CHANGE IN SEDIMENTATION REGIME DUE TO BRIDGE CONSTRUCTION ACTIVITIES: A FIELD STUDY AT FM 2478 BRIDGE OVER WILSON CREEK, MCKINNEY, TEXAS

by

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ABSTRACT

CHANGE IN SEDIMENTATION REGIME DUE TO BRIDGE CONSTRUCTION ACTIVITIES: A FIELD STUDY AT FM 2478 BRIDGE OVER WILSON CREEK, MCKINNEY, TEXAS

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Bridge construction activities can cause soil disturbances that introduce sediments into a receiving stream and potentially impact its quality and the ecosystem. The impacts of bridge construction activities are studied in two ways: overland erosion and in-stream sediment concentration. For this research, the overland erosion of Wilson Creek in McKinney, Texas was monitored from four erosion plots constructed on its banks, near the bridge construction activities zone. The instream water quality was examined during the construction period by measuring the Total Suspended Solids (TSS) and the turbidity of water samples, and the sediment and water samples were collected and analyzed to scrutinize the quantitative effect that the construction activities had on the quality of the water from January to November 2021.

The data obtained from the erosion plot was used to predict the amount of sediment that would potentially be released to the stream during both disturbed and undisturbed soil conditions. The result shows the soil loss from the erosion plot in disturbed surface conditions increased sediment by 2 - 5 times than in undisturbed surface conditions. The soil loss can reduce with

the implementation of vegetation by a significant amount. The measured sediment was within the range of predicted sediment by the modified universal soil loss equation (MUSLE) model, and the variations in the TSS and the turbidity of the creek water sample revealed the impacts of each bridge construction activity.

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1 Introduction

Bridge construction activities such as grading, excavation, and backfilling disturb the surface of soil and cause an increase in the concentration of sediment that discharges into the stream. The construction of bridges over a river or stream also plays a significant role in damaging the physical, chemical, and ecological quality of the aquatic system.

1.1 Construction activities

The major bridge construction activities that result in yielding sediment are discussed below.

- **Clearing, grubbing, and stripping of topsoil:** Before construction activities can commence, the site must be cleared, grubbed, and stripped. Clearing is accomplished by removing and disposing of all vegetation, trash, and surface boulders; grubbing is accomplished by removing and disposing of stumps and roots; and stripping is accomplished by removing and disposing of unwanted topsoil and sod. All of this work that is performed at the very beginning of the project disturbs the topsoil around the construction site.
- **Formation of temporary access**: A temporary access road is necessary for providing access to the site for construction, and its construction also disturbs large areas of topsoil.
- **Dredging activities**: Dredging is performed by a device that creates a vacuum and sucks up and pumps sediment and debris that is present in the bottom of lakes or rivers. In research conducted by Seiyaboh et al. (2013), the turbidity of the sediment increased from 8

NTU to 64 NTU from dredging activities. Courtice and Naser (2020) also found that dredging increases the amount of sediment in streams.

- **Grading**: Large equipment such as dozers, backhoes, and tractors grade sites in preparation for construction activities. Grading may disturb the soil and increase the potential for soil erosion.

- **Excavation**: Excavation is the process of removing layers of soil from a site to prepare it for construction activities. Equipment such as bulldozers are used to trench, create wall shafts, tunnel, and perform other underground work with tools and devices like bulldozers. Excavating, which is basic to preparing a site for construction of a bridge, deeply disturbs the soil and generates more sediment during storm events.

- **Backfilling:** Backfilling is done to return excavated soil to the site to strengthen and support the structure(s) built upon it. It is vital that the soil be well compacted in several layers; otherwise, it may erode during storms.

- **Slope protection works:** Slope protection works are conducted to reduce erosion and scouring at the bank of the stream during bridge construction and may produce the sediment.

- **Drilling mud from bored piling**. Bored piling is a technique that is commonly used for constructing foundations for bridge piers. Drilling mud (bentonite and polymer mud) is used to fill the boreholes to prevent them from collapsing. The bored piling directly increases the amount of sediment inside streams.

1.2 Soil erosion

Soil erosion is one of the main sources of sediment that is discharged into streams from a construction site. It is a two-phase process: detachment of individual soil particles from the soil mass and their transport by erosive agents such as running water and wind. If there is no medium to transport the sediment, then the soil particles settle. Due to an increase in construction, a lot of land has been disturbed and is prone to erosion, as many construction activities, such as clearing, excavation, dredging, etc., directly or indirectly contribute to soil erosion. Figure 1 depicts the types of erosion.

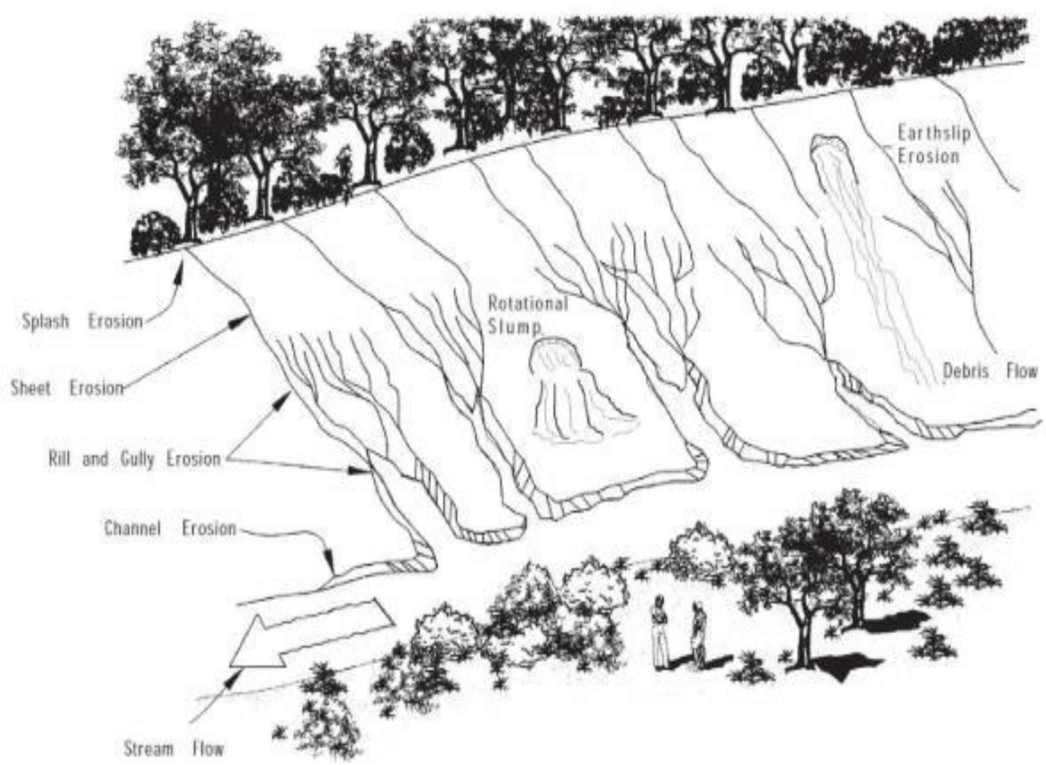


Figure 1 Types of erosion (Leersynder et al., 2016)

Mechanism of overland erosion

The overland flow of water occurs due to rainwater, stormwater, or other sources (Baral et al., 2021) and causes the detachment and movement of soil particles known as erosion. Bridge construction activities such as grubbing, grading, and excavation disturb the topsoil, and overland erosion occurs from the force of splash rain and stormwater runoff to the disturbed soil. Without proper intervention (Adhikari et al., 2021) to prevent the overland erosion, the soil will directly be released to the stream. Most erosion occurs during the first rainy season after construction activities have been completed (Keller and Sherer, 2003). Figure 2 below shows the mechanism of the sediment yield due to overland erosion.

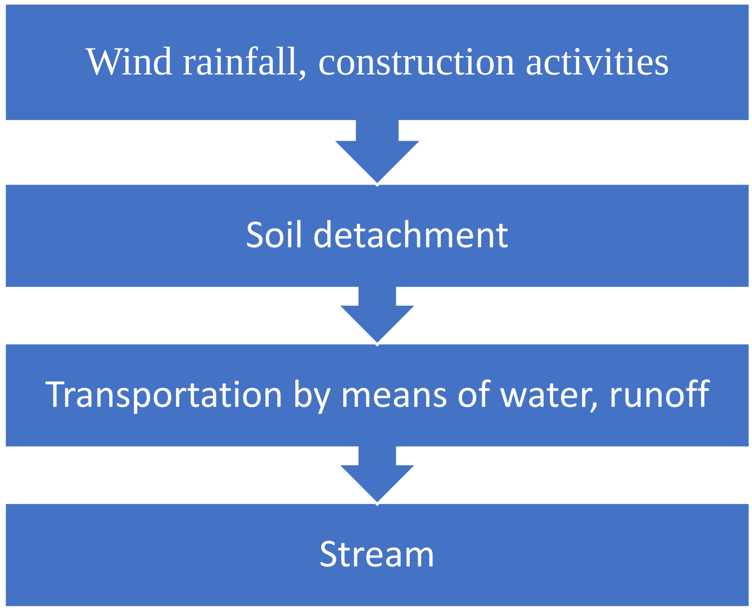


Figure 2 Mechanism of sediment yield

Erosion is a natural phenomenon, but human construction activities have exacerbated the problem, and overland erosion due to bridge construction activities impacts bodies of water. Activities such as grading, excavation, and backfilling disturb the existing soil surface and cause sediment yield around the construction site that discharges into the stream, resulting in an increase in the concentration of the sediment and damage to the physical, chemical, and ecological quality of the aquatic system. Figure 3 shows the disturbance of the land surface caused by drilling for shaft construction in Wilson Creek, McKinney Texas. Brady and Weil (1999) found that the probability of erosion in disturbed land due to construction activities is 100 times greater than that of agricultural land, but despite increasing bridge construction activity and high occurrences of overland erosion, few researchers have shown interest in studying overland erosion in the U.S (Cocchiglia et al., 2012).

Figure 3 Bridge construction at Wilson Creek

The accurate prediction of overland erosion is important to the environmental aspects of streams, and the techniques most commonly used to estimate the amount of erosion are installing erosion pins and constructing plots (Sadeghi et al., 2014; Hudson 1993). Quantitative measurement of erosion can be done by using erosion pins and measuring the stream cross-section. The universal soil loss equation (USLE) is used to determine the amount of sediment yield and determine the extent of the overland erosion based on the experimental erosion plot (Wischmeier and Smith 1978). The rainfall energy factor on the USLE equation is modified with the runoff energy factor to develop the modified universal soil loss equation (MUSLE), which predicts the sediment yield for a storm. The runoff volume and peak runoff rate are used in the MUSLE equation to determine the sediment yield. The energy factor in MUSLE is a function of the product of the runoff volume and the peak runoff rate for an individual storm. Discrepancies remain between the sediment values obtained theoretically and experimentally.

Instream sediment measurement

The instream sediment can be evaluated by measuring the concentration of suspended sediment in the form of total suspended solids or turbidity and by determining the amount of deposited sediment in the streambed. Sediments (both suspended and deposited) and turbidity are the most measured parameters for the effluents coming from the construction sites (Wang et al., 2013). Turbidity and the total suspended solids (TSS) are used to visualize the quality of the stream by measuring the presence of other particles in the water; turbidity is used most often due to its simplicity. There is difference in fundamental principal of measurement (Shen et al., 2018). The TSS are the solid particles in the water that do not settle from gravity and are measured by passing the water sample through a fine filter (0.45 micrometer). Turbidity is the optical property of water that is measured by passing scattered light through the sample. These practices were implemented to evaluate the stream water for several projects (Line and White 2001; Shen et al. 2018). The correlation between the turbidity and TSS are fitted with a linear equation. Memon et al. (2015) found that the correlation between TSS and turbidity is stronger in construction site effluents than in from catchments where there are no construction activities.

1.3 Best Management Practices (BMPs)

Erosion is a natural phenomenon that is difficult to stop completely, but some best management practices BMPs) can reduce the sediment yield across the stream. These are physical, structural, and/or management practices, used either singularly or in combination, to minimize the discharge of pollutants. The construction of a silt fence is the most-used practice for reducing the movement of soil caused by construction activities. BMPs play a significant role in reducing the sediment yield across streams.

In addition to reducing the sediment yield across streams, best management practices can also control overland erosion. Silt fences have been shown to be 75 percent effective in controlling erosion (Barett et al., 1995). In the United States, compost and mulch filter berms have been used as an alternative to silt fences and have demonstrated that they are better at controlling overland erosion and providing stormwater protection (Keller and Sherer 2003). Figure 4 below shows the implementation of a silt fence to control erosion in Wilson Creek.

Figure 4 Silt fence installed in Wilson Creek

Several studies have been conducted on the effects on streams of overland erosion caused by construction activities related to roads (Chen et al., 2009; Shen et al., 2018). Fewer studies have been conducted, however, on the effects of overland erosion caused by the due to construction of bridges. Cocchiglia et. al (2012) studied the effects of erosion due to construction activities in the aquatic system, but their study did not incorporate the prediction of sediment yield due to bridge construction activities.

Erosion plots have been effectively used to measure the sediment yield due to overland erosion. Nearing et al. (1999) compared the measured rate of erosion with predicted values, using an erosion plot, and obtained 14%-150% of the variation in sediment prediction. The empirical model USLE and its modified version MUSLE are used in the hydrology and environmental aspects of engineering for computation of potential erosion and sediment yields (Mishra et al., 2006). Sadeghi et al. (2014) studied the worldwide application of the MUSLE model to predict overland erosion, and after reviewing 49 papers, concluded that the accuracy of the model depends on the study period, calculation manner, and the prediction of input to the model.

Problem statement

Sediment is a concern during the construction of bridges across streams since the release of sediment to the stream influences its water quality and aquatic habitat. Cline et al. (1983) found that during bridge foundation construction, the TSS of water increased from 3.2 to 15.8 mg/l. The accurate prediction of sediment input to the stream is vital to some of the environmental aspects of streams and can be measured in two ways: by land and by water. Several studies have measured overland erosion, but they did not assess the changes in the concentration of the sediment due to construction activities, and there were still discrepancies between the prediction of the overland erosion by taking actual measurements and using a model. Further study is required to evaluate the sediment input to streams due to overland erosion and instream sediment concentration changes. It is also important to evaluate the effectiveness of stormwater sediment control practices during construction to minimize the amount of sediment released during construction.

Research Objectives

The main objective of this study was verify that the GIS model developed for TxDOT effectively assesses the ecological impacts of construction activities. This was accomplished by monitoring the construction of a bridge over Wilson Creek, located at FM 2478 in McKinney, Texas. Several parameters were monitored, including the actual sediment release to the stream. Overland erosion is typically monitored based on the data obtained by four erosion plots, as the sediment measured from the disturbed and undisturbed erosion plots gives the approximate sediment yield to the stream. It is also studied during bridge construction by separating the impacted zone for each activity. Instream sediment will be studied in this research by monitoring the TSS and turbidity of the water sample. The impact on the quality of the stream water will be provided for each construction activity.

This study predicts the approximate amount of sediment released to a stream due to bridge construction activities, which is important because the sediment changes the stream characteristics and eventually impacts its ecology. The effectiveness and efficiency of best management practices in controlling the movement of sediment to a stream are also explored and evaluated.

Thesis organization

This thesis is structured as follows. Chapter 1 introduces the thesis and provides the background of the research. Chapter 2 summarizes the literature review of the impacts on steam from construction activities, erosion control measures and best management practices, TSS and turbidity measurements, and overland erosion prediction models. Chapter 3 presents the methods and procedures used for to measure the impacts of bridge construction activities on streams. Chapter 4 describes the data analysis and results from lab and field activities. Chapter 5 summarizes the thesis and presents a conclusion.

2 Literature Review

Bridge construction activities include site clearing and grubbing of soil, grading, excavation of a foundation, and backfilling, all of which disturb the soil. During storm events, runoff flowing through a construction site transports the sediment and releases it to the receiving water bodies. Sediment control best management practices (BMPs) have been implemented to control the movement of sediment in streams, and the impacts of sediment loadings across the downstream of the stream released from construction activities have been studied and documented by several researchers (Reed 1980; Hainly 1980; Cline et al., 1982; Wellman et al., 2000; Cocchiglia et al., 2012).

2.1 Previous studies on construction activities

Changes in the sediment load and water quality of the river due to bridge construction downstream of the river can be either short or long term (Wheeler et al., 2005). Bridge construction has been shown to increase the concentration of sediment, suspended solids (SS) downstream of the construction site (Barton 1977; Cocchiglia et al., 2012; Wheeler et al., 2005; Hedrick et al., 2010). Wolman and Schick (1967) studied and compared the sediment concentration of streams receiving the effluent from a construction site to other areas in Baltimore, Maryland with no construction activity and found that the sediment concentration of the stream on the construction site was 200 times greater. The sediment loads generated due to construction activities impact the stream quality and river ecology (Reid and Anderson

1999). Most of the previous studies were conducted on the effects of highway construction activities; few tried to incorporate the impacts of bridge construction activities. Vice et al. (1969) studied the sediment levels across a drainage bas in Virginia, where highway construction was being performed, and the data showed that the sediment level of 10 percent higher than in areas where there were no construction activities.

An early investigation to document the effects of construction activities due to culvert construction across a modern highway in a creek in southern Ontario was carried out by Barton (1977). Sediment concentrations were measured before, during, and after the construction. The concentration of the sediment level increased from less than 5 mg/l prior to construction to 1390 mg/l after the construction was completed. The study also revealed an increase of ten-fold in sediment deposition just below the construction zone. The bulldozer activity increased the localized turbidity during the construction period, and the concentration of the suspended sediment was higher than the normal levels due to the lack of protection of the stream banks after the construction activities ceased.

Reed (1980) studied the suspended sediment in highway streams due to highway construction activities in five creeks in Pennsylvania. The sediment samples were collected by installing an automatic sampler to monitor the stream water during storms. Seeding, mulching, and jute netting were used as best management practices to reduce the exposed areas. For three streams, Reed (1980) found that the average concentration of sediment was 6 mg/L before construction and 17 mg/L during construction. The concentrations of the suspended sediment were increased about two-fold during the construction of the highway. After the completion of construction, the concentration of the sediment returned to normal. Reed (1980) also found that erosion control best management practices initiated during the early stages of construction were not effective for reducing the concentration of suspended solids in the stream.

The effects of highway construction were studied by Hainly (1980) for five years in Blockhouse Creek and Steam Valley in Pennsylvania. The study monitored the suspended sediment, stream temperature, and water discharge in four locations in the stream. The 5-year sediment samples were measured for one year before construction, two years during construction, and two years after construction. Sediment control practices were implemented, and their effectiveness was studied. The data indicated that 32300 metric tons of suspended sediment were transported, and 8,300 metric tons were added during the period of construction. The normal sediment yield for the two basins was determined to be 28 metric tons per square kilometer per year. The sediment was transported during high flows storms.

The effect of highway construction activities on a stream in the mountains was studied by Cline et al. (1982). The three-year study found that the proportion of fine sediment level increased when construction activities bean and returned to a normal level after they ceased. During the construction period, the concentration of fine sediment was twice that prior to construction; the sediment level increased from 3.2 mg/l to 15.8 mg/l during the construction period.

The effects of bridge construction along with logging on the stream were studied in Jefferson County in Kansas (Tieman 2004). Their study found changes in the stream substrate that were caused by river construction and logging and showed that the bridge construction caused changes in the in-stream habitat in the disturbed area. The study also investigated the effectiveness of employing boulder riprap as a best management practice to measure the siltation during construction activities, and they found that it helps to reduce sediment concentration.

Fifteen water quality parameters were measured during highway construction at the Lost River watershed in Hardy County, northeastern West Virginia (Chen et al. 2009). The major parameters, total suspended solids, turbidity, total iron, chloride content, sulfate content, acidity, and nitrate, were measured downstream of the bridge location. The study concluded that construction activities increased the sediment concentration downstream in the short term but had not significant impact in the long term.

A study by Cocchigilia et al. (2012) reviewed the ecological quality of streams downstream of construction sites**.** They reviewed 200 papers and found that very limited research had been conducted to measure the deposited sediment. Several of the studies that measured the impact of construction, based on suspended solids and turbidity of the stream, recommended measuring the sediment deposited across the stream due to construction activities. The importance of recognizing potential impacts before, during, and after construction was highlighted.

A study by Seiyaboh et al. (2013) discussed the long- and short-term effects of bridge construction activities on water quality, sediment quality, and biology. A water quality study was conducted during the construction of a motorable bridge with a length of 639.2 m and a width of 11 m. Groups of pile steel casings with diameters of 914 mm and 812 mm were installed, and water samples were collected and used to measure the turbidity before and after the bridge construction across several stations. The test results showed high turbidity values of 64 NTU in the bridge construction stations; 8 - 18 NTU were measured down-and upstream stations of the bridge. The higher sedimentation was due to construction activities; the range and variation of the concentration may have been due to the several ongoing construction activities and disturbance of the topsoil in the exposed areas.

Wang et al. (2013) studied the changes in turbidity and suspended sediment due to the construction of a stream crossing in West Virginia, USA and concluded that turbidity and suspended sediment concentration values increased because of construction. The average sediment load per storm and total annual sediment load increased by the factor of 1.8. The mean turbidity due to the construction activities increased almost eight times, from 3 to 26 NTU. The suspended solid increased from 10 to 23.8 mg/l. The study also found that the effectiveness of the silt fence BMPs decreased with the onset of the construction activities.

The table below shows the effect of construction activities on the quality of the stream water.

Table 1 Suspended solids due to construction activities

Highway and crossing type	**Suspended solids(preconstruction)(mg/l)**	**During construction (mg/l)**	**References**
Bridge foundations	3.2	15.8	Cline et. al 1983
Culvert	<5	1390	Barton et. al 1977
Pipeline	7	7620	Tsui and McCart 1981
Culvert	144	1237	Lane and Sheridan 2002
Stream crossing	10	23.8	Wang et. al 2013
Highway and bridge	35	179	Barrett et al. 1995
Pipeline	25	140	Reid and Anderson 1999

Previous studies related to sediment yield due to construction activities across Texas

Several researchers studied the quality of water samples across Texas that was e impacted by construction activities (Barrett et al., 1996; Kelbin et al., 1998; Crosby and Spindler 2003; Kearfott et al., 2005). Barrett et al. (1996) conducted a stream-monitoring program to evaluate the water quantity and quality in creeks flowing across the Austin area in Texas that were affected by new highway construction. In Danz Creek, the runoff from the highway was collected in a storm sewer system and connected to two permanent stormwater control systems. The flow was measured in upstream and downstream stations of the highway construction, using a flat-V weir-shaped measuring device.

Barrett et al. (1996) collected 14 samples at each of two sites at Danz Creek after 10 storms. These samples were collected from June 11, 1992, through October 10, 1993 during the construction of a new highway. Parameters commonly found in highway runoff were total suspended solids (TSS), oil and grease, volatile suspended solids (VSS), zinc, and iron. The concentration of these parameters was measured along the upstream and downstream stations, and it was found that the number of upstream total suspended solids increased twice that of the downstream. The concentration of VSS and Zinc did not increase, but the oil and grease concentration increased by 0.05mg/L. The content of other different metals was either increased or decreased from the detection limit excluding iron. From highway construction, these monitoring parameters had raised in concentrations in many studies regarding stormwater runoff quality.

