment and data collection onto Rockbridge County after the first year of operation. Primarily, the training objective of this project took the form of creating resources for Rockbridge County to refer to including standard operating procedures, quality assurance documents, instructional videos, and more.

The Impact of Sediments

Overview

Nationally, sediment is responsible for 15% of the physical habitat stressors seen in the over 1 million miles of assessed waters (EPA, 2017). Additionally, it has been found that streams with excessive streambed sediments are around twice as likely to be rated as having poor biological conditions when compared to streams with normal levels of streambed sediments (EPA, 2017). Between the two types of pollution sources discussed above, point source and non-point source, sediment pollution is representative of the latter. There are two main classifications of sediments in water, these being deposited sediment, and suspended sediment. Deposited sediment accounts for the particles that have settled and accumulated on the beds of water bodies. Suspended sediments are often encompassed by the term total suspended solids (TSS) which represents the total amount of unsettled solids that are in the water column (Ji, 2017). Among sediment movement, these processes of sediment deposition and resuspension are extremely important in the ways that sediment particles, and their effects, are distributed. Each of these types of sediments carries its own potential for ecological issues and these two in-stream processes are essential to understanding the dynamics of sediment discharge and distribution within the Little Calfpasture River.

Sediment Dynamics and Transport

There are many complex intricacies involved in sediment movement throughout stream ecosystems. In relation to this project, many of the instream conditions experienced by aquatic life are determined by these complex sediment transport processes. Within the context of Lake Merriweather and the Little Calfpasture River, the DEQ recognized that these processes are highly influenced by both lake management practices and naturally occurring events. As natural storms with increased precipitation intensities take place within the area, the velocity of the water moving throughout the watershed increases. This increase in flow can also often result in an increase in forces acting on previously deposited sediment particles in the waterbodies. In turn, the number of suspended particles within the water increases as deposited sediment is forced off the beds and back into the fluid to be deposited once more. This redeposition has been found to last for weeks after the occurrence of such high velocity events. Additionally, the same general process can be seen when river flow is increased due to dam operations on Lake Merriweather as this affects the deposition and resuspension of sediments below the lake (VDEQ, 2010).

Sediments in rivers are typically sourced from two main processes, overland flow, and erosion. The process of erosion causing sediments to enter waterbodies is typically in the form of bank or bed erosion, where the land in direct contact with the water is eroded away and sediments enter the waterbody directly (Droppo et al. 2015). Almost all sediments enter streams as suspended sediment; however, individual particles are continually going through deposition and resuspension cycles as they are affected by flow and other factors.

Moreover, natural relationships between stream biological communities and sediments can also cause suspended solids to act differently in the water. Among other factors, studies have found certain types of bacteria that produce substances in the water that can induce the flocculation of solids and the stabilization of beds (Droppo et al. 2015). Figure 2 below shows a more complex diagram of the sediment transport process; however, many basic principles can also be seen.

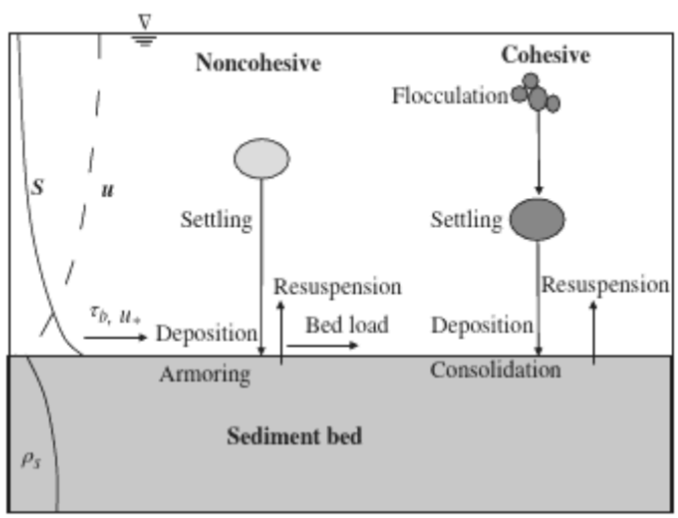

Figure 2: Sediment Transport Process Diagram (Ji, 2017)

Sediment Effects on Aquatic Life

The issue of increased sediment deposition in waterways can be detrimental to an ecosystem's health in a variety of ways. First and foremost, suspended sediments within a river impair the amount of light that penetrates the water as well as the water's overall clarity. This simple concept can have vast ramifications for the operations that take place within aquatic ecosystems. When photons of light enter water, they naturally are subject to scattering and absorption by the water molecules. As sediments enter these systems, and overall clarity decreases, the absorption and scattering increase, therefore making it harder for photons of light to reach deep into the water. Primarily, light penetration is important for such environments due to the need for light in the process of photosynthesis. Just as terrestrial plants need sunlight to photosynthesize, so do aquatic plants, and the presence of suspended sediments within these ecosystems and the decreased availability of sunlight into the water subsequently means less aquatic photosynthesis (Davies-Colley & Smith, 2001).

In conjunction with this decrease in photosynthesis can also come a problem in the amount of dissolved oxygen within the water. As plants photosynthesize to create energy for themselves, they also create and release oxygen as a byproduct; in aquatic ecosystems, this oxygen enters the water as dissolved oxygen which can be an important water quality indicator on its own and is essential for many aquatic functions (EPA, 2021).

Sediment loads are often examined in streams due to the many different relationships it has been found to have with overall benthic communities. In the more localized area of the Appalachian Mountains, it has been found that sedimentation is likely the main cause of environmental impairment in headwater streams. Additionally, it was found that entire macroinvertebrate communities in these areas are highly sensitive to changes in fine sediment presence (Angradi, 1999).

A number of habitat assessments on the impaired reach of the Little Calfpasture have been conducted to help analyze exactly what stressors are present in this river section. Primarily, these studies have found that, among other stressors such as food supply changes and dissolved oxygen, sediment presence is the most likely stressor for this specific area (VDEQ, 2010). When sediments are discharged into waterways such as the Little Calfpasture, they typically either settle to the riverbed or are continued to be carried with the moving water. As sediment particles make their way to the bottom of the river, they fill in the spaces between larger particles and accumulations of substrate. One influential effect that this has on aquatic life is the smothering of flora that naturally rely on these spaces for growth. Additionally, the cover that this sediment creates over top of the existing growth also reduces the amount of light that is able to reach the flora which subsequently reduces the ability of such organisms to thrive (Wilson, Et al., 2007).

In addition to the reduction of space for aquatic flora growth, fine sediment deposition and settling can also directly affect important benthic macroinvertebrates. In a similar way to the impact that sediments have on flora, the settling of such particles into natural spaces within the riverbed can also reduce the potential habitat areas for many macroinvertebrates. Moreover, fine sediment particles can more directly affect aquatic organisms such as macroinvertebrates by being deposited onto essential respiration structures. This can both reduce the ability of organisms to take in oxygen as well as negatively affect overall oxygen concentrations (Wilson, Et al., 2007).

Moreover, an increase in deposited sediments in streams can cause other problems such as benthic smothering (Davies-Colley et al. 2001). As sediments settle on the beds of waterbodies, they have the possibility of covering less mobile benthic organisms and reducing their ecological functionality as well as their ability to live (Pineda et al. 2017).

Increased suspended and deposited sediment often cause changes in macroinvertebrate communities by disrupting the ecosystem’s food supply. As particulate matter in the water column increases, more food naturally becomes available for filtering organisms. This can sometimes be seen in the benthic community as a decrease in organisms such as shredders, predators, and scrapers, and an increase in filterers as their food becomes more available. Figure 3 below shows an example of changing feeding groups between stream reaches with varying sediment presences (VDEQ, 2010). This figure outlines three different reaches of the Little Calfpasture River and shows an overall decrease in the number of scrapers downstream as they are replaced by the increasing populations of filterers and collectors. This change in benthic community is representative of a change in the type of organic carbon available for consumption in each reach of the river.

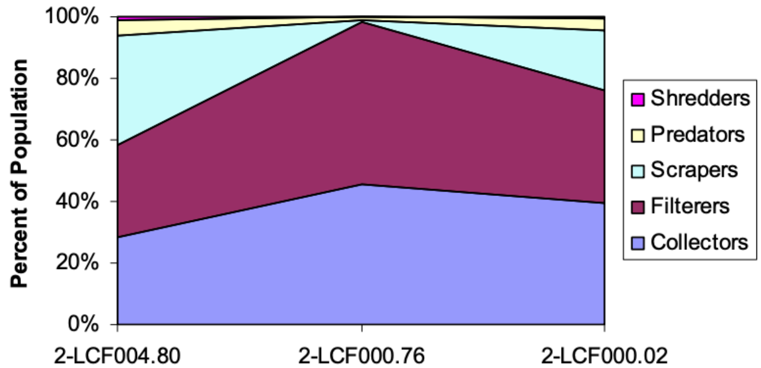

Figure 3: Functional Feeding Groups Across Three Reaches of the Little Calfpasture River (VDEQ, 2010)

Sediment particles themselves also naturally have both cohesive and adhesive properties that highly influence the dynamics between sediments and stream ecosystems. Due to these properties, sediments can often pick up polar contaminants and other organic/inorganic micropollutants that adhere to fine-grained sediments and are later deposited in the streams (Droppo et al. 2015).

Benthic macroinvertebrates often prove to be reliable indicators for the overall condition of water sources by providing insight into the functional viability of aquatic ecosystems. Macroinvertebrates further play an important role in larger predator/prey relationships and are highly influential in dictating the food webs of ecosystems (Wilson, Et al., 2007). Due to the significant connections that exist between sediments and macroinvertebrates, the importance that increased levels of sediment deposition in the Little Calfpasture holds becomes clearer. Past studies on the effects that Lake Merriweather has on the lower reach of the Little Calfpasture have concluded that its management practices can be directly correlated to the increased turbidity found in the impaired river section. As the outlined effects that sediments can have on macroinvertebrate health and overall stream quality are well documented, it is only natural that entities such as the Department of Environmental quality have concluded that the most probable stressor of the river is indeed excess sediment presence (VDEQ, 2010).

TMDL Development

In 2010 the Virginia Department of Environmental Quality took a closer look at the impairment of the lower reach of the Little Calfpasture River. Their overall study included a stressor analysis to see what the root causes of the water quality issues were. They concluded that one of the primary stressors responsible for the impairment of the Little Calfpasture was excess sediments. In response to these findings, a TMDL report was created. TMDL stands for Total Maximum Daily Load and essentially represents a budget for the maximum amount of pollutant a river can take before it fails to meet water quality standards. Moreover, TMDLs include specific allocations as to where pollutants may come from and how much should be allowed from each source.

The Little Calfpasture River TMDL includes a description of the overall purpose of the document, essentially stating that it is there to decide how to meet water quality standards by enforcing necessary pollutant load reductions. Within this TMDL, the objectives are to have an average annual sediment load of less than 1138 tonnes/yr and an elevated TSS concentration of >3 mg/L for no more than 22% of the year (VDEQ, 2010).

Stakeholders

The Department of Conservation and Recreation

The Department of Conservation and Recreation is the primary regulator for qualified dams within the state of Virginia. According to the DCR's website, there are currently over 2,900 dams that are regulated in the state and their department works to "ensure that dams are properly and safely designed, built, operated, and maintained" (Department of Conservation and Recreation, n.d.). Specifically, the DCR classifies the dams they regulate by the potential hazard and risk associated with their possible failure; these categories are high, significant, and low (Department of Conservation and Recreation, n.d.). While managing the risk of dam failure is, of course, an important task, the historical actions of the DCR have seemed to be focused primarily on this direct physical integrity risk and less on the operation and maintenance aspect of their mission. Even though the current operation of Goshen Dam does not typically threaten the lives of downstream inhabitant the way that a full dam failure would, the prospect of increased sediment discharge does still pose a real and imminent issue. Much like with the Boy Scouts, the DCR also works in the area of finding a balance between physical and environmental safety. Historically, the DCR has acted more on the side of physical flood safety; one example of this is seen in 2013 when the DCR accepted BSA recommendations to lower the lake for long periods of time outside of peak camping seasons despite documented studies from the DEQ warning about such practices. Additionally, according to a chronological outline of the lake's sediment problem, the DCR, "did not require analysis of alternate management techniques for inspection, removal of debris, and removing sediment to maintain lake depth that would also protect downstream water quality." (Rockbridge Conservation, 2015).

When looking at actions such as these by the Department of Conservation and Recreation a juxtaposition of priorities can be seen. While the DCR is responsible for maintaining and regulating dam management across Virginia, their main focus seems to be centered around the risk of direct, measurable, physical harm and economic loss as they likely view these as riskier when compared to environmental harm. According to the DCR's classifications, Goshen Dam is a Class I high hazard for dam's safety and failure risk. Specifically, this classification is defined as having a probable loss of life and excessive economic loss if a failure occurs (Rockbridge County, n.d.). The extensiveness and severity of this classification further outlines the likely justification for the DCR's decisions to focus more on physical risks than environmental risks, nevertheless, finding a balance between these two must still be made a priority if this problem is to be truly solved.

Rockbridge County and the Citizens of Goshen

While this may be a more generalized group of stakeholders, Rockbridge County, the local town of Goshen, Virginia, and its citizens are very involved in this issue. The Goshen Dam and Lake Merriweather are not public property, so not many individuals have much direct interaction with the sources of the sediments in the lake themselves, however, actions upstream from Lake Merriweather can still affect the problem and downstream residents realize the effects of this issue. Landowners upstream of the lake are primarily influential to this problem due to their ability to affect the amount and types of sediments that get deposited into the lower reach of the Little Calfpasture.

Most of the deposited sediments have been found to come from non-point sources such as runoff and erosion of land surfaces above the lake. The main land uses found upstream appear to include a wide variety of pasture, cropland, residential, impervious, and forest areas (VDEQ, 2010). It should also be noted that many upstream reaches have also been found to have no riparian buffers on their banks as well as provide unobstructed access for cattle into the waterway. The upstream presence of cattle can be detrimental to the stream banks and river turbidity as their constant traffic can often degrade the banks at high rates by dislodging large sediment loads at a time (VDEQ, 2018). The soil types, slopes, patterns of precipitation, vegetation, and compaction can also be large contributing factors to how much sediments are deposited from the land lying above Lake Merriweather. Due to these potential upstream stressors, associated land owners can be viewed as very influential stakeholders as their actions are currently very connected to the present sediment issue. Additionally, this connection gives them an even larger stake in the problem as these areas could prove to be valuable in the future mitigation of the issue if managed differently.

In terms of the Goshen residents downstream from Lake Merriweather, they likely care about this issue and how it may be solved because they care about their own ability to use the affected areas as they have for many years. An article by Rockbridge Conservation on the chronological development of Goshen Dam, Lake Merriweather, and their environmental issues states, “Local citizens also consider the Goshen Pass a very special place and visit it frequently for picnics, reunions, tubing, kayaking, swimming, birding, hiking, and for fishing and hunting year round.” (Rockbridge Conservation, 2015).

Moreover, the recreational opportunities that the area below the Goshen Dam allow also add economic motivation for the local community to have a stake in this issue. The Rockbridge Conservation article further goes on to state that, “… tourism is a major contributor to the local economy and the Pass is a very desirable tourist destination.” (Rockbridge Conservation, 2015). With this added aspect of Goshen’s general investment in what happens to their ecosystems, their overall stake in the issue becomes clearer. If the issue of increased sediment discharge is not properly addressed, a whole community could potentially lose an entire local recreational resource and stream of local revenue. On the other hand, if it is addressed properly and a solution is found, their resource and incomes could be protected and likely prosper as an ecosystem that is not constantly under environmental strain.

The Boy Scouts of America

One of the primary stakeholders that interact with the issue of increased sediments in Lake Merriweather, and the surrounding aquatic environments, is the institution of the Boy Scouts of America (BSA). Lake Merriweather, as well as Goshen Dam, are and have been since their creations operated and owned by the Boy Scouts of America. The dam was constructed in 1966 and is what created Lake Merriweather on the Boy Scout Reservation Property (Rockbridge Conservation, 2015). Given this institution’s history and ownership of the lake, it would make sense that they are likely the biggest stakeholder in the present sediment issue. Not only does the sediment affect their own environments, as is seen in the BSA's recent plans for dredging the lake, but all of the indirect effects their property has on other environments is also their responsibility and affects their operations.

Moreover, this responsibility of the BSA reservation can also extend to the responsibility to address the issues. Because it is their land and their practices that cause the turbidity issues, some may view it as their responsibility to take on remediation efforts as well. This makes them an extremely large stakeholder in the issue and how it is possibly resolved as both will determine their potential land use, economic gain, and economic loss. If a solution is implemented that is both time consuming and expensive, the BSA reservation will lose potential revenue as well as not be able to offer their full services to campers.

The Boy Scouts of America's motivation in addressing this issue is hard to specifically define. The problem of increased levels of sediments in Lake Merriweather and downstream waters, such as the Little Calfpasture River and the Maury River, has prevailed for many years without much action coming from the BSA. When looking at the issue historically, it could seem to some that the BSA organization does not hold fixing the sediment issue in high regard. While they have agreed to work with environmental regulatory organizations in the past, their actions have represented a balance between environmental concerns and other interests. Due to the BSA's need to remain a viable organization, they have historically naturally prioritized economic, physical risk, and maintenance interests. This, when paired with a lack of complete communication about their own role in the issue, has typically led to less of a priority on the environmental concerns regarding their management of the lake (Rockbridge Conservation, 2015). It is important to note that this lack of compliance is not likely due to an absence of concern, but rather an absence of information and a balancing of priorities.

