VTRC
Virginia Transportation Research Council

We Bring Innovation to Transportation

The Effect of In-Stream Construction Activities on Turbidity, Suspended Sediment, and Sediment Loads

https://vtrc.virginia.gov/media/vtrc/vtrc-pdf/vtrc-pdf/26-R39.pdf

LEWIS N. LLOYD, P.E.
Research Scientist

BRIDGET M. DONALDSON
Associate Principal Research Scientist

Final Report VTRC 26-R39

VIRGINIA TRANSPORTATION RESEARCH COUNCIL
530 Edgemont Road, Charlottesville, VA 22903-2454
vtrc.virginia.gov

Standard Title Page—Report on State Project

Report No.: VTRC 26-R39	Report Date: May 2026	No. Pages: 36	Type Report: Final	Project No.: 122843
			Period Covered: January 2023–May 2026	Contract No.:

Title:
The Effect of In-Stream Construction Activities on Turbidity, Suspended Sediment, and Sediment Loads

Key Words: Cofferdam, turbidity, sediment, freshwater mussels, in-stream construction

Author(s):
Lewis N. Lloyd, P.E., and Bridget M. Donaldson

Performing Organization Name and Address:
Virginia Transportation Research Council
530 Edgemont Road
Charlottesville, VA 22903

Sponsoring Agencies' Name and Address:
Virginia Department of Transportation
1221 E. Broad Street
Richmond, VA 23219

Supplementary Notes:

Abstract:

Transportation construction activities involving in-stream work can mobilize sediment and elevate turbidity, which can affect sensitive aquatic species such as freshwater mussels. Although cofferdams are used to isolate construction areas and limit sediment mobilization, their installation and removal create some degree of sediment release as a result of unavoidable streambed disruptions. To support more informed impact assessments and survey requirements for aquatic species protection, this study determined the transport distances of sediment associated with the installation and removal of cofferdams. Related objectives were to compare the effect of cofferdam-related construction events on sediment loads and to document the factors that affect recovery times and sediment loads.

Streams associated with two bridge replacement projects in Virginia involving different but commonly used cofferdam types (sheet pile and sandbag or Jersey barrier) were instrumented with 19 turbidity sensors positioned upstream and up to 2,600 feet downstream of construction. In addition to continuous turbidity monitoring, data collection included water sampling and field measurements used to determine suspended sediment concentration and site-specific rating curve development. Suspended sediment loads were calculated using stream discharge, suspended sediment concentration, and duration of cofferdam-related construction events.

Across both sites, peak turbidity increases occurred immediately downstream of the cofferdam, with values as high as 238 Formazin Nephelometric Units at Site 1 and 3,324 Formazin Nephelometric Units at Site 2, which returned to background levels within 50 to 100 feet downstream. Sediment loads attributable to construction ranged from 3 to 636 pounds, and for most cofferdam-related construction events, more than 75% of the sediment load occurred in the first 50 feet downstream. The use of sandbag or Jersey barrier cofferdams generated higher turbidity and sediment loads than sheet piles, largely because installation and removal required more streambed disturbance. For all cofferdam-related construction events, turbidity levels returned to background levels between 5 and 90 minutes. Sediment load calculations from evaluated precipitation events were one to three orders of magnitude higher than loads from cofferdam-related construction events.

The findings can help inform assessments of potential mussel impacts from in-stream projects involving cofferdams conducted under comparable conditions. It is recommended that the Virginia Department of Transportation's Environmental Division share this report with the Virginia Field Office of the U.S. Fish and Wildlife Service and aquatic program staff of the Virginia Department of Wildlife Resources to support agency evaluation of area-of-impact determinations and associated survey requirements for projects comparable with those this study examines.

FINAL REPORT

THE EFFECT OF IN-STREAM CONSTRUCTION ACTIVITIES ON TURBIDITY, SUSPENDED SEDIMENT, AND SEDIMENT LOADS

Lewis N. Lloyd, P.E.
Research Scientist
Virginia Transportation Research Council

Bridget M. Donaldson
Associate Principal Research Scientist
Virginia Transportation Research Council

Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

May 2026
VTRC 26-R39

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Virginia Department of Transportation, the Commonwealth Transportation Board, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. Any inclusion of manufacturer names, trade names, or trademarks is for identification purposes only and is not to be considered an endorsement.

Copyright 2026 by the Commonwealth of Virginia.
All rights reserved.

ABSTRACT

Transportation construction activities involving in-stream work can mobilize sediment and elevate turbidity, which can affect sensitive aquatic species such as freshwater mussels. Although cofferdams are used to isolate construction areas and limit sediment mobilization, their installation and removal create some degree of sediment release as a result of unavoidable streambed disruptions. To support more informed impact assessments and survey requirements for aquatic species protection, this study determined the transport distances of sediment associated with the installation and removal of cofferdams. Related objectives were to compare the effect of cofferdam-related construction events on sediment loads and to document the factors that affect recovery times and sediment loads.

Streams associated with two bridge replacement projects in Virginia involving different but commonly used cofferdam types (sheet pile and sandbag or Jersey barrier) were instrumented with 19 turbidity sensors positioned upstream and up to 2,600 feet downstream of construction. In addition to continuous turbidity monitoring, data collection included water sampling and field measurements used to determine suspended sediment concentration and site-specific rating curve development. Suspended sediment loads were calculated using stream discharge, suspended sediment concentration, and duration of cofferdam-related construction events.

Across both sites, peak turbidity increases occurred immediately downstream of the cofferdam, with values as high as 238 Formazin Nephelometric Units at Site 1 and 3,324 Formazin Nephelometric Units at Site 2, which returned to background levels within 50 to 100 feet downstream. Sediment loads attributable to construction ranged from 3 to 636 pounds, and for most cofferdam-related construction events, more than 75% of the sediment load occurred in the first 50 feet downstream. The use of sandbag or Jersey barrier cofferdams generated higher turbidity and sediment loads than sheet piles, largely because installation and removal required more streambed disturbance. For all cofferdam-related construction events, turbidity levels returned to background levels between 5 and 90 minutes. Sediment load calculations from evaluated precipitation events were one to three orders of magnitude higher than loads from cofferdam-related construction events.

The findings can help inform assessments of potential mussel impacts from in-stream projects involving cofferdams conducted under comparable conditions. It is recommended that the Virginia Department of Transportation's Environmental Division share this report with the Virginia Field Office of the U.S. Fish and Wildlife Service and aquatic program staff of the Virginia Department of Wildlife Resources to support agency evaluation of area-of-impact determinations and associated survey requirements for projects comparable with those this study examines.

FINAL REPORT

THE EFFECT OF IN-STREAM CONSTRUCTION ACTIVITIES ON TURBIDITY, SUSPENDED SEDIMENT, AND SEDIMENT LOADS

Lewis Lloyd, P.E.
Research Scientist
Virginia Transportation Research Council

Bridget Donaldson
Associate Principal Research Scientist
Virginia Transportation Research Council

INTRODUCTION

The Virginia Department of Transportation (VDOT) owns more than 21,000 bridges and large culverts and is responsible for their continued maintenance (VDOT, 2022). VDOT's *Road and Bridge Manual* describes the procedures for their construction and maintenance, including measures to minimize the effects on streams (VDOT, 2020). In-stream construction activities often require the use of cofferdams, temporary structures designed to exclude water from the work area. Cofferdams allow water to be pumped out so that construction can occur under dry conditions. VDOT typically uses sheet pile cofferdams in streams and rivers where substrate conditions permit pile installation. Sheet pile cofferdams consist of interlocking vertical sheets (most commonly steel) driven into the streambed to form a continuous wall (U.S. Army Corps of Engineers [USACE], 1994). For smaller projects or streams where the substrate is too rocky to allow sheet pile driving, VDOT typically uses sandbag and Jersey barrier cofferdams.

Properly designed cofferdams are effective at keeping sediment out of the adjacent waterbody during construction. The construction and removal of cofferdams, however, create some degree of sediment release as a result of unavoidable streambed disruptions.

These streambed disruptions can affect sensitive aquatic species such as freshwater mussels. Freshwater mussels are sedentary filter feeders that are particularly sensitive to water-quality degradation, and excessive sediment inputs are recognized as a major factor contributing to mussel population declines. Of Virginia's 82 mussel species, approximately 70% have declining populations (Virginia Department of Wildlife Resources [VDWR], n.d.).

The Effects of Sediment on Freshwater Mussels

Several studies have quantified the degree to which water quality affects freshwater mussels. Turbidity is one of several parameters used to measure water quality and is typically expressed in Nephelometric Turbidity Units (NTU) or Formazin Nephelometric Units (FNU), depending on the type of sensor used for analysis. Turbidity is defined as "the measurement of light scattered at 90 degrees to the incident light by suspended particles in an aqueous medium" (Uhrich and Bragg, 2003). Elevated turbidity in streams can be the result of various factors, such

as suspended inorganic solids, dissolved material, organic matter, color, and air bubbles (Uhrich and Bragg, 2003). Although some studies on the effects of water quality on aquatic species measure turbidity levels, most mussel studies quantify suspended material directly as either suspended sediment concentration (SSC) or total suspended solids, both of which are measured in mg/L.

Research evaluating the effects of sediment on freshwater mussels indicates that the impacts vary among species, life stages, and the duration of exposure. Studies show that mussels can tolerate high sediment concentrations for short periods, but sustained or repeated exposure to even moderate sediment concentrations can significantly impair mussel feeding, reproduction, and recruitment. In the United States, pond experiments on ebonyshell (*Reginaia ebenus*) and pondmussel (*Ligumia subrostrata*) found that exposure to sediment concentrations (SSC above 20 mg/L) for several months resulted in complete loss of gravid females and significantly reduced clearance rates at approximately 8 mg/L SSC (Gascho-Landis et al., 2013; Gascho-Landis and Stoeckel, 2015). Alternatively, short-term (96-hour) exposures of juveniles of fatmucket (*Lampsilis siliquoidea*), Arkansas Broken-ray (*Lampsilis reeveiana*), and washboard mussel (*Megalonaias nervosa*) to suspended solids up to approximately 5,000 mg/L total suspended solids showed no significant mortality, indicating acute survival tolerance. However, in longer (28-day) exposures, high concentrations (greater than 10,000 mg/L) impaired mussel growth (Zhu et al., 2023).

In Sweden, field studies of freshwater pearl mussel (*Margaritifera margaritifera*) indicated that recruitment occurred only in streams with turbidity levels typically below 2 NTU, emphasizing the importance of clear-water conditions (Österling et al., 2010). Similarly, an Irish synthesis for *M. margaritifera* set management thresholds around 1 to 2 NTU and suspended solids of less than 30 mg/L to sustain viable populations (Walsh et al., 2012).

Regulatory Coordination Requirements

Section 7 of the Endangered Species Act requires VDOT, as a designated non-federal representative for the Federal Highway Administration or the U.S. Army Corps of Engineers, to consult with the U.S. Fish and Wildlife Service (USFWS) on projects with a federal nexus (e.g., those that require federal permitting or funding, or both), when any project or action may affect a listed species or designated critical habitat (USFWS, 2022). In Virginia, VDOT is also required to coordinate with the Virginia Department of Wildlife Resources (VDWR) for projects conducted in the vicinity of habitat suitable for freshwater mussels or other protected resources. VDOT uses the USFWS Information for Planning and Consultation screening tool to identify protected resources within a project action area. This coordination (Section 7 consultation or state coordination) may result in additional project requirements designed to reduce the potential effects on mussels. These effects include direct impacts from construction activities and indirect impacts downstream as a result of sedimentation and effluent discharge from the project site (USFWS and Virginia Department of Game and Inland Fisheries [VDGIF], 2018).

USFWS and VDWR may recommend four general types of assessments and surveys, depending on the scope of the construction activity and whether mussel habitat or known populations are in the vicinity of the project area. These types include land-based reviews, site

assessments, abbreviated surveys, and full surveys. The assessments and surveys require contracting with a qualified mussel surveyor and conducting stream surveys upstream and downstream of the project area at the following distances:

- 20 meters (66 feet) upstream and 80 meters (262 feet) downstream from the project footprint (site assessment).
- 100 meters (328 feet) upstream and 400 meters (1,312 feet) downstream of the project footprint (abbreviated survey).
- 200 meters (656 feet) upstream and 800 meters (2,625 feet) downstream of the project footprint (full survey).