Erosion control practices such as the installation of silt fences and rock berms were not effective in reducing suspended solids. Turbidity and iron increased. Land used above the station was instrumental in the concentration of the runoff and was highly dependent on the ambient concentrations of the creek prior to construction. The study did not account for activities that might produce lower sediment content and enhance water quality.

Keblin et al. (1998) conducted a study to address the concerns of the storm water runoff in the Edwards Aquifer recharge zone in Austin, Tx. During this study, the highway runoff was treated to evaluate the working efficiency of the sedimentation/filtration system. The area of the watershed was 33.6 ha and extended from the Capitol of Texas Highway to Balcones Woods Drive, adjoining the commercial development nearby and frontage roads. The four major components of the sedimentation/filtration system were an influent channel, a hazardous materials trap (HMT), a sedimentation basin, and a sand filter. The runoff collected from the recharge zone was delivered to the sedimentation basin through the influent channel. The HMT was a temporary storage basin with a volume of 38 m3 that was built to gather hazardous materials on the highway. The sedimentation basin had a volume of 4,320 m3 and was designed to capture the first 7cm of runoff. Runoff passed through the sedimentation basin, entered the sand filter by the hole at the bottom of the retaining wall, then was driven by the rock gabion structure that distributed the flow and helped to prevent erosion of the sand filter.

Samples were gathered from the influent channel, the basin effluent, and the filter effluent to check the efficiency of the removal of run-off constituents (Keblin et al. 1998). The particulate material was removed by entrapment of the sand medium and screening located on the surface of the filter. The data indicated that removal rate of the Seton Pond facility was superior to that of other facilities.

Favorable conditions and limitations were identified from the performance of the Seton Pond (Keblin et al. 1998). A longer detention time was determined to contribute it is strong performance, as it allowed the constituent and particulate material to settle. The result of this study indicated that sedimentation/infiltration had a better removal rate for total suspended solids and organics and a low-to-moderate removal rate for nitrogen constituents. The study denotes that the Seton Pond sedimentation/filtration facility, established by the Texas Department of Transportation (TxDOT) and regulated by the City of Austin, is the best management practice for controlling pollutants across the highway, and it accumulates stormwater runoff for treatment to the watershed. Biannual maintenance is required to efficiently remove the top pollutant filtered by the sand and collect the sediment at the bottom. To perform effectively, it should have an area of the high impervious layer, which is difficult to find out.

Crosby and Spindler (2003) developed the highway stormwater sampling depicted in Figure 5. Their research produced a sampler that could collect the stormwater sample directly from the pavement's surface at normal driving speeds. A global positioning system (GPS) was installed with the sampler to record the location of the sample quickly. The roadway runoff sample was delivered to the GIS to enable corresponding geographical reference for further analysis and assessment of runoff quality.

Three different tires were designed, in accordance with the different roadway surfaces (Crosby and Spindler 2003). The "ET Drag Slick" was used due to its effectiveness in continuously discharging samples from highway surfaces. Small commercial flatbed trailers, connected with a third wheel attached between two wheels, used to stage the platform. The sample water was thrown upwards by the staging platform was collected over the chamber.

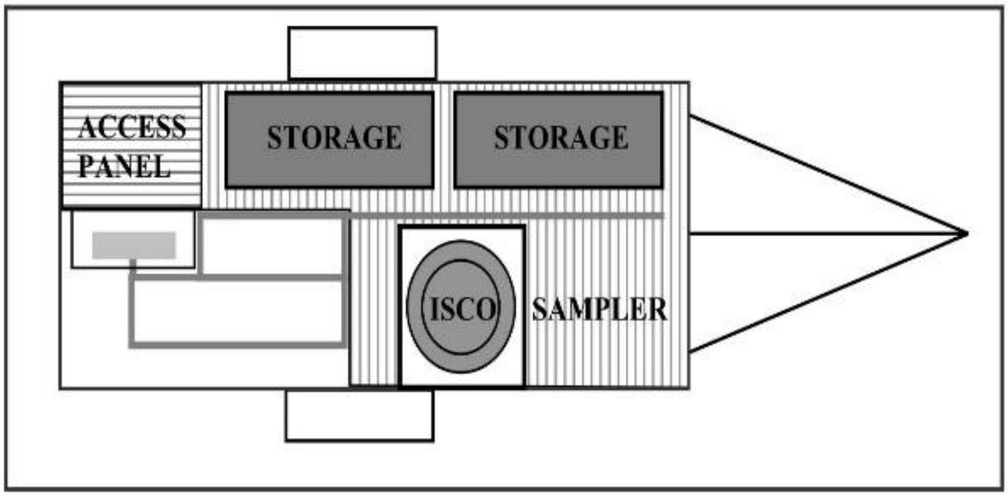


Figure 5 Mobile storm water sampling system (Crosby and Spindler 2003)

Four storm event samplings from the highway corridor were collected during rainfall events (Crosby and Spindler 2003). Two sections of Interstate Highway 30 were used to collect highway samples that were forwarded to a commercial testing center. The concentration of pH, BOD, COD was comparable to that achieved at local creeks, but the TSS constituent was consistently higher in concentration than that of a local creek. (Crosby and Spindler 2003).

This sampler could achieve storm water runoff from any roadway surface without the installment of high structures (Crosby and Spindler 2003). Problems encountered were that the third wheel had to be raised and lowered manually and a hydraulic automatic system was required to control the wheel efficiently. Although the sampler has advantages, it was difficult to determine whether the collected samples were from a direct roadway or were transported from adjoining land.

2.2 Best management practices

Sediment control practices entrap soil particles after they have been detached and transported by the erosive action of wind or water. Filtration and settling of the soil particles are commonly used techniques for sediment control, which can be categorized as temporary or permanent. Temporary BMPs control the sediment during the construction phase, while permanent BMPs stabilize the site after the construction has been completed. The sediment control BMPs protect the water quality in receiving water bodies during construction work by preventing and reducing the movement of sediment due to runoff.

Sediment control BMPs play a significant role in controlling overland erosion and have been implemented to prevent the movement of sediment. A silt fence is the most commonly used BMP in construction activities, as it has 75 percent efficiency (Barrett et al., 1995), but in the United States, compost and mulch filter berms have been used more effectively to control overland erosion and protect the stormwater (Bakr et al. 2012). BMPs can be classified as structural or landscaping, based on their construction process.

Structural BMPs

Structural BMPs are check dams, turbidity curtains, erosion control logs, rock filter dams, contour drains, pipe drop structures, diversion channels, dewatering and cofferdams, diversion dikes and swale combinations, and channel liners.

Landscape BMPs

Planting, top soiling and seeding, geotextile applications, buffer zones, sodding, preservation of natural resources, and composting of manufactured topsoil are considered landscape BMPs.

The description of commonly used BMPs are as follows.

1. Silt fence

A silt fence, the most commonly used type of erosion control, is a geotextile fabric barrier supported by a metal post or wooden stakes. It is used to prevent the movement of soil but is not intended to control all types of sediment runoff and has to be installed properly to be effective. Silt fences are not used in high concentrated flows; they are constructed to store runoff behind it so that it does not damage the fence or the submerged area. They cannot hold soil particles smaller than 0.02mm in diameter due to their short detention time and the fabric's large pores. EPA guidelines for installing the vertical fences include a six-inch wide and six-inch deep trench and a metal post or wooden stake for support. Proper installation will prevent its undercutting, overlapping, and collapsing. Figure 6 shows a typical silt fence used in construction.

Figure 6 Silt fence installed at edge of construction works

2. Vegetative filter strips

Kearfott et al. (2005) conducted a study of the characteristics of storm water treatment of vegetated highway side slopes in Texas. The research indicated that side slopes might reduce pollutant concentration and loads, thereby improving the quality of runoff to receiving streams. They installed 12 sampling systems to accumulate storm water runoff at three sites in the Austin area. Four samplers were installed in each site, one at the edge of the roadway to store samples directly and three in a two-meter gap from the pavement edge. The pipes and samplers were arranged through a schematic that was developed in the study. They collected 13 storm samples over a period of14 months to analyze the pollutants commonly found in storm water;

an average daily traffic (ADT) of at least 35000 was maintained to ensure sufficiently dirty water. A strip of vegetation, 8m from the pavement shoulder to the borrow ditch and shoulder slopes of 1:6 to 1:8 was maintained. The length of the vegetated areas towards the roadway was fixed at 40 m to accommodate the sampling chambers and collection systems. Runoff accumulated and shifted to the laboratory for the preservation and analysis for each of the three sites. (Kearfott et al. 2005). Figure 7 shows the design of filter strip.

Figure 7 Filter strip (Kearfott et al., 2005)

The study (Kearfott et al., 2005) revealed that pollutant removal was more efficient in densely vegetated areas. In one of the sites that was 8 mm from the edge of the pavement, 89 percent of the pollutants were removed; in another, that was less densely vegetated, 73 percent was removed. A greater reduction of TSS concentrations was evaluated for all three sites, and it was found that significant amounts of copper and lead concentrations were also removed from all three sites. The results from this study indicated that 4 m wide filter strips with 90 percent vegetation density would improve the quality of the roadway storm water runoff. Kearfott et al. also determined that the concentrations of runoff from porous asphalt-coated surfaces and traditional runway surfaces were different. The water from runoff of the asphalt-coated surfaces was of good quality for concentrations of total suspended solids and total metals.

This study indicates that vegetated filter strips can be considered as an effective best management practice for controlling and treating highway stormwater runoff, as they remove a large number of pollutants. In addition to their effectiveness, they also have the advantages of being easy to implement and maintain and providing pleasing aesthetic benefits to the surrounding highway environment.

3. Bioretention

Li Ming-Han et al. (2010) conducted a pilot experiment, using bioretention as the best management practice for improving the quality of storm water in Texas. The bioretention box, comprised of vegetation, water storage space, soil filter media, and a gravel layer, was designed to remove pollutants from sedimentation, filtration along with the attachment of one particle with other. Diverse types of vegetation were planted at the top of the box, and microorganisms regulated the biodegradation process. Figure 8 shows the typical design of a bioretention box.

Five bioretention boxes were designed on April 24, 2008, at the TxDOT/TTI Hydraulics, Sedimentation, and Erosion Control Laboratory (HSECL) located at Texas A&M University's Riverside campus. The boxes were fabricated of polyvinyl chloride (PVC) pipes, the inner surfaces of the boxes were coated with a spray liner, and each was filled with unique layers of gravel, pea gravel, and composted soil. A type of vegetation was randomly assigned to four of the boxes (shrubs, native grasses, a TxDOT seed mix, Bermuda grass); the control box had no vegetation. Stormwater was collected one foot above the upper surface of the soil.

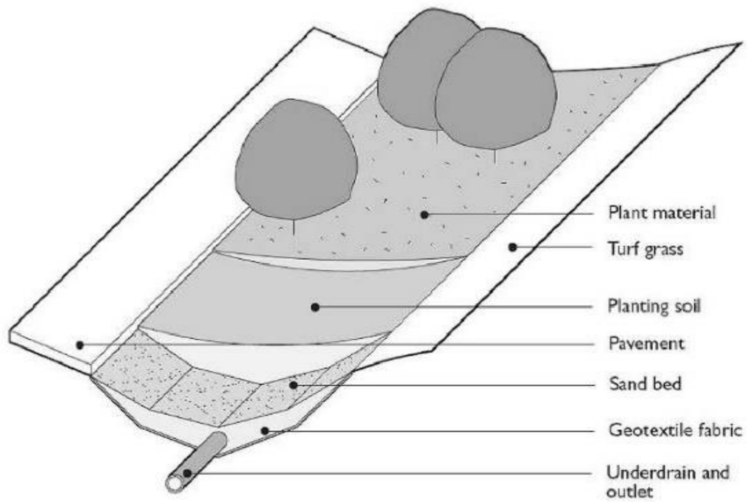


Figure 8 Bioretention for stormwater quality improvement (Li Ming Han et al., 2010)

The effectiveness of the removal of pollutants varies widely and is largely determined by the type of pollutant. The results of the pilot study showed that Zn, Pb, TSS, NH3-N, and *E. coli were* effectively removed, while Cu, NO3-N, TN, and TP were not. Bioretention is effective in many cases, but soil contains chemical cu, which might increase turbidity. It can, however, be flushed out with storm water. Further study is needed before firm criteria for the bioretention boxes can be established, but even then, it is a difficult system to adopt during the construction of highways.

4. Sediment trap

A sediment basin is a temporary pond that is built on a construction site to capture eroded or disturbed soil before it can be transported in storm runoff. It is designed to capture and slowly release the runoff to allow time for it to settle prior to discharge. Sediment basins are often constructed in locations that will later be modified to serve as post-construction storm water basins. Figure 9 shows a sediment retention pond.

Figure 9 Sediment retention pond (TxDOT 1993)

Sediment traps and basins are settling ponds formed by excavation and/or an embankment that intercept and retain sediment-laden runoff from a construction site to allow the sediment to settle prior to being released from the site.

5. Erosion control compost logs

Erosion logs are used along the contours or at the base of slopes to reduce soil erosion and retain sediment, as well as to shorten the length of the slopes to reduce the water velocity and trap soil particles. They are lightweight and have pre-drilled sleeves, making installation easy - even on a 30-degree slope. They can reduce flow velocities, minimize sediment runoff on jobsite perimeters, and filter and divert sediment from inlets. The GEI Works erosion control coir log is a natural fiber product that is designed to provide soil stabilization and support along riverbanks, slopes, streams, hillsides, and other erosion-prone areas. In the fall and winter of 2017, invasive woody weeds were removed from a hillside, and erosion control logs were successfully used to stop the erosion of soil into a sensitive river habitat. This spring, the area in and around the logs will be planted to bring the area back to its natural state. Figure 10 shows how control logs are used for erosion control.

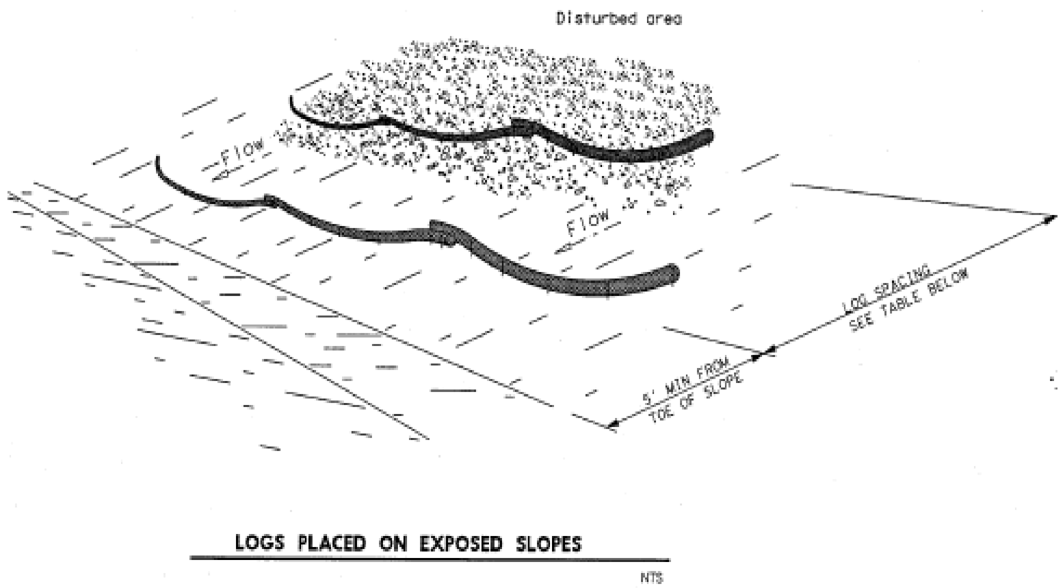


Figure 10 Erosion control logs ((TxDOT 1993)

6. Rock filter dam

The purpose of a rock filter dam is to convert runoff into sheet flow and intercept sediment-laden runoff. In this method of stream erosion control, riprap, a layer of different sized rocks (usually Class D or E revetment stones, broken limestone, dolomite, or quartzite) is prepared at the affected stream zone. Rough rocks with angular surfaces are suitable for riprap because they fit together tightly and form a dense layer over the bank face; smaller rocks or broken concrete are used to fill the spaces between the larger rocks. Figure 11shows a typical rock filter dam.

Figure 11 Rock filter dam (TxDOT 1993)

A rock filter dam is typically used when the runoff volume cannot contain by a silt fence, as it is able to withstand greater force. It is not effective for removing small-particle sediment but works well for reducing the bedload by serving as a check dam.

7. Check Dam

A check dam is usually a temporary structure that is constructed on a waterway to counteract erosion by decreasing the velocity of the runoff flow. Check dams have been constructed on streams during the construction period to trap soil and retain floodwaters and were effectively used to reduce the amount of coarse sediment entering the Yellow River in China (RAN et al. 2008). RAN et al. analyzed the performance of a check dam with typical five catchments in an area with coarse sediment and found that it reduced the sediment by 60 percent; consequently, it can be considered a rapid and effective measure for reducing sediment (Da-Chuan et al. 2008). Figure 12 depicts a typical check dam used for controlling sediment.

Figure 12 Check dam (Da-Chuan et al., 2008)

8. Hydroseeding

Hydroseeding uses equipment to spray a slurry of seed and other materials, a process that is fast and flexible. It can quickly establish vegetation steep slopes that cannot be easily accessed by laborers; however, its use is limited because of the specific equipment, experienced engineers, water, and funds that it requires. Newly planted hydroseed is also vulnerable to intense rainfall. Figure 13 shows hydroseeding used as a BMP.

Figure 13 Hydroseeding (CALTRANS 2017)

9. Mulching

Mulch is protective material that is used to cover and stabilize the surface of the ground to protect exposed soil from rainfall and overland flow and provide a relatively stable ground surface environment (temperature and humidity) to support vegetation growth. Mulch is made of materials that are usually loose and non-cohesive (straw, bark, and other plant fibers), so it is not practical for steep slopes or for use in areas with flowing water, strong winds, or intense rainfall. Because of its Mulch is organic and degradable, so it also serves as fertilizer, but has a short service period of several months. Specific machines are required to spread it if the needed coverage is broad. Figure 14 depicts mulching used for agricultural purposes.

Figure 14 Mulching (Harding 1990)

Table 2 BMP Performance

Best Management Practices	**Performance for sediment reduction**
Slope benches	49% less erosion than a uniform slope (Zhu et al. 2001)
Temporary or permanent seeding	90+% (Fifield 2001)
Hydroseeding	50-60% (CALTRANS 2017)
Mulching	53-99% (Harding 1990)
Turfing	98-99% (EPA 1996)
Phasing of construction	42% reduction (Claytor 1997)
Surface roughening	18% (County D 2007)
Sediment retention pond (no chemical treatment)	50-80%
Sediment retention pond (w/chemical treatment)	75-95%
Silt fence	40-75%, depending on type of fabric, overflow rate and detention time (Barrett et al. 1995)
Filter socks	62%-87%, depending on sock fill material (straw, compost, PAC)
Decanting earth bund	60% depending on sizing of device and rainfall intensity
Buffer zones	45-100% (Zhang et. al 2008)
Check dam	60% (Da- Chuan et. al 2008)
Flocculation	54-63 % (Mcfalls et al., 2014)
Vegetated filter strip	73-89% (Kearfott et al., 2005)
Bioretention	42.9 % (Li et al., 2010)
Sediment trap	35.7-99.9% for 100year storm depend on size (Claborn, 1992)
Compost/ mulching	72% for 5 cm applications -74% for 10 cm applications
Triangular filter dike	75% of total captured volume (TxDOT 1993)

2.3 Literature review on measurement of overland erosion measurements

Accurate prediction of overland erosion is important to environmental aspects of streams. The flow of rainfall over slopes causes soil erosion, but it is difficult to determine the amount of erosion that occurs because of imperceptible changes in the soil's surface. Several methods for measuring overland erosion, such as installation of erosion pins and preparation of field erosion plots, have been described by researchers (Hudson 1993, Boix-Fayos et al., 2006), but the lack of technology and skilled personnel make progress slow and difficult (Stroosnijder 2005).

Stroosnijder (2005) investigated various techniques for measuring overland soil erosion at different spatial and temporal scales, such as remote sensing (RS), the formation of erosion plots, and preliminary reconnaissance, in which high- and low-resolution images are used to predict the amount of overland erosion. High resolution arial images (m-scale) are used for larger areas of 2000-10000 ha scale, and low-resolution RS data (15-m scale) are used for areas larger than 10,000 ha. The fundamental way to determine the amount of soil erosion is to observe the changes in the soil surface (changes in weight, surface elevation, and channel cross section) and collect the data from erosion plots that measured the sediment. measurements of sediment, the data for which was collected from erosion plots. The equipment required for these techniques is not available on the commercial market (Hudson 1993), funding is not adequate, and there is a lack of skilled personnel to implement the techniques (Stroosnijder 2005, p. 172). Some of the experimental methods used to measure erosion are as follows.

Reconnaissance methods

Reconnaissance methods for estimating overland erosion are inexpensive, simple, flexible, and easily conducted in the field. Some of the methods discussed by Hudson (1993) are described below.

Point measurement

This method demonstrates changes in the soil's surface at individual points. The material can be wooden pegs, metal rebars, or any other pin-like substance, as the mean soil loss is obtained from pins that are marked and inserted in the ground to provide a reference point for the changes that occur. Pins with a diameter of 5 mm are preferable (Hudson, 1993). Thomaz and Vestena (2012) installed forty erosion pins in five erosion plots and used digital calipers to measure the mean soil loss over three-month intervals.

The limitations of point measurement of soil erosion include the potential loss of pins from high-velocity storm water, and its inability to measure the soil loss when a lot of soil surrounds the pin. Using a washer at the pedestal of the pin can reduce the amount of erosion, but overall, point measurement is often not an effective method for evaluating soil loss. Figure 15 shows the point measurement of soil erosion.

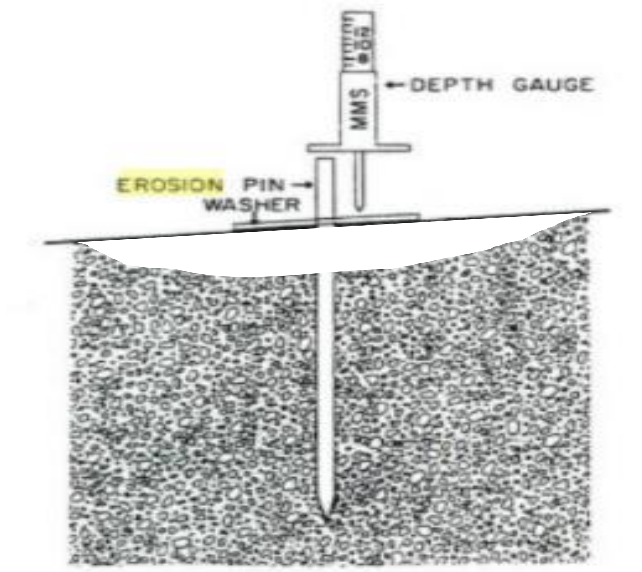


Figure 15 Erosion measurement by pin methods (Hudson, 1993)

Profile meters

Profile meters have a datum point that is used to measure small variations in the level of the soil’s surface level (Hudson 1993) by lowering the rods of a lightweight aluminum or similar horizontal bar between two end supports. The profile can be recorded for later analysis by using a camera when lowering the pins. soil erosion. The disadvantage of using a profile meter to measure soil loss us that it is unable to calculate the soil loss value when storm water splashes the measurement datum. Figure 16 shows a profile meter used for erosion measurement.