In general, Goshen Dam was constructed to provide the BSA with a lake and reserved area for them to carry out strictly recreational activities such as boating, fishing, camping, and more. Historically, the BSA likely has had to balance the issues of ecological health and safety with those of physical flood control safety. Between these two justifications, there is a palpable impasse that has been created in which action in either direction will likely cause risk in the other. A more ecologically safe dam will likely cause a greater risk for floods as the lake will be maintained at higher levels, while a safer dam in terms of flood control will likely continue the environmental harm of the downstream reach as lower levels cause increased sediment deposition. Nevertheless, whatever solutions or plans are proposed or implemented will likely always be subject to the will of the Boy Scouts of America as they hold the most stake in the issue at hand.

Cultural and Ethical Dimensions

The true rational behind the actions of the Boy Scouts of America and the way they have 'dealt' with this problem throughout the years can be seen in the underlying culture, ethics, and motivation of the BSA. Specifically, these aspects of the organization become clearer when comparing them to the perspective of environmental and regulatory agencies such as the Department of Environmental Quality. What is seen at its most simple form is an issue of competing interests. The Boy Scouts of America are in the business of recreation; their focuses seem to naturally be centered on providing a service to a specific demographic and maintaining a functioning facility that serves their own interests. Despite what their actions may seem like on the outside, it can be assumed that the organization as a whole is not operating under any malintent, but instead does not hold all of the same values or see the same meaning in their actions as other invested parties.

The BSA's historical norm of operation has not been in the world of environmental management or remediation, nor was the dam built for some greater ecological purpose; it was instead constructed to further the goal of recreation and education. According to their website, the BSA mission is to "prepare young people to make ethical and moral choices over their lifetimes by instilling in them the values of the Scout Oath and Law" (Boy Scouts of America, 2019). Within the context of this statement, the BSA can be viewed as an educational and developmental. This organization has its own interests and, in the case of the Lake Merriweather reservation, they are centered around outdoor recreation. The BSA is likely interested more in their ability to carry out their mission in the Goshen reservation than what inadvertent environmental effects they may be contributing to. What is seen here is primarily a case of competing interests between the Boy Scouts whose interests lie more in the realm of their own operations and the regulatory organizations who are centered on improving and protecting environmental health.

The primary example of the organizations on the other side of these competing interests is the Department of Environmental Quality. This agency, along with many other smaller governmental stakeholders, views the larger Goshen Dam area from an ecological perspective. Due to the nature of the department, all areas are likely seen through this lens first before other considerations such as recreation may be taken into account. The DEQ has a culture of protection and enhancement, and while providing outdoor recreational services does align with their overall values, it is trumped by the prioritization of environmental regulation and enforcement. Ethically, there likely is not much dilemma for the DEQ; for them, moving towards a more ecologically healthy system is the more ethical and moral path to take when compared to the alternative of ignoring the sediment issue.

This differences in interests seen between the Boy Scouts of America and the Department of Environmental Quality seems to be the main issue when it comes to the Goshen Dam/Lake Merriweather problem today. The negative ecological impacts have been known of and have been taking place for decades at this point. With multiple agencies and organizations attempting to instate policy, offer advice, and fix the environmental problems for such a long time period, the main issue has slowly shifted from being about what to do and rather to how to get stakeholders and landowners involved. These differing cultures and opinions seem to be the driving force of the current problems; what ecological information that is known is likely not being communicated effectively enough to represent its severity when compared with other interests.

Materials and Methods

Design and Installation

When designing the systems to be used for monitoring of sediments and lake management practices of Lake Merriweather, there were many different accuracy and usability considerations accounted for. In order to gain an accurate understanding of downstream sediment deposition as it relates to lake conditions, the location of the monitoring equipment used was carefully considered. To best retrieve reliable data, one permanent monitoring station was installed along the sidewall of Goshen Dam, adjacent to the exit of Lake Merriweather into the Little Calfpasture River. This location was thought to be the most promising in terms of data accuracy since the water quality at the outlet of the lake would be most representative of the quality of water being discharged into the Little Calfpasture. Additionally, the location of this equipment is ideal for lake level monitoring as there is a visual lake level indicator on the opposite dam wall and a clear view of all dam gates.

This station included three main components: the in-water testing equipment used to take measurements, the junction box used for easy access to equipment for maintenance and tests, and the control box that houses the essential components such as the datalogger, battery, and wireless data transmitter among others. Figure 4 below shows a diagram of the locations of the installed equipment that was used for the primary planning process of the project.

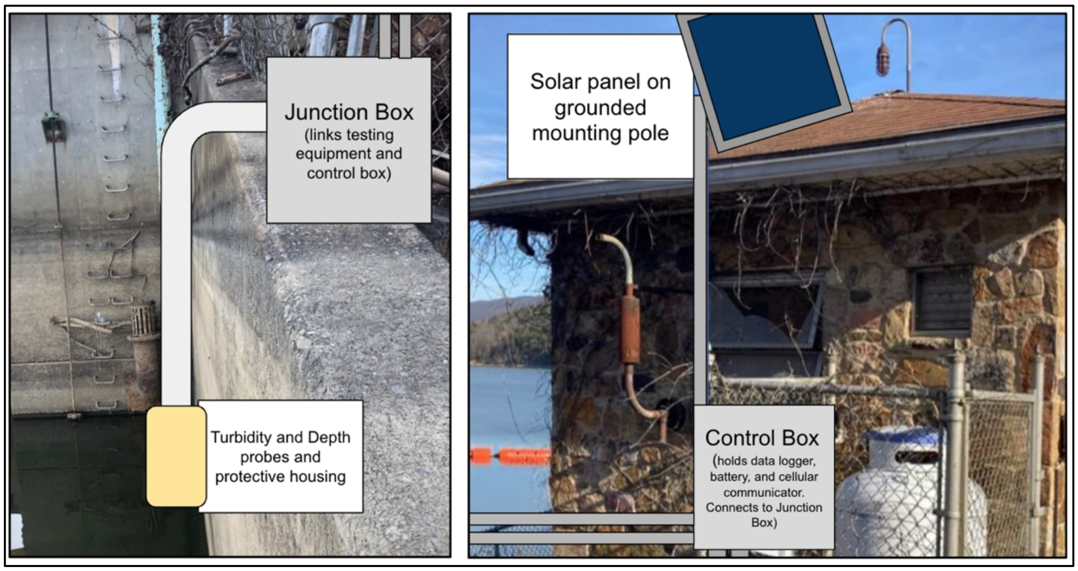

Figure 4: Diagrams and Descriptions of the Equipment Installation Locations for the Lake Merriweather Testing Station

A variety of materials were used in the installation process, however the primary equipment that is used in the process of data collection at this station is sourced from Campbell Scientific. The measurement equipment that is used to take data on turbidity and lake level are the ClariVUE10 Turbidity Sensor and the CS451 Pressure Transducer respectively. The ClariVUE 10 uses a near-infrared laser and a photodiode for detecting the intensity of light scattered from suspended particles in water. The detector is positioned at 90 degrees to the emitter to measure the side-scatter energy. Additionally, the ClariVUE 10 meets side scatter standards for turbidity measurements. The CS451 pressure transducer provides a reliable, accurate pressure/level measurement that is fully temperature compensated. Its 24-bit A/D has simultaneous 50/60 Hz rejection and automatic calibration for each measurement. The data collected by these sensors is logged by the CR350 Datalogger and can be collected using the Loggernet application either directly or remotely through the use of the CELL210 4G Cellular

Module. All of this onsite equipment is powered by a 12V battery housed in the control box and powered by a 20W solar panel.

On-Site Field Measurements

While the permanent testing station that was installed along the outlet of Lake Merriweather does collect other data such as temperature, the primary measurements that were taken were on lake level and turbidity of the water. The two sensors that were taking data are set up to do so in 15 minute intervals as set by the program being run in the Loggernet application. The sensors themselves are constantly taking data, however, the program being run dictates over what intervals the values are logged. Every 15 minutes data is logged on the battery voltage, temperatures, lake level (including any input offsets or corrections), minimum turbidity, maximum turbidity, mean turbidity, median turbidity, the standard deviation of turbidity, and the relative standard deviation of turbidity over the given time period of 15 minutes.

The sensors themselves sit within plastic housings set into the dam wall and are accessible from the junction box on the above fence. Each of the housings for the probes are constructed to allow water and smaller solids to pass freely through them to be read by the sensors, however, block any larger debris from entering and interfering with the data collection process. Maintenance and calibration checks on the probes are able to be completed by taking the sensors out of the water through the junction box and performing the necessary tasks. The data taken from these probes is collected and viewed either through direct USB connection between a computer and the datalogger or through the cellular transmitter and a computer capable of remote downloads.

Upstream and Downstream Field Measurements

On site measurements of turbidity and lake level were additionally supplemented with data retrieved temporarily both upstream and downstream of the permanent Lake Merriweather testing station. This data was collected using two YSI multiparameter sonde probes. These probes were deployed for two weeks at a time at locations both above and below Lake Merriweather. During their deployment the YSI probes took data on turbidity, depth, conductivity, dissolved oxygen, pH, and temperature. The deployment process itself consisted of finding an adequate location both upstream and downstream of the lake that was easily accessible and had exposed roots along the banks of the river that the probes could be attached to. Figure 5 shows an enlarged image of the Little Calfpasture River watershed with two red dots representing the approximate locations of the upstream and downstream YSI probes.

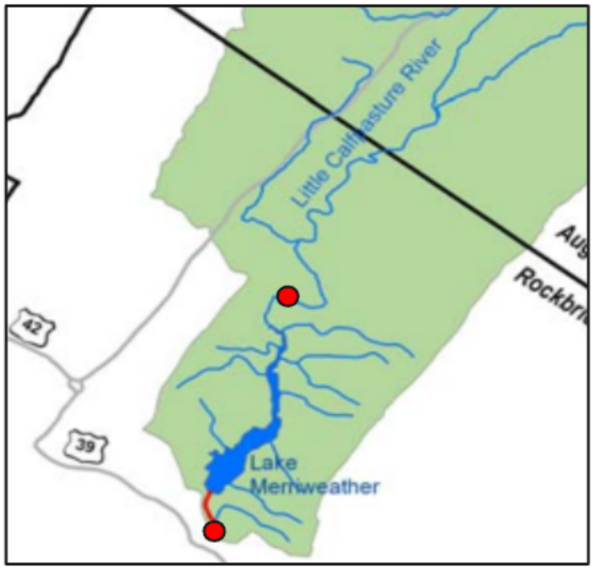

Figure 5: Approximate YSI Deployment Locations along the Little Calfpasture River

The probe itself was set to take data on all parameters every 15 minutes, thus giving an accurate representation of water quality conditions consistently throughout the days. For this specific project, the probes were deployed for the majority of the peak summer months, however, general maintenance and recalibration of all the sensors was carried out every two weeks. The data collected from these temporary sites was gathered in hopes of providing a more complete picture of the watershed and how certain pollutants and effects move throughout a larger section of the Little Calfpasture River.

Total Suspended Solids

In order to draw accurate estimates on how much sediment is discharged from Lake Merriweather into the Little Calfpasture River, a series of field and laboratory tests were performed. Primarily, these tests took the form of finding the correlation between lake turbidity and total suspended sediments (TSS). To approximate the TSS of the lake water, practices from *Standard Methods for the Examination of Water and Wastewater 20th edition* were used in conjunction with sediment samples taken from the downstream portion of the Little Calfpasture. These samples were dried and then sieved through a #230 filter. This sieving process ensured that all sediment used for further tests were approximately 0.05mm or less in size. Sieving down to this size leaves only the silt and clay fraction of sediment and is representative of the smallest sediment particle types. Known amounts of this sediment was then added to specific amounts of deionized water to create mixture samples of known sediment concentrations. These samples ranged from 0 mg/L to 200 mg/L with periodic duplicates used for quality assurance purposes. In order to find the total suspended solids within these samples, they were run through standard glass-fiber filters which caught any suspended sediment in the mixture. These filters were then dried to constant weights, and the mass of sediment left on them was calculated using the known weight of the filter before testing. This was done for each of the 50 samples and gave a clear correlation between the mass of sediment added to water and the TSS found within the mixture.

To gain a better understanding of the effect that Lake Merriweather has on the Little Calpasture River, the turbidity of the created samples also had to be found. This was done by taking the mixtures out to where the Clarivue was installed on Lake Merriweather and taking turbidity calculations of each of the samples. Using this data, correlations were able to be seen between measured turbidity and calculated total suspended solids. Using this correlation, an equation was able to be made that uses the Clarivue sensor's measure of turbidity to find the amount of total amount of solids being deposited over the dam at any given time. The main components of this calculation includes converting turbidity into TSS using the numeric values of their plotted relationship, using the data on lake level and number of dam gates open to account for flow over a weir, and accounting for the time difference between measurements to get the total mass deposited over each period of turbidity measurements.

Data Analysis

Among the different parameters that the testing station at Lake Merriweather measured, the primary values of interest were the measurements of median turbidity. Turbidity is a measurement that inherently has many fluctuations as it is measured over periods time. The movement of suspended sediment, flow speed, direction of flow, and the presence of other larger biotic and abiotic features in the water can all affect how sensors perceive the turbidity of a water sample from minute to minute. In the initial testing and installation phase of this project, it was found that the value for median turbidity was typically more representative of the true water quality than other values such as mean turbidity. Mean turbidity still gave accurate data, however, was more susceptible to be skewed by outliers over the recording time periods than median calculations. Due to this, nearly all analysis of the turbidity data uses the median values over the 15 minute recording periods to maintain consistency and precision.

The primary mode of data analysis consisted of using the relationship that was found between total suspended solids and turbidity from the TSS tests described in the above section. By plotting the measured TSS against the measured turbidity of samples, a line of best fit and subsequent equation for such line was found. This equation became the basis of the calculations made to estimate the sediment loads being discharged over the dam into the Little Calfpasture River based on the measured turbidity at any given time. The final equation used to estimate sediment load in the datasheet can be seen in the equation below which combined the equation for flow over a weir with the TSS/turbidity relationship.

$$TSS\ Load = 2.84 + \left(L * C * H^{1.5} * \frac{Median\ Turbidity}{1.0348} * 10^{-9} * 86{,}400 * \Delta time * 28.3168\right)$$

Where,

L = Length of the weir (39ft)

C = Constant (3.33)

H = Head over the weir (ft)

In addition to flow over the spillway, this equation also accounts for the flow of water through the cold water release structure that is in place below the dam. The dam contains two cold water release valves that can be opened in addition to the lowered gates which allows water from deeper within the lake to be discharged downstream into the Little Calfpasture River. According to the Little Calfpasture TMDL, only one of these valves is typically opened and its flow can be estimated as 2.84 cubic feet per second (cfs) (VDEQ, 2010). The variable for change in time is representative of the time between turbidity measurements which is set in the program to be 15 minutes. If there is a gap in the data within the datasheet, the time difference will be corrected to account for the missing time and will estimate the sediment loads for that time period based on the next available turbidity value. The rest of the values within this equation represent unit changes so that the final value for TSS found is in metric tonnes and can be easily compared to the TMDL set pollutant limit of 1138 tonnes/year (VDEQ, 2010).

Quality Control and Assurance

In order to ensure that the data taken and reported for this project were of sufficient quality, a quality assurance project plan (QAPP) was created. In the process of finalizing this document, there were three steps, the initial creation of the plan, the comment period on the plan by multiple Environmental Protection Agency (EPA) editors, and the revision of these comments in order to create an extensive and governmentally recognized document. Within this document, there were certain data quality objectives that were outlined including an average of >90% accuracy for turbidity data, and an acceptability criteria of >80% accuracy for individual data batches. Additionally, seven data quality indicators were identified for how data can be characterized; these indicators are precision, bias, accuracy, representativeness, completeness, comparability, and sensitivity.

In addition to outlining overall objectives and identifying data quality indicators, certain quality control elements were set for both turbidity and depth monitoring at the testing station. Primarily, these quality control elements outlined the processes for measurements, calibration checks, and precision checks that would be carried out within the first year of the equipment's installation. Tables 1 and 2 below show the specific quality control elements that were created for this project.