Plans for initial surveys and any necessary mussel relocations must be presented to the agencies for comment and approval prior to construction (USFWS and VDGIF, 2018).

Related Studies and Information Gaps

Studies on in-stream construction projects indicate that the magnitude and extent of turbidity and suspended sediment increases vary among construction types, site conditions, and geographic settings. Low-water fords and temporary crossings were found to generate short-duration peaks in turbidity from 100 to 300 NTU (Gilbert et al., 2021), and pipeline and open-cut trenching projects resulted in higher turbidity increases of more than 2,000 NTU during trenching that dissipated rapidly downstream (Moyer and Hyer, 2009; Reid and Anderson, 1999). Culvert replacements and bridge installations resulted in short-term, localized turbidity increases that were generally confined to within 328 feet downstream of construction (Foltz et al., 2013; Pugh and Gill, 2021).

Although these studies highlight some general turbidity patterns with in-stream construction activities, they do not capture conditions specific to VDOT construction practices in streams. Agencies lack detailed, Virginia-specific suspended sediment data needed to refine area-of-impact determinations and survey requirements for aquatic species protection. Needed but presently unavailable empirical data include turbidity and suspended sediment data at defined distances upstream and downstream of VDOT project sites before, during, and following in-stream construction activities involving cofferdam construction and removal.

PURPOSE AND SCOPE

The purpose of this study was to determine, using Virginia-specific data, the transport distances of sediment associated with the installation and removal of cofferdams. Related objectives were to (1) compare the effect of cofferdam-related construction events on sediment loads and (2) document the factors that affect recovery times and sediment loads.

The study scope included monitoring two Virginia bridge construction projects that used cofferdams to mitigate sediment release from in-stream construction activities. This task entailed determining turbidity and SSC at defined distances upstream and downstream of project sites before, during, and following cofferdam construction and removal.

METHODS

The following tasks were conducted to fulfill the study purpose:

1. Site selection.
2. Site instrumentation and turbidity monitoring.
3. Construction observations.
4. Water sample collection to determine SSC.
5. Stream discharge measurements and rating curve development.
6. Data processing and analyses.

Site Selection

Two in-stream construction projects and associated streams were selected for monitoring and evaluation. Study sites were selected to represent different but commonly used cofferdam types while maintaining soil and substrate characteristics similar to those preferred by Virginia's freshwater mussels. The research team met with review panel members to review and discuss the characteristics of each potential site prior to selection. Site selection was guided by three primary factors, in order of importance:

1. Representative of typical VDOT in-stream projects and cofferdam types (e.g., sandbag cofferdams in areas with rocky substrate where sheet pile installation is feasible, such as non-rocky soil conditions).
2. Potential for measurable sediment and turbidity effects (i.e., sites with sufficient fine sediment to produce visible turbidity during disturbance).
3. Representative of freshwater mussel habitat (e.g., streams with continuous flow and a variety of water depths and substrates of sand, pebble, and embedded fine sediment such as silt) (Krstolic et al., 2011).

Although the site selection approach considered key characteristics of suitable freshwater mussel habitat (e.g., continuous flow, mixed substrates, and variable depths), greater weight was placed on selecting locations with sufficient fine sediment (such as silt) to ensure measurable turbidity and sediment effects. Finer particles, such as clays and silt, remain suspended longer and settle further downstream than coarser materials, such as gravels and coarse sand (Reid and Anderson, 1999). Sites with higher silt content than what is found in optimal mussel habitat would provide a "worst-case" scenario for evaluating construction impacts because finer sediments are more likely to produce elevated turbidity.

Site Descriptions

The selected sites were along Briery Creek in Prince Edward County near Farmville and along Wheeler Creek in Louisa County. VDWR mussel occurrence records (e.g., Upper James, Clinch, Powell, and Roanoke basins) overlap with areas mapped as having similar alluvial loams (e.g., sand, gravel, and loam substrates) as those along the creeks of both study sites (VDWR, n.d.). Although soil profiles at the study sites were not directly compared with those from areas supporting Virginia's listed mussel species, the upper soil layer at both sites (characterized as silt

loam) also contained small pebbles and gravel, which are typical of mussel habitat. The proportion of silt was likely greater than that found in substrates preferred by Virginia's protected freshwater mussel species (Table 1 and Figure 1). In addition, both sites were in the Piedmont physiographic province, and results may not be fully representative of streams with differing physical characteristics, which can influence turbidity dynamics.

Table 1. Stream and Soil Descriptions at Project Sites

Site	Location	Stream	Drainage Area (acres)	Soil (upper, mid, lower horizons)[a]	Surrounding Land Use
1	Farmville	Briery Creek	27,218	Silt loam, loam, loamy sand	Riparian/agriculture
2	Louisa	Wheeler Creek	19,270	Silt loam, silt clay loam, sandy loam	Riparian/agriculture

[a] Site specific soils data collected from the U.S. Department of Agriculture's (2019) Web Soil Survey.

Figure 1. Wheeler Creek in Louisa County, Virginia (left), and Substrate Containing Small Pebbles and Gravel (right)

Construction Descriptions

Construction took place during the winter of 2024 and the spring of 2025. Both sites involved complete bridge replacements, including replacement of both abutments. Although both sites required in-stream work, the stream sizes, scale of disturbance, construction methods, and types of cofferdams varied. Figure 2 and Table 2 provide an indication of the bridge size differences.

Figure 2. Site 1 Bridge (54.8 feet long, left) and Site 2 Bridge (18 feet long, right) before Construction

Bridge replacement work at both sites included using cofferdams and generally followed the same sequence of cofferdam-related construction events, hereafter referred to simply as "construction events" (Table 2). The cofferdam at Site 1 was constructed of interlocking sheet piles that were driven into the streambank (Figure 3). In contrast, the cofferdam at Site 2 was constructed using a combination of Jersey barriers, sandbags, and plastic sheeting that lined the stream channel of the work site—an approach that may differ from the more common use of limiting plastic sheeting to encase the Jersey barriers (Figure 3). At Site 2, sandbags were used to create a stable, level foundation for the Jersey barriers, and the plastic sheeting was used to make the cofferdam more "watertight." At both sites, cofferdam construction proceeded from upstream to downstream, and removal occurred downstream to upstream. Cofferdams were installed sequentially at both sites (i.e., one side of the stream was completed before work moved to the other side). Because the Site 1 bridge was larger in length and width, its corresponding cofferdam extended farther along the channel than the cofferdam at Site 2 (Table 2). At both sites, the cofferdams extended approximately 5 feet into the typical flow path.

Table 2. Bridge Replacement Descriptions

Site	Bridge Length (feet)	Cofferdam Method and Length	Dewatering Operation	Construction Events	Construction Period
1	54.8	Sheet pile, 115 feet along channel	Dewatering bag 50 feet from stream, continuous operation, no discharge into stream	Cofferdam installation (east side of bridge) Dewatering Cofferdam removal (east) Cofferdam installation (west) Cofferdam removal (west) Reprofile of streambed	Approximately 19 weeks (February 16 to June 27, 2024)
2	18	Sandbag and Jersey barrier, 30 feet along channel	Dewatering bag 30 feet from stream, intermittent operation, intermittent discharge into stream	Cofferdam installation Dewatering Cofferdam removal (east) and relocation and installation (west) Reprofile of streambed and dewatering Cofferdam removal (west)	Approximately 3 weeks (May 9 to May 21, 2025)

Figure 3. Sheet Pile Cofferdams at Site 1 (left) and Jersey Barrier-Sandbag Cofferdam at Site 2 (right)

Dewatering operations were conducted at both sites to provide a dry work environment within the cofferdam (Figure 4). These operations consisted of pumping turbid water from within the cofferdam into a non-woven geotextile dewatering bag to filter out particulate matter. At Site 1, dewatering was continuous during the course of in-stream construction. Effluent water from the bag infiltrated into the surrounding soil and did not directly discharge into the stream. Conversely, dewatering at Site 2 was only active for 2 days of the project, and effluent from the bag was observed discharging back into the stream just downstream from the cofferdam after flowing through a densely vegetated area.

Figure 4. Dewatering Operations at Site 1 (left) and Site 2 (right)

Site Instrumentation and Turbidity Monitoring

Seven monitoring transects, designated D1 through D7, were installed at each site. As Figure 5 shows, each transect was equipped with one or three turbidity sensors for 19 total sensors. D1 was positioned approximately 50 feet upstream of the construction area at each site, and D2 was installed as close as possible to the downstream edge of the cofferdam. The remaining transects were installed at progressively greater distances downstream, extending to a maximum distance of 2,600 feet from the cofferdam, corresponding to the farthest distance required for a full mussel survey. Each transect used a cable suspended between trees across the width of the stream to hang the turbidity sensors. This mounting method was selected because of its low cost, flexibility (allowing for variations in-stream width), and ease of installation.

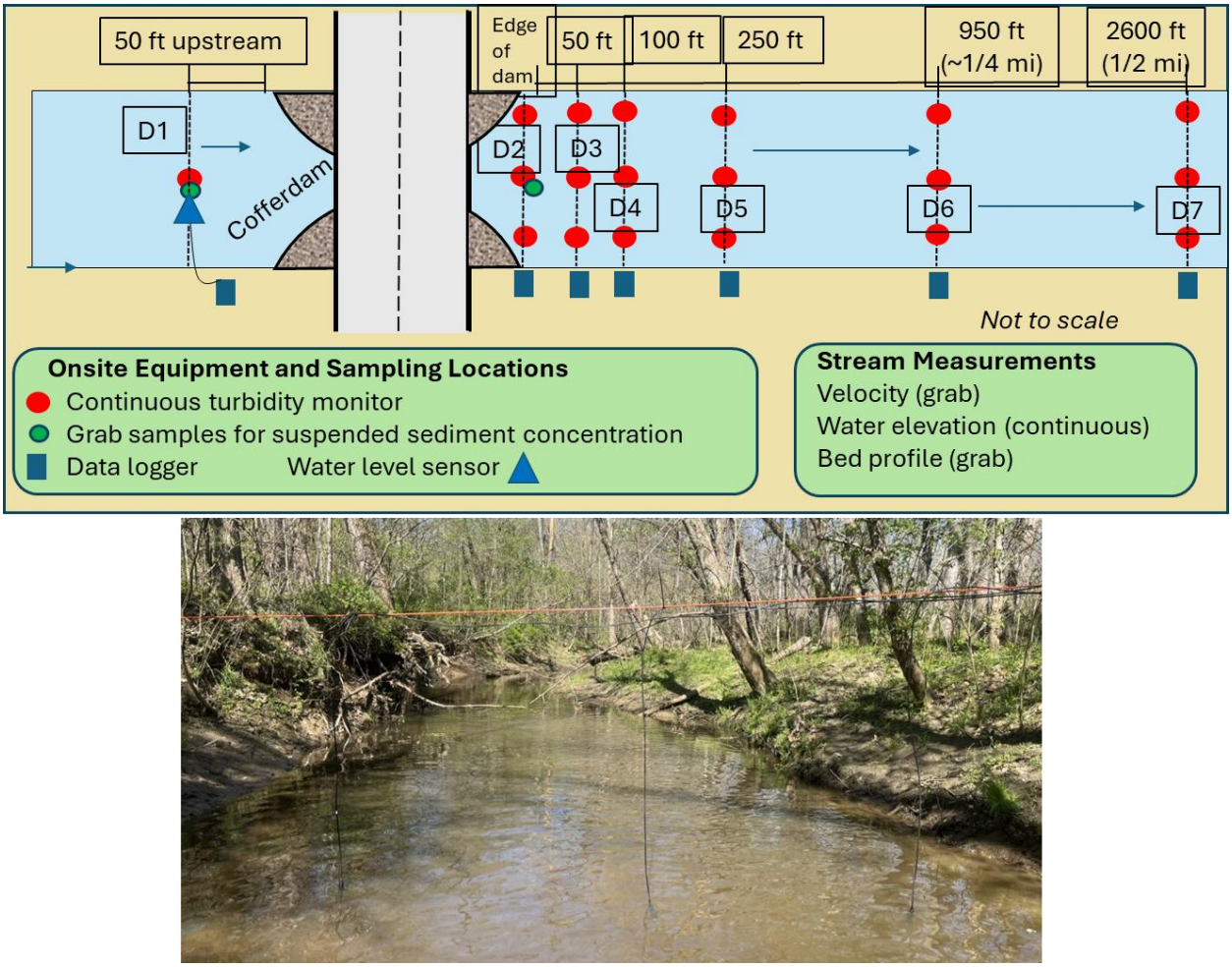


Figure 5. Layout of Monitoring Transects (D1–D7) and Instrumentation Installed at Both Sites (top) and Monitoring Transect with Bank Left, Center, and Bank Right Turbidity Sensors (bottom)

Transects were equipped with battery- and solar panel-powered Campbell Scientific CR350 dataloggers and with ISO 7027-compliant Campbell Scientific ClariVue 10 turbidity sensors. Sensors reported turbidity values in FNU. These values are comparable with NTU but should not be considered directly interchangeable. Transect D1 consisted of a single turbidity sensor and a Campbell Scientific CS451 pressure sensor anchored to the streambed at the

centerline of the streams' flow paths to monitor upstream turbidity and water levels, respectively. The pressure sensor measured stream stage (the water surface height above a fixed reference point). These values were later used to calculate streamflow (described in a subsequent section).