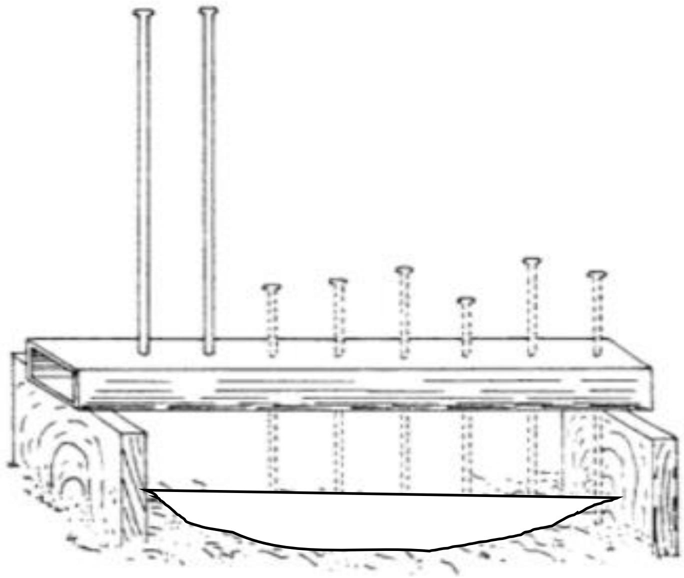


Figure 16 Profile meters (Hudson 1993)

Volumetric measurement

Volumetric measurement is three-dimensional and is useful for measuring soil loss from rills, gullies, and stream banks. The average cross-section area and length are used to measure the volume, and the eroded length and change in the cross section are measured to determine the soil loss. Photographs of different intervals of erosion can also be used to measure changes in the soil's surface. This method is too tedious for large areas but can be useful for small ones. Figure 17 shows the volumetric measurement of erosion.

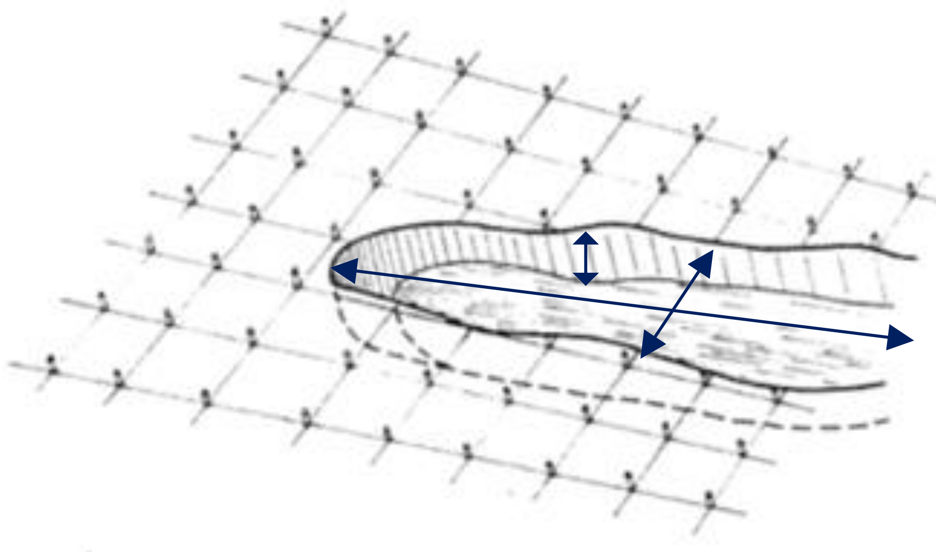


Figure 17 Volumetric measurement (Hudson 1993)

Erosion plot

Erosion plots are rectangular or square structures that are constructed to measure soil loss in contained area. The plots are separated from the surrounding land by fixed boundaries, and the plot design, instrumentation, and sample collections depend upon the site location; there are no criteria for the length and width of the plots (Hudson 1993). Sediment is collected from the plots after each rainfall and is taken to the lab for measurement and analysis. The soil loss rate is obtained by the analysis of the collected sediment volume. The universal soil loss equation (USLE) E$\boldsymbol{\alpha}$L0.6 is assumed (Hudson 1993), where E denotes the width and L denotes the length of plots. Thomaz and Vestena (2011) compared the soil loss from different-sized plots and determined that the soil loss for 1 m^2 and 10 m^2 were 6.33 kg/m^2 and 6.26 kg/m^2, respectively. In other words, the size of the plot did not affect the data. Sites for erosion plots should not have a regular gradient and no gullies or cracking problems.

Laser Scanning

Laser scanning is the process of obtaining information by emitting light towards an object at a very high speed. The laser light strikes, reflects off the object, and sends a return pulse to the receiver, and the travel time for completing the trip is used to calculate the distance within the area. Repetitions of this process provide an estimate of the characteristics of the objects or area.

Two types of laser scanning are used: aerial and terrestrial. Aerial laser scanning (ALS) can be used to precisely measure an object with high resolution (Snyder, 2009) and is suitable for measuring gullies, stream banks, etc. It is particularly effective for surveying erosion in coastal areas and detecting structures in densely populated cities or urban areas. In the areas with a steep slope, ALS shows a gentle slope which may reduce the soil eroded volume (James et al., 2007). Terrestrial laser scanning (TLS) was developed from ALS in the mid-1990s and can be significantly more accurate in measuring volume changes and soil movement (Baldo et al., 2009). Nettles (2009) provided a detailed description of the laser scanning process.

2.4 Measurement of in-stream sediment

Stream regulations and water quality issues determine the appropriate water sampler for in-stream sediment Davies (2009). The federally approved samplers were explained by Davies (2009) as he espoused that instream sediment can be measured in three ways:

1. Suspended sediment measurement
2. Bedload measurement
3. Bed material measurement

1. Suspended sediment measurement

Suspended sediment is that which is suspended across the flow of a channel. Samplers that can be used to measure suspended sediments include point integrating samplers, depth integrating samplers, and single-stage samplers.

Depth integrating samplers

Depth integrating samplers can be either handheld or lowered by a cable that extends across the depth to collect a water-sediment mixture. US DH-81 and US DH-48 are examples of depth integrating samplers. The type of sampler is selected based on the depth of the stream and whether they are handheld or a cable system.

Point integrating samplers

Point integrating samplers have electrically operated valves that start and stop the collection of the sample. The sampler is lowered to the desired depth in the water column, the sample is collected by remotely opening and closing the valve, and the sampler is raised to the surface for removal of the sample container. US P-72 is an example of a point integrating sampler.

Single-stage samplers

Single-stage samplers are used in flashy streams with fast-moving water in removed areas where other types of samplers are not practical.

2. Bedload measurement

Different bedload samplers have been developed by researchers. Manually operated bedload samplers are the most inexpensive, but they require that operators be on the site. An example of a wading-type hand-held bedload sampler is the US BLH-84 which has fine mesh that allows water to pass through, while containing the sediment.

3. Bed material measurement

Bed material measurements provide the composition and properties of soil. The pebble count method is suitable for large materials, but other samplers have small openings. Materials can also be measured by grab buckets, drag buckets, and vertical samplers.

2.5 Literature review on erosion prediction model

During construction activities, the delivery of sediment to fresh water threatens the wellbeing of river ecosystems (Barton 1977; Hedrick et al., 2011). Erosion is a natural process, but it can be accelerated by human interventions. Barton (1977) found that soil disturbance and the use of heavy machinery inherent in construction activities can induce 100 times more erosion than naturally occurs on than agricultural land. The prediction of soil erosion due to construction activities is a complex phenomenon due to the difficulty in determining the soil properties and characteristics, but several empirical and synergistic models such as USLE, RUSLE, MUSLE, WEPP and YOUNKIN have been developed to estimate the amount of sediment yield in a stream due to overland erosion. The applicability of the models for estimating overland erosion is briefly discussed below.

KINEROS model

KINEROS is a physically based model that is used to predict the amount of surface runoff and erosion from small watershed and agricultural areas. It is used for the prediction of erosion in urban developments, small detention reservoirs, and lined channels; however, it is not effective for predicting the amount of erosion that will be caused by construction activities. Woolhiser et al. (1990) provided details and provides examples of how the KINEROS model calculates potential erosion.

Universal soil loss equation (USLE) model

This mathematical model of water erosion was originally released in 1965 by Wischmeier & Smith and has been used worldwide. It is based on statistical analyses of data from 46 locations in more than 10 states in the central and eastern U.S. and was generated from data collected over more than 10,000 years (Roose 1996). The model can be represented as

$$A= RKLSCP \qquad (1)$$

A is annual soil loss measured in tons per hectare per year, and R is the rainfall erosivity factor having unit megajoules per millimeter per hectare per hour per year. R may be seasonally determined via table or contour maps. K is the soil erodibility factor with unit tons per hector per megajoules per millimeter; the K factor determines the tendency of the soil to erode. L is slope length factor and S is slope steepness factor (unitless). The LS factor is obtained from established values presented in the tables that represent the combined influence of slope length, or how long sediment may travel before deposition, and the steepness of the slope. C is the crop management factor and has no unit. Vegetation cover is determined with the help of a land use cover map. The Environmental Protection Agency (EPA) has collected reasonable ranges for C relative to construction best management practices. P accounts for support practices, which are activities designed for effective sediment control. Since the equation is empirical, it is simple to apply it to the estimation of overland erosion. It can only generate a loading prediction based on averaged data and should not be used on a storm-by-storm basis. Additional problems of this model are that, based on the data from which it was derived, it is primarily intended for agricultural use, as it only considers sheet erosion, neglecting both rill and gully erosion. It cannot be used for construction sites where non-agricultural areas exist, in areas where sub-yearly erosion estimates are required, and where erosion parameters are expected to change with time.

Revised Universal Soil Loss Equation (RUSLE)

RUSLE is a revised form of the USLE model. It uses the same form of relationship as the USLE but accounts for sub-yearly variations in the equation's parameters (Westheimer and Smith 1965). The rainfall erosivity factor (R) determines the impact of the rainfall in the form of kinetic energy and provides the short-term rate and amount of run-off that is directly connected to precipitation events. Though RUSLE is considered the most used soil erosion prediction model, the factors, namely rainfall erosivity(R), soil erodibility (K), slope length and steepness, cover management and practice vary with the climate zone, soil properties, land use, and slope (Ghosal and Bhattacharya 2011). RUSLE uses daily values to determine the annual sediment yield and adjusts it with an equation for deposition. RUSLE considers both rill and inter-rill erosion. Because this model looks at daily values for all components except the slope, it is more responsive to short-term changes. It also determines an annual sediment load via the summation of the daily loads, meaning that any integer daytime period may be evaluated with it. The problem with this model is that it requires both daily precipitation and temperature data to estimate the C factor. Because it uses average rainfall values and a rainfall-erosivity factor that is directly related to intensity, such an approximation may not be ideal for short-term estimations. This model can be used for estimating soil erosion from construction sites, but it is not optimal because of the need for short-term sediment load estimates, temperature data, and daily values of most of the variables,

Modified Universal Soil Loss Equation (MUSLE)

MUSLE is another derivation of USLE. This model, unlike either the RUSLE or USLE, does not make use of the rainfall erosivity factor, R. (Eq. 2*)*. Instead, it relates erosivity to both runoff volume Q (ft3) and peak flow qp (ft3/s). In this equation, S (tons) is the sediment yield for a single event, which this empirical equation is designed for. According to Smith et al. (1984), runoff is better linked to erosivity than rainfall. This method may also better predict erosion in urban areas due to increased peak flows from increased imperviousness. Another claim of Smith et al. (1984) is that the runoff energy factor for an independent deposition formula, as is used in RUSLE. This model can estimate erosion for a single storm or be run multiple times to determine daily, monthly, yearly, or total sediment load for any construction duration. It calculates the total sediment generated by the watershed area for any single event.

The product of runoff volume Q(ft^3) and peak flow qp(ft^3/s) is the major factor in the MUSLE equation. It does not seek to relate erosion to rainfall impact energy. The parameters are as follows:

S=95(Q×qp)0.56K×LS×C×P (2)

S = sediment yield [tons]

Q= flow volume [ft3]

qp= peak flow rate [ft3s-1]

K = soil erosivity

LS = slope length factor

C = crop management factor

P= erosion control factor

Several studies have predicted sediment yield by using the MUSLE equation and compared it with experimental data (Muche et al. 2013, Sadeghi et al. 2007, Sadeghi et. al 2014); however, few of them made appropriate comparisons.

Younkin Model

Younkin (1973) developed an empirical equation for the calculation of rainfall-induced sediment yield from the construction of highways of Interstate 80. The equation was based upon 86 data sets and 5 stream stations and was intended to predict sediment in a way similar to the USLE method. The variables were defined as: S (tons) is the suspended sediment yield at the stream station; R is the rainfall erosivity factor as defined in both USLE and RUSLE, but for a single storm event; A (acre) is the study area; D (yards) is the average depth of disturbed soil, and P is the ratio of the area upslope of the studied stream to the total area of the site. The Younkin and USLE equations were found to perform almost identically when compared against normal stream loading throughout almost 100 storm events (Reed et al., 1985). Younkin's equation is distinct among the empirical equations discussed above because it was derived from data from construction sites; however, has not been as heavily validated as other equations and was found to be slightly inferior to the more established sediment loading estimation methods (Reed et al., 1985).

$$S= 0.034\ R^{0.5}(\mathrm{Log}A)^{02.45\ D}\ P^{-0.72} \quad (3)$$

3 Methodology

The impacts of bridge construction activities on sediment yield can be studied in two ways: overland impacts and in-stream impacts. Bridge construction activities such as grading, excavation, and backfilling disturb the soil surface and cause the formation of sediment around the construction site that will be transported to a stream during storm events. For this research, the overland erosion was monitored by collecting data from field erosion plots, and the sediment weight obtained from field erosion plots was compared calculations made by the MUSLE model and GIS-based sediment predicting toolbar. The in-stream impact due to construction was monitored by measuring the TSS and the turbidity of water samples near a construction area, and the bedload, bed material, and river flow were also monitored. The impact of each construction activity on the sediment regime in the stream is discussed below.

3.1 Site description

The bridge construction site for this research is in Wilson Creek on FM 2478 between

Prosper and McKinney, Texas, where a roadway expansion project is underway to expand the two-lane highway to six lanes. The construction of the bridge is proposed in two phases. Figure 18 (a) shows the location of the construction site and 18 (b) provides a close-up view.

Figure 18 Bridge construction site (a) Enlarged view, (b) close view

The land uses within the watershed of the Wilson Creek are residential and undeveloped agricultural areas. The watershed of Wilson Creek has Oak, Pecan, and Cottonwood trees (Moring, 2009), and the bedrock consists of Austin Chalk (Ferring 1994). The creek lies within the Blackland Prairie, which expands through North Texas to southwest of San Antonio (Moring 2009). Blackland Prairie is dominated by swelling clay soils, which are more prone to widescale surficial erosion (Harmel et al., 2006). Figure 19 shows the subsurface condition obtained by a borehole drilled approximately five- miles from the site. The boring log shows 15 feet of highly organic clay soil with a sedimentary thickness of 20 feet (Nettles 2009).

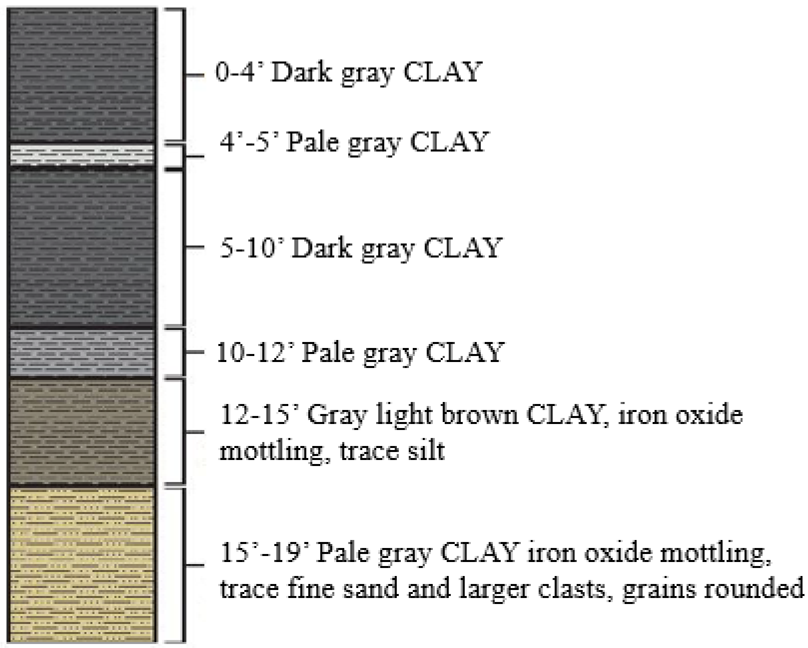


Figure 19 Lithology of Wilson Creek (Nettles 2009)

McKinney received a yearly rainfall amount of 43.5 inches in 2020 (NOAA 2021). The average maximum temperature was recorded as 76.3 F, and the minimum temperature was 54.5 F in 2020(NOAA 2021). The rainfall information for the site was taken from the FRISCO, TX US USC00413370 rain gauge station. Wilson Creek receives an estimated average 2-year peak discharge of 873 CFS(TxDOT 2019). The discharge date is available from the Wilson Creek River gauge station that is located seven miles downstream of the construction site.

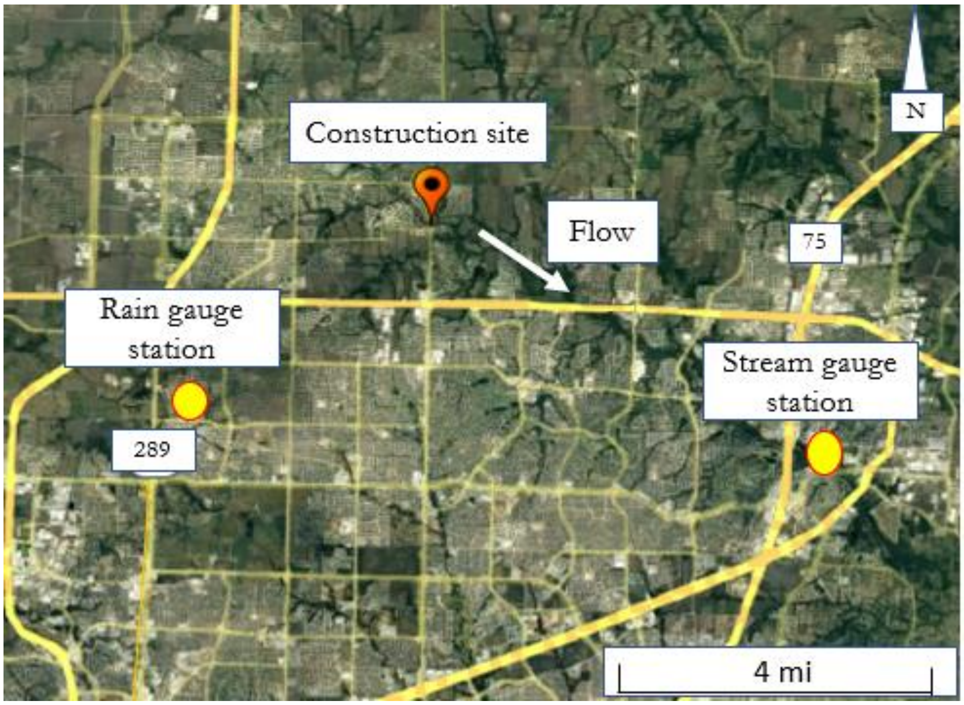


Figure 20 Rainfall and stream gauge stations

Site visit plan

The Wilson Creek bridge construction site was monitored after storm events to observe the impact of rainfall on the construction site. The site visit frequency was around 2-3 times per month, depending on the river flow condition that was observed from USGS 08059590 Wilson Ck Dws of Hwy 75 at McKinney, TX. Table 3 provides details of the site visits: dates, times, and weather conditions, and major site activities that took place on the day of the site visit.

Site monitoring parameters

The impact of bridge construction in Wilson Creek was studied by monitoring the parameters listed in Table 3. The monitoring parameters were divided in two ways: monitoring the overland erosion caused by bridge construction activities and monitoring changes in the in-stream sediment regime. The overland erosion was monitored by the construction of erosion plots; the in-stream impact of bridge construction was monitored by measuring the total suspended solids (TSS), turbidity, bed material, and bedload. The procedure for measurement of site monitoring parameters is discussed below. Table 4 provides a timeline of the activities at the construction site on site-visit days. Details of the site visits are provided in Appendix A.

Table 3 Site monitoring parameters and monitoring timeline

Monitoring parameters	Jan	Feb.	Mar.	April	May	June	July	Aug	Sept	Oct	Nov
Documenting construction activities	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Overland erosion (erosion plot)			✓	✓	✓	✓	✓	✓	✓	✓	✓
BMPs (visual observation)				✓	✓	✓	✓	✓	✓	✓	✓
TSS measurement					✓	✓	✓	✓	✓	✓	✓
Turbidity measurement						✓	✓	✓	✓	✓	✓
Bedload measurement								✓	✓	✓	✓
Sediment depositional area			✓	✓	✓	✓	✓	✓	✓	✓	✓
Pebble count							✓			✓	
Discharge and velocity measurement						✓	✓	✓	✓	✓	✓

Each monitoring parameter was observed during the site visit and an attempt was made to correlate it with the impact of bridge construction in the stream. A brief description of the procedure for site monitoring is discussed below.

3.2 Monitoring of construction activities

The schedule for each bridge construction activity was monitored during the site visit. The boundary for the approximate area impacted by each construction activity was observed and marked on the map. The boundary that was created for each construction activity was further used to create shapefiles to determine the sediment yield by using the GIS toolbar. The TSS and turbidity of the water sample from the stream near the construction area were monitored and used to correlate the impacts of construction activities on the stream. An approximate timeline and brief descriptions of construction activities are as follows.

Table 4 Timeline for construction activities

Site construction activities	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov
Site clearance										
Grading/Labelling										
Temporary access road construction										
Installation of silt fence and rock trap										
Drilled shaft formation										
Foundation constuction										
Plantation and bank protection										
Backfilling (South Bank)										
Backfilling (North Bank)										
Slope formation										
Super structure (Beams)										

Site clearing

Site clearing activities on both banks of Wilson Creek were performed from January 2021 to February 2021. Figure 21(a) shows the approximate site-clearing boundaries and Figure 21(b) shows the deployment of an excavator to clear the working area. The installation of a silt fence reduced the impact of site clearance work in the stream.

Figure 21 Site clearing works (a) Approximate site clearing area (b) Ongoing site clearing works

Grading work

The grading work was completed during two weeks in March. Figure 22 (a) shows the approximate boundary for the grading works, and Figure 22 (b) shows the ongoing grading works in the field. The sediment regime in the stream was affected by the addition of extra earth material caused by grading work performed to level the area between the two sides of the bridge abutment. Silt fences reduced the effect of construction on the stream.

Figure 22 Grading work (a)Boundary for grading work, (b) Site grading works

Temporary access road construction

As shown in Figure 23 (a), a temporary access road was constructed along both banks of the stream during the first week of April 2021 to transport construction equipment and materials below the bridge. The impact of the access road on the stream in shown in Figure 23(b). The TSS of the water sample was measured to determine the effect of construction on the stream.