Table 1: Quality Control (QC) Elements for Turbidity Monitoring

DQI Type	QC Element	Frequency	Criteria	Corrective Action
Precision[1]	Repeated measures	3 measurements averaged over the course of 1 minute, every 15 minutes	RSD < 25%	Repeat measurements in the next minute
Bias, Accuracy, and Sensitivity	Calibration Check - Low (0 NTU)	At every field visit (Summer: max 15 days; Winter: max 30 days)	<2 NTU	Re-clean, refill standard, retest. Return sensor to manufacturer for recalibration if 2 consecutive months fail
Bias and Accuracy	Calibration Check - High (250-1000 NTU)	At every field visit (Summer: max 15 days; Winter: max 30 days)	RPD < 5%	Re-clean, refill standard, retest. Return sensor to manufacturer for recalibration if 2 consecutive months fail
Precision and Comparability	Precision Check – Pre-service	At the beginning of every field visit (Summer:	If >10 NTU: RPD < 20%	Flag data

		max 15 days; Winter: max 30 days)	If <10 NTU: +/- 2 NTU	
Precision and Comparability	Precision Check – Post-service	At the end of every field visit (Summer: max 15 days; Winter: max 30 days)	If >10 NTU: RPD < 20% If <10 NTU: +/- 2 NTU	Reclean, readjust probe, retest. Flag data if still outside criteria
Completeness	Total data points and duration	While at full pool	>8640 data points >3-month duration	Extend monitoring
Completeness	Total data points and duration	While gates and lake level are lowered	>8640 data points >3-month duration	Extend monitoring

Table 2: Quality Control (QC) Elements for Depth Monitoring

DQI Type	QC Element	Frequency	Criteria	Corrective Action
Precision[1]	Repeated measures	3 measurements averaged over the course of 1 minute, every 15 minutes	RSD < 25%	Repeat measurements in the next minute
Precision and Comparability	Precision Check – Pre-service	At the beginning of every field visit (Summer: max 15 days; Winter: max 30 days)	+/- 0.5 ft	Flag data
Precision and Comparability	Precision Check – Post-service	At the end of every field visit (Summer: max 15 days; Winter: max 30 days)	+/- 0.5 ft	Reclean, readjust probe, retest. Return sensor to manufacturer for recalibration if 2

				consecutive months fail or at 2 years
Completeness	Total data points and duration	While at full pool	>8640 data points >3-month duration	Extend monitoring
Completeness	Total data points and duration	While gates and lake level are lowered	>8640 data points >3-month duration	Extend monitoring

Moreover, to ensure that the quality of the data being reported is upheld, additional quality assurance checks were put in place to evaluate the gathered data once downloaded. Due to the higher possibility of turbidity data to be skewed by outside factors during the data collection process, two checks were made on all data points gathered from the Lake Merriweather station. First, a formula was added to the final datasheets that checks if data points may be considered outliers. To do this, a specific definition of an outlier had to be created so that data exhibiting these characteristics could be identified. It was decided that if a data point was greater than 125% than either the point before or after it, or less than 75% of either former or latter value, it would be considered an outlier. A formula was added into the final datasheet that checked all datapoints to see if they matched this criterion; if they were considered outliers, they were flagged but not removed. Data points were only removed if they were flagged for both quality assurance checks. The second quality assurance check used was to check the relative standard deviation of each datapoint. This value was automatically gathered and reported by the Loggernet program. A simple equation was added into the final datasheet to flag a value if it had a relative standard deviation greater than 0.25. Data points would then be removed from the monthly reports accordingly if they were considered both outliers and to have an RSD that is greater than 0.25. The equation to find the relative standard deviation can be seen below.

$$RSD = \frac{STD}{(\mathrm{C1} + \mathrm{C2} + \mathrm{C3})/3} * 100$$

Where,

RSD = Relative Standard Deviation

STD = Standard Deviation of three repeated measures (C1, C2, C3)

Training Materials

To help aid in the future collection and analysis of data at this testing station, extensive documents and other training materials were created. As outlined in the Department of Environmental Quality grant for this project, JMU would maintain control of the installed equipment for approximately the first year of its lifespan. After this period runs out in the Spring of 2023, control and ownership will be taken over by the Boy Scouts of America as the equipment is installed on their property. Additionally, assistance for maintenance will be provided by the local government of Rockbridge County, Virginia. The training materials made for this project serve as informational guidelines to the proper operation, maintenance, and data analysis that is associated with the installed equipment. The primary components of the training materials are extensive standard operating procedures, quality assurance and quality control plans, and instructional field operation videos to be used by the groups taking on ownership after JMU.

Results and Discussion

Total Suspended Solids/Turbidity

The tests carried out on the total suspended solids and turbidity of the sediment/water mixtures served as the basis for the majority of the data analysis within this project. Table 3 below shows the values used for the TSS and turbidity tests performed within the lab. The far left column of the table represents the mixtures' sediment concentrations based on the amount of sieved sediment that was added to the water. The cells that are labeled dup represent a duplicate sample of the same concentration that was also tested for quality assurance purposes. The column labeled Calculated TSS represents the final amount of total suspended solids for the sample. Additionally, the far right column labeled Measured Turbidity represents the associated turbidity that was found for each sample.

Table 3: Total Suspended Solids and Turbidity Sample Results

Concentration (mg/L)	Estimated Mass in 500mL (g)	Measured mass (g)	Added TSS (mg/L)	Estimated Amount Filtered (mL)	mass retained (mg)	Filter #	Preweight (g)	Final Weight 1 (g)	Final Weight 2 (g)	Measured TSS (mg/L)	RPD	Measured Turbidity (NTU)
0	0	0	0	500	0	D2188	0.3173	0.3177	0.3176	0.6		4.6
2	0.001	0.001	2	500	1	D2189	0.3167	0.3206	0.3206	7.8		5.13
5	0.0025	0.0024	4.8	500	2.5	D2190	0.3192	0.3209	0.3209	3.4	0.74074	5.5
5 dup	0.0025	0.0024	4.8	500		D2191	0.3188	0.3226	0.3225	7.4		4.81
10	0.005	0.0048	9.6	500	5	D2192	0.3174	0.3216	0.3216	8.4		6.35
15	0.0075	0.0075	15	500	7.5	D2193	0.3174	0.324	0.3239	13	0.10219	7.22
15 dup	0.0075	0.0075	15	500		D2194	0.3189	0.3264	0.3261	14.4		7.14
20	0.01	0.0094	18.8	500	10	D2195	0.3164	0.3247	0.3244	16		21.45
25	0.0125	0.0127	25.4	500	12.5	D2196	0.3164	0.3287	0.3288	24.8		29.54
30	0.015	0.015	30	500	15	D2197	0.3168	0.33	0.3301	26.6	0.05839	32.12
30 dup	0.015	0.015	30	500		D2198	0.3181	0.3322	0.3322	28.2		28.63
35	0.0175	0.0175	35	500	17.5	D2199	0.3283	0.3449	0.3448	33		33.23
40	0.02	0.0198	39.6	500	20	D2200	0.3161	0.3339	0.3337	35.2		37.36
45	0.0225	0.0227	45.4	500	22.5	D2101	0.3158	0.3365	0.3365	41.4		46.28
50	0.025	0.025	50	200	10	D2178	0.3187	0.3278	0.3274	43.5	0.12195	37.32
50 dup	0.025	0.025	50	200		D2179	0.3189	0.327	0.3266	38.5		45.15
55	0.0275	0.0275	55	200	11	D2180	0.3177	0.3266	0.3263	43		45.28
60	0.03	0.0302	60.4	200	12	D2181	0.3204	0.3301	0.3299	47.5		52.01
65	0.0325	0.0325	65	200	13	D2182	0.3161	0.3268	0.3264	51.5		53.22
70	0.035	0.0351	70.2	200	14	D2183	0.3189	0.3307	0.3307	59		58.08
75	0.0375	0.0374	74.8	200	15	D2184	0.3171	0.3298	0.3295	62	0.04724	67.01
75 dup	0.0375	0.0374	74.8	200		D2185	0.3173	0.3308	0.3303	65		60.79
80	0.04	0.04	80	200	16	D2186	0.3167	0.3289	0.3285	59		62.05
85	0.0425	0.0425	85	100	8.5	D2170	0.3175	0.3245	0.3249	74		68.54
90	0.045	0.0449	89.8	100	9	D2171	0.3266	0.3337	0.3342	76		67.56
95	0.0475	0.0474	94.8	100	9.5	D2172	0.3265	0.3335	0.3332	67		74.55
100	0.05	0.0503	100.6	100	10	D2187	0.3202	0.3283	0.3282	80	0.08383	84.9
100 dup	0.05	0.0503	100.6	100		D2173	0.3289	0.3378	0.3376	87		83.2
105	0.0525	0.0528	105.6	100	10.5	D2152	0.323	0.331	0.3307	77		83.4
110	0.055	0.0555	111	100	11	D2153	0.3188	0.3266	0.3267	79		95.7
115	0.0575	0.0576	115.2	100	11.5	D2154	0.3278	0.3349	0.3348	70		92.6
120	0.06	0.0597	119.4	100	12	D2156	0.3177	0.3278	0.3281	104		99
125	0.0625	0.0629	125.8	100	12.5	D2157	0.3173	0.3282	0.3277	104		101.7
130	0.065	0.0647	129.4	100	13	D2158	0.3178	0.3284	0.3283	105		106.8
135	0.0675	0.0674	134.8	100	13.5	D2159	0.3179	0.3296	0.3294	115		102.9
140	0.07	0.0699	139.8	100	14	D2160	0.3258	0.3384	0.338	122		114.3
145	0.0725	0.0724	144.8	100	14.5	D2161	0.3167	0.328	0.328	113		118.6
150	0.075	0.0753	150.6	100	15	D2162	0.3174	0.3306	0.3306	132	0.09524	124.4
150 dup	0.075	0.0752	150.4	100		D2165	0.3173	0.3288	0.3293	120		126.5
155	0.0775	0.0774	154.8	100	15.5	D2163	0.3198	0.333	0.3329	131		139.6
160	0.08	0.0801	160.2	100	16	D2164	0.3175	0.3308	0.3304	129		131.9
165	0.0825	0.0824	164.8	100	16.5	D2155	0.3182	0.33	0.3301	119		133.3
170	0.085	0.0851	170.2	100	17	D2166	0.3167	0.3304	0.3304	137		143.2
175	0.0875	0.0873	174.6	100	17.5	D2167	0.3281	0.3434	0.3431	150		146.9
180	0.09	0.0902	180.4	100	18	D2168	0.327	0.3415	0.3414	144		159.3
185	0.0925	0.0925	185	100	18.5	D2169	0.3165	0.3296	0.3295	130		154.4
190	0.095	0.0954	190.8	100	19	D2174	0.3173	0.3326	0.3328	155		167.3
195	0.0975	0.0975	195	100	19.5	D2175	0.3195	0.3348	0.3353	158		164.8
200	0.1	0.0999	199.8	100	20	D2176	0.3186	0.334	0.3341	155	0.10398	168.3
200 dup	0.1	0.0999	199.8	100		D2177	0.3168	0.3338	0.334	172		166.1

By looking at both the Measured TSS and Measured Turbidity columns, correlations were able to be found between the two sets of values. In order to find the relationship between the two measured sets of data, the Measured TSS and Measured Turbidity values were plotted against each other. Figure 6 shows the graph comparing these two sets of values. The equation related to these data sets can be seen in blue text on the plot area of the graph. The R^2 value related to the line of best fit of this data is 0.978 and the equation is $y = 1.0348x$ which was used to help create the calculated sediment load equation as described in the above materials and methods section. This equation allowed for the turbidity data taken to be approximated as a TSS load, providing a simple method of sediment load estimation.

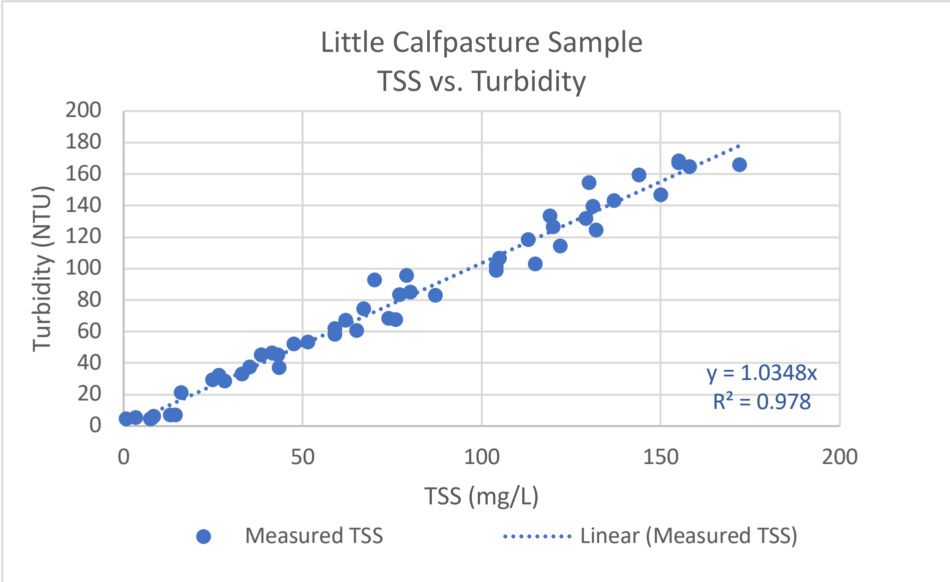

Figure 6: Little Calfpasture Sediment Mixture Calculated TSS vs. Measured Turbidity

Quality Assurance Results

In order to maintain quality data collection, a variety of quality assurance tests were performed on the monitoring equipment. As partially outlined in above sections, calculations on relative percent differences and relative standard deviations were used to filter out unreliable data. To ensure quality data was being collected, maintenance and calibrations were performed every two weeks in the late spring and summer months and once a month in the late fall and winter seasons. There were four main practices that these maintenance and calibration checks consisted of; these practices were pre-service precision tests, general maintenance/cleaning, instrument calibration, and post-service precision tests.

The pre-service and post-service tests primarily consisted of calculating the relative percent differences between the visual lake level and the pressure transducer as well as between turbidity measurements from the Clarivue turbidity sensor and a secondary sensor. Among the nine data points that are available for this period's tests, there were never any violations in the RPD criteria for the post-service precision tests. Additionally, the pre-service precision tests only had one instance of a test not meeting the RPD criteria. In this instance, proper standard operating procedures were followed and the data was examined accordingly; these standard operating procedures can be found in the appendix of this report.

The general maintenance practices were mainly composed of cleaning procedures for the equipment. Most primarily, the turbidity and pressure transducer sensors were cleaned of all sediment buildup and bioaccumulation to ensure that they could continue taking reliable data. The calibration that was performed was done so using the Clarivue turbidity probe and standard solutions. After the pre-service tests and general maintenance, the probe was used to test two solutions, one of deionized water (approximately 0 NTU) and one 400 NTU solution. In order for the probe to be redeployed, the measured turbidities had to be +/-2 NTU of 0 for the deionized water and +/-20 NTU of 400 for the 400 NTU solution. Throughout all the tests performed, the probe never failed to meet these criteria.

Overall Trends

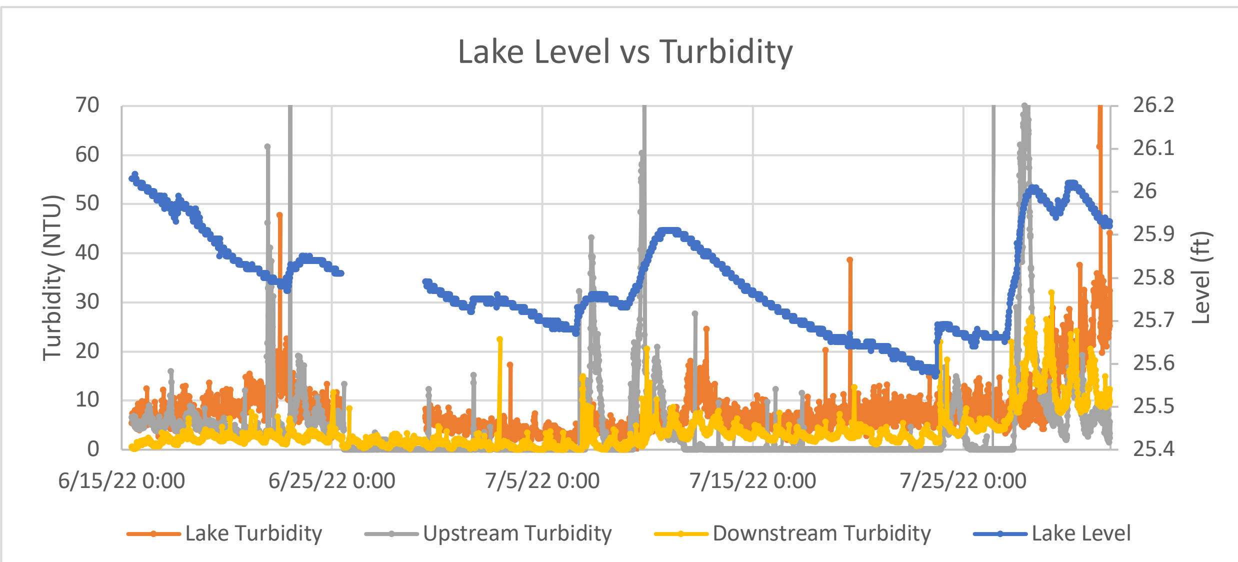

Figure 7: Lake Level and Full Data on Full Stream Turbidity

The above figure depicts data taken from the Lake Merriweather testing station as well as the turbidity data collected by the temporary YSI probes that were deployed over the summer of 2022. By plotting all of this data on a single graph, more complete assumptions are able to be drawn and larger, stream wide trends are able to be seen. Within this dataset, one of the most prominent patterns depicted is the relationship between turbidity and lake level data. This project is centered on the employment of proper management strategies based around the premise that a relationship exists between the lake and turbidity values. The peaks of this graph are able to highlight some of this relationship by showing the correlation between the spikes in turbidity and lake level. While the data sets do not match completely, may similarities can be seen in the timing of high levels of turbidity and high lake levels. These spikes are likely due to precipitation events that both cause an influx of water, which raises the lake level, as well as an increase in sediments being carried down the Little Calfpasture River. Below sections will further discuss the relationship that is seen between sediment loads, flow, turbidity, and the lake, however, Figure 7 does an adequate job at depicting some of the simpler correlations that exist between these data sets.