Downstream transects (D2–D7) were outfitted with three turbidity sensors positioned at the centerline, bank left, and bank right of the stream. These bank left and right sensors captured data from sediment plumes that moved along the stream banks before dispersing across the stream channel. Sensors were suspended high enough to avoid contact with the bottom of the stream, yet low enough to remain submerged during periods of low flow. Sites were visited every 2 to 3 weeks to download data and clean the turbidity sensors, removing any buildup that could affect readings.

Turbidity monitoring was conducted during the course of the construction periods of 19 weeks (Site 1) and 3 weeks (Site 2), and pre- and post-construction turbidity monitoring was also conducted for 59 and 28 days at Site 1 and Site 2, respectively. Site 1's monitoring period was extended to ensure that all equipment was functioning properly.

Construction Observations

The research team or construction site supervisors monitored construction activities throughout both bridge replacement projects. Prior to the start of the projects, site supervisors were asked to complete a form documenting the timing and key details of each construction activity. These supervisor records served as a backup source of information when researchers were not present for every construction event. The timing and details of any activities that could influence turbidity were recorded (e.g., workers in the stream, excavation inside the cofferdam, observations of incidental leaks of sediment-laden water, and periods of dewatering system operation).

Water Sample Collection to Determine Suspended Sediment Concentration

SSC grab samples were collected from transects D1 and D2 during significant construction events. A total of 12 and 21 1-liter samples were collected from Site 1 and Site 2, respectively. SSC grab samples were also collected from Site 2 at the point of discharge from the dewatering bag operation, but these samples were collected only when discharge from the operation was visibly entering the stream.

SSC samples were collected in 1-liter Whirl Pak bags from the middle of the water column and stored at 4˚C prior to analysis. Samples were held for no longer than 3 days prior to analysis via EPA Method 160.2.

Stream Discharge Measurements and Rating Curve Development

Site 1 Streamflow Rate

To calculate streamflow (or stream discharge) and water velocities at Site 1, an existing Federal Emergency Management Agency HEC-RAS flood plain model of the Bush River

Watershed was downloaded from the Virginia Department of Conservation and Recreation's website and calibrated against field data.

To compare field measurements of water flow with estimates from the model, stream measurements were collected at D1 during periods of higher and lower flows. The stream width was measured and divided into six equal segments. At the center of each segment, the depth of the water column and the water velocity at the water's surface were measured using a small floating buoy. Using these measurements, the estimated discharge was calculated within each segment. These values were summed to calculate the total discharge of the stream. This total discharge value was compared with those the HEC-RAS model generated, using HEC-RAS version 6.5 and assuming steady flow conditions (USACE, 2024). The modeled results showed good agreement with the empirically derived discharge measurements. Therefore, average stream stage values measured at D1 during each construction event were fed into the model, and water velocities at each transect were extracted for bank left, center, and bank right positions.

Site 2 Streamflow Rate

Because a HEC-RAS model was not available for Site 2, stream rating curves were developed for each transect using empirical data. To create these curves, discharge first had to be measured directly under several flow conditions. At each transect, four paired measurements of stage and discharge were collected under various flow regimes ranging from 0.64 cubic feet per second (cfs) to 35.4 cfs. Discharge was calculated from field measurements of stream width, water depth, and water velocity. The stream width at each transect was measured and divided equally into 10 segments. Total water depth and water velocities at 20 and 80% of the total depth were collected within each segment using a Flo-Mate Model 2000 portable flowmeter (Marsh-McBirney, 1990). Appendix Figure A1 provides these rating curves.

These rating curve data were then used to calculate the instantaneous discharge at each transect during the course of the monitoring period. Because stream stage was only measured continuously at D1, it was assumed that the discharge measured at this point was constant across all transects. To verify this assumption, rating curves generated from stage and discharge data collected at all transects on the same day were compared using a linear regression (see Appendix Figure A2). This analysis assessed whether discharge estimates were similar among transects to justify applying the D1 discharge at each location. The slopes of calculated linear regression equations were low, ranging from -7.6×10^{-3} to 9.7×10^{-2} ft^3/s, indicating that discharge remained constant along the monitored segment of stream. Therefore, it was assumed that the discharge measured at transect D1 remained constant at transects D2 through D7. Working from this assumption, discharge versus cross-sectional area linear regressions were conducted for transects D2 through D7. Discharge values measured at D1 were applied to these regression equations using Equation 1 to calculate instantaneous water velocities.

$$v_{Dn} = \frac{Q_{D1}}{(mQ_{D1})+b} \quad \text{(Eq. 1)}$$

Where:
v_{Dn} = instantaneous water velocity at transect Dn.
Q_{D1} = discharge measured at D1.

m = slope of the linear regression between discharge and cross sectional area at Dn.
b = Y − intercept of the linear regression between discharge and cross sectional area at Dn.

Data Processing and Analyses

Raw Turbidity Data Cleanup

A MATLAB script was developed to apply a multi-step data cleanup process uniformly to each sensor and transect. The intent of this script was to both preserve the integrity of the dataset while omitting artificially elevated datapoints created by sensor fouling or obstruction. This process included extracting data from each transect that corresponded with specific construction events, using streamflow rate and downstream distance to determine when water from a construction event would reach each transect. The Appendix and Figure A3 provide a detailed description of this process.

Precipitation Data

Daily precipitation data were collected from the National Oceanographic and Atmospheric Administration's National Climatic Data Center. Data were pulled from the closest weather station with data coverage throughout the monitoring periods. For Site 1, data were obtained from station USC00442941 in Farmville, Virginia, approximately 4 miles from the project site. Precipitation data for Site 2 were collected from station USC00445050 in Louisa, Virginia, approximately 8 miles from the project site.

Regression Analysis of Turbidity and Suspended Sediment Concentration

Turbidity values (measured as FNU) and their corresponding SSCs were log transformed and plotted against each other. Because turbidity and SSC have been found to be linearly correlated, a linear regression was conducted using the least squares method. The equation of the resulting linear trendline was then used to convert continuously measured turbidity values to SSC.

Suspended Sediment Load Calculation

Estimates of suspended sediment loads that were generated from the construction events were calculated using Equation 2 (Meals et al., 2013). The time interval encompassed the period from when a construction event began to when it ended. The summation of these instantaneous load values represents the total suspended sediment load generated by specific construction events at each transect.

$$Suspended\ Sediment\ Load = k \sum_{i=1}^{n} SSC_i Q_i \Delta t \qquad \text{(Eq. 2)}$$

Where:
k = unit conversion factor.
SSC_i = suspended sediment concentration.

Q_i = streamflow rate.
Δt = time interval.

To estimate the amount of sediment that was mobilized from each construction event and theoretically deposited between each transect, the downstream load was subtracted from the upstream load (e.g., D2–D3, D3–D4, and so on). This difference was then divided by the distance between each transect to calculate the normalized sediment load. To isolate the effects related to construction activities, the average turbidity levels measured at D1 were also subtracted from the downstream data prior to conversion to sediment load. Because of this subtraction and the natural variability in background (or naturally occurring) turbidity levels between transects, a negative sediment load was calculated for some transects. In these instances, the sediment load was set equal to zero and interpreted as having no increase in sediment load relative to background levels. This normalization allowed for direct comparisons between transects. Although actual sediment deposition was not directly measured, these values suggest the amount of sediment loss in each transect. These values should not be confused with sedimentation rates because they do not account for particle size, settling velocity, turbulence, or other factors that influence sedimentation rates in open channel flow. Instead, these calculations utilize a simple mass balance principle based on turbidity measurements from the D2 transect at the downstream boundary of the construction area.

RESULTS AND DISCUSSION

The results are considered across five areas:

- Relationship of SSC to turbidity.
- Turbidity findings.
- Sediment loads associated with construction events.
- Recovery time.
- Implications of turbidity and sediment loads for freshwater mussel impacts.

Relationship of Suspended Sediment Concentration to Turbidity

Because literature on freshwater aquatic species commonly reports sediment thresholds as SSC or total suspended solids, turbidity measurements from this study (in FNU) were converted to SSC values to allow comparison with research on mussel impacts. Figure 6 illustrates the SSC versus turbidity regression analyses conducted for each site. Because turbidity shows a strong linear relationship with SSC, explaining more than 82% of the variation in SSC at Site 1 and more than 90% at Site, 2, using SSC to report results is appropriate.

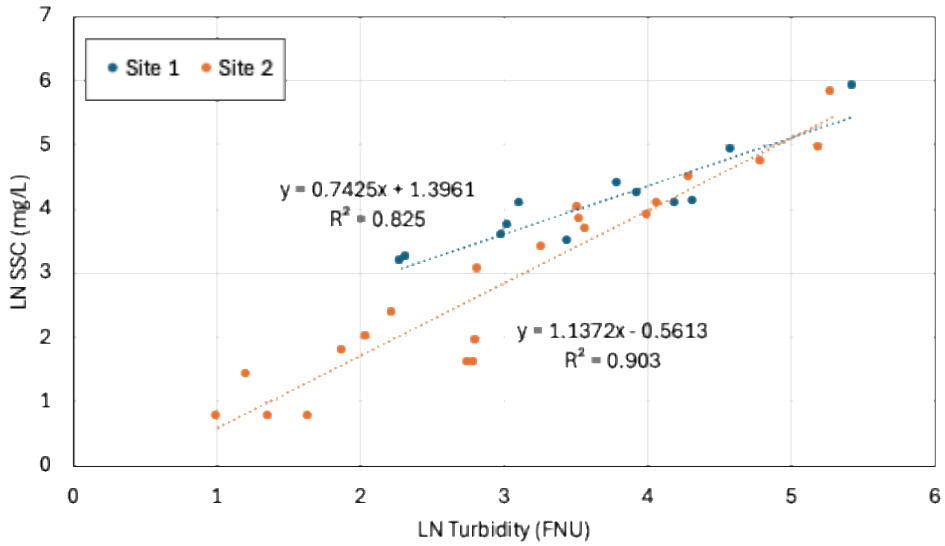


Figure 6. SSC versus Turbidity for Sites 1 and 2. FNU = Formazin Nephelometric Units; LN = natural log; SSC = suspended sediment concentration.

Turbidity Findings

Distinct spikes associated with each construction event were evident in the turbidity data, making construction impacts easily distinguishable from background conditions (Figure 7). Throughout this report, background levels refer to turbidity values outside these distinct windows and upstream turbidity values recorded at D1.