Figure 23 Formation of access road (a) boundary, (b) site works

Foundation construction

Drilled shafts were constructed on all sides of Wilson Creek from the first week of April 2021 to the first week of May 2021. The impact on the stream due to the drilled shaft construction was monitored by measuring the TSS of the water sample near the drilled shafts, and it was observed that effective implementation of silt fences reduced the impacts of bridge construction. The installation of a rock trap along the downstream of the bridge construction helped reduce the movement of sediment from the bridge construction area to downstream. Figure 24 shows the position of the drilled shafts.

Other activities, such as the construction of footings, foundation walls, and abutments, took place in May, June, and July 2021, and samples of water obtained near the construction area were tested to determine the impact of the foundation construction on the stream.

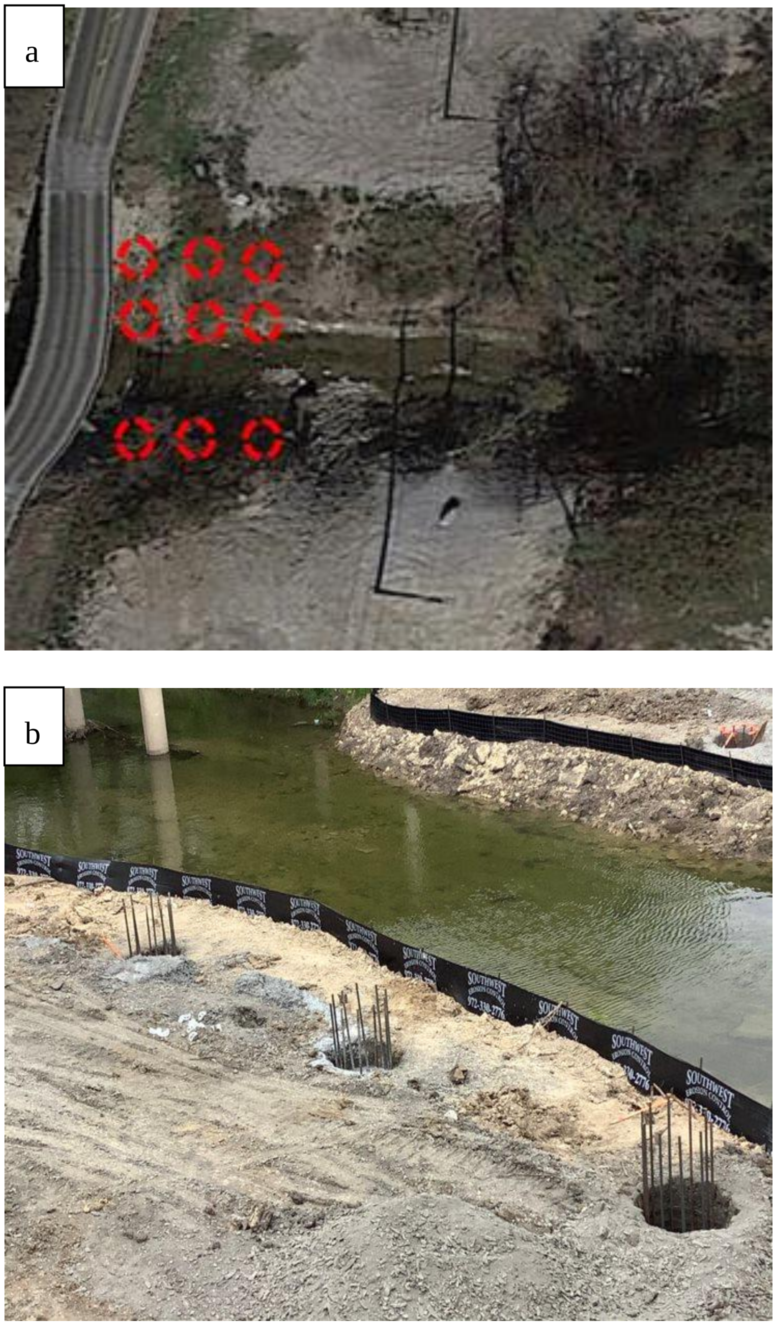


Figure 24 Foundation works (a) Drilled shaft boundary, (b) Ongoing construction work

Backfilling works

The backfilling was done after the construction of the foundation of the bridge. The approximate time for backfilling activity was one month from June to July 2021. After the construction of the foundation, backfilling was done to build the required slope of the road. The installation of a silt fence reduced the impact of backfilling on the stream. Figure 25 shows the location for backfilling work.

Figure 25 Backfilling works (a) Backfilling works boundary, (b) Ongoing backfilling works at site

Slope formation works

The slope formation along both sides of the bridge has a significant impact on the creek. The slope formation activities were conducted from the second week of July 2021 to the end of July 2021. During the slope formation works, the soil was pushed to the stream as shown in the Figure 26(b). Also, the removal of silt fence during slope formation works directly impacted the stream. The TSS and turbidity were monitored during the site visit to observe the impact due to the slope formation works.

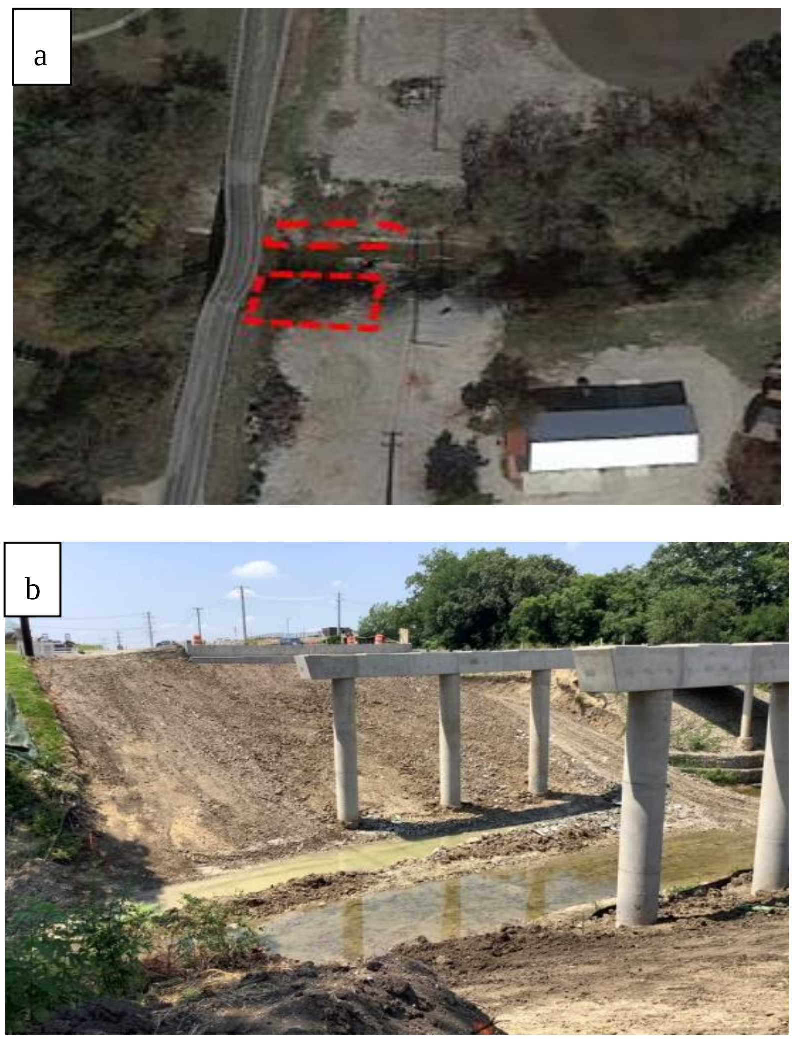


Figure 26 Slope formation work (a) boundary, (b) ongoing work

Best Management Practices (BMPs)

Erosion control best management practices are effective in controlling sediment from construction sites. In this project, silt fences, rock traps, and plantation works were used to control the sediment from the bridge construction site to Wilson creek. The effectiveness of each practice was visually observed and studied, the performance of the rock trap was evaluated by measuring the TSS upstream and downstream of the rock trap.

Silt fence

A silt fence, which is considered a highly effective best management practice for controlling the movement of sediment during store events, was installed along both sides of the bridge construction site, as shown in Figure 27. They were removed during the construction of the drilled shafts but reinstalled after all of the shafts had been drilled. The effectiveness of silt fence was observed during the site visit. Figure 26 shows the silt fence used at the bridge construction site.

Figure 27 Silt fence

Rock trap

A rock trap was constructed in Wilson creek to reduce the movement of sediment from the construction area to a downstream cross section of the creek, as shown in Figure 28. The effectiveness of the rock trap was estimated by measuring the TSS of samples upstream and downstream of the rock trap. The rock trap was damaged by high water flow in June 2021, the deposited sediment flowed downstream. It was reconstructed and performed effectively at depositing a large amount of sediment upstream.

Figure 28 Rock trap

Plantation work

Along the south bank of the creek, plantation and slope protection works were done to reduce the erosion from the construction site, as shown in the Figure 29. The seeding works inside the net effectively worked to lower the transportation of sediment from the construction area to the creek.

Figure 29 Plantation work

Table 5 Timeline for construction activities and BMPs

Construction activities	**Timeline**	**BMPs**	
		Structure	**Landscape**
Site clearing	Feb - Mar 10	No	No
Grading	Mar 11- Mar 26	No	No
Temporary access road construction	Apr1- Apr 5	No	No
Drilled shaft formation	Apr 10- May 3	Silt Fence, Rock trap	No
Foundation construction	May 6 - July 01	Silt Fence, Rock trap	Plantation
Backfilling work	June 18- June 29	Silt Fence	Plantation
Slope formation	July 15- July 29	Silt Fence, Rock trap	Plantation
Upper structure	July 15- now	Silt Fence, Rock trap	Plantation

3.3 Overland erosion measurement

It is difficult to predict the amount of soil disturbed by construction activities and the quantity of soil released to streams. Every construction activity was monitored, and it was observed that building access roads and drilling shafts had stronger impacts than most of the other activities. The formation of slopes also increased the amount of soil that was disturbed and moved directly to the river.

The overland erosion was monitored by field erosion plots comprised of a conveyance unit, storage tank, filtering mesh that were separated from surrounding land by fixed boundaries. Sediment was collected from the plots after rainfall events and was taken to the lab for measurement and analysis. The plot locations, plot numbers, required materials for their construction, and other aspects are discussed below.

Erosion plot

Four identical 10 ft. x 10 ft. erosion plots were constructed across the bridge construction site at Wilson Creek to measure the overland erosion. The plots were constructed to identify the properties and weight of the sediment transported to the stream during storm events, and the results were compared with manual calculations that employed the MUSLE equation.

Identification of plot location

It was difficult to find enough space to install four erosion plots near the bridge construction area, in December 2020, we installed three on the southern side of the bridge and one on the northern side. One of the three installed on the southern side had to be removed in January to facilitate the construction activities but was reconstructed in an area beyond the construction zone. Initially, the plot boundary was bounded by a silt fence, but it was not effective in directing all of the runoff water to the storage bucket; consequently, metal sheets were used to orient the flow inside the plot to the storage bucket. The locations of the other two plots were also changed due to ongoing construction activities around the plot's boundary. Plot 4, which was effective for measuring the erosion from undisturbed and vegetated soil, was constructed outside the construction area after permission was granted by the nearby Richardson Glasshouse. The effective erosion plots are shown in Figure 30 and detailed descriptions are provided below.

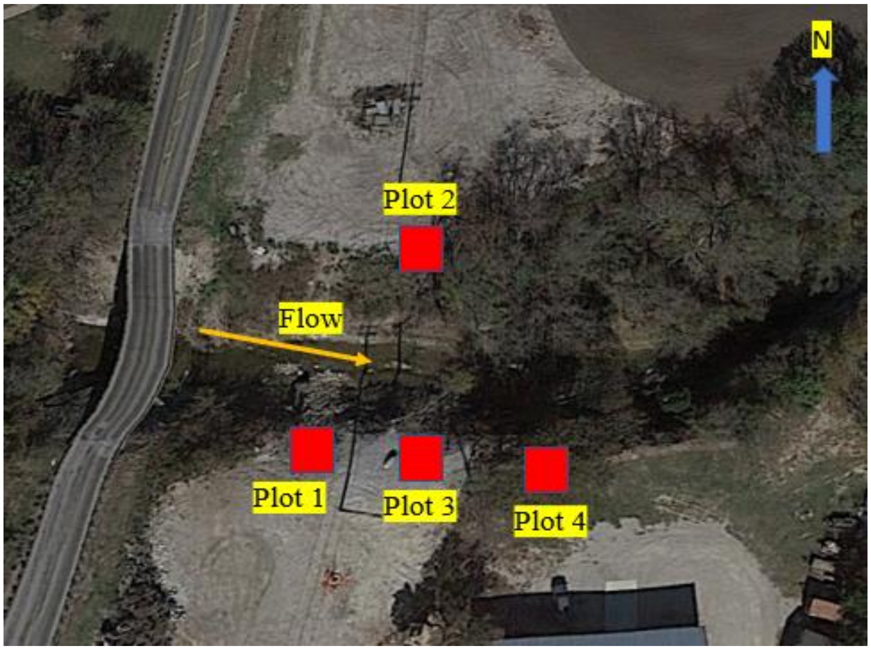


Figure 30 Erosion plot locations

Plot size

Hudson (1993) used a 22.13 m x 1.83 m to measure overland erosion, but we decided to construct a 3.28 m x 3.28 m plot despite it being difficult to find the space in the bridge construction area for a larger size plot.

Plot design

Erosion plots, which consist of a plot boundary, storage bucket, and inlet and outlet pipes, should be separated from the surrounding area so that they only collect the sediment from the plot. Estimates of the materials required for their construction are shown in Table 4. The plots were constructed in the slope to facilitate an unobstructed flow of runoff to the storage bucket. Sediment collected in the plot will be taken to a laboratory for the measurement and analysis. A typical design of an erosion plot is shown in Figure 31.

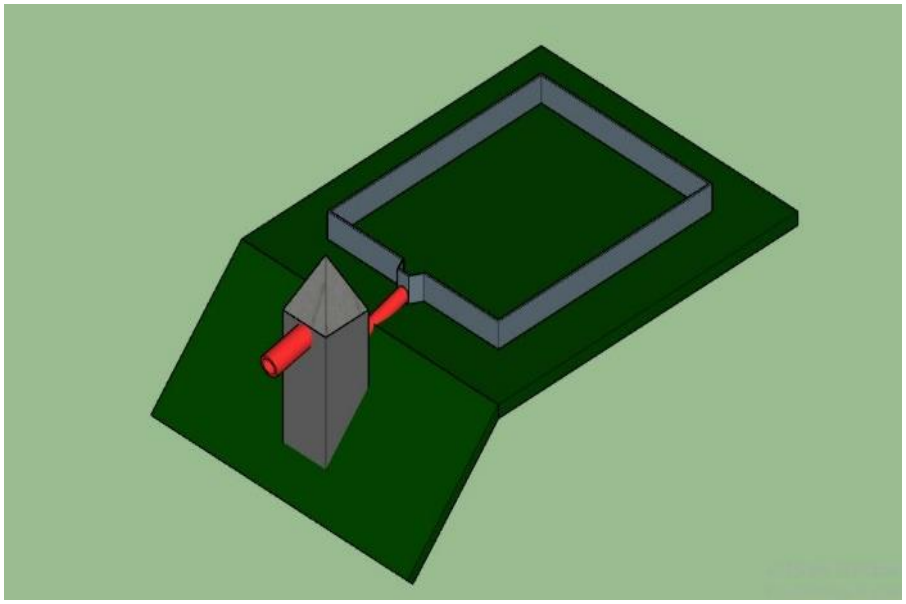


Figure 31 Erosion plot model

Plot boundary

A plot boundary is constructed to separate the plot from the surrounding land. The boundary should be tight enough to control the movement of the runoff from the inside to the outside and vice versa. Brick walls, concrete walls, metal strips, and plastic strips have been used to make erosion plot boundaries; among them, metal strips are the easiest to construct and maintain.

Conveyance unit

The conveyance unit collects the runoff from the plots and carries it to a storage tank. A pipe with a wide enough diameter is an effective conveyance unit.

Storage unit

A storage unit collects the eroded soil for further analysis. It must have an inlet that connects with the conveyance equipment for the runoff inflow and an outlet for the passing overflow, as well as a cover to protect the sediment from evaporation and outside influences.

Filtering mesh

A Screen is used to separate large debris particles from runoff so that the runoff can pass through the conveyance unit without clogging.

Table 6 Plot construction materials

Materials	Quantity
Metal sheet (10"* 10')	5
Lead covering container 7 gallons	1
Pipe (4" * 10 ‘)	1
Pipe connector (Inlet, Outlet)	1
Mesh screener (0.5' * 2'*5')	1
Wooden stakes to keep metal sheet vertical (0.25"* 4’)	8
Hand tools (Sheet cutter, Pipe cutter, Soil Digger)	1 each
Staple gun	1

Design and data collection from plots

Erosion plots are designed to collect sediment after storm events. Each plot is constructed in a different slope, based on the space that is available near the construction. The nature of the sediment samples and data collection timeline for the four erosion plots are discussed in the following.

Plot 1

Plot 1 was constructed on the south bank of the creek. It was initially surrounded by a silt fence, but after it was shown to be ineffective for collecting the runoff in a storage bucket, an aluminum metal sheet was placed outside the silt fence to direct the water flow. Plot 1 was used to collect sediment from March 2021 to May 2021, during which time several sediment samples were collected and analyzed. At the end of May, Plot 1 was damaged by construction activities, so it was removed. The average slope inside the plot is 5. 41%. Figure 32 shows the design of Plot 1.

Figure 32 Erosion Plot 1

Plot 2

Plot 2 was constructed on the north bank of Wilson Creek. It also initially had a silt fence as a boundary that was modified by adding an aluminum metal sheet outside the fence. This plot was used for the collection of both disturbed and undisturbed soil samples. Undisturbed sediment samples were collected after rainfall without disturbing inside the plot. Disturbed samples were collected by raking the topsoil inside the plot. The plot was used for collecting undisturbed samples until May 2021, after which it was used for collecting disturbed samples. Several disturbed and undisturbed sediment samples were collected after storm events and were taken to the laboratory for gradation analysis and to be weighed. The average slope inside the plot is 5.63 percent. Figure 33 shows the design of Plot 2.

Figure 33 Erosion Plot 2

Plot 3

Plot 3 was constructed on the south bank of the creek by using an aluminum metal sheet as the boundary. A filtering mesh was not used in this plot since it can block the runoff flow from the pipe inlet. This plot was also used to collect both disturbed and undisturbed samples of soil. The topsoil was raked for to collect the disturbed sample. Sediment samples were effectively collected until June 2021, when it was removed due to the installation of slope protection nets as BMPs. The average slope inside the plot is 10.42 percent. Figure 34 shows the design of Plot 3.

Figure 34 Erosion Plot 3

Plot 4

Plot 4 was constructed in a vegetative cover area on the south bank of the creek to collect undisturbed sediment samples without disturbing the natural grassland. The sediment from this plot will be compared with the plots constructed over no-vegetation zones and the results will be discussed. The average slope of the plot is 7.32 percent. Figure 35 shows the design of Plot 4.

Figure 35 Erosion Plot 4

Plot maintenance

Maintenance is important for the effectiveness of erosion plots, as the runoff has to be directed in such a way that the sediment is collected inside the storage bucket. The plot should be checked and maintained to prevent leakages, and the plot should be tight enough to prevent the runoff from the outside from entering the plot. Checking and maintaining all the erosion plots are necessary for directing the flow to the storage bucket.

Rainfall/discharge measurement

Rainfall information is vital since the collection of sediment inside the plot depends on the amount of rain that falls during a storm event. The information is obtained by the rain gauge station closest to the bridge construction site, which in this case is FRISCO, TX US

USC00413370, located 4.5 miles southwest of the bridge construction site. The USGS river gauge station, located approximate seven miles downstream of the construction site, is used to collect information about the streamflow at Wilson creek. The rainfall and river flow information will be used for the analysis of the field data. For example, rainfall data will be compared with the sediment weight from field plots to see the correlation between them.

Overland erosion sediment collection

The site visit depends on the rainfall value and river flow information that is obtained from the gauge station. Generally, the site is visited after a storm event for data collection, monitoring the erosion plots, and collecting sediment samples. After sediment water has been collected from the erosion plots, it has to be measured to determine the amount of soil lost from the plots during the storm event. The collected sediment water is transferred to the bucket and taken to a lab to be analyzed. Because it is important that all of the sediment water is transported to the lab, the bucket should be covered and watertight to prevent the leakage or spillage of any of the sediment. The sediment water sample is filtered, dried, and weighed to determine whether any soil loss has been experienced at the plots. The content of sand, silt, and clay is measured after the gradation of the soil.

Filtration and drying of sediment

The samples are filtered through 15 cm wide Whatman filter paper with a pore size of 2.5 micron, to separate the sediment particles from the sediment/water mix samples. If the sediment is deposited at the bottom of the bucket and the water above it is clear, the water can be pumped out without disturbing and losing the deposited sediment. The filtered sample should be dried in an oven to measure the dry weight of the sediment.

3.4 Instream data collection

Instream sediment information is required to monitor the impact of construction activities on the stream. The major parameters for monitoring the sediment concentration are the TSS and turbidity of the water samples. Turbidity and the total suspended solids (TSS) are parameters used to visualize the quality of the stream water by measuring the presence of other particles in the water. The fundamental principles of measuring TSS and turbidity are different (Shen et al., 2018). TSS directly represents the solid particles in the water that do not settle because of gravity and are measured by passing the water sample through a fine filter. Turbidity is the optical property of water that is measured by passing a scattered light through the sample. Measuring the bedload and bed material also provides information on the instream sediment, and the flow velocity and discharge information are also measured during some sites visits to get an idea about the flow condition of the creek and its relationship with in-stream sediment concentration. The measurement techniques for instream parameters are discussed below.

Measurement of total suspended solids (TSS)

TSS were monitored upstream, downstream, and in front of the construction site to observe the impacts of construction activities on a stream. The data obtained at these three cross-sections help to identify the differences in water quality. Figure 36 shows the approximate measurements of the three cross sections of the water samples taken from the creek.