Moreover, one of the main trends that is seen in this data is the tendency for turbidity to be higher downstream of Lake Merriweather rather than upstream. Further analysis of this figure also shows that the turbidity within the lake is also typically higher than the upstream Little Calfpasture turbidity values. This is primarily significant when paired with the fact that this data was collected over the drier summer months of the year when there weren't many large storm events. Despite the lack of frequent large precipitation events, these months still depict steady baseline levels of turbidity both within the lake and below it that are above 0 NTU. This presence of solids is likely not all sediment since there are very little events that would consistently deposit and discharge sediments through the lake in these months.

One explanation for these higher baseline turbidities in Lake Merriweather and the lower reach of the Little Calfpasture River is that solids are being generated within the river and lake systems. Due to the sheer size of Lake Merriweather in comparison to the Little Calfpasture as well as the lack of large storm events forcing high discharge, the lake is able to act as a reservoir for a variety of nutrients that are deposited in it. Additionally, the summer months contribute a plethora of sunlight into the aquatic ecosystems of the lake. This combination of available sunlight and nutrients can often cause higher levels of algae growth within the aquatic community. It is likely that this blend of conditions caused by the drier summer months in the Goshen area is causing an increase in lake algae and subsequent biosolids. The increased presence of biosolids within the lake environment would cause a decrease in clarity and a rise in turbidity as the equipment measures this effect. This is likely the cause for a lake turbidity in the summer that is higher than the upstream turbidity. Furthermore, the lake discharges its water containing biosolids into the lower reach of the Little Calfpasture River which would cause the downstream turbidity data to also be higher than the upstream observations.

Monthly Turbidity Data

Data was gathered from the Lake Merriweather testing station monthly and was formatted and analyzed accordingly. This gives an accurate view of how the water quality conditions vary both monthly and as lake management practices change throughout the seasons. Data collection began in the middle of May 2022 and has run consistently since then through the present time of mid-November. In addition to the monthly data that was collected, the temporary YSI probes that were deployed collected around a month and a half of data from mid-June through July.

Despite the data collection time frame being more limited for the month of May, this month still had some of the most variation in data out of all of the months so far. The wide range of turbidity values seen in the month of May is likely seen due to the weather patterns in this time of year. Often times spring months receive more rainfall than summer and fall months which leads to increased flow events in river. As described in above sections, these events can cause increased sediment deposition rates within waterbodies. Precipitation data is limited in the Goshen area due to a lack of monitoring stations in close proximity to the Little Calfpasture River. In order to best view the effects that increased flow has on turbidity, the equation used for sediment load calculation was modified to instead estimate Little Calfpasture flow. Figure 8 below shows a graph generated from these calculations and represents flow in cubic feet per second (cfs) across the entire testing period.

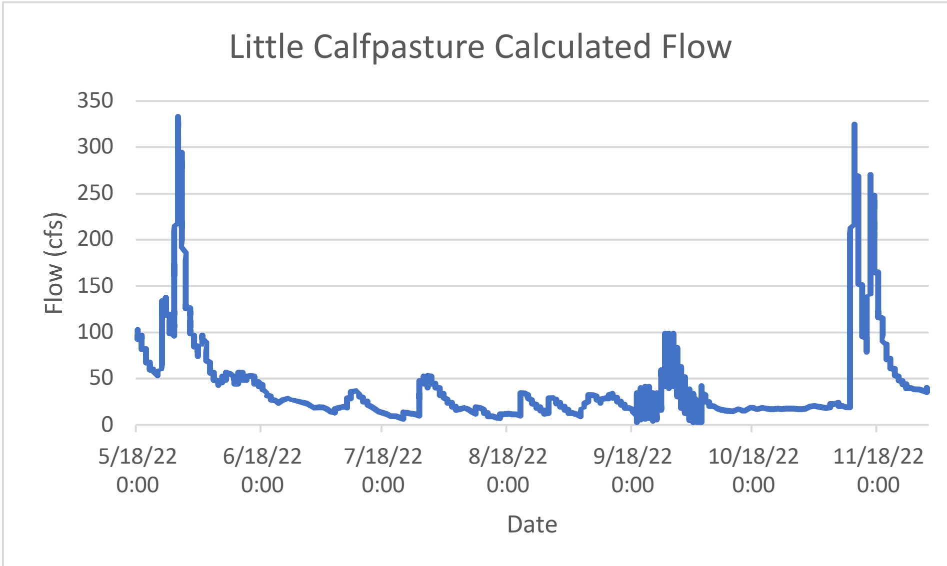

Figure 8: Little Calfpasture River Calculated Flow Data

As seen in the above figure, the month of May had some of the highest flows of the past six and a half months. These higher flow rates are almost certainly due to high levels of precipitation in the Rockbridge/Augusta County area at the time. The effects of this on lake turbidity and level can be seen on Lake Merriweather in the monthly May graph generated by the installed testing station data. Table 4 below shows a report on different components of the median turbidity data found for each month. This table can be referred to for all of the following monthly graphs shown within this section. Here, the minimum, maximum, average, and median turbidities are reported as well as the standard deviation of each monthly dataset.

Table 4: Parameters of Monthly Median Turbidity Data

	Min Turbidity	Max Turbidity	Average Turbidity	Median Turbidity	Standard Deviation
May Median Data	5.06	82.40	22.44	12.45	18.56
June Median Data	2.40	131.80	32.55	32.48	25.51
July Median Data	0.89	157.00	7.90	6.19	7.07
August Median Data	0.00	406.30	20.23	18.31	10.30
September Median Data	10.65	342.80	25.78	23.05	15.17
October Median Data	3.41	108.40	22.64	21.82	8.43
November Median Data	6.01	175.30	27.35	24.62	13.48

Figure 9 below shows a graph of the median turbidity and lake level across the May testing period.

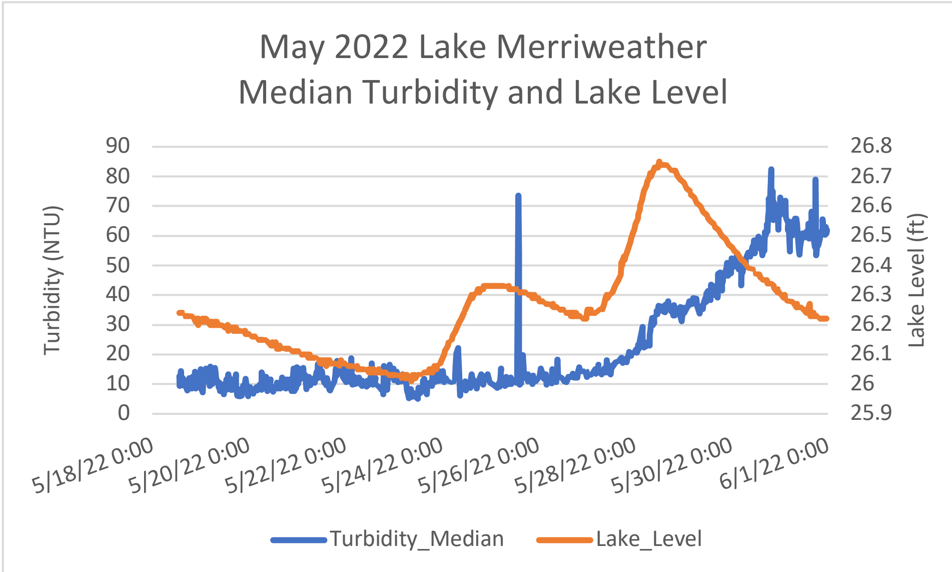

Figure 9: Graph of Median Turbidity and Lake Merriweather Level in May 2022

As seen in the above figure, the level of Lake Merriweather began to rise sometime around May 24th for the first time before rising significantly again around May 28th. During this time period, a rise in lake turbidity can also be seen with values reaching just above 80 NTU; this is likely due to the increased flow into the lake. This month had one large storm event that was captured near the end of the month. This storm event lasted approximately the last three days of May and caused the maximum monthly turbidity. It had a peak discharge of approximately 332 cfs. The minimum turbidity for the month of May was 5.06 NTU which is representative of water with high clarity and veery little suspended solids. The average median turbidity measured by the sensors over the entire testing period of May was 22.44 NTU which is representative of a relatively average value when compared to other months. The standard deviation of this month's median turbidity, however, is 18.56 NTU which is representative of a very variable and data set when compared to such a relatively low average.

In reference to Figure 8 again, the month of June can be seen to have less severe high flow events than May as the peak slowly declines as the month progresses. Additionally, the maximum occurred in the first half of the month and was likely residual effects from the same high flow even that affected the May data. In total, there were two main high flow events, one in the beginning of the month and another in the middle. Figure 10 below shows the median turbidity and lake level graph of the month of June where a decline in both turbidity and level can be seen after the first half of the month. Near the middle of the month some significant variation in turbidity and lake level can be seen which is indicative of another small storm or other event in the area. It should be noted that there is a gap in the data near the end of the month that is due to the removal of a period of data from a calibration error during a maintenance check, however, the last half of the month does remain steadily low otherwise.

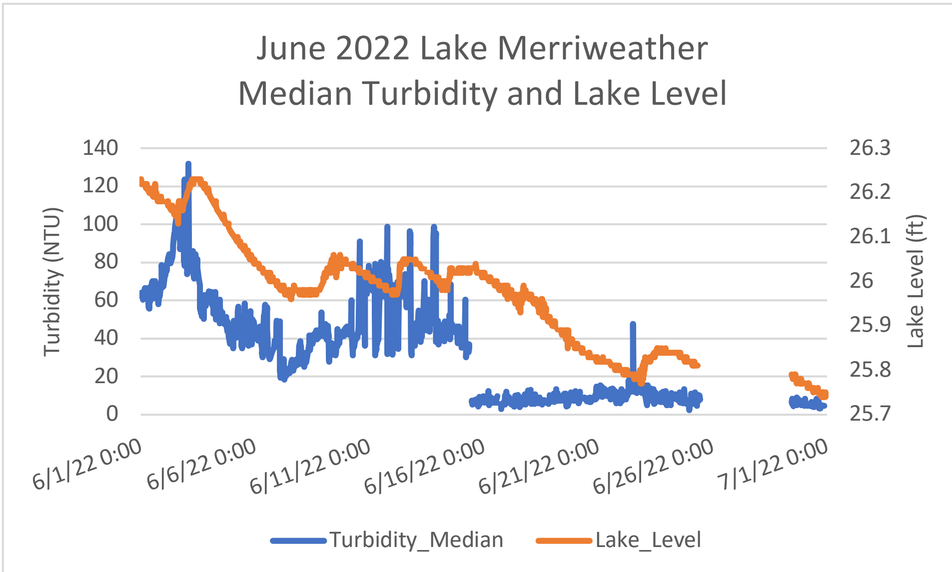

Figure 10: Graph of Median Turbidity and Lake Merriweather Level in June 2022

The minimum and maximum turbidities for the month of June were 2.4 and 131.8 NTU respectively and are again indicative of a month with a wide range of variation. The average median turbidity found was 32.55 NTU and there was a standard deviation of 25.51 NTU. Much like the month of May, this data shows a very volatile month with significant changes in overall lake conditions.

In addition to the data collected at the Lake Merriweather station, June also marked the beginning of data collection with the YSI probes at both the upstream and downstream locations along the Little Calfpasture River. Figure 11 shows the lake level and turbidity data from the Lake Merriweather plotted alongside the turbidity data gathered by the upstream and downstream YSI probes. Within this figure, slight delays can be seen in turbidity across the stream. Near the middle of the graph around the 21st, a spike can be seen in the upstream turbidity, just after this, a spike is seen in the turbidity measured at the lake location. This delay likely represents the travel time of sediment downstream due to a storm event. One consistent trend that is not speculatory, however, is the hierarchy of turbidity values seen in the graph.

During dry periods, the lake turbidity has often been found to be the highest of the three, followed by the downstream turbidity and upstream turbidity. This trend supports the idea that the lake is acting as a depositional area or catchment for sediments as they move throughout the Little Calfpasture River channel. During storm events, the turbidity is typically highest upstream, then in the lake, then downstream, showing the depositional patterns of sediment within the lake. The upstream probe was found to have an average turbidity of 3.89 NTU while the downstream probe had an average of 1.93 NTU.

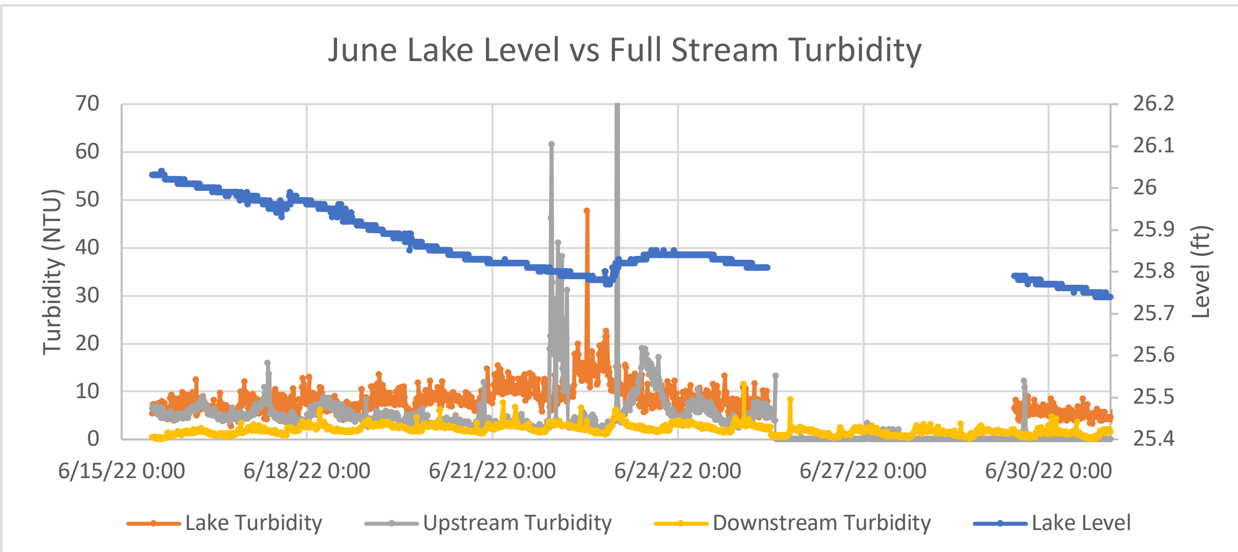

Figure 11: June Lake Level and Full Stream Turbidity

According to the trends seen in Figure 8, the month of July had significantly less high flow events in the Goshen area than May and June. The end of the month experienced one medium sized event which had a maximum flow of 52 cfs and a maximum turbidity of 157 NTU. Figure 12 below shows the monthly July graph of lake level and turbidity. The average turbidity of this month is significantly lower than the previous at just 6.06 NTU, however, there was still a monthly maximum of 157 NTU during the storm event. The standard deviation of the median turbidities for this month was just 2.63 NTU and the minimum median turbidity for the month of July was 0.892 NTU.

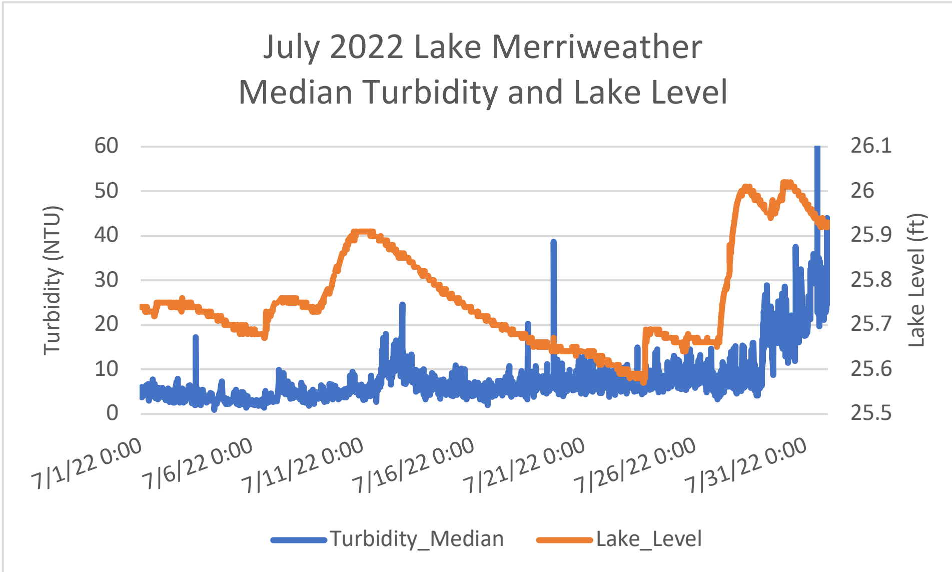

Figure 12: Graph of Median Turbidity and Lake Merriweather Level in July 2022

Figure 13, seen below, shows the graph of the Lake Merriweather data along with the YSI gathered data for July. Here, the lake turbidity is still consistently higher than the other two, however, the downstream turbidity is typically higher than the upstream turbidity throughout the majority of the month. This supports the idea that sediments are accumulated within the lake and further deposited downstream from there. The upstream turbidity typically still has higher spikes than the rest and relationships can be seen between the upstream turbidity spikes and the reactions of other data sets. The average upstream turbidity value is 4.15 NTU while the average downstream turbidity is 4.72 NTU.