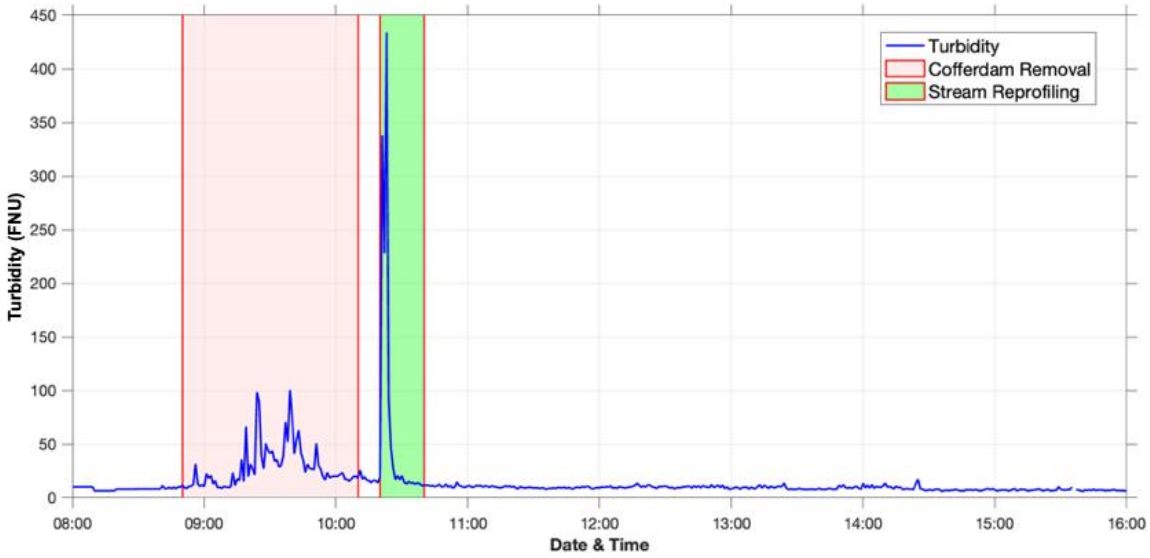


Figure 7. Turbidity Data Collected at Transect D2 during Removal of the West Cofferdam at Site 1 Illustrating Distinct Peaks during Construction Events. FNU = Formazin Nephelometric Units.

Site 1

Flow rates in the stream were relatively constant across each of the in-stream construction events, with the exception of the installation of the east cofferdam, where the flow

rate was more than double that of the other events (Table 3 3). In addition, the installation of the east cofferdam took the longest amount of time to complete. Although this event generated a negligible increase in downstream turbidity, the elevated flow rate and long duration had a significant effect on the sediment load the event released.

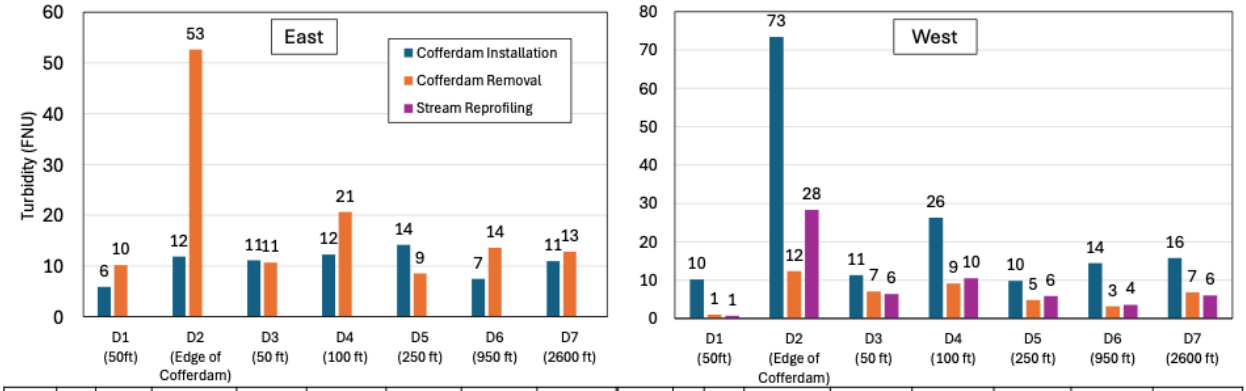
Table 3. Average Stream Discharge during Each Cofferdam-Related Construction Event at Site 1

Event	East Cofferdam Installation	East Cofferdam Removal	West Cofferdam Installation	West Cofferdam Removal	Stream Reprofiling
Average Discharge (cfs)	17	6	5.5	6.5	6.5
Duration (min)	980	320	490	82	20
Date	2/16/24 & 2/19/24	4/8/24	4/9/24	5/17/24	5/17/24

cfs = cubic feet per second.

In the monitored time periods before and after each construction event, turbidity levels remained relatively stable, except for precipitation events. Turbidity findings suggest that the sheet piles were effective at preventing stream water from exiting the excavation area. In addition, while operating continuously, discharge from the dewatering operation was effectively directed away from the stream and infiltrated into the surrounding soil for the duration of the construction project.

Figure 8 depicts the average turbidity levels from the three sensors at each transect during each construction event. The accompanying table lists the maximum and minimum turbidity values across all sensors at each transect. Appendix Table A1 provides these values converted to SSC. When reviewing figures that depict turbidity and SSC, it is important to keep in mind that extremely high, short-lived turbidity values occurred both during and outside construction events, and these values likely reflected isolated instances of sensor fouling (e.g., temporary obstruction by debris, such as a leaf). Therefore, the average values provide a more accurate representation of turbidity and associated SSC conditions.



		D1 (50ft)	D2 (Edge of Cofferdam)	D3 (50 ft)	D4 (100 ft)	D5 (250 ft)	D6 (950 ft)	D7 (2600 ft)
Install	Max	11	17 (C)	230 (L)	79 (L)	203 (R)	37 (C)	24 (L)
	Min	4	4.3 (L)	4 (C)	3 (R)	3 (C)	3 (L)	4 (C)
Removal	Max	14	177 (L)	28 (L)	45 (L)	21 (C)	28 (R)	24 (R)
	Min	57	7 (R)	4 (R)	3 (R)	3 (R)	4 (L)	5 (C)

		D1 (50ft)	D2 (Edge of Cofferdam)	D3 (50 ft)	D4 (100 ft)	D5 (250 ft)	D6 (950 ft)	D7 (2600 ft)
Install	Max	2834	238 (L)	48 (R)	78 (L)	44 (C)	39 (R)	36 (R)
	Min	5	10 (R)	4 (R)	0.3 (R)	4 (R)	4 (L)	6 (C)
Removal	Max	2	157 (R)	17 (R)	20 (C)	11 (C)	10 (C)	5 (R)
	Min	0.02	6 (C)	4 (L)	2 (L)	1 (R)	5 (C)	2(L)
Reprofile	Max	2	434 (R)	10 (R)	25 (C)	17 (C)	8 (C)	9 (C)
	Min	0.03	8 (L)	4 (L)	2 (L)	2 (R)	1 (R)	4 (R)

Figure 8. Site 1 Average Turbidity Measurements Recorded East and West Cofferdam Installation and Removal and West Bank Stream Reprofiling. Tables below each chart provide the maximum and minimum turbidity values recorded at each transect and the specific sensor. C = center; D1–D7 = designated monitoring transects; FNU = Formazin Nephelometric Units; L = bank left; Max = maximum; Min = minimum; R = bank right.

Because of an equipment malfunction, turbidity data collected at transect D1 during the removal of the east cofferdam and installation of the west cofferdam were not used for the analysis. The D1 data in Figure 8 reflect D1 data collected 1 and 2 days prior to the removal of the east cofferdam and the installation of the west cofferdam, respectively.

As Figure 8 illustrates, a significant spike in average turbidity occurred at D2, ranging from 12.3 to 73.4 FNU. The greatest turbidity increases were associated with the removal and installation of the east and west cofferdams, respectively, with a maximum turbidity level at D2 of 177 FNU during the removal of the east cofferdam and 238 FNU during the installation of the west cofferdam. Based on turbidity values associated with the east cofferdam construction events, where the cofferdam removal generated greater turbidity values than its installation, it was assumed that the same would be true for the west cofferdam. However, as Figure 8 shows, the reverse occurred (i.e., installation of the west cofferdam generated greater turbidity levels than its removal). Because the same sheet piles were used on both sides of the stream, this observation could be a result of residual soil washing off the sheets during installation.

After the removal of the west cofferdam, a mound of soil was present on the streambed where the cofferdam had once been. This material had accumulated on both sides of the sheet piles during construction and was not observed during the removal of the east cofferdam (Figure 9). Once the west cofferdam had been removed, an excavator was used to reprofile this area and return the channel to its original shape. This streambed reprofiling generated a significant plume of sediment, with average turbidity levels of more than 28 FNU at transect D2 and maximum levels reaching up to 434 FNU along the right side of the stream (Figure 8 8). It is likely that a similar accumulation of material was present on the east side prior to the placement of riprap, but as Figure 99 (left) shows, riprap was placed much closer to the east cofferdam prior to removal, covering any accumulated sediment. This riprap placement not only likely slowed the release of sediment-laden water but also eliminated the need for streambed reprofiling.

Although these in-stream activities significantly increased turbidities compared with upstream conditions (an average increase between 87 and 92%), turbidity levels returned to upstream levels by the time the water reached D4 (100 feet downstream). At D4, turbidity levels were 9.10 to 26.25 FNU, approximately a 62% reduction from D2 levels.

Although turbidity levels downstream of the construction site were less than those measured upstream at D1, these comparisons do not account for local ambient conditions present at each monitoring point. Post-construction monitoring indicated that background turbidity can vary significantly from point to point. For example, turbidity levels at D1, D2, D3, D4, D5, D6, and D7 were 6.1, 19.4, 113.6, 7.5, 7.0, 67.0, and 7.9 FNU, respectively, 10 days prior to the start of cofferdam installation, and 6.6, 5.2, 12.1, 4.6, 24.0, 1.7, and 10.6 FNU, respectively, 3 days after completion of cofferdam removal. This local variability was also present before construction began and indicates that local ambient conditions differ by stream location, and downstream turbidity levels would not necessarily match D1 levels even in the absence of construction activities.

Figure 9. Visible Sediment Plumes during the Removal of the East (left) and West (right) Cofferdams at Site 1. Riprap was placed against the east cofferdam and on top of accumulated sediment, potentially slowing its release and eliminating the need for streambed reprofiling, whereas a space was left between the riprap and west cofferdam (indicated by the yellow arrow).

Site 2

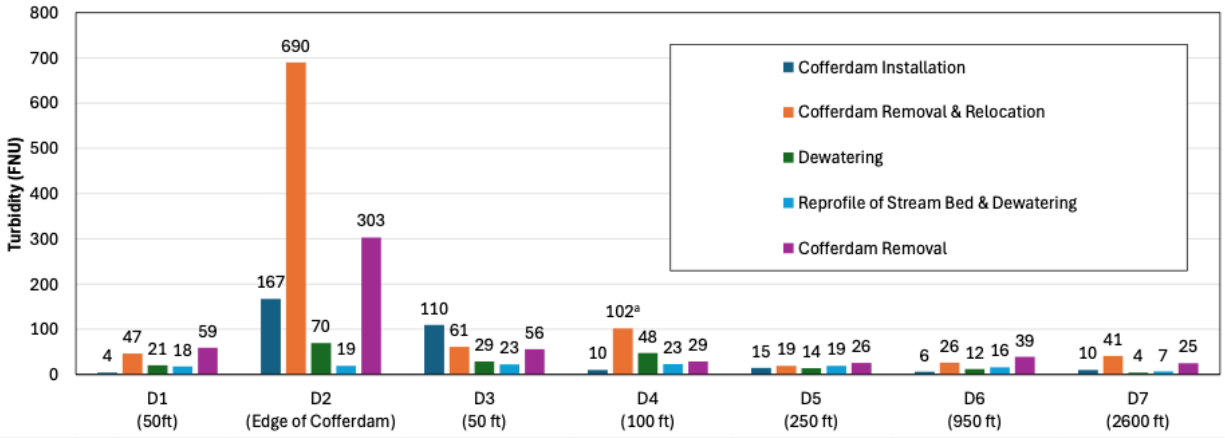
The cofferdam used at Site 2 consisted of sandbags and Jersey barriers wrapped in plastic sheeting. The cofferdam was moved from one bank of the stream to the other within a 4-hour (240-minute) period and was therefore treated as a single "cofferdam removal and relocation" event for the analyses. As Table 44 shows, stream discharge remained relatively constant during these construction events, except for the final cofferdam removal, where lower flow rates were observed.

Table 4. Average Stream Discharge during Each Construction Event and Construction Event Date and Duration at Site 2

Event	Cofferdam Installation	Cofferdam Removal and Relocation	Dewatering	Reprofile of Streambed and Dewatering	Cofferdam Removal
Average Discharge (cfs)	1.7	1.4	1.4	1.8	0.7
Duration (min)	390	240	420	300	180
Date	4/22/25	4/29/25	4/30/25	5/5/25	5/6/25

cfs = cubic feet per second.