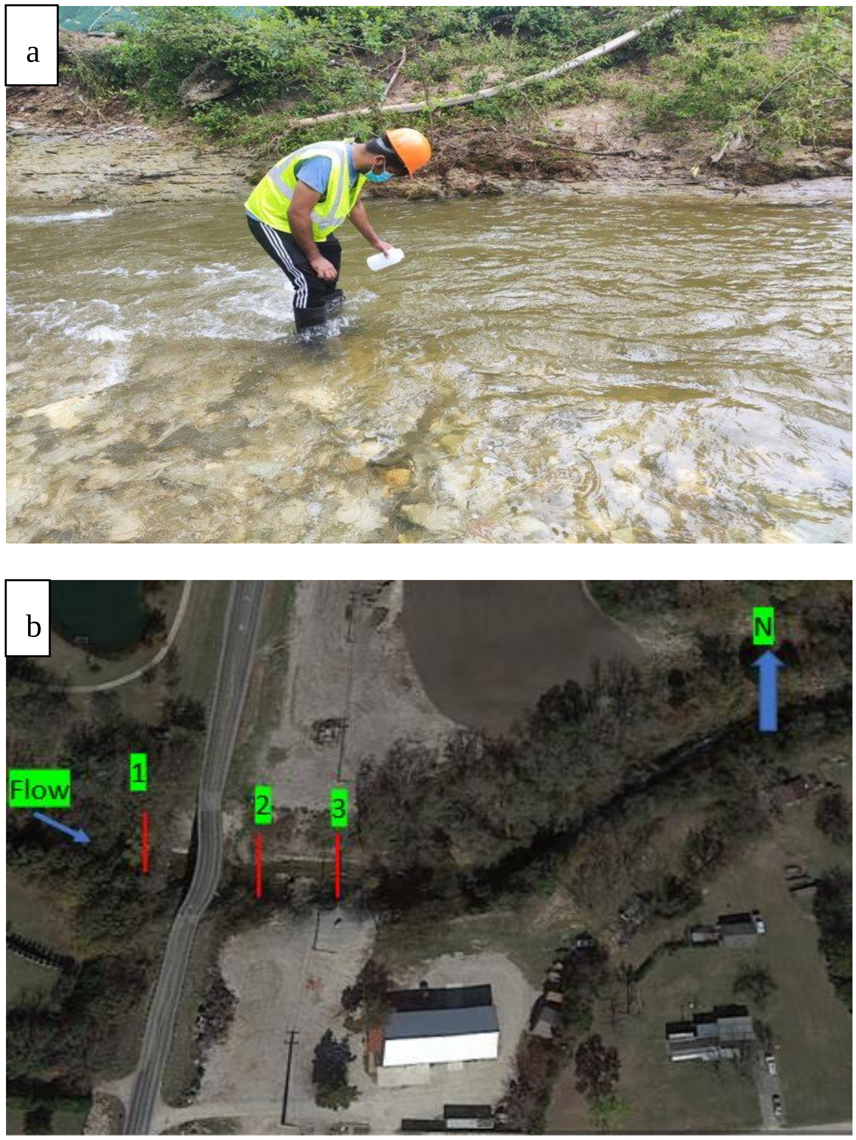


Figure 36 TSS sampling (a) Field sampling, (b) Three cross sections of sampling

Measurement of Turbidity

The turbidity of water samples represents the content of the sediment, which is measured inside a nephelometric turbidity unit (NTU). Water samples were collected, and a turbidimeter was used to measure its turbidity in three cross sections, as shown in Figure 35. Turbidity values are used to distinguish the impact on stream water from construction activities. The turbidity of water samples is measured upstream of the construction, near the construction, and downstream of the construction, as shown in Figures 37 (a) and (b).

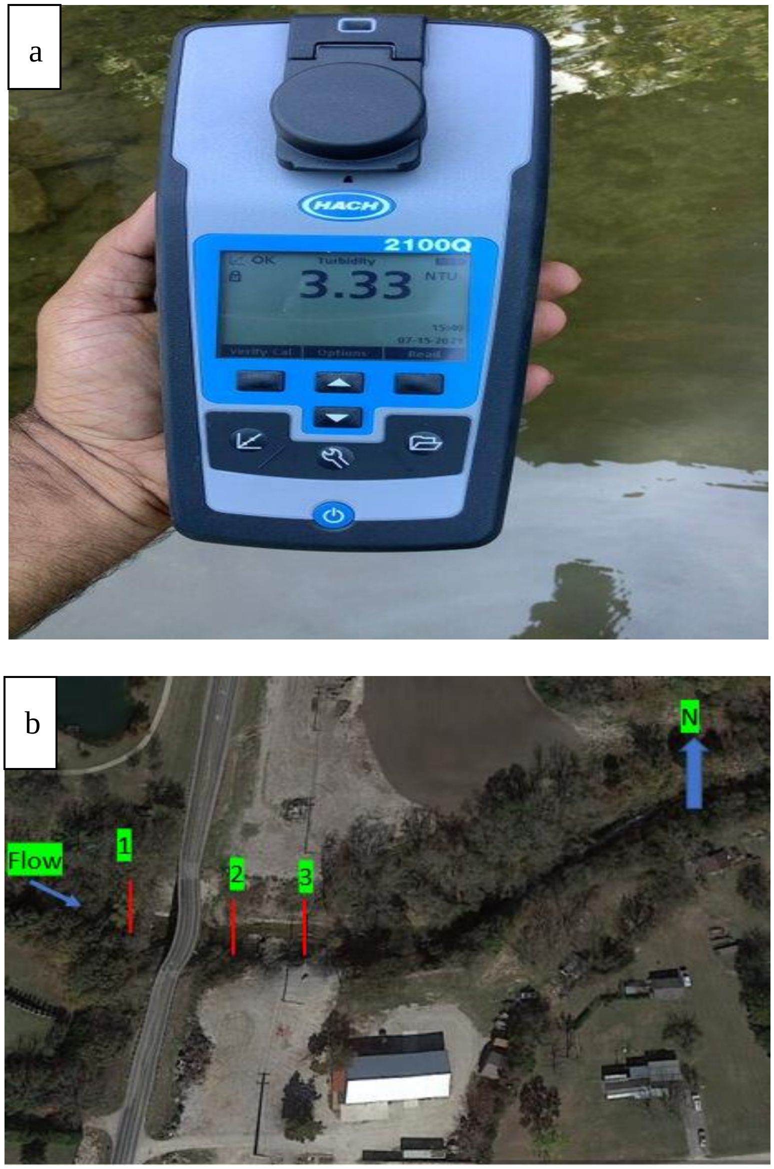


Figure 37 Turbidity sampling (a) Field sampling (b) Three cross sections of sampling

Measurement of Pebbles

The pebble count method was used to determine the composition of the streambed material, which is an important facet of the stream’s character for erosion rates, sediment supply, and other instream parameters (Leopold et al., 2020). We collected representative samples of bed materials by using the Wolfman pebble count method to count out 100 pebbles. The intermediate axis of the three perpendicular sides of each particle were measured, and a graph plotted their gradation of sizes. Figure 38 shows the field measurements of the pebbles at the bridge construction site.

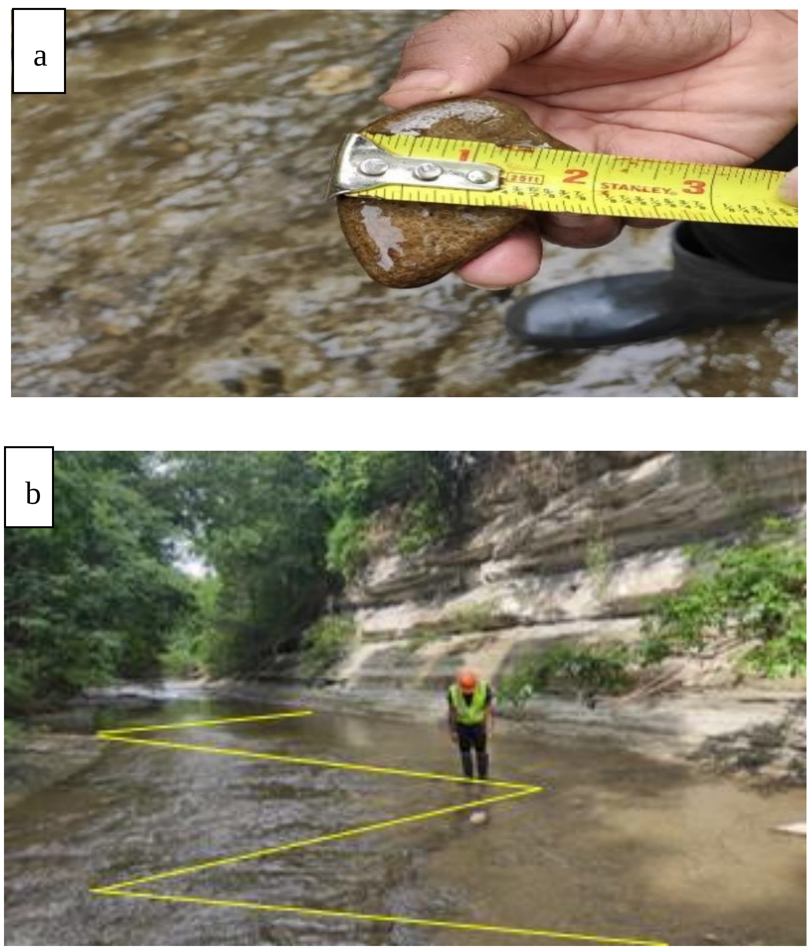


Figure 38 Pebbles measurement (a) Approximate cross section, (b) Measuring size of the pebble

Bedload trap

A bed load trap was constructed and installed in the stream to obtain bed soil data from the construction activities. The purpose of the 8.5 in. by 12 in. trap frame was to catch the sediment from the upstream side.

Preparation of bed load trap in the laboratory at UTA

The bedload trap for this research has a 12.5 in. by 8.5 in. frame and a 16 in. by 12 in. base plate that were fabricated in the Mechanical Engineering Department's lab at UTA. Two cold-rolled steel stakes hold the trap in its position and four nylon straps with metal friction buckles and with plastic tension buckles connect the steel rod with the bedload trap frame. Two nylon nets capture the bedload by providing enough strength to hold the material inside it. The nylon net with a mesh diameter of 0.8 mm was used from inside and one with a diameter of 3.2 mm was used from the outside. Nylon nets with a mesh diameter less than 0.5 mm cannot be used, since the small-sized mesh retards the rate of flow through the bedload traps (Bunte 2007). The frame is attached to the ground plate by four adjustable webbing straps that connect the frame to the stakes and are installed downstream of the construction site in Wilson creek.

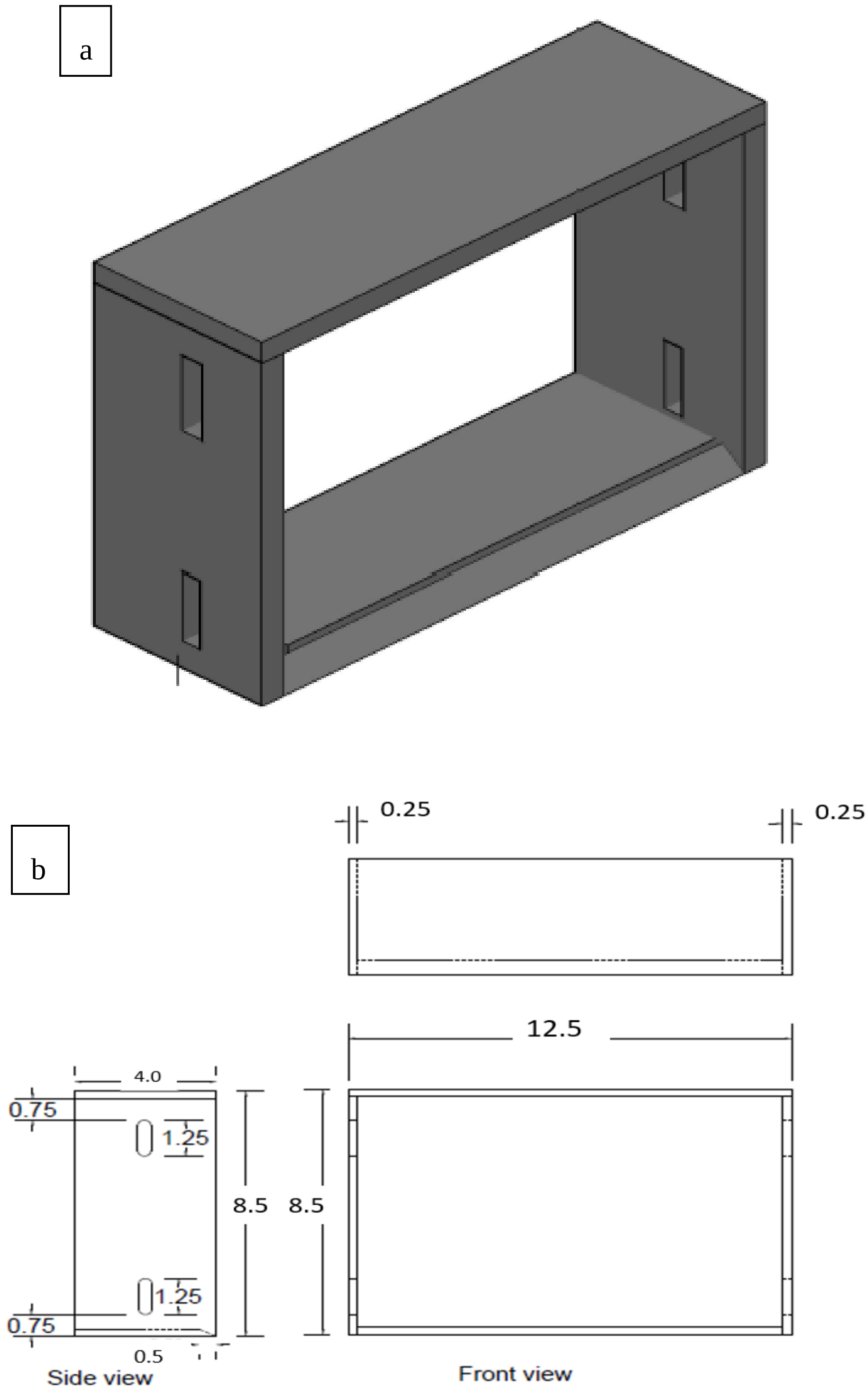


Figure 39 Bedload trap (a) 3D drawing, (b) 2D plan and elevation

The bedload trap was checked at each location to see whether any bedload had been collected inside it. The bedload material, if any, was then transferred to another container to bring the sample to the laboratory for analysis. From samples collected in August 2021, it was obvious that the bedload trap was collecting sediment as well as debris, including tree leaves, wood and bark pieces, algae, and grass. In particularly high flows, the bedload trap also collected small fish, ants, and aquatic insects. The bedload samples were analyzed after the debris was removed from the samples. Figure 39 shows the design of the bedload trap and Figure 40 shows its installation in the creek.

Figure 40 Bedload trap installed in Wilson Creek

Sediment deposition

It is important to visually inspect a construction site to observe its effects on overland and streams. The deposition of sediment in the creek after a storm event and movement of traces of the soil and water provide information about the effects of construction activities on streams.

The sediment deposition in Wilson Creek was basically due to the to the rock trap that was constructed downstream of the bridge construction area, as it blocked the movement of the sediment from the construction zone to downstream. Figure 41 above shows the observed approximate area of the sediment deposition. The sediment was measured by using tape and the obtained data is reported in the results of this research.

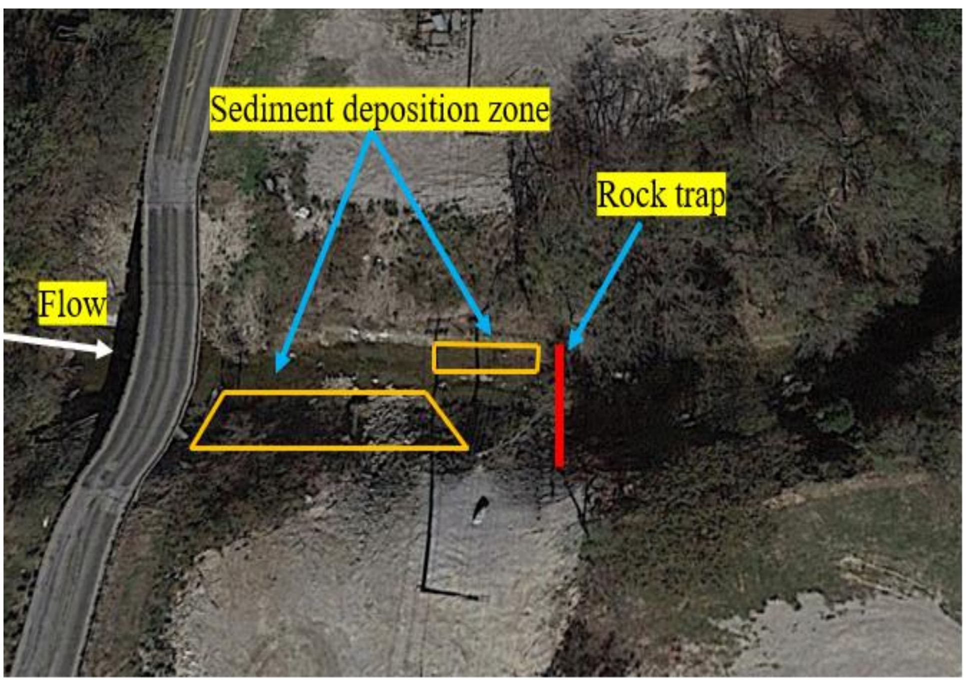


Figure 41 Sediment deposition zone

Measurement of flow

The flow of water in Wilson Creek was measured several times by using a handheld ADV sampler. The Flow Tracker Handheld ADV gives the velocity of stream within a certain interval of time for each location for which parameters such as location, water depth, and measurement depth are provided. The flow tracker uses these parameters to calculate the discharge and real-time data is displayed on an LCD screen. The velocity and discharge information from the flow tracker will be used to analyze the impacts of construction activities. Figure 42 shows velocity being measured in Wilson Creek.

Figure 42 Measurement of velocity by using handheld ADV flow tracker

Data collection and analysis

More than 30 sediment samples were collected from 4 erosion plots after the bridge construction began. Each sample was weighed and dried in the oven at around 220 F temperature. The weight of the sediment was crucial information for the overland erosion measurement. The overall soil loss that results from construction activities is related to the information of sediment obtained from the plots, so a gradation analysis was performed to obtain information about the grain size of the sediment collected. A sieve analysis was conducted for the coarse grains and a dry sieve analysis was conducted for the fine grains. Brief descriptions of sieve and hydrometer analysis are provided below.

Gradation analysis

Gradation analysis was used to determine the grain size of soil particles, and the grain size, uniformity coefficient, and coefficient of curvature are used to classify the soil and predict its behavior. The ASTM standard procedure was used to determine the particle size distribution of soils. Standard sieve sizes in the U.S. range from 4.75 mm to 0.075 mm. Sieve analysis was used for soil particles larger than 0.075 mm and hydrometer analysis was used for soil particles smaller than 0.075 mm.

MUSLE equation

The modified MUSLE model was used to determine the weight of the sediment in a 10 ft by 10 ft plot and was then compared with the weight of the sediment obtained from erosion plots. The MUSLE equation requires that several factors be determined for the calculation of the sediment's weight. The SCS curve number method was used to determine the peak flow rate, and the time of concentration for the precipitation was calculated using the rainfall and plot slope information. The brief descriptions of each factor used in MUSLE equation are discussed below.

The MUSLE model relates erosivity to both runoff volume $Q(ft^3)$ and peak flow q_p

(ft^3/s). It does not seek to relate erosion to rainfall impact energy, because impact energy may not be as useful in urban environments due to increased development. The parameters are as follows:

$$S=95(Q\times qp)^{0.56}\,K\times LS\times C\times P \quad (4)$$

Where,

S = sediment yield [tons]

Q= Volume of runoff (Acre feet)

q_p= peak flow rate [ft^3s^{-1}]

K = soil erosivity

LS = slope length factor

C = crop management factor

P= erosion control factor

SCS method for calculation of peak discharge (qp)

The SCS method, also known as NRCS, was selected to obtain both total flow volume and peak flow rate. This design procedure is accepted by NCTCOG and TxDOT, in addition to other local and state governing bodies. This analysis is performed on a daily time step; hydrographs are not produced. The following parameters and equations were used for the analysis:

$$t_c = \frac{L^{0.8}(S+1)^{0.7}}{1140Y^{0.8}} \quad (5)$$

$$t_p=0.67\times tc \quad (6)$$

$$Pe = \frac{(P-0.2S)^2}{P+0.8S} \quad (7)$$

$$CN = \frac{1000}{10+S} \quad (8)$$

$$qp = \frac{484A \cdot Pe}{tp} \quad (9)$$

Here,

t_c = time of concentration (hr.)

L= flow length (ft)

S = storage (in)

CN = curve number

Y= slope percent (%)

t_p= time to peak (hr.)

Pe = effective rainfall (in)

P= total rainfall (in)

A = watershed area (mi^2)

q_p= peak flow rate (ft^3/s)

Volume (Q) factor

The volume factor was determined by multiplying the plot area with effective rainfall (Pe).

Volume(Q) = Area of plot (A) * effective rainfall (P_e). (10)

Soil erosivity factor(K)

Wischmeier et al. (1997) found that soil erosivity can be obtained by using a nomograph. A nomograph for estimating the K factor was developed from rainfall simulation experiments and validated data by long-term erosion plot experiments. The K factor was derived from five variables: silt, very fine sand content, clay content, organic matter content, an aggregation index, and a permeability index.

Slope length factor (LS)

Slope length can be determined by separate calculations of the L and S factors, as shown below. The slope length of the plot was measured and used in the equation below to calculate the slope length factor. McCool et al. (1987) presented the expression to compute the slope length factor L by using following expression:

$$L = 1.4 \left(\frac{\lambda}{22.1}\right)^{m} \quad (11)$$

Where λ is the field slope length of the plot, m is the dimensionless exponent depend upon slope as 0.5 for greater than 5%, 0.4 for 4 %, and 0.3 for less than 3% slope.

The slope steepness factor is derived in two groups (McCool et al., 1987)

$$S = 10.8 \sin\theta + 0.03 \quad s < 9\% \quad (12)$$

$$S = 16.8 \sin\theta - 0.05 \quad s \geq 9\% \quad (13)$$

Similarly,

The LS factor for a plot can be calculated by using the Wischemeier and Smith (1978) method,

$$LS = (\lambda/72.6)^{m} (65.4 (\sin\theta)^2 + 4.56\sin\theta + 0.065) \quad (14)$$

where m = 0.5 for slope exceeding 5% And λ is the field slope length in feet and θ is the slope angle in degrees. The appropriate use of these methods is described in result section.

Crop management factor (C)

The C factor measures the combined effects of all the interrelated cover and management variables. C-factor values are obtained from studies conducted by the Texas Department of Transportation's Texas Transportation Institute and the Hydraulics and Erosion Control Laboratory (TTI), using computational methods developed at San Diego State University's Soil Erosion Research Laboratory (SERL) (Karpilo and Toy, 2004). The evaluated data of c factors the compared with the c factor value assigned by erosion control product manufactures and described based on Texas.

Practice factor (P)

The practice factor is based on the BMPs used for erosion control in the project. Although silt fences, rock traps, and plantation were used to control the erosion at the construction site, no BMPs were applied inside the erosion plots. Hence the practice factor can be assumed as one.

4 Analysis and Results

Samples collected from a bridge construction site and analyzed provide information about the impacts of construction on a stream. The results obtained from the measurement of parameters on the Wilson Creek bridge construction site exemplify the overall construction impacts on the overland and instream sediments. The overland erosion was estimated from the sediment obtained from the four erosion plots; the instream water quality was analyzed by the results obtained from TSS and turbidity measurements. Sediment samples collected from the bedload trap and sediment deposition zone verified the impacts on the stream.

4.1 Overland erosion measurement

The short-term erosion was assessed across the construction area at Wilson Creek by constructing erosion plots. Erosion plots of 10 ft by 10 ft were constructed to collect the sediment yield after each rainfall event, and a storage bucket was installed in the erosion plot to collect the runoff that flowed through the plot. After a storm event, the collected sediment was taken to the lab to be weighed. The weight of the sediment obtained from the erosion plot was compared with the weight of the sediment obtained from the MUSLE model for the same area of the plot. The results of the sediment weight obtained from erosion plots and hand calculation of the MUSLE equation were used to determine the approximate sediment yield due to overland erosion. The results obtained from the gradation of soil correlated the soil obtained from erosion plots and the nature of the soil in the stream.