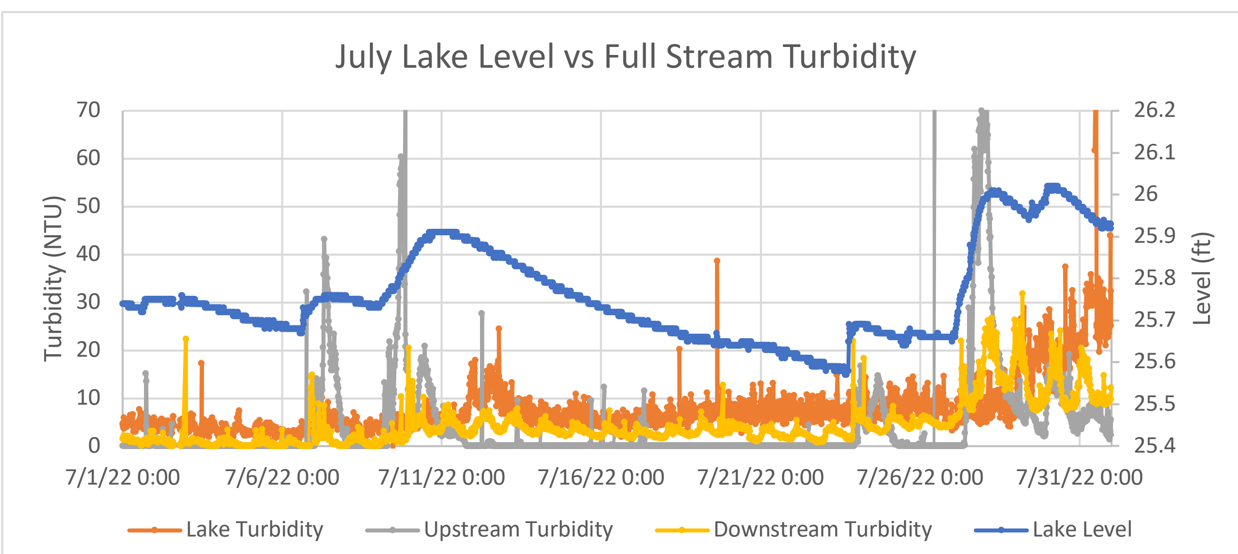

Figure 13: July Lake Level and Full Stream Turbidity

Figure 14 below shows the Lake Merriweather station data for the month of August. As expected from the trends in Figure 8, there is very little variation in turbidity values for the majority of the month with only a few events causing any significant deviation. Specifically, there appeared to be one larger storm event near the later half of August that had a maximum discharge of 32 cfs and a maximum turbidity of 406.3 NTU. The average median turbidity of this location for the month of August was 20.15 NTU with a standard deviation of 11.09 NTU. The minimum median turbidity for August was 0 NTU while the maximum median turbidity was 406.3 NTU from the storm event. The end of July also brought the completion of the YSI testing period so the next four months (August, September, October, November) will not include upstream or downstream data.

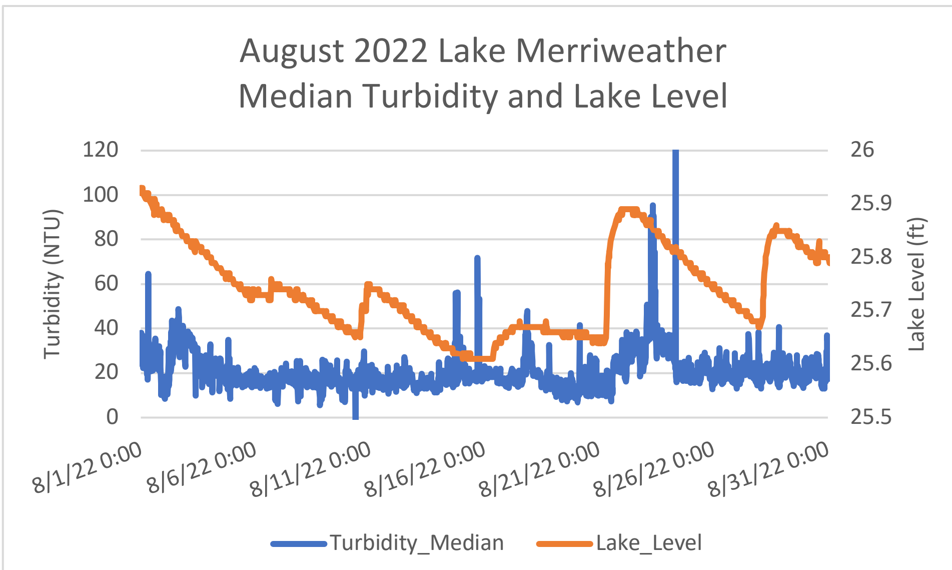

Figure 14: Graph of Median Turbidity and Lake Merriweather Level in August 2022

September experienced one large storm event in the middle of the month which had multiple peaks, the largest of which reached 342.8 NTU. Additionally, the peak flow of this event was 41 cfs. The average median turbidity for the month of September was 25.57 NTU and there was a standard deviation of 15.26 NTU. The graph showing lake level and turbidity can be found below labeled as Figure 15. September was notable for the significant decrease in lake level as the gates were lowered for the usual winter maintenance and debris removal that typically takes place in Lake Merriweather at this time of year. In Figure 15 the steady decrease of the lake level can be seen as it drops from nearly 26ft to almost 20ft. Additionally, while there aren't many long lasting variations in the data, September is marked with some very high peaks in turbidity throughout the month. The maximum median turbidity of the month was 342.8 NTU from the storm event, and the minimum median turbidity was 10.65 NTU.

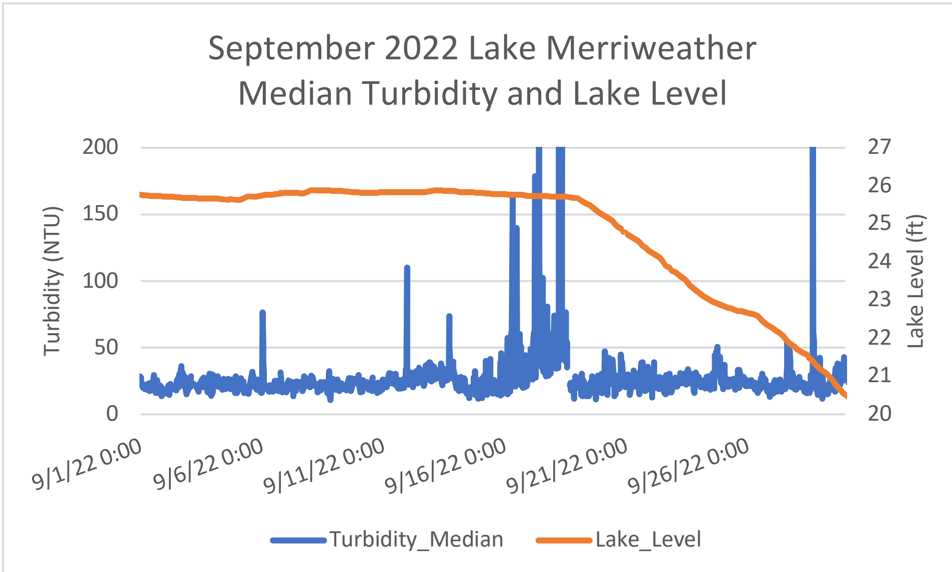

Figure 15: Graph of Median Turbidity and Lake Merriweather Level in September 2022

Figure 8 shows very low and stable data points in terms of the flow for October. Figure 16 below shows the lake level and median turbidity graph from the Lake Merriweather station for this month. Here, an even greater decrease in lake level can be seen as the lake is dropped down to around 17ft where it stays for the winter season. The first half of October is marked with some small variation in turbidity, however, there are no extreme peaks as have been seen in earlier months so there were likely no real significant high flow events. The average median turbidity measured for this month was 23.72 NTU and there was a standard deviation of 8.71 NTU. October had a maximum median turbidity value of 108.4 NTU and a minimum of 3.41 NTU.

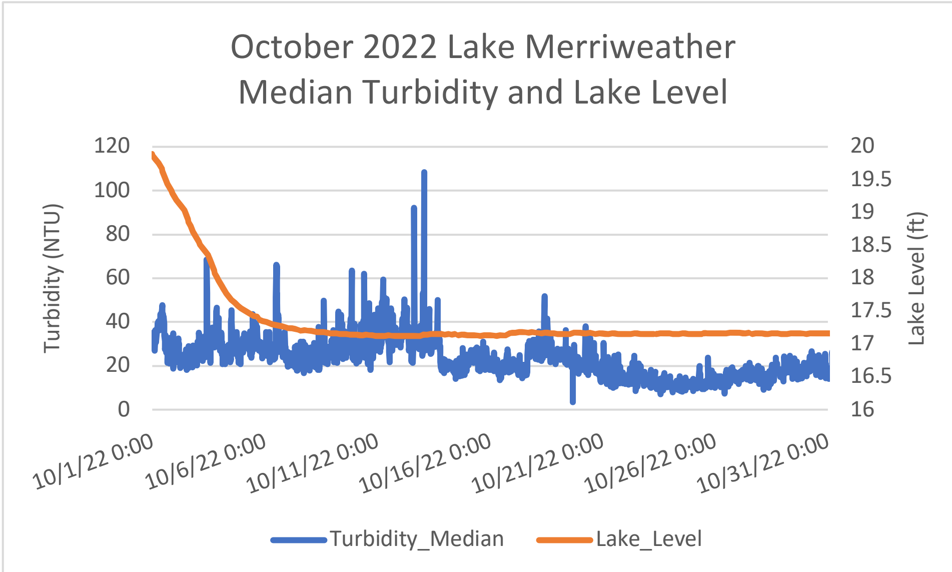

Figure 16: Graph of Median Turbidity and Lake Merriweather Level in October 2022

By referring to Figure 8 again, it can be seen that the month of November had some of the highest peaks in flow as well as high volatility in the range of flow. These high flow events near the middle of the month are representative of high amounts of precipitation, and their effect on lake conditions can be seen in Figure 17 below. The event in the middle of November caused a maximum discharge of 326 cfs and had a high turbidity of 86.3 NTU. The average median turbidity seen in November was 27.35 NTU with a standard deviation of 13.48 NTU. This month had a maximum median turbidity value of 175.3 NTU and a minimum of 6.01 NTU.

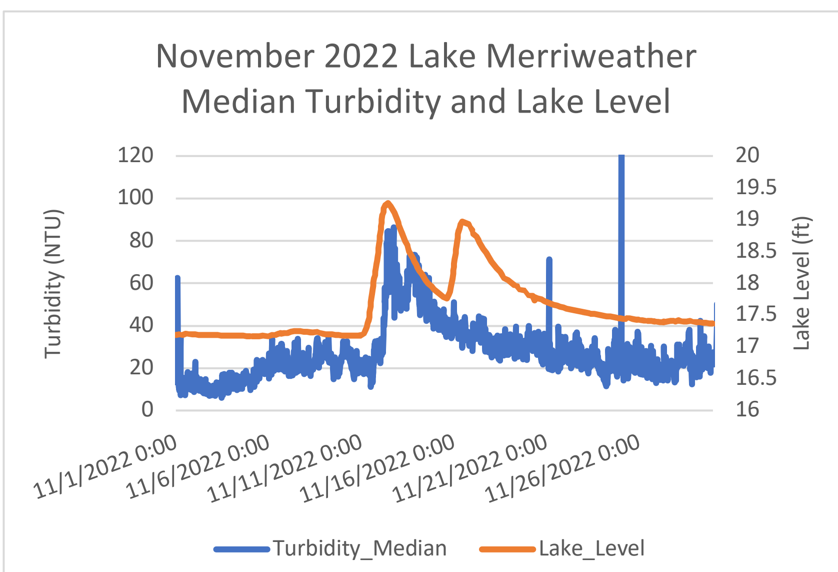

Figure 17: Graph of Median Turbidity and Lake Merriweather Level in November 2022

Sediment Loads

In order to get a better understanding of how the measured turbidity of Lake Merriweather directly affects the sediment loads being discharged into the Little Calfpasture River, load estimates were made for each turbidity datapoint and added together to give an estimate of the overall monthly sediment load being deposited downstream from the lake. Figure 18 below shows the calculated sediment load data for the months of May through November.

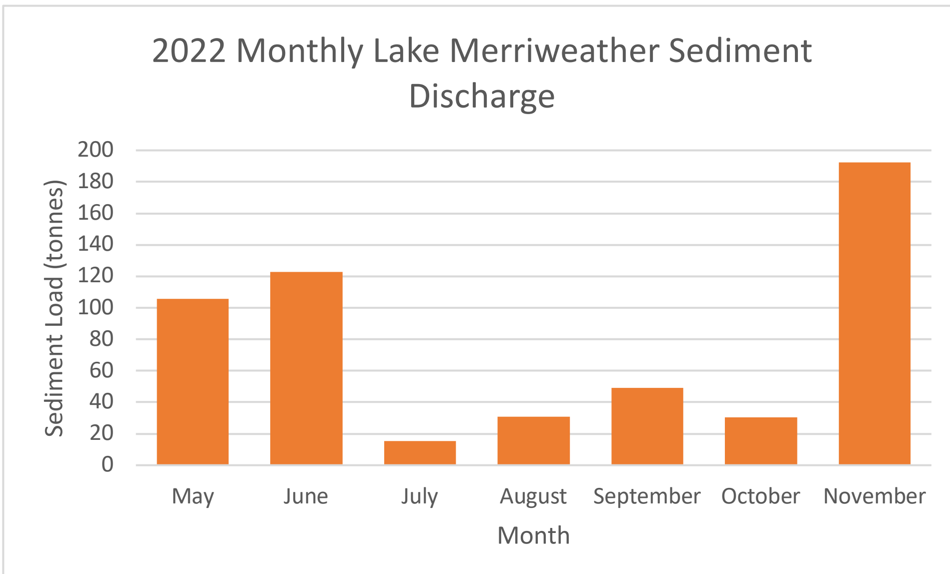

Figure 18: Monthly Comparison of Lake Merriweather Sediment Discharges in 2022

For the partial month of May that there was data collection for, the total sediment load discharged into the impaired reach of the Little Calfpasture River was 105.67 metric tonnes. For the full month of June there was a total of 122.59 tonnes discharged downstream. In July, a total of 15.24 tonnes of sediment were discharged downstream. In the month of August, 30.73 tonnes were deposited. In September, the number jumped back up to 49.24 tonnes of sediment. In October, there was only 30.39 metric tonnes discharged into the Little Calfpasture River. November ultimately had the highest level of discharge over this collection period with 192.26 tonnes of sediment discharged into the impaired reach of the Little Calfpasture River. Table 5 below further displays these values along with data on monthly average flows and median turbidities.

Table 5: Monthly Sediment, Flow, and Turbidity Data

Month	Sediment Load	Average Flow	Median Turbidity
May	105.66	123.24	12.45
June	122.59	48.56	32.48
July	15.24	21.54	6.19
August	30.73	18.89	18.31
September	49.24	27.21	23.05
October	30.39	18.10	21.82
November	192.26	73.83	24.62

In total, these roughly six and a half months saw 545.45 metric tonnes be discharged from Lake Merriweather over the dam and into the impaired reach of the Little Calfpasture River. As discussed in the above sections of this document, the TMDL report set the maximum yearly sediment load for the Little Calfpasture River to be 1138 tonnes per year for the reach to maintain water quality standards for the support of aquatic life (VDEQ, 2010). Figure 19 expresses the monthly sediment discharge data in relation to this TMDL limit of 1138 tonnes, represented by the red dashed line on the chart. Here, it can be seen that the total amount of sediment discharged between the months of May and November in 2022 make up around half of the allowed sediment in the Little Calfpasture. More specifically, these six and a half months discharged approximately 48% of the 1138 tonne limit. When this percentage is looked at in relation to the time frame, these discharge values do not seem extremely threatening to the TMDL limit. In terms of the ratio of discharged sediment to length of time, this data seems promising since the amount of sediment discharged hasn't reached half the allowed yearly amount in these six and a half months. This way of thinking, however, cannot be used when analyzing these results. Only further monitoring will determine how closely the 2022-2023 season compares to the TMDL limit.