Figure 10 presents average turbidity levels measured during each of the five construction events, including maximum and minimum levels. Appendix Table A1 provides a table of these values converted to SSC.



Install	max	13	3324 (L)	2853 (R)	33.6 (C)	49 (R)	41 (C)	246 (L)
	min	2	0.807 (L)	2 (L)	3 (L)	3 (R)	3 (C)	2 (C)
Remove & Relocate	max	150	4000 (L)	1258 (R)	302 (R)	65 (R)	104 (R)	227 (R)
	min	15	11 (L)	10 (L)	4 (L)	4 (R)	3 (L)	6 (L)
Dewatering	max	105	1643 (C)	163 (L)	271 (R)	44 (L)	222 (R)	61 (L)
	min	5	3 (R)	6 (R)	6 (R)	5 (C)	3 (R)	2 (R)
Reprofile & Dewatering	max	68	110 (L)	102 (C)	59 (L)	34 (C)	63 (C)	14 (C)
	min	12	7 (R)	6 (R)	10 (R)	8 (R)	5 (L)	4 (R)
Removal	max	132	603 (R)	887 (C)	59 (C)	43 (R)	148 (R)	637 (C)
	min	30	9 (C)	24 (C)	15 (C)	13 (L)	5 (L)	4 (R)

Figure 10. Site 2 Average Turbidity Measurements Recorded during the Five In-Stream Construction Events. The table provides the maximum and minimum turbidity values recorded at each transect for each event. [a] Evidence of biofouling of the D4 right bank sensor, which was not evident on the other two sensors, artificially increased turbidity readings during this cofferdam removal and relocation event. Omitting this sensor from the average turbidity calculation results in 24 FNU. C = center; D1–D7 = designated monitoring transects; FNU = Formazin Nephelometric Units; L = bank left; max = maximum; min = minimum; R = bank right.

The highest turbidity levels occurred at D2 during the relocation and removal of the first cofferdam and the removal of the second cofferdam, averaging 690 and 303 FNU, respectively. However, compared with background (D1) levels, cofferdam installation produced the largest increase, with a nearly 4,075% increase at D2. Turbidity levels returned to background (D1) levels before reaching the D4 transect for all construction events, except for the cofferdam removal and relocation event, where turbidity levels stabilized by D5. Evidence of biofouling of the D4 bank right sensor, which was not evident on the other two D4 sensors, artificially increased turbidity readings during this event. Omitting this sensor from the average turbidity calculation results in 24 FNU.

Turbidity increased 49 FNU at D2 relative to D1 during a dewatering period. However, as noted previously, the effluent from the dewatering operation was observed discharging back into the stream between D2 and D3. These results indicate that sediment was released from the cofferdam during this period.

Sediment Loads Associated with Construction Events

Sediment loads for each construction event were calculated using flow rate, SSC, and duration of each event. As Equation 2 explains, stream flow rate and event duration are multiplying factors in the sediment load calculation. Because of this factor, as flow rate and duration increase, so does the sediment load. This relationship contrasts with the effect of flow

rate or duration on turbidity and SSC values, where an increase in flow rate can reduce turbidity and SSC, and duration has no effect on turbidity or SSC.

Table 55 provides sediment loads measured at D1 and D2 for all construction activities. The differences between D1 and D2 sediment loads ranged from 3 to 636 pounds. Gilbert et al. (2021) reported a similar average sediment load value (871 lb.) associated with the construction of temporary gravel stream crossings, which ranged from 159 to 1,830 pounds. It should be noted that the sizes of the streams monitored by Gilbert et al. (2021) were significantly smaller than those monitored here, with discharges ranging from 0.46 to 9.2 cfs.

Table 5. Total Sediment Loads Calculated from Turbidity Data Upstream (D1) and Immediately Downstream (D2) of Construction Events

Site	Construction Event	Total Sediment Load (pounds)		
		D1	D2	Contribution from Construction Event (D1–D2)
1	East Cofferdam Installation	417	757	340
	East Cofferdam Removal	61	239	178
	West Cofferdam Installation	68	460	391
	West Cofferdam Removal	10	48	39
	West Reprofiling of Streambed	0.9	11	10
2	Cofferdam Installation	11	413	402
	Cofferdam Removal and Relocation	65	701	636
	Dewatering	49	173	123
	Reprofile of Streambed and Dewatering	40	43	3
	Cofferdam Removal	32	149	117

Normalized Sediment Loads

Table 5Table 5 lists the total sediment loads for each construction event, and Figure 11 illustrates how those loads were distributed across the downstream transects. Because the distances between transects were variable, sediment loads were normalized per foot of transect length for each construction event. This measure allowed for a comparison of the downstream changes in sediment load. These calculations approximate potential deposition of sediment in each transect, although actual sediment deposition was not determined.

Figure 11 also includes the maximum normalized sediment load among transects for each construction event. It is important to consider the maximum normalized sediment load provided in Figure 11 for each transect when interpreting results. For example, for the cofferdam installation at Site 1, the highest normalized load occurred in the transect spanning 250 to 950 feet downstream, although the magnitude was relatively low (0.45 lb/ft). Similarly, load calculations for the streambed reprofiling at Site 2 resulted in all the sediment load occurring within 100 to 250 feet downstream, but the load was only 0.06 lb/ft. These small load values should be viewed in context because they may result from sensor error or natural fluctuations in turbidity rather than meaningful differences in sediment transport. In contrast, for all construction events with high sediment loads, more than 75% of the load occurred in the first 50 feet downstream. For example, the site cofferdam removal and location had a maximum normalized load of 12.6 pounds per foot within 50 feet of the work area.

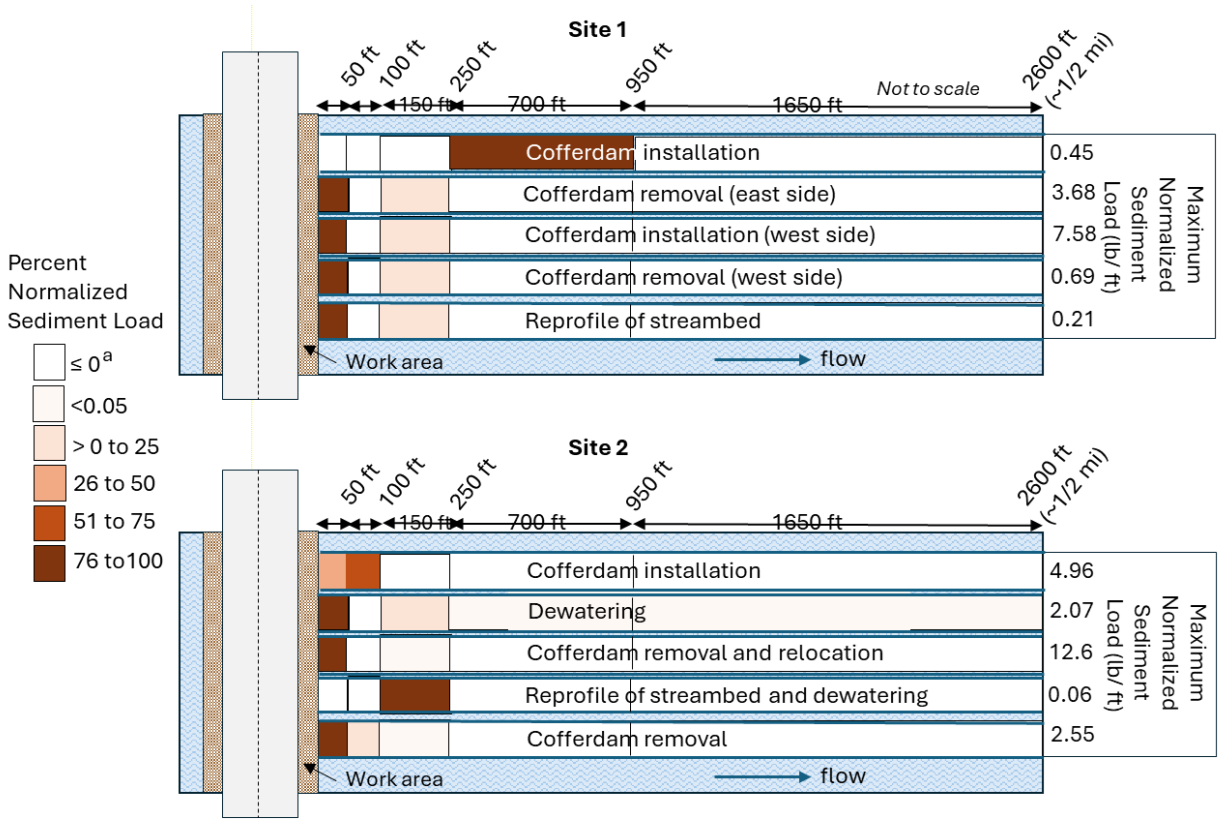


Figure 11. Percent Normalized Sediment Loads Calculated for each Construction Event and Each Event's Maximum Normalized Sediment Load among Downstream Transects (lb/ft). Maximum normalized sediment load values on the right indicate the highest sediment load among the downstream transect intervals. [a] Calculations resulting in values less than 0 were set to 0 and interpreted as no increase in sediment load relative to background.

Site 2's cofferdam removal and relocation had the highest sediment load, most of which (12.6 lb/ft) occurred within 50 feet downstream of construction (Figure 11 and Table 6). Although this event did not have the longest duration or discharge relative to the other events (Table 6 6), it did have the highest average SSC recorded at transect D2 at 784 mg/L (Appendix Table A1). Although sediment load is the product of these three values, these results indicate that elevated SSC concentrations were the dominant factor contributing to increased sediment loads from this event. Due to the nature of the sandbag and Jersey barrier cofferdams used at this site, this construction event involved the longest duration of streambed disturbance because it required personnel to be in the stream to move sandbags and guide the placement of Jersey barriers. A similar study found that in-stream construction activities that involve significant "shuffling" of streambed material typically generate the greatest sediment inputs (Gilbert et al., 2021). In that study, the authors found that the excavation and stabilization of bed material during the construction of temporary stream crossings caused more than 30% of sediment inputs (Gilbert et al., 2021).

The second and third highest normalized sediment loads occurred during the west cofferdam installation at Site 1 (7.58 lb/ft) and the cofferdam installation at Site 2 (4.96 lb/ft). Both events involved longer durations (490 and 390 minutes, respectively) and elevated average turbidity levels at transect D2 (73 and 167 FNU, respectively).

Table 6. Site 1 and Site 2 Normalized Sediment Load, Average Discharge, and Duration for Each Construction Event

Site	Event	Average Turbidity (FNU)	Normalized Load (lb/ft)	Average Flow Rate (cfs)	Duration (min)
Site 1 at D2	West Install	73	8.25	5.5	490
	East Removal	53	4.04	6	320
	West Removal	12	0.74	6.5	82
	East Install	7	0.45	17	980
	West Reprofile	28	0.24	6.5	20
Site 2 at D2	Cofferdam Removal and Relocation	690	13.3	1.4	240
	Cofferdam Installation	167	7.73	1.7	390
	Cofferdam Removal	303	2.86	0.7	180
	Dewatering	70	7.63	1.4	420
	Reprofiling and Dewatering	19	0.08	1.8	300

cfs = cubic feet per second; FNU = Formazin Nephelometric Units.

In contrast, the streambed reprofiling at Site 1 generated significant spikes in turbidity (up to 434 FNU), but its short, 20-minute duration limited the overall sediment load, keeping it below that of longer construction events. Similarly, the average turbidity at D2 during Site 2's cofferdam removal equaled 303 FNU. However, due to its short duration (180 minutes) and lower flow rate (0.7 cfs) the event produced the third lowest normalized sediment load recorded at the site (2.86 lb/ft). This outcome is in line with the results from Gilbert et al. (2021), which found that sediment inputs from the construction of temporary stream crossings were minimized when working in low-flow conditions (Gilbert et al., 2021).