The erosion plots were divided into distinct categories based on the type of sample collection. The samples obtained from disturbed and undisturbed erosion plots were analyzed and the results were compared. The impacts of vegetation on sediment yield were compared with the sediment weight results obtained from erosion plots. The potential outcomes of disturbing topsoil inside the erosion plot for sediment-water collection was discussed. Although the erosion plots were constructed in soil with different properties, the results of the erosion plots were comparable, especially concerning soil loss. In summary, the plots were useful for short-term assessments of soil erosion.

Erosion plot sediment results and analysis

Figure 43 shows the sediment weight obtained from four erosion plots and the trend of sediment generation in all the erosion plots. The plots are categorized as first, second, third, and fourth, based on the constructed location and the nature of data collection. The first plot collected sediment from undisturbed soil, the second and third plots collected sediment from both undisturbed and disturbed soil, and the fourth plot mimicked the sediment characteristics of vegetation without disturbing the natural soil. A comparison of the weight of the sediment from all the erosion plots revealed that the most sediment was generated in Plot 1 (1568 grams of sediment from 2.55 inches of rainfall on March 2, 2021). The least amount of sediment was collected from Plot 4, due to it being in the vegetation zone. Detailed results of sediment weight for each erosion plot are discussed below.

Plot 1

On March 2, 2021, 11.9 liters of a sediment-water mixture were collected from the bucket in Plot 1, the result of a 2.55-inch rainfall. The dried sediment weight was 1568 grams. Sediment was continuously collected until April 28, 2021, when approximately 9.5 liters were collected; the dried weight was 1051 grams. The huge amount of sediment collected after this two-storm event was due to the disturbance inside the plots that were the result of the plot's maintenance activities. Between March 02 and April 28, 33.6, 142, 75, and 832.3 grams of dried sediment was collected without disturbing the topsoil inside the plot. The antecedent moisture variation inside the erosion plot between two storm events impacted the sediment weight.

Plot 2

Plot 2 was constructed on the north bank of the bridge construction zone and like Plot 1, was effective from March 2, 2021. The maximum amount of sediment, 1070 grams, obtained from Plot 2 was generated by a 6.11-inch rainfall; the minimum amount of sediment obtained from Plot 2 was only 25 grams. Plot 2 was used for the collection of undisturbed soil until May 06, 2021, when it began to be used to collect disturbed soil samples by raking the topsoil. Just after raking the topsoil inside Plot 2, the sediment weight increased to 1070 grams from an average sediment weight of 30 grams. This shows there was a huge increase in the sediment weight after disturbing the topsoil inside the plots.

Plot 3

Sediment was first collected from Plot 3, located on the south side of Wilson Creek, on April 14, 2021, and yielded 16 grams. Since the amount of sediment generated inside this plot was very small, the topsoil inside the plot was raked before the rainfall event. After raking the topsoil, the amount of sediment collected increased up to 656 grams. Plot 3 was constructed on the high slope, and the topsoil surface appeared to have eroded and left large gravel particles. The topsoil was very hard to penetrate, and large boulders inside the plot made it difficult to install metal sheets to direct the water flow to the bucket. Although there were several reasons for the minimal sediment collection, gently raking the topsoil increased the rate of generation. The amount of sediment collected Plot 3, however, was always inferior to that from Plots 1 and 2.

Plot 4

Plot 4 was constructed in a vegetation zone, where the topsoil was not disturbed, and the sediment weight that it yielded mimicked the amount and characteristics of sediment coming from untouched land. The results from Plot 4 were used to compare the variations in the amount of eroded sediment in all the erosion plots and construction zone. In comparison with other erosion plots, only a small amount of sediment was collected from Plot 4; 49 grams was the most collected, and the least amount was zero. The impact of vegetation reduced the soil erosion inside Plot 4. Plot 4 was effectively used for sediment data collection only from July 2021.

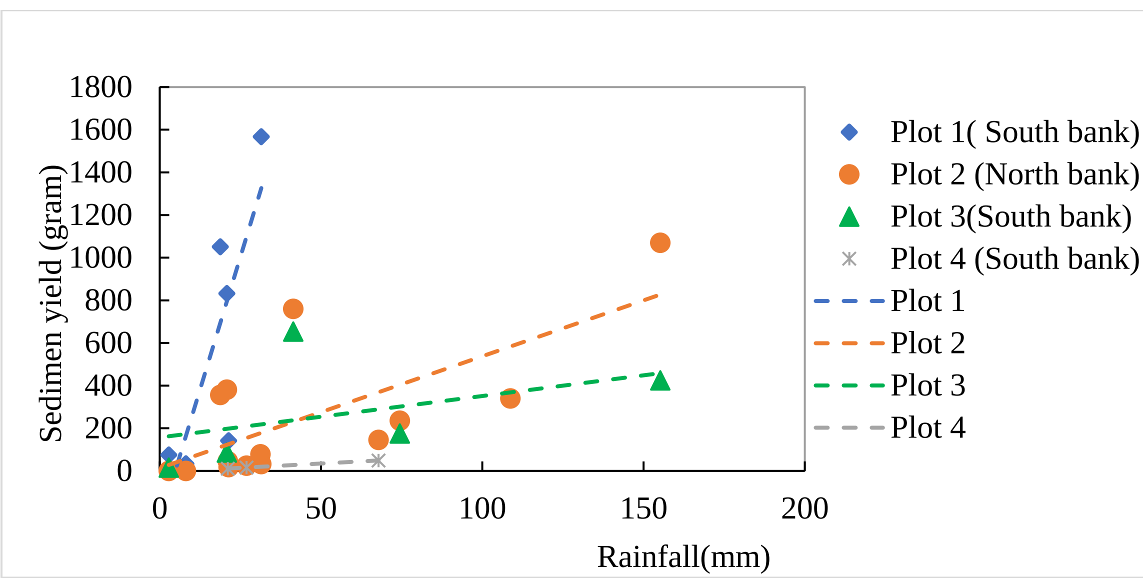


Figure 43 Sediment yield from plots

Analysis of results obtained from erosion plots

The sediment loads in Plot 1 were heavier than those of Plots 2, 3, and 4, which was due primarily from the slopes in the plots. The surface grade inside Plot 1 was smoother than that of the other plots, and the runoff from land with less undulation reaches the storage bucket more rapidly. Plot 2 was constructed on land with more undulation, and it had no trees or outside environment to divert the rainfall. Plot 3 was constructed on a steeper slope that had already experienced severe erosion and was mostly comprised of gravel. The soil compaction ratio also directly influences the sediment yield. Plot 1 was constructed in a less compacted and disturbed zone than the other plots, and the area around plot 4 was more compacted during its construction so it generated less sediment. Soil type is another contributing factor to the difference in sediment loads. Plot 3 was constructed over a zone that had a high gravel content at the time of construction, and Plot 4 was constructed in soil that had not been disturbed, so it generated a smaller amount of sediment.

The intensity of the rainfall and runoff during storm events are major causes of sediment collection, and the time lapse between the event and sample collection impacts the volume of sediment collected. The soil's infiltration capacity also plays an important role in producing runoff, and the overland flow of the sediment depends upon the infiltration capacity and antecedent moisture content of the soil, resulting in yields being different from place to place. The results of the analyses of the sediment obtained from the four erosion plots show that actual soil erosion is difficult to predict due to the variety of factors that contribute to it. Detailed data from erosion plots are shown in Appendix B.

Comparison of sediment and precipitation

The rainfall amount impacts the amount of sediment collected from a plot. The trend line plotted in Figure 42 above shows an increase in overland erosion with rainfall. Storm events that produce a lot of precipitation cause more erosion than those with less precipitation. Plot 4 was less impacted by rainfall because the construction was performed over natural vegetation. Plot 1 was highly impacted by rainfall since it was constructed in more disturbed areas that had not had the benefit of BMPs.

Impact of vegetation

Figure 43 below shows the difference in the weight of the sediment obtained from plots constructed with and without vegetation, but with the same amount of rainfall. The erosion plot constructed in the zone without vegetation yielded more sediment weight than the plot with vegetation. The trend line for Plot 3 lies exactly above the trend line for Plot 4 in the figure, from observation of the field data, it seems that vegetation was beneficial for controlling the erosion. In essence, the vegetation acts as a BMP for controlling sediment movement and erosion.

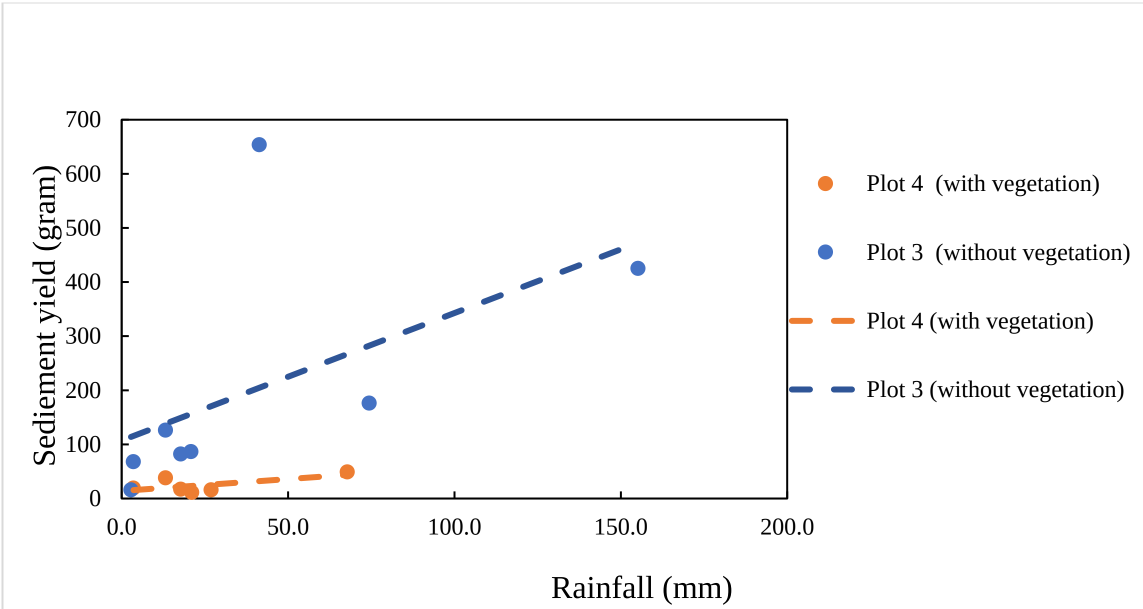


Figure 44 Impact of vegetation on sediment yield

Impact of raking topsoil

The erosion plots were raked to disturb the topsoil so that sediment generated by construction activities could be collected. The topsoil was disturbed about 1-2 inches to mimic the soil in the erosion plots where the sediment load came from the construction site. The raking was usually done during site visits and the length of time between the raking and storm events affected the collection of sediment loads. Storm events that occurred shortly after raking increased the sediment load, but if no storm events occurred immediately after the raking, the sediment load would probably be less. Even gentle raking increased the sediment load noticeably. For example, raking the topsoil on April 28 resulted in twice the amount of sediment collected on May 6 when approximately 65 mm of rain fell. (See Figure 44.) After strong storm events that produced heavy rainfall, the sediment load from raked plots increased by 2-5 times. The nature of the sediment from raked plots can be studied to relate it to the total amount of sediment from the construction activities.

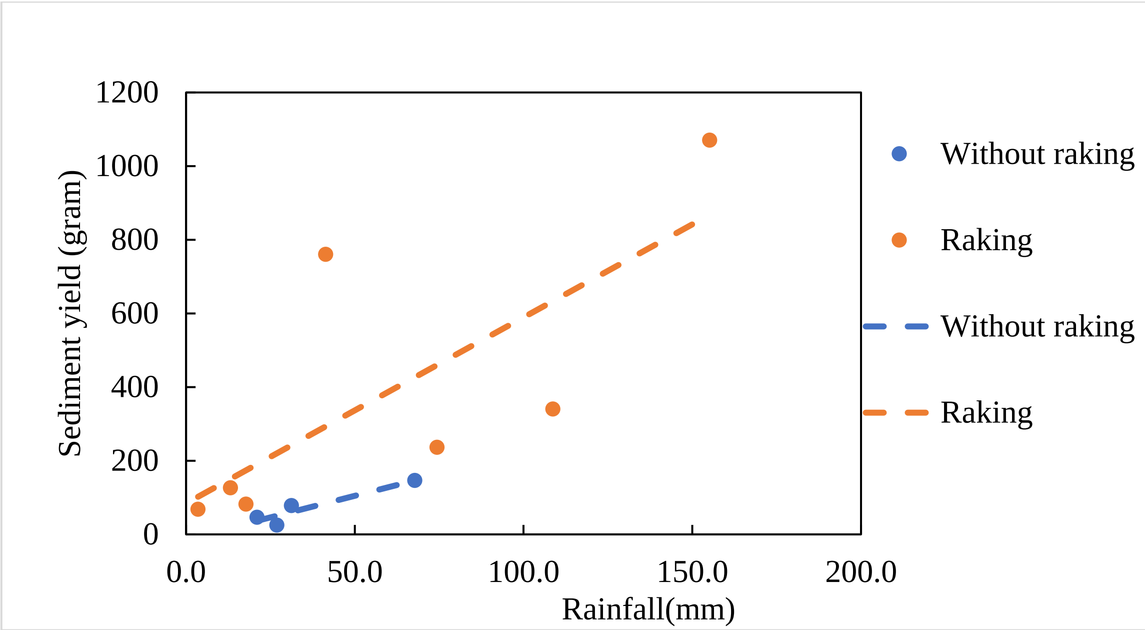


Figure 45 Influence of raking

Gradation analysis of sediment in obtained from erosion plots

All the sediment samples collected from erosion plots were graded to determine the type of soil. Dry sieve analysis was conducted for coarse-grained soil; wet sieve and hydrometer analysis were conducted for the coarse-grained soil. The graph below shows the dry sieve analysis for representative samples collected from all plots. The sediment samples in Plots 1 and plot 2 weighed 1000 grams, in Plot 3 weighed 653 grams, and in Plot 4 weighed just 49 grams. Approximately 500 grams of a sample are needed for gradation analysis; therefore, the sample from Plot 4 may not represent the actual soil condition inside the plot.

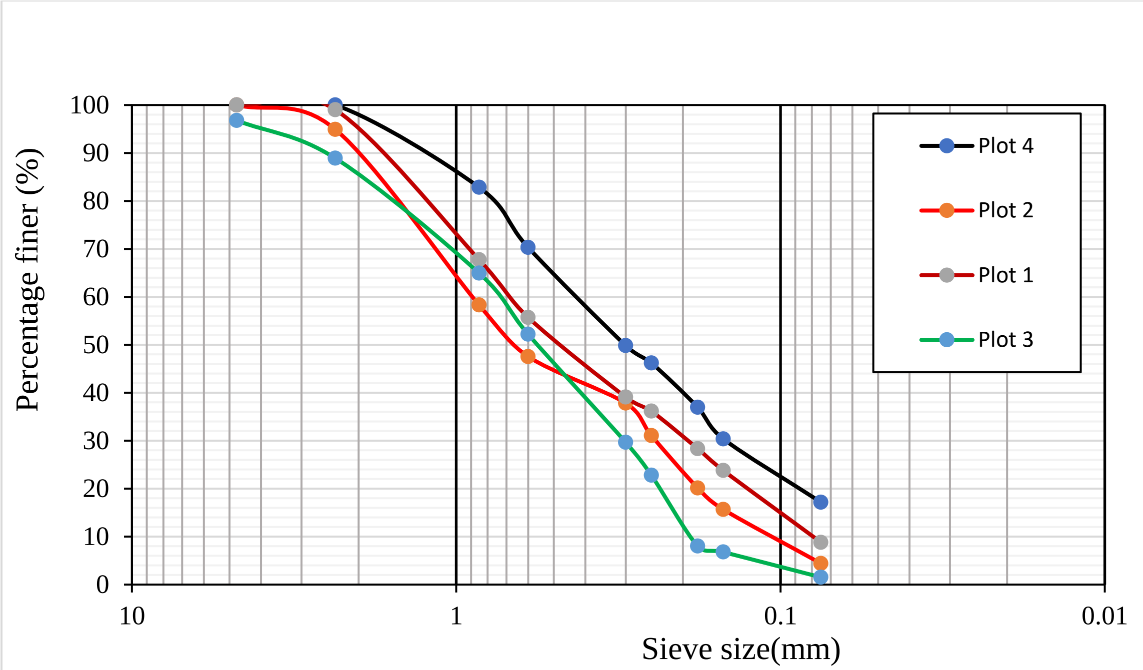


Figure 46 Erosion plot sediment gradation analysis

The graph above shows the fine soil obtained from Plot 4. None of the plots had more than 20 percent fine soil. The soil in Plot 3 had the coarsest particles, as it contained more sand and gravel.

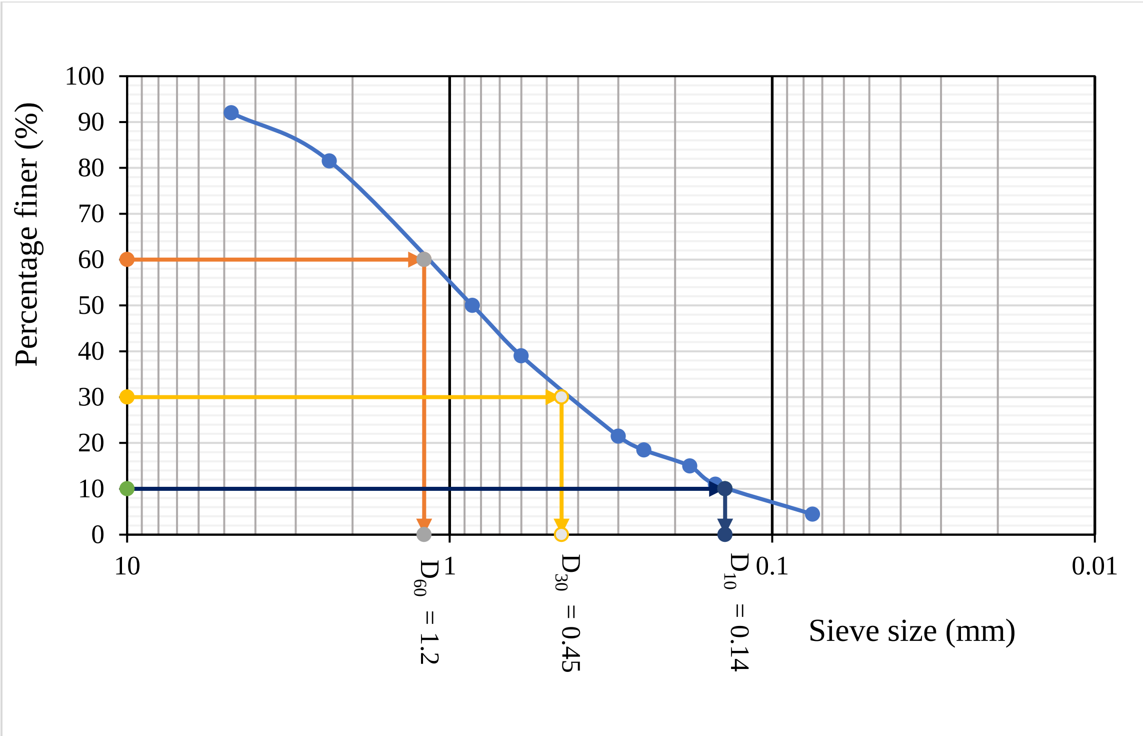


Figure 47 Determining D_{10}, D_{30}, D_{60} from gradation curve

For each soil sample obtained from the plots, the soil type was determined by using the sample calculation method below. The value of D_{60}, D_{30}, and D_{10} was obtained by the graph, then the coefficient of curvature and coefficient of uniformity were obtained by the formula and the soil type was defined based on C_c, C_u, and finer percentage. The well-graded sand was obtained from Plots 1 and 3, as well as during the categorization of the soil type in Plot 2. The poorly graded sand was obtained from Plot 4. It should be noted that the samples may be different for other site visits. The detailed calculations are shown in Appendix C.

4.2 Instream sediment measurement

The sediment yield from construction activities is released to the stream through overland erosion, resulting in an increase in its concentration. The sediment concentration of water samples is typically measured for TSS and turbidity upstream, downstream, and in the construction zone of the creek, and the difference between the concentration of the water taken from the upstream and the construction zone provides information about the impacts of the construction activities. The instream sediment measurement data are shown in Appendix E in the appendix.

Total Suspended Solids (TSS) analysis

Total suspended solids (TSS) of the water samples were continuously monitored across the stream for determining the impacts of the construction activities and BMPs used in the project.

Comparison of TSS measurement with construction activities

The TSS were measured to determine how each bridge construction activity changed the characteristics of the stream, and the results are shown in Figure 48. As can be observed from the table, the TSS value was highest (averaging 48.51 mg/l) during the 4-week construction of the riverbank slope, which was probably due to the direct pushing of the topsoil inside the stream. The average TSS for the slope formation activities was higher than for other activities. The lowest TSS was measured during the drilled shaft construction activity because it involves little disturbance to the soil’s surface; however, moving a small flume to the stream during the drilled shaft construction increased the TSS to 772 mg/l, the highest among all the monitored TSS values.