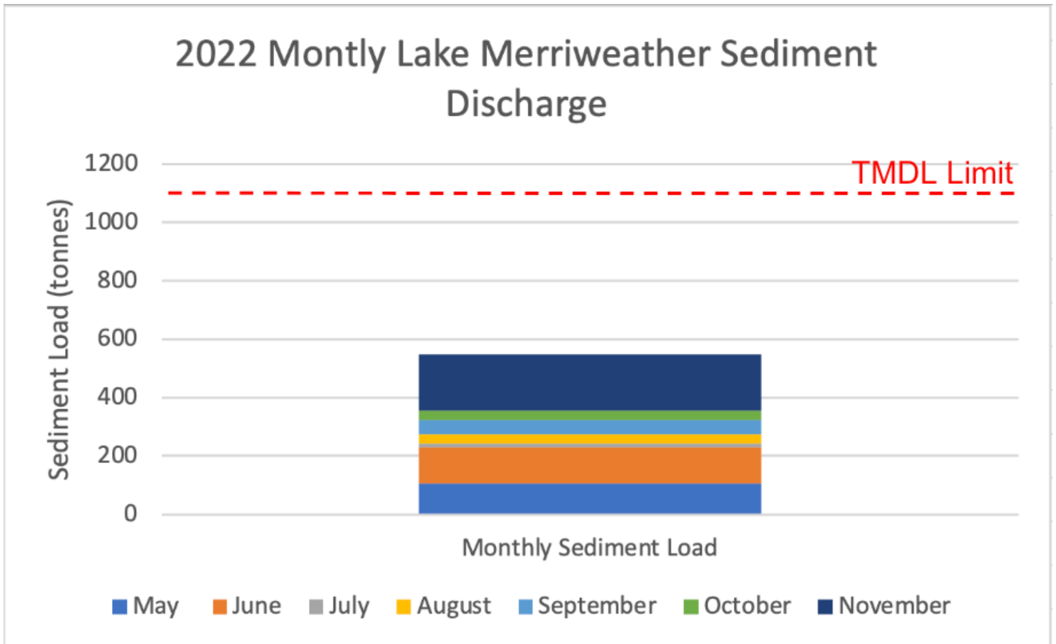

Figure 19: Stacked Bar Graph of 2022 Monthly Sediment Discharges in Comparison to the TMDL Sediment Limit

Storm Events

To better understand the dynamics of how different weather patterns and natural forces affect the movement of sediment throughout the Little Calfpasture River channel, data from certain high flow events in the area were isolated to be viewed more closely. Figure 20 shows a graph of the calculated flow of and sediment discharge into the Little Calfpasture River over the 6 and a half month testing period. This figure outlines the relationship that exists between these two parameters. Since these two values are derived from the same basic equation for flow over a weir, there are naturally correlations in the data. The addition of turbidity inputs into the sediment discharge equation primarily accounts for discrepancies between the two data sets.

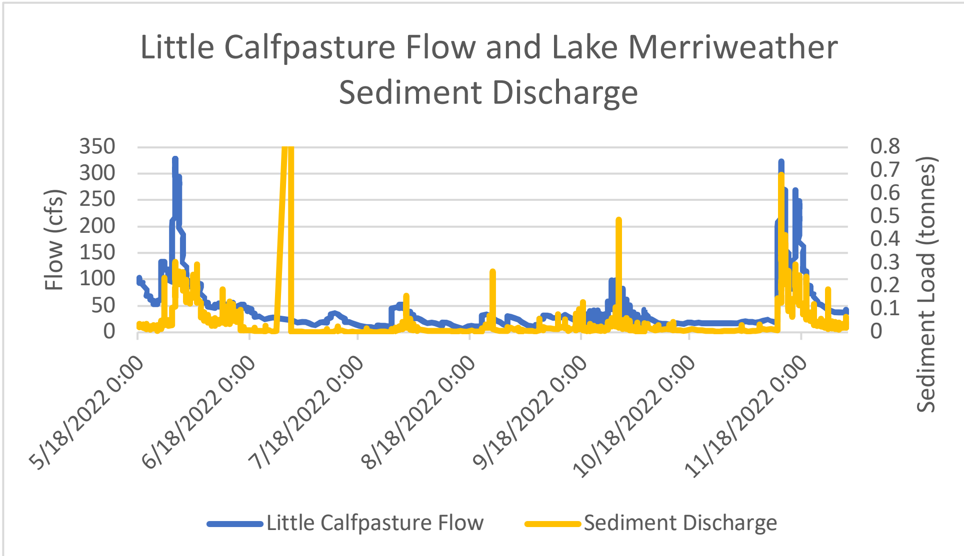

Figure 20: Little Calfpasture Flow and Sediment Discharge

Using the above figure, high points in flow and sediment were able to be more easily identified so that the Lake Merriweather data surrounding the time periods of these peaks could be extracted. Figure 21 below shows graphs of turbidity and sediment discharge over these four high flow events from the past six and a half months.

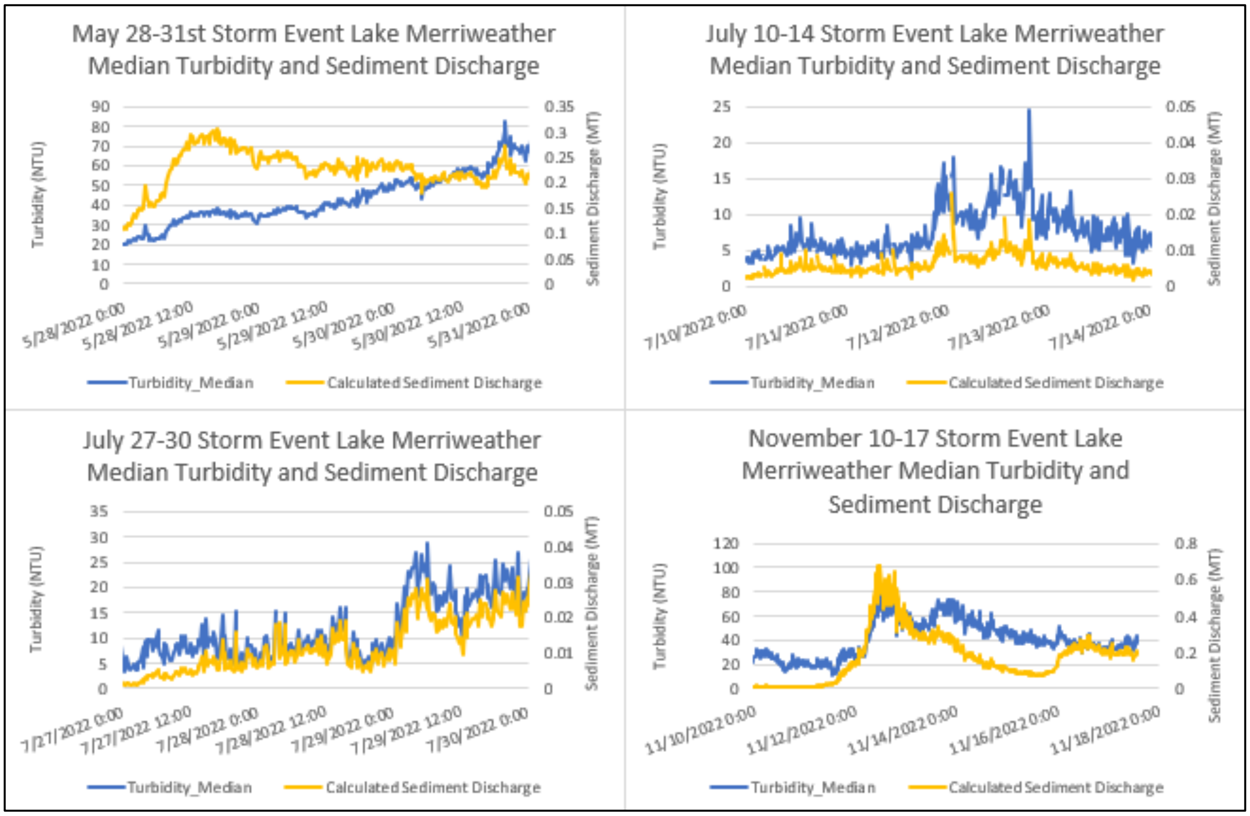

Figure 21: Turbidity and Sediment Load Graphs of Four Separate Storm Events

Using the peaks in turbidity and sediment discharge in these graphs, the four different storm events were able to be more closely analyzed. Each event is representative of different conditions. There are two mild summer storms and two heavier flow storms. Within these scenarios, patterns and conditions are able to be related to find more defined trends.

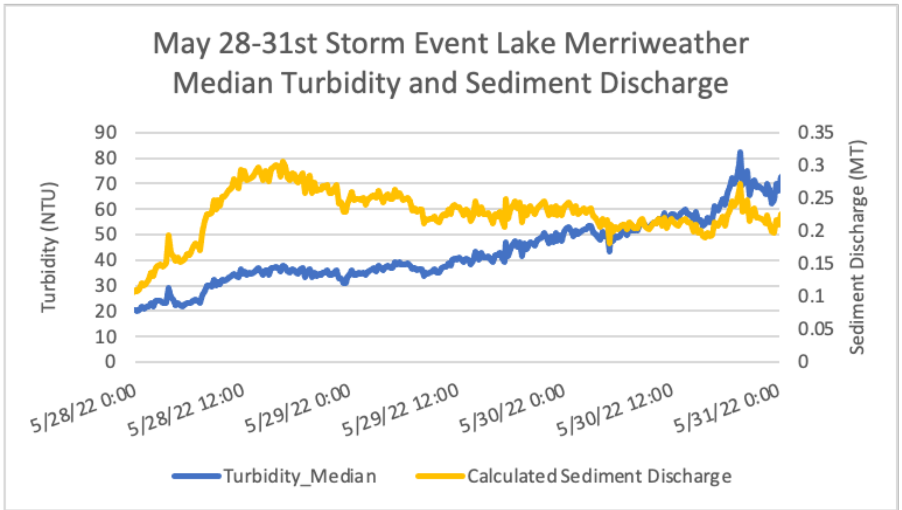

Figure 22: May 28-31 Storm Event Turbidity and Sediment Discharge

The first significant high flow event of the 2022 testing period occurred between approximately May 28th and May 31st and can be seen in the top left graph of Figure 21 and more closely in Figure 22. Within this figure, simple correlations can be seen in between the turbidity and sediment load data. There was an average flow of 231.19 cfs over this period of time with a high of 332.77 cfs. The turbidity rose steadily throughout this event which could be due to multiple reasons. One theory for this rise in turbidity could be that it is caused by an accumulation of sediments as they are deposited in the lake from the storm. The average turbidity during this event was 42.94 NTU with a high of 82.4 NTU. The sediment discharge over this time period rose quickly but evened out more as the event continued. The total amount of sediments discharged during this event was 65.48 tonnes over the three day period. When compared to the 105.66 tonnes discharged over the entirety of the May collection period, it can be calculated that this single storm event was responsible for 61.97% of May's total sediment discharge into the Little Calfpasture River.

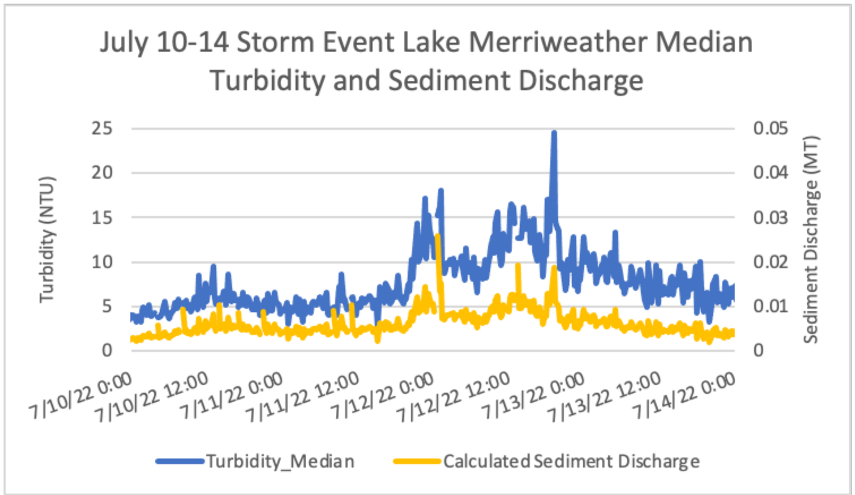

Figure 23: July 10-14 Storm Event Turbidity and Sediment Discharge

The next significant high flow event of the 2022 in July, approximately between July 10th and July 14th and can be seen in Figure 23. While this event was not nearly as severe as the May storm event, there were significant peaks in turbidity and discharge. This time period was looked at due to its exemplification of how a mild summer storm might affect sediment dynamics in the river. There was an average flow of 32.25 cfs over this period of time with a high of 36.93 cfs. The turbidity was slightly volatile and had multiple peaks throughout the high flow event. The average turbidity during this event was 7.73 NTU with a high of 24.53 NTU. The sediment discharge over this time period also showed just a few peaks with a mild ups and downs otherwise. The total amount of sediments discharged during this event was 2.33 tonnes over the four day period. When compared to the 15.24 tonnes discharged over the entirety of the July collection period, it can be calculated that this single storm event was responsible for 15.3% of July's total sediment discharge into the Little Calfpasture River.

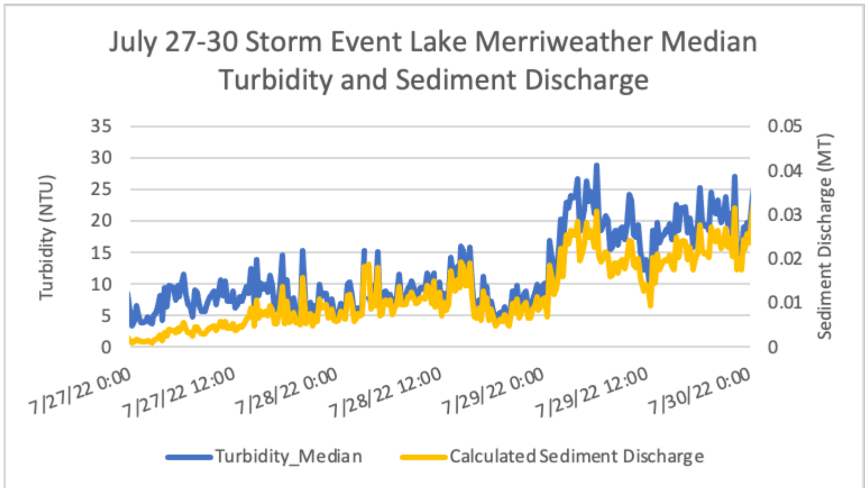

Figure 24: July 27-30 Storm Event Turbidity and Sediment Discharge

Another mild storm event also took place in July, between approximately July 27th and July 30th. This graph can be seen above in Figure 24. Much like the other July storm event, this event was not nearly as severe as the May incident, however, there was a significant rise in both turbidity and discharge throughout the period. There was an average flow of 39.78 cfs over this period of time with a high of 52.82 cfs. The turbidity rose semi-steadily throughout the high flow event with slight dips and variations. The average turbidity during this event was 11.61 NTU with a high of 28.87 NTU. The sediment discharge over this time period acted just as the turbidity data. The total amount of sediments discharged during this event was 3.42 tonnes over the three day period. When compared to the 15.24 tonnes discharged over the entirety of the July collection period, it can be calculated that this single storm event was responsible for 22.46% of July's total sediment discharge into the Little Calfpasture River. Between the two July storm events, they contributed 37.76% to the month's total sediment load.

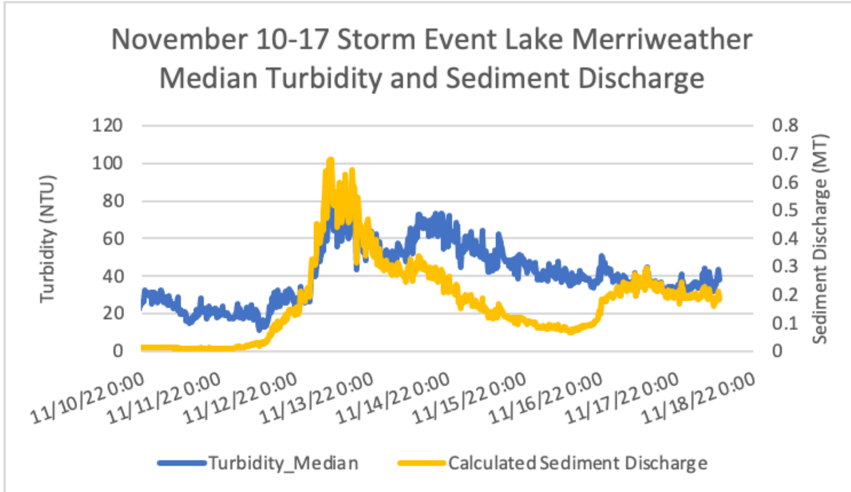

Figure 25: November 10-17 Storm Event Turbidity and Sediment Discharge

According to Figure 18 in the Sediment Loads section above, the month of November contributed the most sediments to the Little Calfpasture throughout the entire testing period. The most significant high flow event of the 2022 testing period occurred between approximately November 10^{th} and November 17^{th} and can be seen above in Figure 25. There was an average flow of 157.25 cfs over this period of time with a high of 326.26 cfs. This event contained a more gradual climb and decline of turbidity over the time period. The sediment discharge, however, exhibited a more intense rise and fall but also deviated from the turbidity trend more towards the end of the event. The average turbidity during this event was 39.58 NTU with a high of 86.3 NTU. The total amount of sediments discharged during this event was 136.01 tonnes over the seven day period. When compared to the 192.26 tonnes discharged over the entirety of the November collection period, it can be calculated that this single storm event was responsible for 70.74% of November's total sediment discharge into the Little Calfpasture River.