These results highlight the importance of managing not only the intensity (in terms of streambed disturbance) of the in-stream work but also the duration. The results indicate that cofferdam installation can be the primary contributor to increased construction-related sediment loads due to the additional time needed for proper installation. The results also suggest that increases in sediment loads could be mitigated by conducting in-stream construction events during periods of low flow when practical.

The Effect of Cofferdam Type on Normalized Sediment Load

Although both evaluated cofferdams effectively achieved the same goal of creating a dry work area for construction crews, their effects on normalized sediment loads differed during installation and removal. Activities related to the installation and removal of the sheet pile cofferdams at Site 1 generated approximately 58% less normalized sediment load than those related to the installation and removal of Site 2's sandbag and Jersey barrier cofferdam. Although installation and removal at Site 1 required substantially more time (1,892 minutes compared with 810 minutes at Site 2) and occurred in a larger stream, the sandbag and Jersey barrier cofferdam at Site 2 still produced greater sediment disturbance. This result indicates that the cofferdam type and associated streambed disturbance played a more significant role with regard to sediment load than stream size or construction duration alone.

Comparison of Sediment Load to Precipitation Events

Precipitation causes runoff, which leads to the erosion and mobilization of soil particles from the surrounding drainage area (Giménez et al., 2012; Mather and Johnson, 2015; Rodríguez-Blanco et al., 2010). Because precipitation events cause an increase in turbidity and sediment load in receiving streams (Alkhadher et al., 2025; Mather and Johnson, 2015), they were compared with construction activities to evaluate their influence on sediment load.

The evaluated precipitation events at Site 1 occurred during the construction of the east abutment on March 23, 2024, and at Site 2 following completion of the project on May 13, 2025 (Table7). Calculations of precipitation-related sediment loads for each site were calculated using the same time duration of the construction events that generated the greatest total sediment loads (i.e., 980 minutes at Site 1 and 420 minutes at Site 2). Sediment loads (lbs.) were then calculated using the data within these time windows, centered on the peak sediment load. This adjustment enabled the direct comparison between these precipitation-related sediment loads and those from construction events. The precipitation event at Site 1 occurred while the east cofferdam was installed. However, as Figure 12 demonstrates, the precipitation event that occurred during the east cofferdam installation did not lead to increased sediment loads during the west cofferdam installation.

Table 7. Characteristics of Precipitation Events during the Monitoring Periods at Site 1 and Site 2

Characteristic	Site 1	Site 2
Date	3/23/24	5/13/25
Precipitation depth (inches/24 hours)	1.8	1.6
Average flow rate (cfs)	13.5	61
Peak flow rate (cfs)	18	1259

cfs = cubic feet per second.

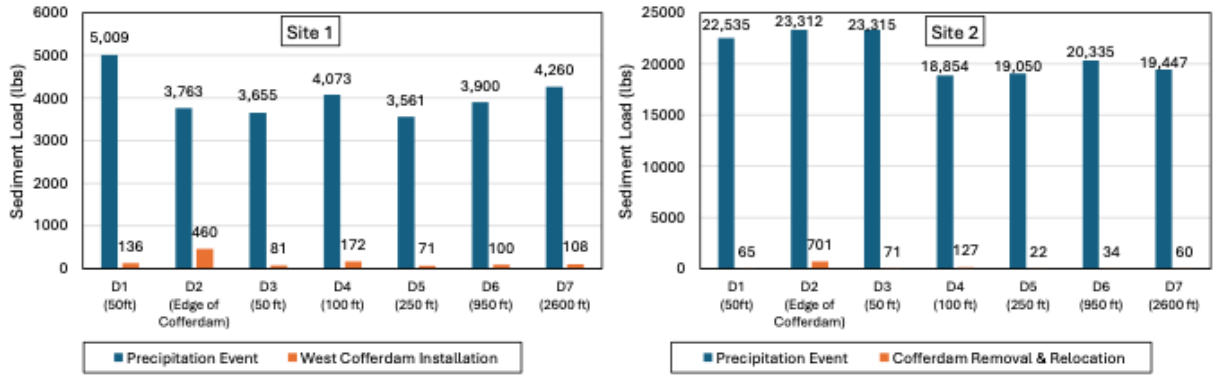


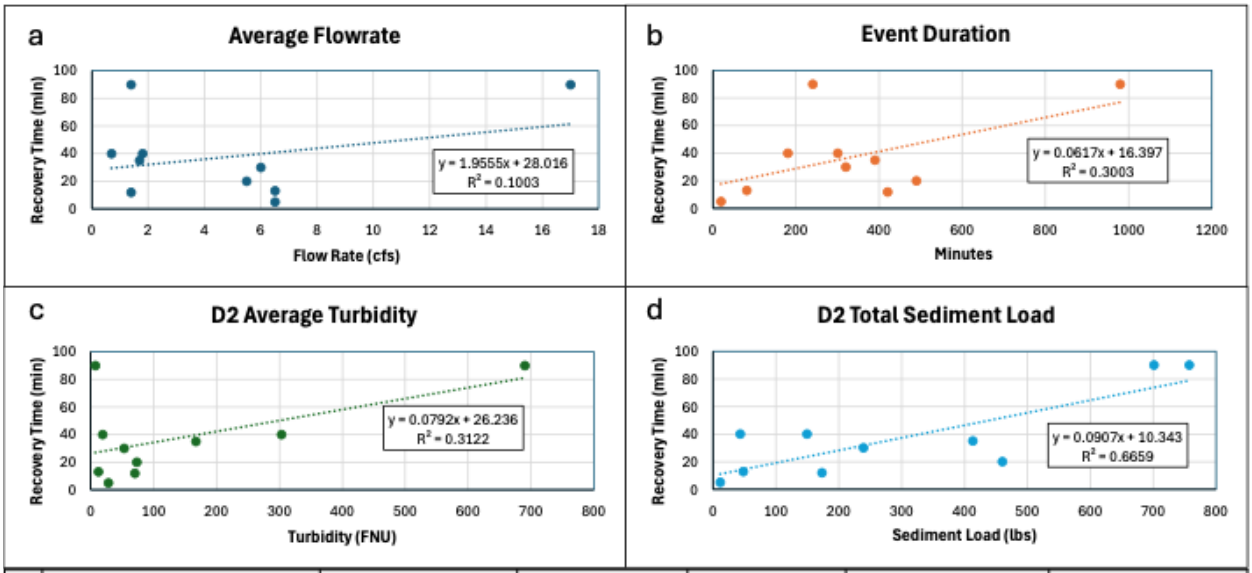
Figure 12. Sediment Loads Associated with Precipitation Events Compared with the Construction Events that Produced the Highest Loads

Sediment loads from precipitation events were one to three orders of magnitude higher than loads from construction events (e.g., Figure 12 at D4 shows 127 lbs. for cofferdam removal and relocation compared with 18,854 lbs. for a precipitation event). Although construction-related loads at Site 1 and Site 2 measured at D2 equaled 460 and 701 pounds, respectively, those generated from precipitation events reached 3,763 and 23,312 pounds, respectively. These differences between precipitation-driven and cofferdam-related sediment loads were also

observed upstream (D1), indicating that the construction site was not a source of sediment that was mobilized and carried downstream during precipitation events.

Recovery Time

Recovery time is the amount of time required for turbidity to return to pre-event levels from the event's peak (see Appendix Figure A4). Figure 13 (bottom) shows that recovery times at D2 ranged from 5 to 90 minutes across the 10 construction events monitored. Figure 13 (top) regresses recovery time to average flow rate, event duration, average turbidity, and total sediment load and indicates that recovery time is most dependent on the total sediment load (R^2 = of 0.67). Although this analysis is somewhat limited by the number of events (n = 10), clearly reducing sediment loads has the greatest influence on shortening recovery time.



Site	Event	Recovery Time (min)	Average Flowrate (cfs)	Event Duration (min)	D2 Average Turbidity (FNU)	Total Sediment Load at D2
1	East Cofferdam Installation	90	17	980	7	757
	East Cofferdam Removal	30	6	320	53	239
	West Cofferdam Installation	20	5.5	490	73	460
	West Cofferdam Removal	13	6.5	82	12	48
	Stream Reprofiling	5	6.5	20	28	11
2	Cofferdam Installation	35	1.7	390	167	413
	Cofferdam Removal & Relocation	90	1.4	240	690	701
	Dewatering	12	1.4	420	70	173
	Reprofile of Stream Bed & Dewatering	40	1.8	300	19	43
	Cofferdam Removal	40	0.7	180	303	149

Figure 13. Scatterplots of Recovery Time to Background Turbidity Levels versus: (a) Average Flow Rate; (b) Event Duration; (c) Average Turbidity at D2; and (d) Total Sediment Load at D2 for 10 Monitored In-Stream Construction Events. Each panel shows linear regressions and coefficients of determination. cfs = cubic feet per second; FNU = Formazin Nephelometric Units.

These results indicate that reducing cofferdam installation and removal duration, conducting them during low-flow conditions, and mitigating sediment disturbance are means of shortening recovery times. These methods should be considered together with the goal of reducing sediment loads generated by the event. For example, if additional labor or equipment can significantly shorten the installation time, installing the cofferdam during moderate flow

conditions would have a greater effect on sediment load reduction than waiting for low-flow conditions and extending the overall duration of the work. The tradeoffs between these three conditions can be site- and resource-dependent.

Implications of Turbidity and Sediment Loads for Freshwater Mussel Impacts

The turbidity and sediment load results from this study provide a clearer understanding of how certain in-stream construction disturbances may influence aquatic species habitat. Although this study focused on freshwater mussel habitat, the findings are likely applicable to the habitats of a range of freshwater species. Literature indicates that although mussels can tolerate high sediment concentrations for short periods (Zhu et al., 2023), sustained and repeated exposures adversely affect freshwater mussels (Gascho-Landis et al., 2013; Gascho-Landis and Stoeckel, 2015). At both sites evaluated in this study, elevated turbidity levels and calculated sediment loads were limited to distances well below the abbreviated mussel survey requirement of 400 meters (1,312 feet) and the full survey requirement of 800 meters (2,625 feet). Turbidity increases were highly localized and short term, with elevated concentrations consistently returning to background levels within 50 to 100 feet downstream of the cofferdams.

Turbidity spikes immediately downstream of the construction (D2) occasionally reached several hundred FNU, particularly for sandbag-Jersey barrier cofferdams, but the short duration of these events limited the magnitude of the sediment loads. Sediment load calculations suggest that most of the sediment mobilized from the evaluated construction activities is likely deposited within the first 50 feet downstream. These short-term disturbances contrasted with precipitation events, where normalized sediment loads reached more than an order of magnitude higher than loads from construction events (e.g., 466 versus 14 lb/ft at Site 2 or 75 versus 9 lb/ft at Site 1). This comparison suggests that sediment mobilized during cofferdam installation and removal is small relative to sediment loads generated during storm events. These findings, combined with the limited extent of elevated turbidity and the fast recovery times (5 minutes to 1.5 hours), suggest that the distance where the effects to mussels need to be assessed may be shorter than previously considered for comparable projects and site conditions.

Summary of Findings

The following summarizes the key findings from the study:

- Turbidity increases were consistently greatest immediately downstream of the cofferdam (D2), with a maximum of 238 FNU (178 mg/L) at Site 1 during cofferdam removal and 3,324 FNU (3779.5 mg/L) at Site 2 during cofferdam installation.

- Elevated turbidity levels reduced rapidly downstream, with turbidity comparable with background levels beyond distances of 50 to 100 feet.

- Background turbidity varied substantially among transects, indicating that downstream values should not be directly compared with upstream D1 values without considering ambient variability.

- Sediment loads attributable to construction events ranged from 3 to 636 pounds, and for most construction events, more than 75% of the sediment load occurred in the first 50 feet downstream. Cofferdam removal and location at Site 2 was associated with the highest normalized sediment load (13.3 lb/ft).

- Findings specific to cofferdam type and construction activities that influenced turbidity and associated sediment loads include the following:
  - Sandbag-Jersey barrier cofferdams generated higher turbidity and sediment loads than sheet pile cofferdams, likely because of greater streambed disturbance.
  - Because construction duration, stream discharge, and turbidity drive total sediment load, cofferdam installation and removal or relocation, which required a relatively long timeframe that prolonged streambed disturbance, was the primary contributor to increased construction-related sediment loads.
  - Activities with a comparatively shorter duration but higher turbidity, such as streambed reprofiling, produced relatively low sediment loads.
  - Placement of riprap directly against the sheet pile cofferdam, rather than leaving a gap where water can flow, appeared to reduce the average turbidity during cofferdam removal, likely because it slowed the release of sediment.