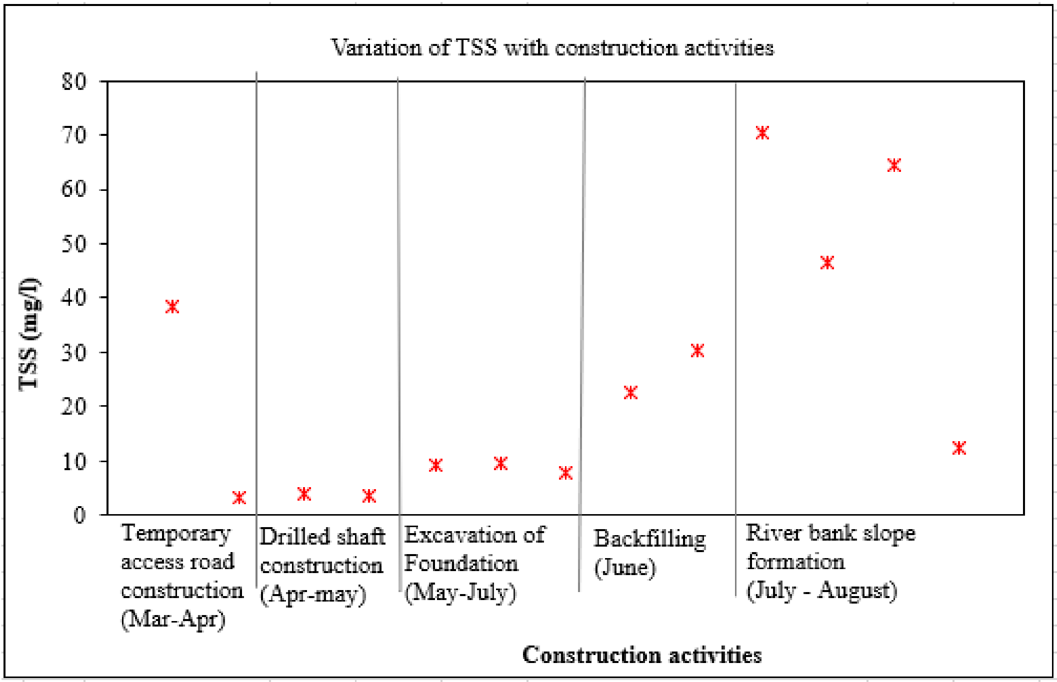


Figure 48 TSS of water sample variations from construction activities

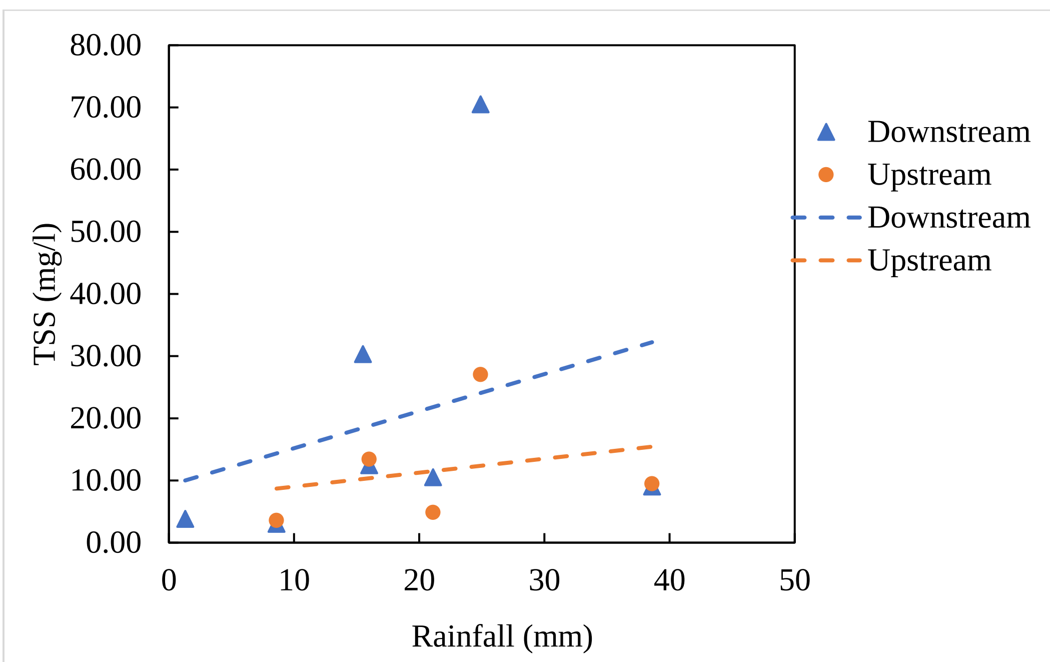


Figure 49 Comparison of TSS upstream and downstream of the construction

Figure 49 shows a comparison of the TSS upstream and downstream of the construction site. The trendline in Figure 49 shows that the downstream TSS value was typically higher than that of the upstream. This clearly shows that the construction activities have impacted the stream.

Variations in TSS data due to BMPs

Silt fences and rock traps were installed in Wilson Creek to control the movement of sediment downstream from the construction site.

1. Silt fence

A silt fence reduces the TSS of streams receiving runoff from construction sites. For this research, a silt fence was installed, but was removed at the end of June. The effectiveness of silt fences is analyzed by turbidity data.

2. Rock Trap

A rock trap of about 1.2 m height and 1 m width was constructed to control the movement of sediment downstream of the construction site. TSS values in the non-deposition and deposition zones created by the rock trap were measured and compared, as shown in the figure below. Comparatively higher values of average TSS were obtained in the deposition zone than in the non-deposition zone. The rock trap effectively reduced the velocity of the stream by creating a small dam that helped settle more particles above the rock trap, allowing only fine sediment to flow downstream. Figure 50 shows variations in the TSS that were due to the construction of the rock trap. Figure 51 shows the three cross sections of water sampling in the creek.

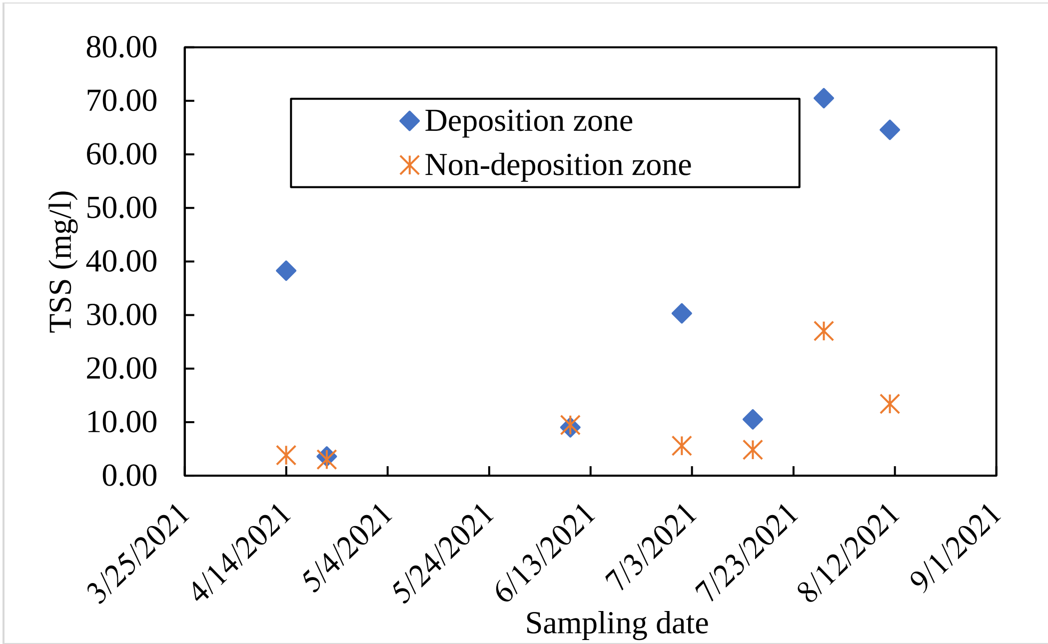


Figure 51 Performance of rock trap for TSS control

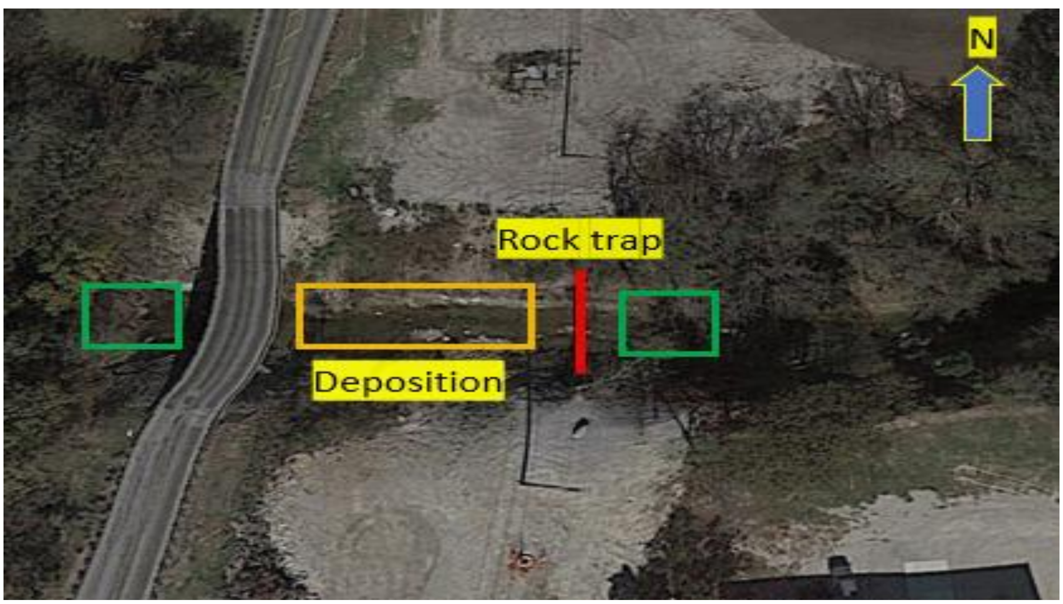


Figure 50 Location showing rock trap influence on the site

Turbidity analysis

Turbidity meters measure the loss of intensity of a light beam as it passes through a fluid containing suspended particles. It is often measured by the Nephelometric Turbidity Unit (NTU). For this research, the turbidity was measured in the water samples that were collected upstream, downstream, and in front of the construction, and upstream and downstream below the rock trap. The reduction reflected in the turbidity data upstream and downstream of the rock trap was used to analyze the efficiency of the rock trap. The impact of silt fences was also analyzed by measuring the turbidity of water samples taken from streams with slopes with and without a silt fence.

Turbidity variations due to rock traps

The turbidity of water samples in areas where there were rock traps upstream and downstream was measured in the Nephelometric Turbidity Unit (NTU) and revealed significant differences. The rock traps reduced the soil contaminants by depositing the turbid water above it, resulting in the average value of the turbidity downstream being an average of 63.5 percent lower than the value of the turbidity upstream. Figure 52 shows the turbidity variations that can be attributed to the construction of rock traps.

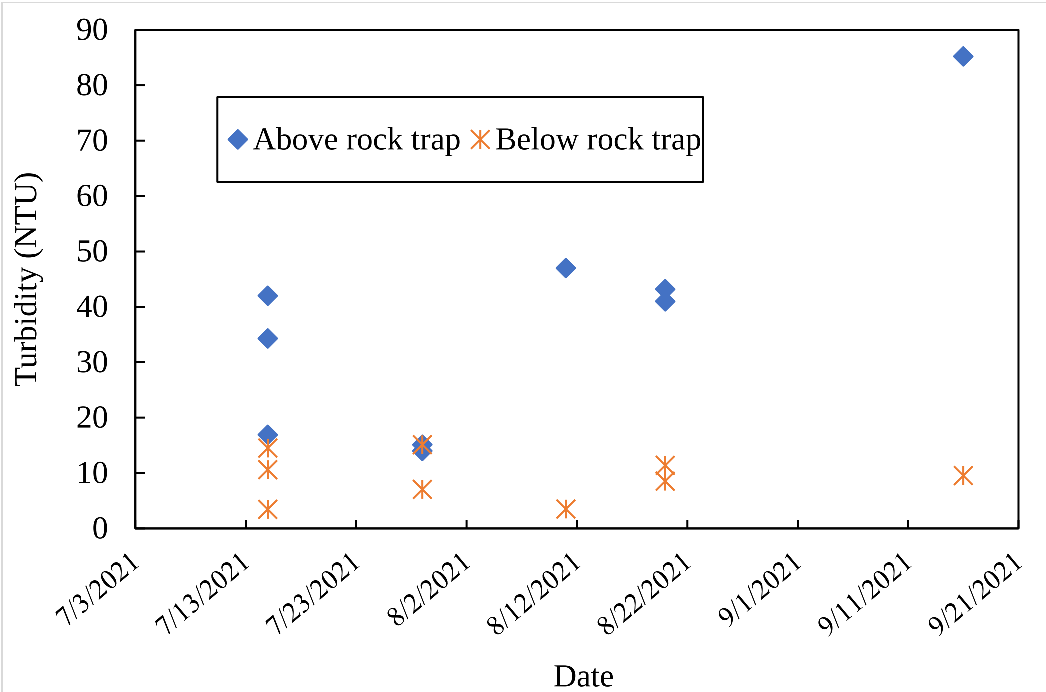


Figure 52 Turbidity variations due to rock trap

The turbidity of the water samples increased with an increase in the rainfall amount. Three trend lines were plotted to separate the trends of turbidity upstream, downstream, and in front of the construction, as shown in Figure 53. The turbidity values in front of the construction zone were revealed to be greater than those upstream and downstream, indicating the water quality in front of construction activities is greatly impacted.

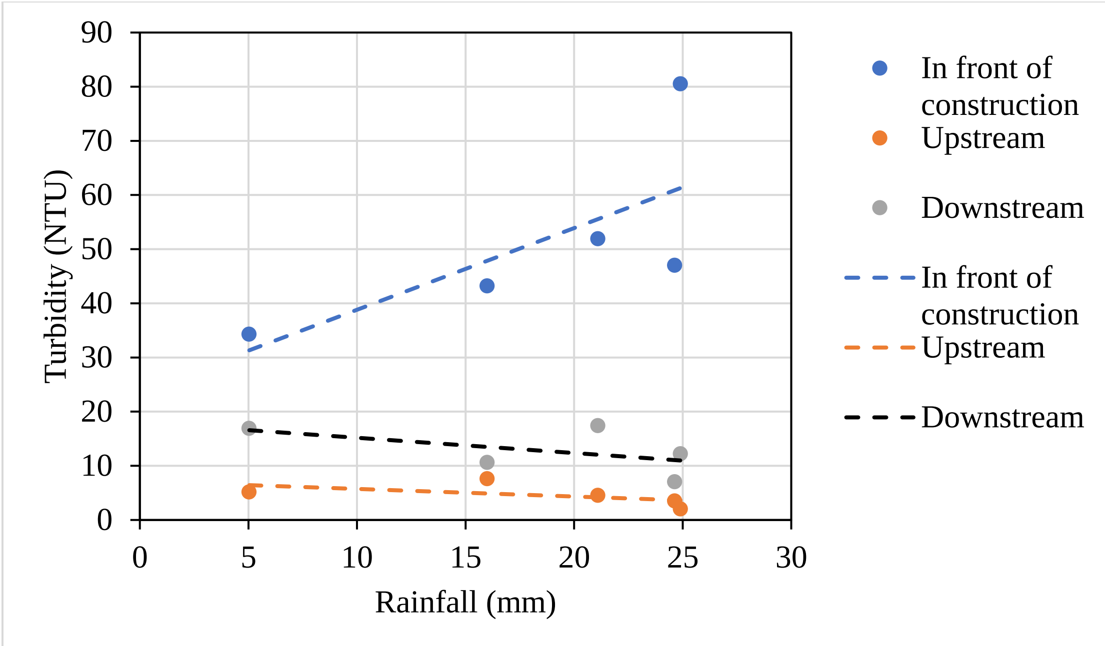


Figure 53 Turbidity variations in three cross sections of construction site

Turbidity variations due to silt fence

The turbidity of the water samples was measured before and after construction of a silt fence and it was determined that a silt fence slightly lowers the turbidity. This is because it reduces the movement of sediment towards the stream. Silt fences are the commonly used BMPs for controlling the movement of eroded sediments to streams. In this research, a silt fence was built at the onset of the bridge construction, but it had to be temporarily removed during the construction. The graph below shows the variations in the turbidity of the water samples taken with and without the presence of a silt fence, just in front of the construction zone. The data presented in Figure 54 shows the difference in turbidity of the water samples.

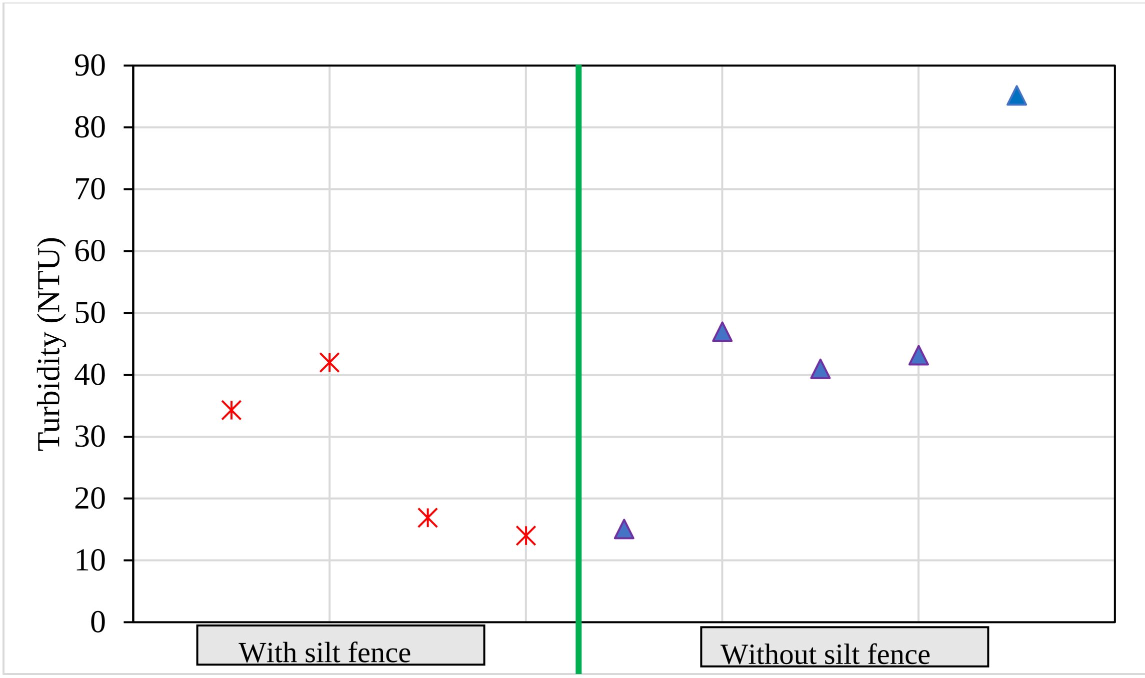


Figure 54 Impact of silt fence on turbidity

Relationship between turbidity and TSS

Turbidity and TSS are important parameters for measuring instream sediment regimes. In the figure below, the trend line is plotted to show the relation between them:

Turbidity = 0.52 * TSS

The turbidity values and TSS for all the samples were collected and plotted to find the relationship between them, and the linear relationship, shown in Figure 55, verifies the correlation between the measured values of TSS and turbidity in water sample taken from Wilson Creek.

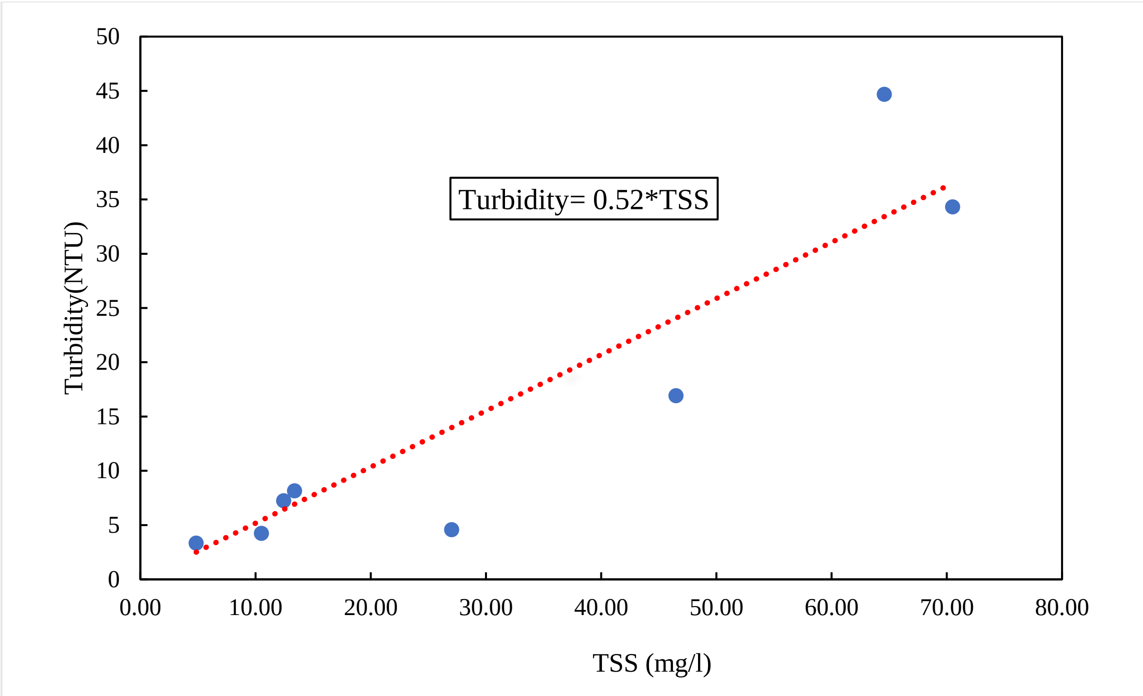


Figure 55 Relationship between TSS and turbidity

Observation of sediment deposition

Sediment deposited up to 22 inches above the rock trap was measured, using tape, after a storm event and revealed that the rock trap was effective for reducing the sediment load downstream of the construction. The storm event damaged the rock trap, but after it was reconstructed, it was again effective. Sometimes it is difficult to measure actual erosion and deposition from a construction site because of the ongoing activities, and it is useful to visually inspect erosion and deposition to predict the amount of soil loss. The height and depth of the sediment were measured during the breakdown of the rock trap to observe the thickness of the soil deposition. Figure 49 shows than an average of 15 inches of 25 ft long and 8 ft wide sediment deposition was observed, which equates to approximately 250 ft^3 of sediment deposition from two banks of Wilson Creek. Most of the sediment was initiated at the bridge construction site.

Since the rock trap effectively reduced the velocity of the stream by creating a small dam, it helped settle more particles above the rock trap and only very fine sediment was able to flow downstream. A bedload trap was installed to check the deposited particles across the stream.

4.3 MUSLE equation analysis and comparison of sediment from erosion plots

The sediment value was measured, using the MUSLE equation developed by Williams and was compared with that obtained from the erosion plots. However, the prediction of sediment weight obtained by using the MUSLE equation was greater than that obtained from experimental plots. It should be noted that the erosion plots were larger than the experimental plots.

Results from MUSLE equation

The MUSLE equation is used to compare and verify the amount of sediment generated from the erosion plots. The calculations of the peak flow rate and volume are based on the SCS curve number method, in which the assumed CN number is the main factor controlling runoff and peak flow rate. According to our assumption of the CN number for construction sites, a minimum of 15 mm rainfall is needed to create flow, which means that the MUSLE equation does not generate sediment caused by less than 15 mm rainfall. However, from field observations, it appears that 15 mm of rainfall is sometimes sufficient to create runoff from vegetated areas. In addition, the distance between the construction site and rainfall gauge station was approximately 4.5 miles, so that too may affect the difference in the amount of rain that fell on the site and that measured by the gauge station. The MUSLE equation was used to calculate the sediment weight of all the plots, and the detailed data are shown in Appendix D.

In Plot 2, the highest sediment weight measured was 1306 grams; however, the sediment weight obtained by the MUSLE equation for the same plot size was 3878 grams, meaning that the equation overpredicted the sediment weight by five times the actual field measurement. An overprediction of sediment was also mentioned in previous studies (Sadeghi et al., 2007; Muche et al., 2013; and Jaramillo 2007). Figure 56 shows a comparison of measured sediment weight and predicted sediment results.