It is only natural for an event that lasts longer, such as the November storm event, to take up a larger percentage of the month's total discharge. This being said, it is easy to understand why November would have the greatest sediment discharge load out of the four storm events. Between the two largest storm events analyzed, May and November, May had a larger average flow, maximum flow, average turbidity, and average sediment load discharge. Despite this, the November storm event still discharged more total sediment and its sediment load took up more of a percentage of the total month discharge than May. While this is partially due to the differences in length between the two storm events, it is also likely lake management practices also played a part in the significance of the storms' impacts.

During the May precipitation incident, the level of Lake Merriweather was around 26.5 ft while the November storm took place when the lake was lowered down to around 18 ft. While the total sediment load was influenced by the time period of each event, the presence of exposed lake banks was likely a significant factor in the deposition and discharge of sediments in November. Even if the time periods are altered to be more comparable, the November event still displays a higher total discharge load despite having lower average flow. Table 6 shows a simple comparison chart between the sediment discharges and average flows of the May storm and the shortened November storm.

Table 6: May and November 3 Day Storm Comparison Table

	Total Sediment Load (tonnes)	Average Flow (cfs)
May 3 Day Storm	65.48	231.19
Nov 3 Day Storm	83.51	207.18

Furthermore, Figure 26 below also shows a comparison of the three day May event beside the primary three days of the November storm event. Even with a timeline shortened to three days, these depictions still show the November storm discharged more sediment at 83 tonnes of sediment. When compared to the 65 tonnes that the May storm discharged, a significant discrepancy is seen. The primary difference between these two scenarios is the difference in lake level and subsequent lake bank exposure. It is likely that the November event experienced more downstream sediment deposition due to its increased exposure to banks eroding into Lake Merriweather. This comparison helps to highlight the importance of having a stabilized bank and depicts the ecological danger that can come from sustained high flow events in times of lake lowering. Put simply, a smaller storm during a period of low level can have more drastic effects on sediment deposition than a larger storm during a period of full pool.

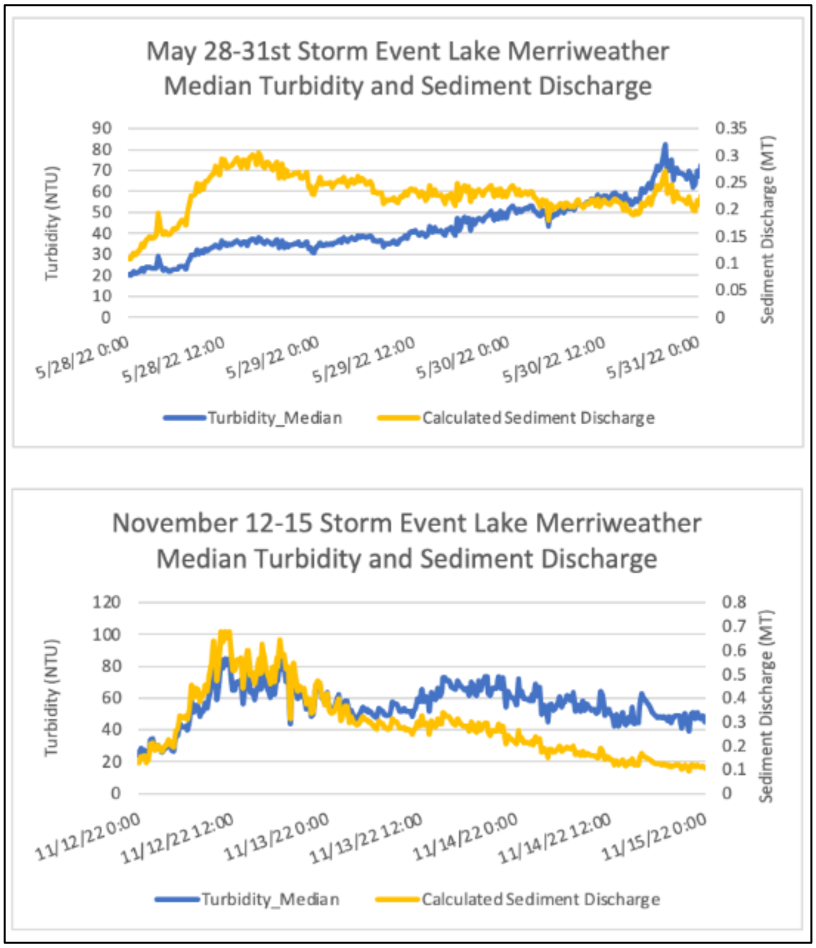

Figure 26: Comparison of May Storm Event with Shortened November Storm Event

As another comparison to the effects of rainfall seen in November during a time of lake lowering, the month of June can be looked at. The entire month of June had an average turbidity of 32.58 NTU, just below the November event's average of 39.58 NTU. Throughout the entire month of June, there was a total sediment discharge of 122.59 tonnes in comparison to the November event's total discharge of 136.01 tonnes. These values further go on to depict the relationship that lake management can have in the discharge of sediments downstream. Despite the month of June having a comparable average turbidity to the November event and a significantly longer time period of discharge, the seven day precipitation event in November still had higher levels of discharge. Again, the main difference between these two scenarios is the lake level. During the November time period, there were significantly more exposed banks and little stabilization along them to prevent erosion into the lake. From these scenarios, it seems that lowered lake levels are likely a large factor in the presence of sediments in the Little Calfpasture River.

This further proves to be a threat to the outlook of meeting the TMDL limit of 1138 tonnes of sediment in the Little Calfpasture River. The 136.01 tonnes of sediment that was discharged in the November storm event made up approximately 12% of the total TMDL sediment allowance. Similar events in the latter half of the year could prove detrimental to the TMDL goal if the lake level is still lowered. Additionally, the precipitation patterns of the area seem to point towards potentially more storm events within the period of lowered lake levels. Figure 27 below shows historical monthly average precipitation data in Lexington, Virginia (US Climate Data, 2022). Additionally, there are two red text markers on the graph that indicate typical times of lake raising and lowering for Lake Merriweather.

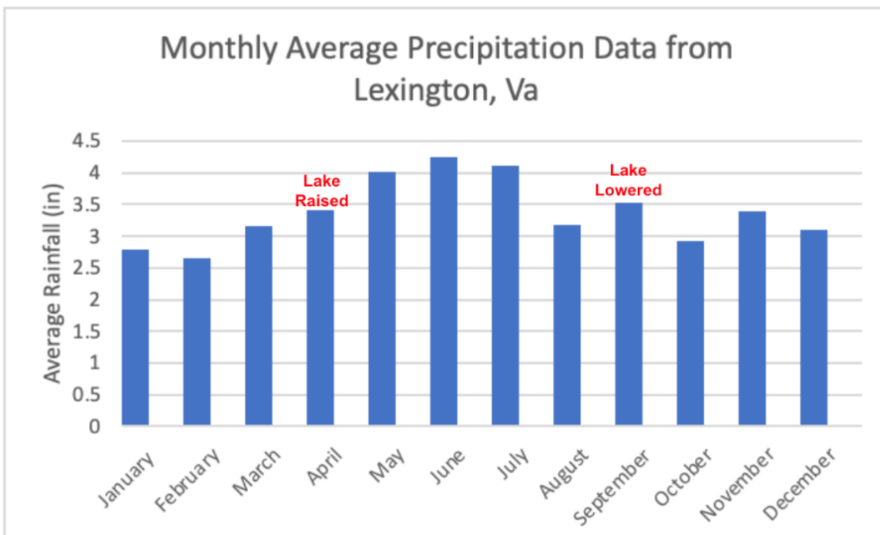

Figure 27: Monthly Average Precipitation (US Climate Data, 2022) and Common Lake Drawdown Times

Primarily, this graph shows the high potential that there will be further precipitation events to occur during the period of lake drawdown this season. According to the data presented on this graph, the season of high rain will typically fall between the months of April and July, however, there is still a significant amount of precipitation that occurs outside of this season. As seen with the November storm event, precipitation during drawdown times is risky and can lead to unnecessary levels of sediment being discharged into the impaired section of the Little Calfpasture. Due to the uncertainty that surrounds precipitation and sediment discharge in the winter months, more monitoring is needed to definitively determine the risks of drawdown during these times.

Conclusion

Within the context of this project, it is important to note that the issue of an impairment due to excess sediment in the Little Calfpasture River is extremely complex. Within this problem, there are many competing considerations, conflicts of interests, and smaller technical and social issues that have arisen. This report marks the halfway point of JMU's association with this project and just scrapes the surface of examining the impairment issue. The root of this team's involvement in this problem stems from the contributions that lake management practices of Lake Merriweather have of the downstream aquatic life impairment. As stated by the DEQ's open TMDL on this river, however, there are many other contributing factors to this impairment aside from lake management. The Little Calfpasture River TMDL states that not only does there need to be a 34% reduction in sediment from lake management, but that a 56% sediment reduction must also come from the total watershed area (VDEQ, 2010). This latter reduction is well outside the scope of the problem statement for this project; however, it does add to the overall complexity of the issue. In order to meet the watershed reductions, a more social and less technical approach will likely need to be taken by agencies such as the DEQ and the Rockbridge County Conservation Council as they work with other upstream land owners to meet these reductions.

Moreover, within the scope of this project, there are also many social factors that must be considered. In moving forward with this project, future partners must be prepared to balance the delicate social interests of all involved parties. The Boy Scouts of America, Rockbridge County, the DGIF, DCR, and DEQ represent just some of the many stakeholders that have competing interests in how this issue is managed. While the technical data and analysis is intended to be the primary source of providing management recommendations for the lake's operations, it is likely that this will have to be supported by stakeholder decisions and interests as well.

In terms of the data found by this team thus far, certain correlations have been found between Lake Merriweather level and sediment discharge loads. Over the past six and a half months, patterns have been found between lake level, upstream turbidity, lake turbidity, and downstream turbidity. This data suggests that not only are there patterns in the hierarchy of stream measurements, but that the stream's ecological health is likely highly affected by the interaction of these factors. Combinations of lake levels and flow events have proven to have different effects on the sediment discharge observed over Goshen Dam. Over a half a year's worth of data has shown that the amount of sediment discharged into the impaired section of the Little Calfpasture is highly sensitive to a variety of factors. The volatility of the monthly loads discharged over this time period helps to highlight just how reliant the downstream ecology is on lake management practices.

While this project is still ongoing and another five and a half months of data collection and analysis is needed, it is important to look at the accomplishments that have been achieved so far. Three main objectives were outlined within the problem statement of this project. Specifically, these objectives were the installation, operation, and instruction of others in the use of remote monitoring equipment at the outlet of Lake Merriweather. Within the last six and a half months, there have been successes in all three of these goals. A permanent real time remote monitoring system was installed on the sidewall of Goshen Dam in April of 2022, the equipment at this station was operated through data collection and maintenance/calibration tests, and training resources were created for project partners in the form of standard operating procedures, quality assurance documents, and instructional videos. While no definitive claims were made on correlations from the data analysis of this station so far, certain tentative suggestions can be made. Data so far points to a relationship between lake drawdown and increased sediment discharge, therefore, it can be suggested that a smaller period of drawdown is adopted by Lake Merriweather dam managers. This smaller range of lowered lake level will likely decrease the risk of large sediment discharge events like the one seen during the November storm instance discussed in the results section above. Less risk of such events will likely lead to greater chance of keeping the Little Calfpasture River below the TMDL limit of 1138 tonnes of sediment per year.

Further Study and Recommendations

Despite seeing relationships in the data collected so far, further collection and analysis of results is necessary to make definitive claims about the relationships between lake management practices and downstream sediment loads. Primarily, the data on the comparison between the

May and November storm events from this collection period have suggested that there is a correlation between increased sediment loads and a decreased lake, however, more data and comparisons are necessary to corroborate this claim. In order to best use future data to back up these current suggestions, a similar analysis of general trends and storm events will likely need to be conducted. Additionally, it is difficult to make definitive predictions on how sediment data will compare to the limits set by the 2010 TMDL each year. It is only in the scope of JMU's partnership with this project to analyze the first year of data. In order to best view trends, however, an analysis of yearly loads in comparison to the TMDL limit will likely need to be performed for multiple years in a row by other project partners after JMU's release of the project.

Within the coming year, the primary analysis that should be done to build upon this report's findings is centered on the further analysis of how storms affect sediment loads during times of lake drawdown. The data from the 2022 summer provided a good baseline of sediment trends at full pool, however, the only real analysis that has been performed on sediments during drawdown comes from the November storm. The continued analysis of how high flow events affect sediment loads will be beneficial to making suggestions for future lake management practices. Ultimately, the goal of JMU's interaction with this project is to be able to definitively suggest how this tool can be used for lake management and to provide recommendations for practices based on the first year's data.

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Appendix

Standard Operating Procedures

Standard Operating Procedure (SOP)

for Field Use of Water Quality Probes at Lake Merriweather

JMU ISAT Environment Lab

1.0 APPLICABILITY

- 1.1 This protocol is for water chemistry testing using the ISAT Environment Lab's Campbell Scientific turbidity sensor and pressure transducer.
- 1.2 Students, faculty, and staff should utilize this SOP unless it is superseded by a more specific project SOP.

2.0 EQUIPMENT

- 2.1 The following checklist can be helpful in identifying all necessary equipment and supplies needed for field deployment of the sensors. Gather these supplies before leaving the lab.

Item	Check
Cooler for liquids	
Protocol and datasheets	
Pencils/Pens	
Field notebook	
Laptop	
USB-C to USB adaptor	
DI Water Storage Bucket	
DI Water Calibration Bucket	
DI Water Calibration Lid	
High NTU Calibration Cup	

Item	Check
Scouring Pad	
400 Grit Abrasive Cloth	
Padlock Keys	

High NTU Cup Attachment			
Analite Turbidity Probe			
Turbidity Standard Solution			
DI Water Spray Bottle			
Sampling Bottles			
Kimwipes			
Gloves & Safety Eye Wear			

3.0 SAFETY

3.1 Users should follow all federal, state, and local laws.

3.2 Users should follow all applicable federal, state, local, and JMU safety guidelines specific to the field activities described in this SOP.

3.3 General Field Safety

3.3.1 Table 1 details potential safety hazards that could be encountered and provides precautions to reduce or eliminate these risks.

Table 1. Specific Safety Hazards and Necessary Precautions.

Potential Hazard	**Description of Potential Hazard**	**Safety Precautions to Reduce or Eliminate Risk**
Unexpected Field Hazards	When working in the field at an unfamiliar site, unexpected hazards can be encountered, so have a plan, have a partner, and let others know your plan	- Notify BSA staff (Mike Jolly) the day before traveling to the field - Before you go into the field, let your supervisor and someone else know where you are going, when you are leaving, and when you plan on getting back - Notify supervisor and contact when you return - Never go into the field alone. Always have a partner.

Vehicle use	Driving to a field site can pose potential hazards for vehicle accidents.	- Drive safely to the field site, obeying all traffic laws. Know where you are going before you set out, so that your driving is not distracted by looking at maps or directions. - No hand-held cell phone use while driving.
Falling from the dam structure	Dam structures can pose a potential fall hazard	- Never work on or around the dam during flooding conditions - Do not approach the downstream side of the dam structure. All of our work will be on the lake-side of the dam. - When working on the lake-side of the protective chain-link fence, always wear a life vest.
Drowning	When working near a lake, potential drowning risks are always present.	- Always travel in pairs, and do not leave line-of-site vision from your partner - Never work on or around the dam during flooding conditions - When operating a boat, always wear a life vest - When operating a boat inside the floating debris screen, always have the boat tethered to the shore, so that the boat will not pass near or over the dam - When drilling from a boat, tether the front and back of the boat to the shore (chain-link fence posts) - Always stay balanced within the boat and never lean over the edge of the boat

Falls, cuts and abrasions	When walking on rip rap surrounding the lake, footing can be unstable and rocks can be uneven and sharp.	- Walk slowly over rip rap, making sure each step is settled on firm footing before moving the other foot. - Wear close-toed shoes that strap onto your feet and have hard but flexible soles (no flip flops)
Infection or gastrointestinal illness	Natural waters always have the potential to carry harmful bacteria that could cause infection or gastrointestinal illness	- Do not get water in your eyes, nose, or mouth - Wash hand thoroughly with soap or hand sanitizer after exiting the lake and before eating - Wash any cuts or abrasions thoroughly with soap after leaving the field site
Sun exposure	Working outside in an unshaded area with direct sun exposure could result in sun burn, dehydration, heat exhaustion, or heat stroke.	- Drink ample fluids before, during, and after the field activities - Wear lightweight, light-colored, breathable clothing - Wear sunscreen, sunglasses, and sun-protective clothing
Stinging/ biting insects	Working in a natural field environment means that stinging/biting insects may be present	- If you are allergic to bee stings, and have a prescription epi-pen, bring it with you in the field and inform your supervisor and partner - Wear clothing that covers the skin (long shirt, long pants)
Allergens	Airborne grass and flower pollens will be present. Skin irritants and allergens such as poison ivy may be present.	- If you are allergic to grass and flower pollens, take preventative over-the-counter allergy medications - If you have asthma that is exacerbated by airborne pollens, bring any rescue inhalers with you - Look for and identify any poison ivy at the site and avoid that area - Wear clothing that covers the skin (long shirt, long pants)

		- Wash hands directly after field work to avoid transferring any allergens to your eyes, mouth, or nose

3.4 Chemical Safety

3.4.1 Calibration Solution – The 400 NTU Formazin solution is a cancer-causing agent. It can also produce lung irritation and skin irritation. Inhalation of the dry powder is the most dangerous form of exposure, so risks are lower in the liquid solution form. Handle solution with care and use the following safety precautions. See MSDS for more information.