- Recovery times 50 feet downstream from the cofferdams ranged from 5 to 90 minutes across the 10 construction events monitored.

- Precipitation-related sediment loads were typically 10 to 100 times larger than construction-related loads.

CONCLUSIONS

- *For construction work that involves using sheet pile or sandbag-Jersey barrier cofferdams, the findings suggest that sediment mobilized from construction activities is likely deposited within 100 feet downstream of the work site.*

- *Cofferdam type influenced sediment release, with sheet pile cofferdams resulting in smaller turbidity and associated sediment loads than sandbag-Jersey barrier cofferdams*.

- *Effective strategies to reduce recovery times include shortening disturbance duration, scheduling in-stream work during lower flow periods, and using construction practices that minimize sediment release*.

- *Sediment loads generated by in-stream construction activities that use appropriate controls and best management practices are small relative to those produced by storm events*.

- *The limited extent of sediment transport and the rapid recovery of turbidity to background levels observed in this study, particularly relative to turbidity generated by precipitation events, suggest that the distance where the effects to mussels need to be assessed may be shorter than previously considered for comparable projects and site conditions.*

RECOMMENDATIONS

1. *VDOT's Environmental Division should share this report with the USFWS Virginia Field Office and VDWR aquatic program staff to support an agency evaluation of area-of-impact determinations and associated survey requirements for projects comparable with those examined in this study.*

IMPLEMENTATION AND BENEFITS

The researchers and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and determine the benefits of doing so. This process is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

Regarding Recommendation 1, VDOT's Environmental Division will coordinate with the USFWS Virginia Field Office and VDWR within 6 months of the date of the publication of this report to discuss how the study findings can inform reviews of VDOT construction projects involving in-stream activities.

Benefits

This study provides findings to inform evidence-based protections for sensitive aquatic species. The findings herein regarding the intensity, duration, and transport distances of sediment associated with the construction and removal of cofferdams may benefit VDOT, USFWS, and VDWR during project reviews and consultations in at least two ways:

- The study results can inform decisions regarding affected area determinations and distance requirements for habitat assessments and surveys for protected mussel populations. For example, based on the results of this study, the area reviewed by USFWS staff for certain projects might be less than the larger distances that are currently used.

- Study outcomes may also lead to more informed Section 7 consultations with USFWS and VDWR-conducted reviews, thereby saving VDOT staff time and costs associated with coordination and survey work. For instance, consultations might consider the activities that reduce sediment transport shown in this study, such as the use of sheet pile cofferdams rather than sandbag-Jersey barrier cofferdams where possible. In addition, although construction during low-flow conditions reduces turbidity compared with construction during moderate flow conditions, the use of additional staff to reduce the

installation time for cofferdams can be more effective than waiting for low-flow conditions.

ACKNOWLEDGMENTS

This study benefited from the insight and feedback provided by the individuals who served on the technical review panel for this study: VDOT staff Kerri Nicholas (project champion), Beau Hoyt, Susan Alexander, Nick Gerardi, and John Miller; USFWS staff Lauren Mastro, Jennifer Stanhope, and Emily Argo; and John Jastram with USGS. Appreciation is also extended to Mike Fitch, John Miller, and Kevin Wright for their support and feedback. The field evaluations would not have been possible without the help of VDOT and contract staff: Timmy Drinker, David Fortune, Kevin Bradley, John Chiles, Rick Crofford, and William Hamblet. The authors would also like to thank the University of Virginia's Teresa Culver and the many Virginia Transportation Research Council engineering technicians and interns who supported this project: Graham Frazier, Paxton Gunn, Emma Weinstein, Rebecca Danese, and Isabel Xiao.

REFERENCES

Alkhadher, S.A.A., Sidek, L.M., Khan, M.S., Al-Habsi, M., and Kurniawan, T. Seasonal Variations in Water Quality and Hydrological Dynamics in a Tropical Reservoir Driven by Rainfall, Runoff, and Anthropogenic Activities. *Nature*, Vol. 15, 2025. https://doi.org/10.1038/s41598-025-09808-z.

Foltz, R., Westfall, B., and Kopyscianski, B. *Turbidity Changes During Culvert to Bridge Upgrades*. RMRS-RN-54. U.S. Department of Agriculture, Fort Collins, CO, 2013. https://www.fs.usda.gov/rm/pubs/rmrs_rn054.pdf.

Gascho-Landis, A.M., Haag, W.R., and Stoeckel, J.A. High Suspended Solids as a Factor in Reproductive Failure of a Freshwater Mussel. *Freshwater Science*, Vol. 32, No. 1, 2013, pp. 70–81.

Gascho-Landis, A.M., and Stoeckel, J.A. Multi-stage Disruption of Freshwater Mussel Reproduction by High Suspended Solids in Short- and Long-term Brooders. *Freshwater Biology*, Vol. 61, No. 2, 2015, pp. 229–238.

Gilbert, K., Jutras, S., and Plamondon, A.P. Suspended Sediment Input from Crushed-stone Ford Construction on the Canadian Shield in Quebec. *Environmental Challenges*, Vol. 5, 2021. https://doi.org/10.1016/j.envc.2021.100388.

Giménez, R., Casalí, J., Grande, I., Díez, J., Campo, M.A., Álvarez-Mozos, J., and Goñi, M. Factors Controlling Sediment Export in a Small Agricultural Watershed in Navarre (Spain). *Agricultural Water Management*, Vol. 110, 2012, pp. 1–8.

Krstolic, J.L., Johnson, G.C., and Ostby, B.J.K. *Water Quality, Sediment Characteristics, Aquatic Habitat, Geomorphology, and Mussel Population Status of the Clinch River, Virginia and Tennessee, 2009–2011*. U.S. Geological Survey, Reston, VA, 2011.

Marsh-McBirney, Inc. *Flo-Mate Model 2000 Portable Flow Meter Installation and Operations Manual* (Rev D). Frederick, MD, 1990.

Mather, A., and Johnson, R.L. Event-Based Prediction of Stream Turbidity Using a Combined Cluster Analysis and Classification Tree Approach. *Journal of Hydrology*, Vol. 530, 2015, pp. 751–761.

Meals, D.W., Richards, R.P., and Dressing, S.A. *Pollutant Load Estimation for Water Quality Monitoring Projects.* Tech Notes 8. U.S. Environmental Protection Agency; Tetra Tech, Inc., Fairfax, VA, April 2013. https://www.epa.gov/polluted-runoff-nonpoint-source-pollution/nonpoint-source-monitoring-technical-notes.

Moyer, D., and Hyer, K. *Continuous Turbidity Monitoring in the Indian Creek Watershed, 2006–08*. Report 2009-5085. U.S. Geological Survey, Reston, VA, 2009. https://doi.org/10.3133/sir20095085.

Österling, M.E., Arvidsson, B.L., and Greenberg, L.A. Habitat Degradation and the Decline of the Threatened Mussel *Margaritifer margaritifera*: Influence of Turbidity and Sedimentation on the Mussel and its Host. *Journal of Applied Ecology*, Vol. 47, 2010, pp. 759–768.

Pugh, A.L., and Gill, A.C. *Effects of Culvert Construction on Streams and Macroinvertebrate Communities at Selected Sites in the East Gulf Coastal Plain of Alabama, 2010–19*. Report 2021-5096. U.S. Geological Survey, Reston, VA, 2021.

Reid, S.M., and Anderson, P.G. Effects of Sediment Released During Open-cut Pipeline Water Crossings. *Canadian Water Resources Journal*, Vol. 24, No. 3, 1999.

Rodríguez-Blanco, M.L., Taboada-Castro, M.M., Palleiro, L., and Taboada-Castro, M.T. Temporal Changes in Suspended Sediment Transport in an Atlantic Catchment, NW Spain. *Geomorphology*, Vol. 123, No. 1–2, 2010, pp. 181–188.

Uhrich, M.A., and Bragg, H.M. *Monitoring In-stream Turbidity to Estimate Continuous Suspended-Sediment Loads and Yield and Clay-Water Volumes in the Upper North Santiam River Basin, Oregon, 1998–2000*. U.S. Geological Survey, Salem, OR, 2003. https://pubs.usgs.gov/wri/WRI03-4098/.

U.S. Army Corps of Engineers. *Engineering and Design: Design of Sheet Pile Walls*. EM 1110-2-2504. Washington, DC, 1994.

U.S. Army Corps of Engineers. HEC-RAS River Analysis System. Version 6.5. Hydrologic Engineering Center, Davis, CA, 2024.

U.S. Department of Agriculture. Web Soil Survey. Natural Resource Conservation Service, 2019. https://websoilsurvey.nrcs.usda.gov/app/. Accessed January 24, 2024.

U.S. Fish and Wildlife Service and Virginia Department of Game and Inland Fisheries. Freshwater Mussel Guidelines for Virginia, 2018. https://dwr.virginia.gov/wp-content/uploads/media/Mussel-Survey-and-Relocation-Guidelines.pdf. Accessed April 13, 2026.

U.S. Fish and Wildlife Service. ESA Section 7 Consultation, 2022. https://www.fws.gov/service/esa-section-7-consultation. Accessed November 23, 2024.

Virginia Department of Transportation. *Road and Bridge Specifications*. Richmond, VA, 2020. VDOT_2020_RB_Specs_acc071522.pdf . Accessed November 23, 2020.

Virginia Department of Transportation. *State of Structures and Bridges*. Richmond, VA, 2022. https://www.vdot.virginia.gov/about/our-system/bridges-tunnels/state-structures-bridges/. Accessed November 23, 2022.

Virginia Department of Wildlife Resources. Freshwater Mussels, n.d. https://dwr.virginia.gov/wildlife/freshwater-mussels/. Accessed November 4, 2024.

Walsh, N., Neill, M., and Lucey, J. *River Sediment Studies in Relation to Juvenile Pearl Mussels and Salmonids*. EPA Report RR-230. U.S. Environmental Protection Agency, County Wexford, Ireland, 2012. https://www.epa.ie/publications/monitoring--assessment/freshwater--marine/EPA_River_Sediment_Studies.pdf.

Zhu, W., Kunz, J., Brunson, E., Barnhart, C., Brown, H., McMurray, S., Roberts, A., Shulse, C., Trauth, K., Wang, B., Steevens, J.A., and Deng, B. Impacts of Acute and Chronic Suspended Solids Exposure on Juvenile Freshwater Mussels. *Science of the Total Environment*, Vol. 905, 2023.

APPENDIX

Site 2 Stream Flow Data

Figure A1 shows stream rating curves for Site 2, and Figure A2 shows rating curves at each transect.

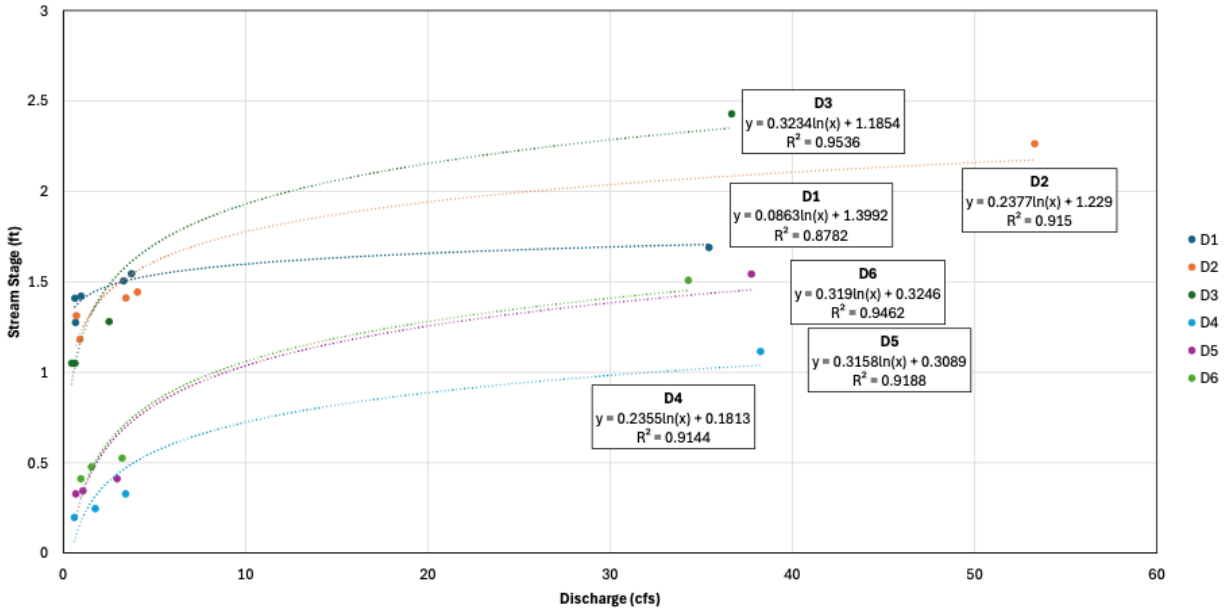


Figure A1. Site 2 Rating Curve Data, Including Logarithmic Regression and Coefficient of Determination. cfs = cubic feet per second.