3.4.1.1 Wear disposable gloves and eye protection when the calibration solution bottle is open.

3.4.1.2 Do not allow calibration solution to directly contact the eyes, nose, mouth, or skin.

3.4.1.3 Wash hands after use and before touching your face or eating.

3.5 Specific Covid-19 Safety Precautions

3.5.1 The specific safety precautions in this section are intended to reduce the risks of Covid-19 infection and transmission based on the current risk level in Harrisonburg. These precautions are always superseded by any applicable JMU, local, state, or federal requirements.

3.5.2 The current community Covid-19 transmission level can be obtained from: https://www.cdc.gov/coronavirus/2019-ncov/your-health/covid-by-county.html

3.5.3 Low or Medium Transmission Risk

3.5.3.1 Users should notify their supervisor if they are in high risk categories for Covid-19 infection (over 65 or underlying health concerns). Specific health details do not need to be discussed beyond the statement that "I am in a high-risk category for Covid-19 infection." If individuals on the field crew are in the high-risk category, additional protection measures may be taken.

3.5.3.2 Pre-screening – Prior to traveling to a field site, each individual should self-screen for signs or symptoms of Covid-19. If any individual shows symptoms (coughing, nasal or chest congestion, runny nose, difficulty breathing, fever of 100.4°F or higher, chills, sore throat, headache, gastrointestinal symptoms, new loss of taste or smell) they should not join the sampling team and report the symptoms to their supervisor. An individual may rejoin the field team with a negative Covid-19 test (at home antigen test or lab PCR test).

3.5.3.3 Self-quarantine – If a close contact (someone that you live with) tests positive for Covid-19, you should not join the sampling team and report this information to your supervisor, regardless of whether you are experiencing symptoms or not. An individual may rejoin the field team after 5 days with a negative Covid-19 test (at home antigen test or lab PCR test).

3.5.4 High Transmission Risk – In addition to the precautions above, add the following precautions when community transmission rates in Harrisonburg are in the High range.

3.5.4.1 Face masks – If travelling together to the field site, all personnel should wear a fabric face mask. The mask should be worn above the nose and below the chin at all times. Face masks should be washed daily between uses. Masks are not required while outdoors.

3.5.4.2 Social distancing – While at the field site, personnel should attempt to stay at least 6-ft apart. This should not preclude assisting one another if some other inherent risk is more pressing (falling, drowning, etc.).

4.0 INSTRUMENT MAINTENANCE

4.1 General Inspections

4.1.1 Visually inspect wiring and physical conditions for any scratches, growth, or debris accumulation and remove accordingly.

4.1.2 Note the equipment condition as well as lake condition and visual lake level (from side wall) on the field sheet.

4.1.3 Check the indicating desiccant and enclosure humidity indicator in the datalogger control box. The desiccant should be orange and will turn a green color when the drying power is lost. The humidity indicator will change from blue to pink when the desiccant needs to be replaced. Note which number, if any, is pink.

4.1.4 Battery life can be checked through the PC400 program when collecting data. On the program ensure that the 12V battery is still charged at an operable level and provide solar panel maintenance or readjustment if necessary. Note on field sheet any readjustment or cleaning.

4.1.5 Ensure that both the control and junction boxes are secure, waterproof, and in operable condition.

5.0 DATA RETRIEVAL/MONITORING

5.1 Direct Connection

5.1.1 Travel to the deployment site with all materials listed on the table on page 1 of this SOP.

5.1.2 Access the control box and use USB-C to USB adaptor cable to connect the lab laptop to the datalogger.

5.1.3 Open up PC400 on the laptop and press the connect icon in the top left corner of the screen. If connection fails check that USB drivers are installed, wiring is secure, and that battery has sufficient charge. Turn switches in the control box off and on again and attempt to reestablish connection.

5.1.4 Click on the ‘Collect Data’ tab on the home screen, ensure that the appropriate tables are checked for collection and that the data is appending to a file, then click ‘Start Data Collection’.

5.1.5 Make notes of the program name being run on the right side of the screen as well as the file name, save location, battery voltage (seen in monitor data tab), start and end times of collection period, and if the clocks on the right hand side of the screen are within a minute of each other.

5.1.6 Open a new Excel file and click ‘file’ then ‘open’ then find the place that the data was downloaded on the computer and open it. You may need to ensure that ‘all files’ is clicked in the bottom right of the window and not ‘all excel files’

5.1.7 In order to format the data correctly, click ‘delimited’ in the popup window, then hit next and check the box next to ‘comma’, click next one more time and select ‘Date’ and ‘YMD’ from the drop down selection.

5.1.8 Once downloaded, find where this period of data starts and the previously collected data ended and copy this data into the appropriate tabs in the full excel document according to their months.

5.2 Remote Download

5.2.1 Open up the PC400 program on the computer being used to download the data.

5.2.2 If connecting remotely for the first time, use the following steps. If you have already viewed/downloaded data on this computer before skip to step 5.2.3.

5.2.2.1 Click the ‘add datalogger’ icon in the top right of the screen.

5.2.2.2 In the popup window under ‘Communication Setup’ click ‘CR300Series’, hit next, click ‘IP Port’, hit next, then type in ‘jaros.konectgds.com’ for the IP Address and hit next.

5.2.2.3 In the ‘Datalogger Settings’ tab ensure that the ‘PakBus Address’ is 1 and the ‘Neighbor PakBus Address’ is 4070.

5.2.2.4 Hit next and type in ‘merriweather1’ for the TCP Password

5.2.2.5 Click next and test the connection if you’d like or simply press ‘finish’

5.2.3 Press the connect icon in the top left corner of the screen then click on the ‘Collect Data’ tab on the home screen, ensure that the appropriate tables are checked for collection and that the data is appending to a file, then click ‘Start Data Collection’.

5.2.4 Make notes of the program name being run on the right side of the screen as well as the file name, save location, battery voltage (seen in monitor data tab), start and end times of collection period, and if the clocks on the right hand side of the screen are within a minute of each other.

5.2.5 Open a new Excel file and click ‘file’ then ‘open’ then find the place that the data was downloaded on the computer and open it. You may need to ensure that ‘all files’ is clicked in the bottom right of the window and not ‘all excel files’

5.2.6 In order to format the data correctly, click ‘delimited’ in the popup window, then hit next and check the box next to ‘comma’, click next one more time and select ‘Date’ and ‘YMD’ from the drop down selection.

5.2.7 Once downloaded, find where this period of data starts and the previously collected data ended and copy this data into the appropriate tabs in the full excel document according to their months.

5.3 Mobile App Monitoring (OPTIONAL)

5.3.1 Download the LoggerLink app from your mobile app store

5.3.2 Open the app and click the ‘+’ in the top right corner to add a datalogger.

5.3.3 Under the TCP Settings, enter “jaros.konectgds.com” for the Address box and “9100” for the Port box.

5.3.4 In Datalogger Settings scroll through the options and click “CR300 Series” and enter a preferred name for the datalogger.

5.3.5 Under PakBus Settings enter “1” as the Address, “4070” as the Neighbor, and “merriweather1” as the TCP Password. Leave everything else blank.

5.3.6 Next, hit save in the top right corner and then you will be able to click on the datalogger from the home page of the app and view live data.

5.3.7 The app defaults to the “public table,” which shows all of the possible data fields. If you would like a simpler view of just the turbidity, depth, battery voltage, and temperature, follow these steps to change the table displayed to the “Tbl_1_Min” table, which shows these main fields every minute.

5.3.7.1 Tap the settings symbol in the upper right corner.

5.3.7.2 Tap the “Select Table/Fields” bar at the top.

5.3.7.3 Tap the “Table” bar

5.3.7.4 Click the “Tbl_1_Min” choice.

5.3.7.5 Tap the “Select All” choice.

5.3.7.6 Tap “Done” in the top right.

5.3.7.7 Tap “Save” in the top right.

5.3.8 When finished monitoring the datalogger, disconnect by tapping “More” at the bottom right, then “Disconnect”, and “Disconnect” again to confirm.

6.0 QUALITY CONTROL/CALIBRATION

6.1 Pre-Service Precision Tests

6.1.1 Calibrate the secondary Analite turbidity sensor using a 0 NTU solution and a 400 NTU solution.

6.1.1.1 Plug in Analite sensor into the center port, lining up the slit with the notch on the port.

6.1.1.2 Press ‘ON/OFF’ then ‘MENU’ then ‘F1’ then ‘F2’ for a 2 point calibration.

6.1.1.3 Ensure that those working with solutions are wearing gloves and safety goggles and that all tests are being performed OUT of direct sunlight.

6.1.1.4 Insert sensor into DI water solution until water reaches the brim of the bottle.

6.1.1.5 Once value is steady, press ‘F2’ to grab it as the first point of calibration.

6.1.1.6 Take out sensor and wipe thoroughly with kimwipes until dry

6.1.1.7 Insert sensor into 400 NTU solution until water reaches the brim of the bottle.

6.1.1.8 Use the arrow buttons to adjust value to be exactly 400, then press 'F2'

6.1.1.9 Rinse sensor with DI water spray bottle and dry thoroughly.

6.1.2 Reinsert the Analite probe into the 0 NTU and 400 NTU solutions and record the values on the data sheet. Ensure that the probe is again wiped down between tests.

6.1.3 The 0 NTU solution should fall within +/- 2 NTU and the 400 NTU solution should be within the range of 380-420 NTU. Record this on the data sheet.

6.1.4 Now test the lake turbidity using both the Analite and the Clarivue turbidity sensors by deploying them over the edge of the fence holding the wire at the indicated mark. Wait for at least 2 minutes after deploying to record data to allow time for water/sediment settling.

6.1.5 The Clarivue value can be found in the 'Monitor Data' tab of PC400 as cv_mean_turb and the Analite value is found on the handheld device.

6.1.6 Using the RPD formula below, find the relative percent difference

$$*RPD = \frac{(C_1-C_2)}{(C_1+C_2)/2} \times 100$$

6.1.7 If the value is greater than 10 NTU then an RPD of 20% or less is acceptable. If the value is less than 10 NTU then the difference should be +/- 2 NTU or less.

6.1.8 If this test fails to meet these requirements, flag the data taken between the last precision test and this one.

6.2 Cleaning Probes

6.2.1 AFTER completing precision checks with a second independent turbidity probe, carefully pull both turbidity sensor and pressure transducer up through the conduit from the junction box.

6.2.2 Visually inspect wiring and physical conditions for any scratches, growth, or debris accumulation.

6.2.3 Check in the indicating desiccant and enclosure humidity indicator in the datalogger control box, service if necessary.

6.2.4 Turbidity sensor specific procedures

6.2.4.1 If encrusted organisms such as barnacles or tube worms are on the sensor window, use a flexible knife blade to gently scrape them off.

6.2.4.2 For other types of fouling, wet a scouring pad and place it on a counter with the pad side aligned with the edge of the counter. Then rub the sensor window back and forth on the secured pad until it is clean.

6.2.4.3 To remove pits from the sensor face, tape a strip of 400 grit wet-or-dry abrasive cloth to the edge of a counter. Add a few drops of water and rub the sensor window on the cloth in one-way strokes until the face is pit free.

6.2.5 Once cleaned, note specifics on field sheet and carefully feed the probes back through the junction box and conduit for continued data collection and quality control tests.

6.3 Calibration

6.3.1 For regular equipment tests, perform preservice checks BEFORE calibrating the sensors (see section 6.1 below).

6.3.2 Both turbidity and pressure transducer sensors are calibrated by the manufacturer, and a calibration check will be made at each field visit (maximum 30 days in summer and 60 days in winter).

6.3.2.1 Both a low level and a high level calibration will be performed. The low calibration will use a 0 NTU deionized water solution while the high calibration will use a 400 NTU solution.

6.3.2.2 First, perform all pre-service checks with the Clarivue sensor, then carefully pull the sensor out of the water through the junction box.

6.3.2.3 Next, rinse sensor with DI water and dry with kimwipes thoroughly and ensure that all the next steps are preformed OUT of direct sunlight.

6.3.2.4 Insert the sensor into the calibration bucket lid by feeding the wire through the large slit in the cap and allowing the metal bit around the wire to rest on the top of the lid.

6.3.2.5 Close the lid on the calibration bucket once filled the inside marks with DI water. Use the PC400 monitor tab to record the cv_mean_turb. Rinse sensor with DI water and dry with kimwipes thoroughly again.

6.3.2.6 Fill the smaller black calibration cup with 400 NTU solution from the brown bottle.

6.3.2.7 Insert the Clarivue sensor into the cup using the clasping lid, again ensuring that this is performed in a shaded area. Use the PC400 monitor tab to record the cv_mean_turb. Rinse sensor with DI water and dry with kimwipes thoroughly again.

6.3.2.8 When testing these solutions with the Clarivue turbidity sensor, the low should fall within +/-2 of 0 NTU and the high should be +/-5% or 20 NTU.

6.3.2.9 If sensors fail to meet these calibration requirements, reclean, refill standard, and retest. If sensor fails 2 consecutive months, return to manufacturer for recalibration.

6.4 Post-Service Precision Tests

6.4.1 Move on to this AFTER sensor has been tested for pre-service precision AND cleaned

6.4.2 Test the lake turbidity using both the Analite and the Clarivue turbidity sensors by deploying them over the edge of the fence holding the wire at the indicated mark. Wait for at least 2 minutes after deploying to record data to allow time for water/sediment settling.

6.4.3 The Clarivue value can be found in the ‘Monitor Data’ tab of PC400 as cv_mean_turb and the Analite value is found on the handheld device.

6.4.4 Using the RPD formula below, find the relative percent difference

$$*RPD = \frac{(C_1-C_2)}{(C_1+C_2)/2} \times 100$$

6.4.5 If the tested value is greater than 10 NTU then an RPD of 20% or less is acceptable. If the value is less than 10 NTU then the difference should be +/- 2 NTU or less.

6.4.6 If this test fails to meet these requirements, reclean, readjust probe, retest. Flag data if still outside criteria.

6.4.7 Record what time all tests were finished and the sensors were redeployed for continued monitoring.

Field Data Sheets

Date: ________ Initials: ________

Lake Merriweather Field Data Sheet

INITIAL CONDITIONS

Visual Lake Level: ________ Current Median Turbidity: _______________

Lake Condition: _______________________ Equipment Condition: _________________

_____________________________________ ____________________________________

Solar Panel	Clean	**Yes / No**
Junction Box	Secure/Waterproof	**Yes / No**
Control Box	Secure/Waterproof	**Yes / No**
Humidity Indicator	Circle Pink 30, 40, 50	Last Desiccant Pack Change Date: ___________
Desiccant Tube	Color Orange	**Yes / No**

DOWNLOAD

Connection Status: ___________ Battery Voltage: __________ Clocks within 1 Minute: **Yes / No**

Current Program Name: ________________________ If No, Reset Date/Time: ________

PRE-SERVICE PRECISION CHECK *Ensure all tests are done OUT of direct sunlight

Time Tests/Checks Started: __________________

Lake Level (side)	Pressure Tans. Level	Criteria	Acceptable
		+/- 0.5 ft	**Yes / No**

Analite Calibration:

Date: _______

Time: ______

0 Standard		0 +/- 2 NTU **(Y/N)**
400 Standard		380 – 420 NTU **(Y/N)**

Lake Measurement* Lowered together through fence hole (not conduit):

Analite	Clarivue	RPD*	Criteria	Acceptable
			If NTU>10: RPD<20% If NTU<10: +/-2	**Yes / No**

*RPD = $\underline{(C_1\text{-}C_2)}$ x 100

$(C_1+C_2)/2$

MAINTENANCE

	Clarivue	Pressure Transducer
Condition?		
Cleaned?	**Yes / No**	**Yes / No**

Comments: ____

____

CALIBRATION CHECK *Ensure all tests are done OUT of direct sunlight

	Standard	Clarivue (mean)	Criteria	Acceptable	Corrective Action?
Low (DI)	0		+/-2 NTU	**Yes / No**	
High	400		380 – 420 NTU	**Yes / No**	

POST-SERVICE PRECISION CHECK *Ensure all tests are done OUT of direct sunlight

Lake Measurement* Lowered together through fence hole (not conduit):

Analite	Clarivue	RPD*	Criteria	Acceptable
			If NTU>10: RPD<20% If NTU<10: +/-2	**Yes / No**

$$*RPD = \frac{(C_1-C_2)}{(C_1+C_2)/2} \times 100$$

Redeployment Time	Redeployment Turbidity (Clarivue)

Lake Level (side)	Pressure Tans. Level	Criteria	Acceptable
		+/- 0.5 ft	**Yes / No**

ADDITIONAL COMMENTS

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