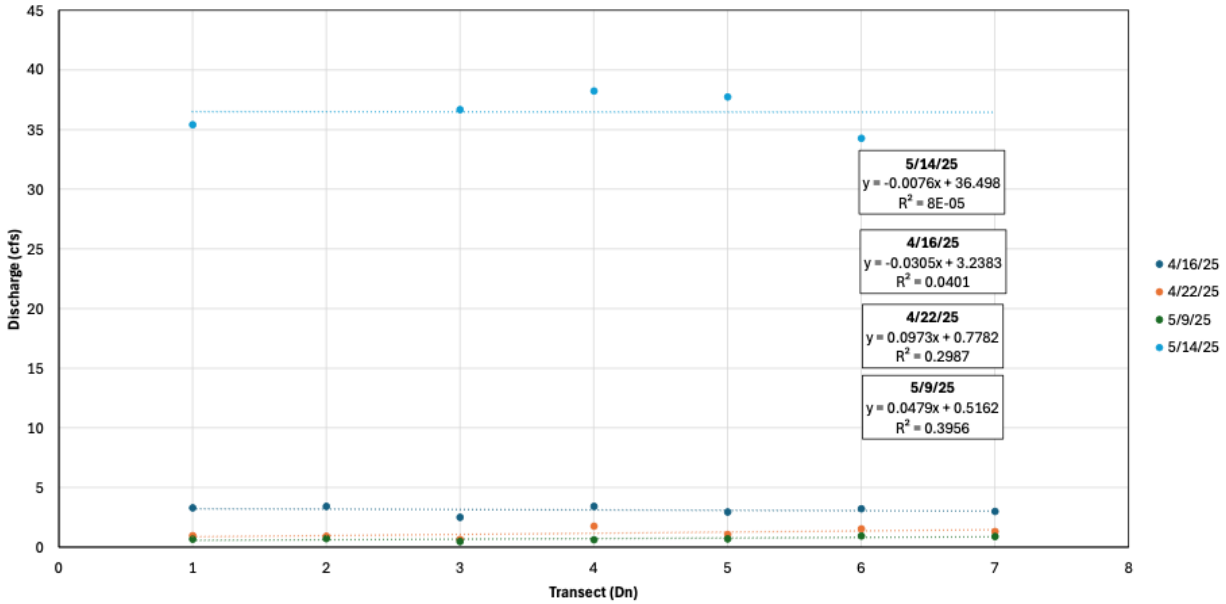


Figure A2. Comparison of Rating Curves Collected at Each Transect, Including Linear Regression and Coefficient of Determination. cfs = cubic feet per second.

Data Processing Procedure

Missing datapoints were filled either through linear interpolation or by averaging data from the other sensors at the same transect. Outliers were identified using a combination of a rate of change threshold and z-score at each datapoint. The rate of change threshold was set to 10 Formazin Nephelometric Units (FNU) per minute, where an outlier would be defined as a datapoint that is 10 FNU above or below the previous and following datapoint. Z-scores were calculated for each datapoint using a 15-minute interval and a threshold value of 4. These z-scores and rates of change were used together to identify outliers for middle and edge points as follows:

- Middle points: if z-score is greater than 4 and both previous and following datapoints are greater than 10 FNU.
- Edge points: if z-score is greater than 4 and the previous or following datapoint is greater than 10 FNU.

This approach provided enough sensitivity to identify rapid spikes in turbidity because of sensor fouling while preserving any short-term changes due to a release of turbid water from the construction site.

Following this cleaning process, the average of the three sensors at each transect was calculated for each minute. These values were then averaged for each transect, and differences between upstream and downstream turbidities were calculated. These differences provided an indication of the turbidity contribution of each construction event relative to upstream levels. The flowchart in Figure A3 depicts each step in this protocol.

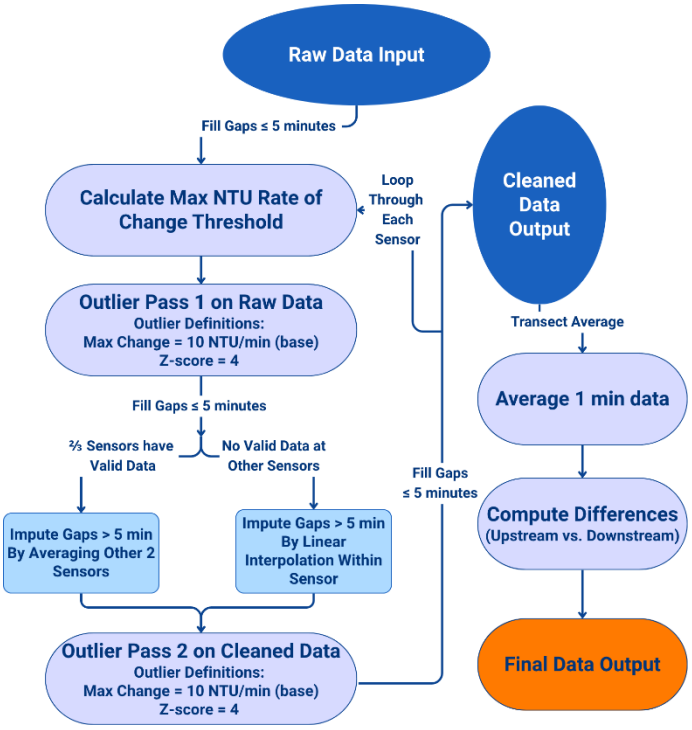


Figure A3. Data Processing Steps to Fill Gaps in the Raw Data and Identify and Omit Outliers. Max = maximum; min = minute; NTU = Nephelometric Turbidity Units.

The suspended sediment concentrations for each site within each transect are given in Table A1.

Table A1. Average, Maximum, and Minimum Turbidity Levels Converted to Suspended Sediment Concentration for all Construction Events Monitored at Sites 1 and 2

Transect	Suspended Sediment Concentration (mg/L)	Site 1 East		Site 1 West			Site 2				
		Installation	Removal	Installation	Removal	Stream Reprofiling	Cofferdam Installation	Cofferdam Removal and Relocation	Dewatering	Reprofile of Streambed and Dewatering	Cofferdam Removal
D1	Average	5.8	8.9	8.9	2.1	1.9	4.2	52.4	23	19.8	66.9
	Max	9.7	12.1	2105.6	2.9	2.6	14.7	169.9	118.7	77.1	149.7
	Min	4.9	6.8	5.4	1.4	1.4	1.4	15.9	5.3	13.2	22.3
D2	Average	10.2	40.5	55.9	10.5	22.4	189.8	784.2	78.5	21.1	344.1
	Max	14.3	132.9	167.3	118.2	323.5	1405	1907.8	939.8	50	742.9
	Min	4.3	6.8	9.0	5.9	6.9	9.8	11.6	8.4	13.9	39.4
D3	Average	9.7	9.3	9.8	6.6	6.1	124.4	69.2	32.3	25.1	63.4
	Max	172.2	22.6	37.1	13.8	9.1	1134	491.3	126.2	52.1	360.8
	Min	4.4	4.7	4.6	4.5	4.3	2.9	19.9	8.9	12.3	21.3
D4	Average	10.5	16.7	20.9	8.1	9.2	11.1	115.2	53.7	25.4	32.1
	Max	59.8	34.8	48.9	16.3	20.1	34.4	150.4	138.8	39.8	60.5
	Min	3.6	3.8	3.6	2.8	2.6	4.4	94.4	8.2	16	22.8
D5	Average	11.9	7.7	8,7	4.9	5.8	16.2	21.6	15.2	21.3	29
	Max	151.9	16.8	33.8	9.2	13.7	55.5	51.2	40.5	33.8	46.9
	Min	3.1	3.8	4.6	2.4	2.7	4.6	6.8	8	15.6	22.6
D6	Average	7.0	11.5	12.1	3.7	4.0	6.7	29.3	13.3	17.5	43.7
	Max	29.1	22.1	30.2	4.8	7.3	358.2	66.6	89.7	34	65.4
	Min	3.5	4.5	4.4	2.9	2.5	4.3	11.9	4.4	9.6	14.4
D7	Average	9.6	10.9	13.1	6.5	5.9	10.9	46	4.2	7.2	28.2
	Max	19.5	19.4	26.0	8.5	7.9	94.6	97.1	45.5	8.4	252
	Min	4.4	5.4	5.7	5.1	4.7	0.7	9.6	2.7	4.8	14.5

Max = maximum; Min = minimum.

Calculation of Recovery Time

Recovery time is the amount of time required for turbidity to return to pre-event levels from the event's peak (Figure A4).

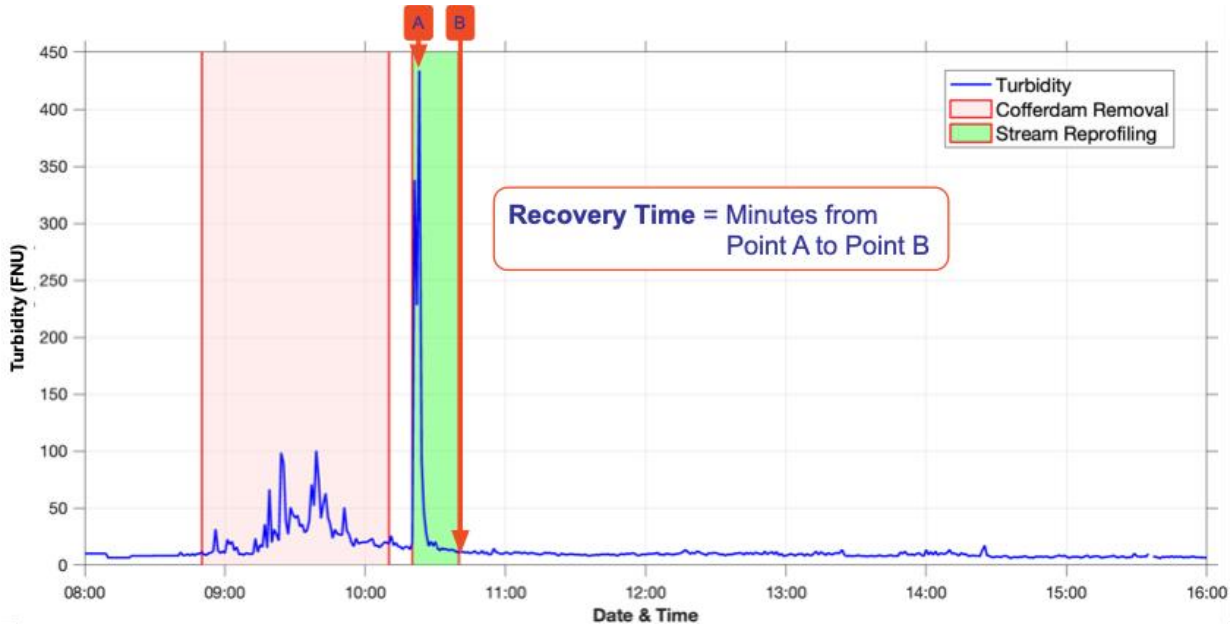


Figure A4. Example Figure Depicting How Recovery Times Were Calculated for Each Event. Point A reflects the peak turbidity level reached during the event window, and Point B reflects the point at which turbidity returned to pre-event levels. FNU = Formazin Nephelometric Units.