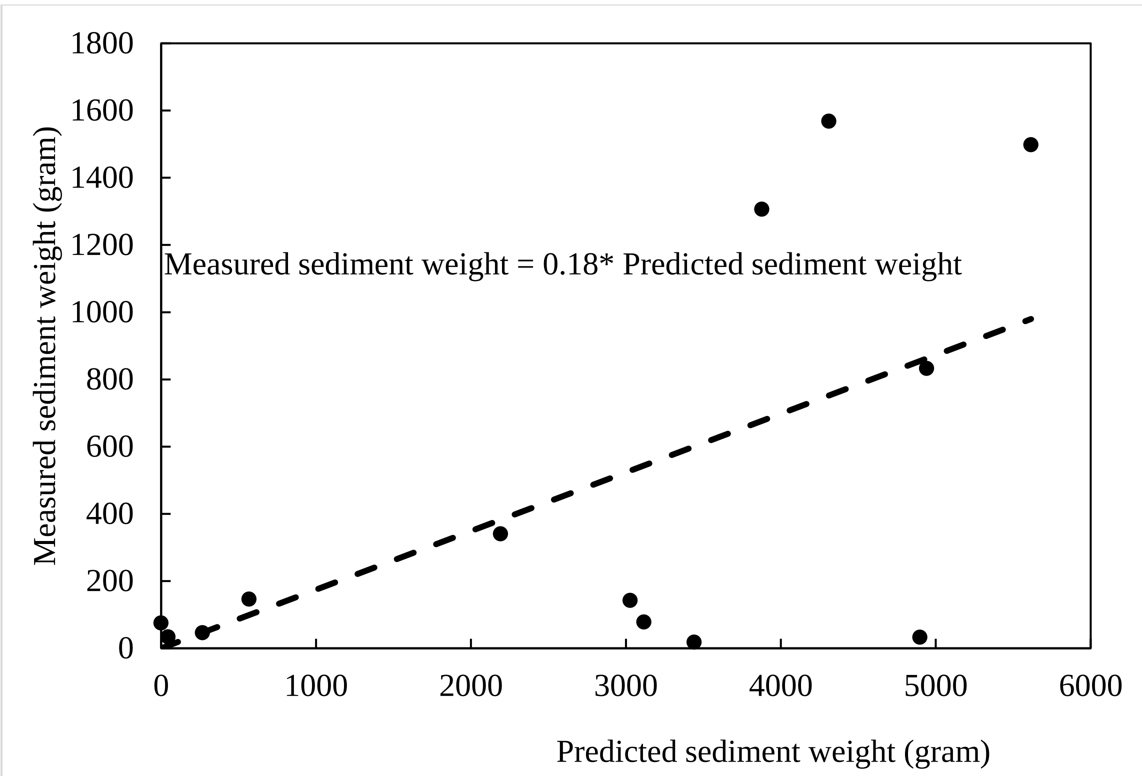


Figure 56 Comparison of sediment yields for Plots 2

Results of factors used in MUSLE equation

The amount of soil loss predicted by hand calculations, using the MUSLE model, are presented in the table below. The peak discharge and volume required in the MUSLE model was calculated by using SCS CN method, and the data obtained for other factors are described below.

Description of SCS curve number method

The SCS curve number method was used to calculate the peak flow rate for each rainfall amount obtained from the rain gauge station. The details methods of calculation are explained in the methodology section above. The curve number (CN) value was corrected, depending on the antecedent moisture condition (AMC) of the soil (the moisture of the pervious surfaces before a rainfall event). The growing season in the US is from June to September, and the dormant season is from October to the following May. For each season, three AMCs are defined by the amount of antecedent five-day precipitation. AMC-I represents the dry condition, when direct runoff is minimized; AMC-III represents the wet condition, when direct runoff is maximized; and AMC-II represents the neutral condition, which is in between the wet and dry conditions. These three conditions are considered in the SCS–CN method for controlling the CN. The CN for AMC-III was the highest derived by analyzing the sufficient length of rainfall-runoff data; the CN for AMC-I was the lowest. The remaining CNs were averaged to obtain the CN for AMC-II. The average CN values for newly graded areas are equal to 77 for hydrologic soil group A. The calculation of the CN number by considering the antecedent moisture condition ranges from 58-88 using the formula below.

$$\mathrm{CN(I)} = \frac{4.2\mathrm{CN(II)}}{10 - 0.058\mathrm{CN(II)}}$$

$$\mathrm{CN(III)} = \frac{23\mathrm{CN(II)}}{10 + 0.13\mathrm{CN(II)}}$$

Peak flow rate

The peak flow rate is calculated by the SCS curve number method. For a rainfall of 0.9-inch, watershed area of 100 ft^2, and time to peak of 0.0042 hour, the peak flow rate is 0.369 ft^3 / sec. The peak flow rates are presented in Appendix D.

Volume of runoff

The volume of the runoff is calculated by multiplying the amount of rainfall by the area of the erosion plot. The effective rainfall is determined by using CN values. For an area of 100 square feet and effective rainfall of 0.26 in, the volume of runoff is 1 cube ft. Details of volume calculations are given in the Appendix D.

Crop management factor

Factor C is the ratio of soil loss from land use under specified cover and management practices. Site clearing and grubbing works remove all vegetation and roots from the soil, and construction activities remove any residual effects, leaving the soil without protection. The C factor for the disturbed soil surface is 1; the C factor for the undisturbed soil surface depends upon the types of vegetation.

Soil erosivity (k) factor

A previous study revealed that the Wilson Creek watershed is formed of Austin chalk (Ferring, 1994). The NRCS soil survey shows that the k factor for an Austin chalk formation is 0.29; however, that will change during various construction activities.

LS factor

The LS factor for a plot is calculated by using the Moore and Burch method, where $L = 1.4\left(\frac{\lambda}{22.1}\right)^m$ where m = 0.5 for slope exceeding 5% And λ is the field slope length in meters. $\lambda = 3.17m$, L factor would be 0.53 and S factor would be 0.61. S factor can be calculated, $S = 10.8\ sin\theta + 0.03$ for slope < 9 % and θ is the slope angle in degrees. Combining L and S factor, LS factor would be 0.32 for Plot 1.

4.4 Observation of bedload samples and eroded soil samples

Bedload samples were obtained from an installed bedload trap and eroded soil samples were taken from the side of the drilled shaft to gain information about the gradation of the soil samples moved to the stream from the construction zone.

Bedload samples

A bedload trap was installed approximately 70 m downstream of the bridge construction to trap the bedload. Several bedload samples were taken from the bedload trap and measured. The sediment samples collected on August 11 weighed 145 grams. These sediment samples represent the nature of those moving downstream of the creek from the construction zone; however, they do not measure all the sediment passing from the construction zone, as a bedload trap only collects sediment samples that are larger than the size of a nylon net whose holes are 0.8 mm. However, due to the clogging of debris between two nets, the bedload trap was able to collect sediment smaller than 0.8 mm. The bedload samples were taken to the laboratory and weighed, and the sample was graded to determine the amount of course content and fine particles. The graph below shows the actual gradation of the bedload trap sample.

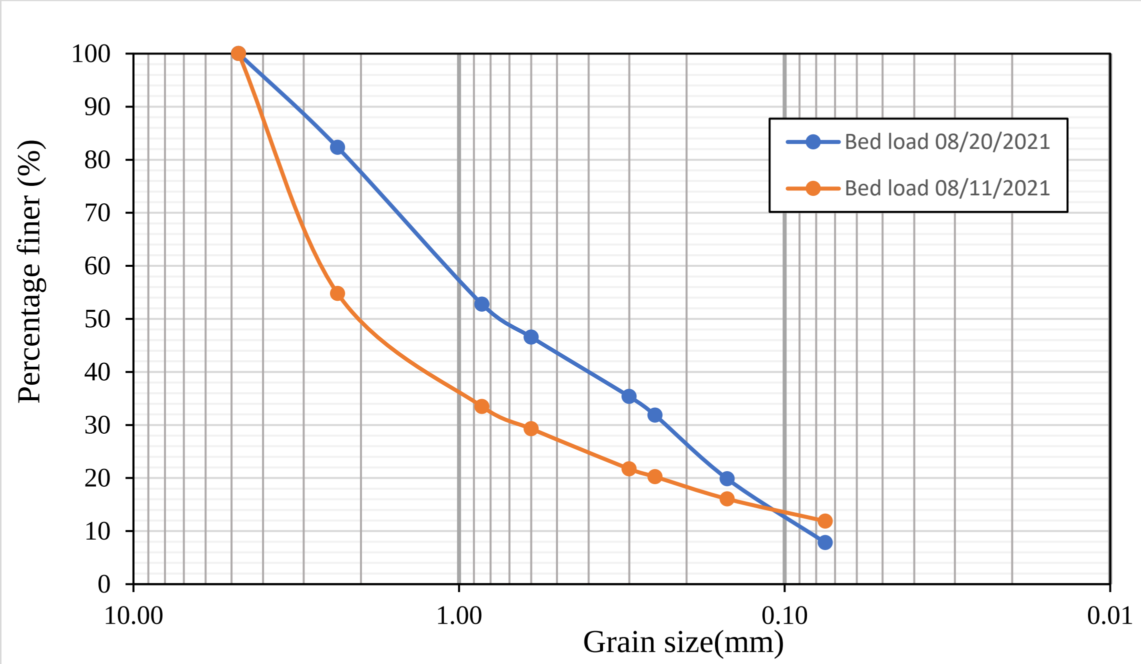
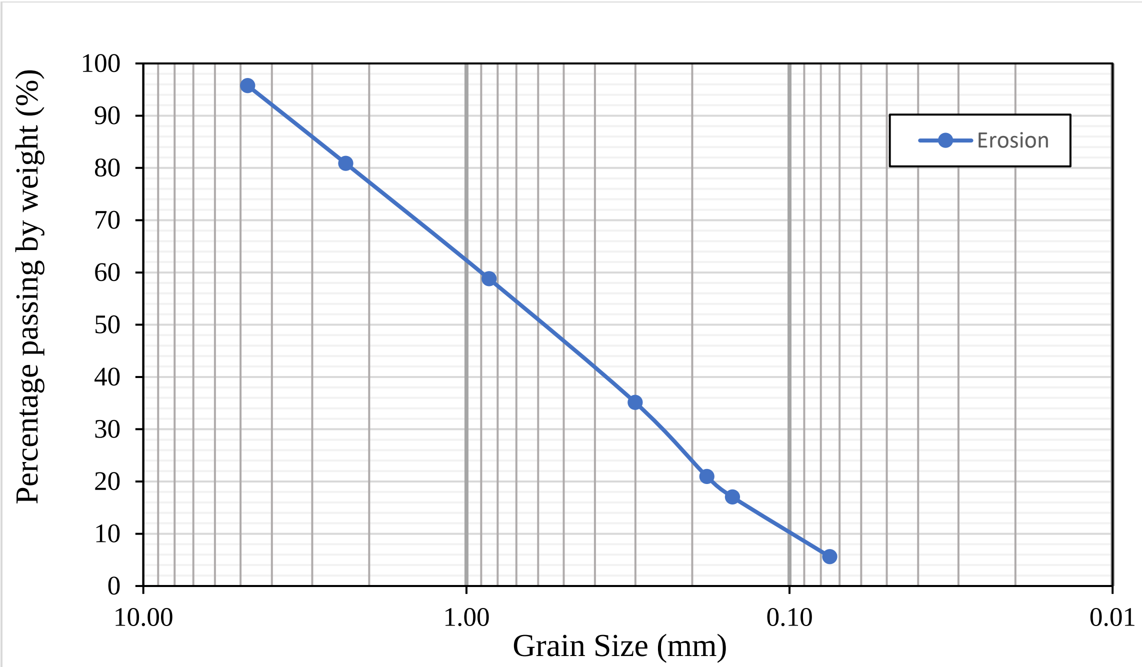


Figure 57 Sediment gradation curve for bedload samples

Eroded soil sample

The soil deposited near the stream bank represents the eroded soil sample. At each site visit, almost 1000 grams of eroded soil were removed from the deposited soil, and gradation was performed for the 1000-gram soil sample to relate the gradation curve of the eroded sample to the site's soil type. The eroded soil was finer than the soil in the plots since runoff only transports fine soil.



The above graph shows the gradation curve for eroded soil taken from the bridge construction zone. During the slope formation at the bottom sides of the bridge, the soil was pushed to the stream and the soil was deposited in the center of the creek. This sample represents the type of soil that was pushed to the inside of the creek.

5 Summary and Conclusion

The impacts of bridge construction activities were studied by monitoring several parameters at Wilson Creek. Monitoring the overland and changes in instream sediment provided an overall picture of how construction activities adversely affect a sediment regime. The overland erosion during rainfall was measured by collecting the sediment from erosion plots. From the results obtained from the erosion plots, we estimated that the plots without vegetation would generate more sediment than the plots with vegetation, and the plots whose construction disturbed the topsoil would yield more sediment than the plots whose topsoil had not been disturbed. It was found that just raking the top 2 inches of the topsoil increases the rate of erosion by up to 10 percent. It was also revealed that smooth slopes without undulation inside the plot perform an important role in carrying the runoff to the storage bucket. The outside environment also has an impact on diverting rainfall outside the plots. In Plot 2, which is under a tree, the amount of rainfall was lessened by the tree’s shade and may not be sufficient rainfall to induce flow.

The MUSLE equation was used for the theoretical prediction of the sediment obtained from the plots. A comparison of data obtained by the MUSLE equation, and the obtained sediment weight showed that the MUSLE usually overpredicts the sediment weight by three times. The length of the plot may be the contributing factor to this, since the MUSLE equation was verified in the plots having lengths three times greater than the width. We constructed a square plot due to the difficulties inherent in constructing a large plot on a construction site.

Impacts on the water quality of the stream from construction activities were obvious from monitoring the TSS and turbidity across several cross sections of the stream. A comparison of three cross sections of the stream showed that the TSS and turbidity of the samples near the construction zone were much greater than those upstream and downstream of the zone. Discrete water samples could not be collected during the peak of the runoff because of the steep slope on both sides of the riverbank. It is likely, however, that the concentrations of solids below the construction site were at times significantly greater when sampled during the peak discharge.

Best management practices for stormwater control play a key role in reducing the sediment inside a stream. The rock filter dam worked effectively in this research to control larger particles upstream, but the measurement of turbidity upstream and downstream of the rock trap was significantly different. The rock trap reduced the turbidity up to 63.5 percent. Silt fences also helped stop the sediment from moving toward the creek; however, when they had to be removed for slope formation and backfilling activities, the TSS and turbidity inside the stream increased. Plantation work also seems effective for controlling overland erosion.

Weighing of deposited sediments showed that there was significant movement of sediments from the construction site downstream to the creek. Although the sediment deposition was due to the dam formation by a rock trap, it verifies that a significant amount of soil had been transported through the stream. The sediments measured from the bedload trap showed that a large amount of sediment that could not be contained by the rock trap was transported downstream.

Recommendations for future research

1. Each bridge construction activity has a different rate of soil disturbance, slope, and soil erosion. To predict the tentative sediment loads released from construction, separate prototype erosion plots will be required for each bridge construction activity.
2. It is difficult to distinguish the sediment loads coming from a construction upstream of a creek. A sediment deposition system above the construction would help contain sediment load coming from upstream.
3. An autosampler is necessary for sampling water frequently during a storm event since, in many storm events, it may not be possible to access the stream.
4. The erosion prediction model is based on large size plots. Further study will be required to predict the amount of soil erosion from small plots.
5. The measurement of actual rainfall at the site is pivotal, but the distance from the rain gauge station to the site can cause discrepancies in the measurements.

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APPENDIX A

Tasks performed, Construction activities and BMPs

Table A 1 Site visit details

Site visit	Time	Temp.	Weather	Major tasks performed
12/17/2021	12:50 PM	55 °F	Sunny.	Erosion plot constructed: 2
12/31/2021	1:30 PM	38 °F	Heavy rain. Fog.	Checked constructed plots
1/29/2021	1:50 PM	57 °F	Sunny.	Constructed plot with metal sheet
2/4/2021	12:50 PM	57 °F	Sunny.	Collected water sample and maintained plot
2/25/2021	1:35 PM	52 °F	Partly sunny.	Checked erosion plots
3/2/2021	11:53 AM	56 °F	Sunny.	Collected first sample from erosion plot
3/17/2021	12:45 PM	68 °F	Sunny.	Collected sediment from plots, constructed third plot
3/26/2021	1:55 PM	73 °F	Sunny.	Checked erosion plots
4/14/2021	12:53 PM	64 °F	Overcast.	Reconstructed damaged Plot 1
4/22/2021	12:53 PM	62 °F	Mostly cloudy.	Collected sediment from plots
4/28/2021	1:53 PM	78 °F	Mostly cloudy.	Started raking of the soil
5/6/2021	11:53 AM	68 °F	Sunny.	Maintained damaged plot
5/25/2021	12:50 PM	71 °F	Light rain.	Removed Plot 1
6/3/2021	12:53 PM	80 °F	Passing clouds.	Measured velocity of creek
6/9/2021	10:45 AM	77 °F	Overcast.	Measured discharge and velocity
6/17/2021	11:50 AM	93 °F	Sunny.	Constructed plot in vegetation
7/1/2021	12:53 PM	90 °F	Partly sunny.	Collected and measured 100 pebbles

7/15/2021	1:55 PM	90 °F	Scattered clouds.	Measured turbidity and sediment deposition
7/29/2021	12:40 PM	93 °F	Sunny.	Installed bedload trap
8/11/2021	1:50 PM	94 °F	Sunny.	Checked all monitoring parameters
8/20/2021	12:55 PM	90 °F	Sunny.	Measured velocity and collected sample
9/16/2021	4:50 PM	90 °F	Scattered clouds.	Collected several samples (plot, water, bedload)

Source: https://www.timeanddate.com/weather/usa/mckinney/historic?month=9&year=2021

Table A 2 Construction activities timeline and BMPs

Construction activities	Timeline	BMPs	
		Structure	Landscape
Site clearing	Feb - Mar 10	No	No
Grading	Mar 11- Mar 26	No	No
Temporary access road construction	Apr1- Apr 5	No	No
Drilled shaft formation	Apr 10- May 3	Silt fence, rock trap	No
Foundation construction	May 6 - July 01	Silt Fence, Rock trap	Plantation
Backfilling work	June 18- June 29	Silt fence	Plantation
Slope formation	July 15- July 29	Silt fence, rock trap	Plantation
Upper structure	July 15- now	Silt fence, rock trap	Plantation

APPENDIX B

Sediment results from plots

Table B 1 Sediment weight from erosion plots

Site visit date	Sediment weight(gram)			
	Plot 1	Plot 2	Plot 3	Plot 4
3/2/2021	1568	32.5	Constructed north bank and removed due to bridge alignment	Not constructed
3/17/2021	33.6	0		
3/26/2021	142	18		
4/14/2021	75	0	16	
4/22/2021	832.3	381.2	0	
4/28/2021	1051.2	356.7	86.5	
5/6/2021	9087	760.3	653.7	
5/25/2021	Removal of plot 1 (Due to construction activities)	1070	425	
6/3/2021		236	176	
6/9/2021		340	Removal of plot 3(Slope protection activities)	
6/17/2021		78		
7/1/2021		25		16
7/15/2021		46		11
7/29/2021		0		0
8/11/2021		0		0
8/20/2021		146		49
9/16/2021		68		19
10/11/2021		82		17
10/27/2021		126		38

Table B 2 Sediment weight Plots 1 and 2

Rainfall (mm)	Sediment wt. (Gram)	
	Plot 1 (South Bank)	Plot 2 (North Bank)
2.8	75	0
8.1	33.6	0
18.8	1051.2	356.7
20.8	832.3	381.2
21.3	142	18
31.5	1568	32.5

Table B 3 Sediment weight of Plot 2 (effect of raking)

Not raking		Raking	
Rainfall(mm)	Sediment wt. (gram)	Rainfall(mm)	Sediment wt. (gram)
21.1	46	41.4	760.3
26.9	25	74.4	236
31.2	78	108.7	340
67.8	146	155.2	1070
		3.6	68
		17.8	82
		13.2	126

Table B 4 Sediment weight in vegetated and non-vegetated plots

Plot 3 (without vegetation)		Plot 4 (with vegetation)	
Rainfall (in.)	**Sediment wt. (gram)**	**Rainfall (in.)**	**Sediment wt. (gram)**
2.8	16	21.1	11
20.8	86.5	26.9	16
41.4	653.7	67.8	49
74.4	176	3.6	19
155.2	425	17.8	17
3.6	68	13.2	38
17.8	82		
13.2	126		

APPENDIX C

Gradation analysis of soil

Riverbed samples

Sample:1

Location: Around 150m (below the bridge opposite to the bed rock, left bank)

Sample weight: 500 Gram

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Table C 1 Gradation analysis of bed soil (Sample 1)

Sieve No.	Grain Size (mm)	m_{sieve} (g)	$m_{sieve+soil}$ (g)	m_{soil} (g)	$P_{retained}$ (%)	Cum. $P_{retained}$ (%)	P_{Finer} (%)
4	4.75	776.60	873.20	96.60	19.32	19.32	80.68
8	2.36	527.90	611.30	83.40	16.68	36.01	63.99
20	0.85	426.00	551.70	125.70	25.15	61.15	38.85
30	0.60	469.30	515.10	45.80	9.16	70.31	29.69
50	0.30	556.70	635.20	78.50	15.70	86.02	13.98
60	0.25	547.90	559.20	11.30	2.26	88.28	11.72
80	0.18	506.80	508.80	2.00	0.40	88.68	11.32
100	0.15	490.10	509.20	19.10	3.82	92.50	7.50
200	0.08	518.10	536.50	18.40	3.68	96.18	3.82
Pan	-	314.20	333.30	19.10	3.82	100.00	0.00
				499.90			

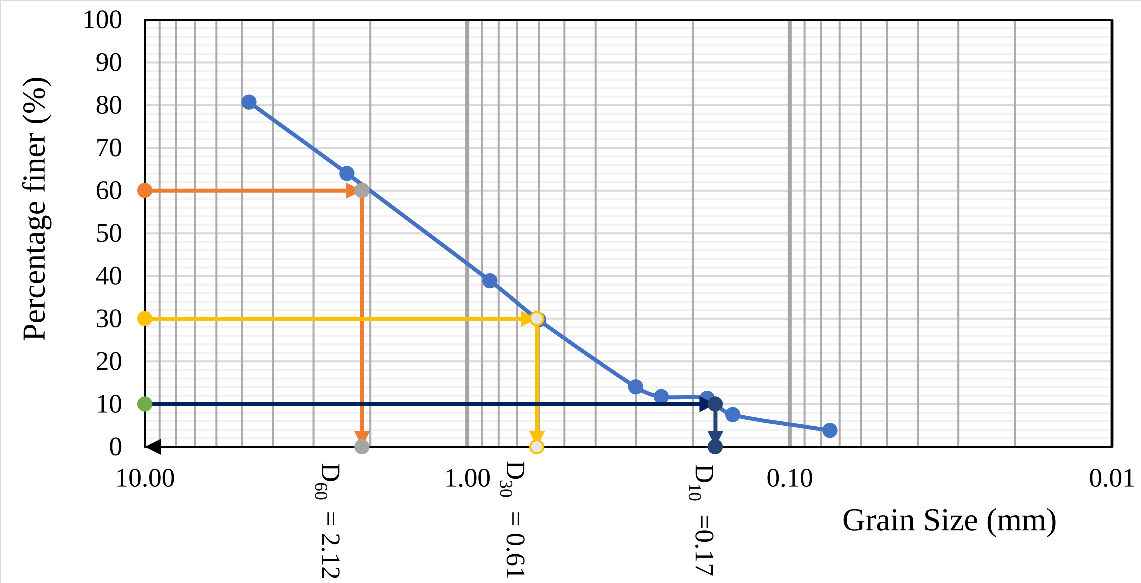

Figure C 1 Sieve analysis bed soil (Sample 1)

Table C 2 Calculation of Cc and Cu, identification of soil type

%Gravel= 19.32	
%Sand= 76.86	
% Fines=3.82	Since F_{200}<5
D_{60} = 2.12	C_u>6, 1<C_c<3
D_{30}=0.61	Gravel> 15%
D_{10}= 0.17	**Soil:**
$C_u = D_{60}/D_{10} = 12.47$	**Well-graded sand with gravel**
$C_c = (D_{30}^2)/(D_{60}*D_{10}) = 1.03$	

Sample:2

Sample weight: 1000 gram

Soil taken: Around 50 meters below the bridge (Right bank)

Table C 3 Sieve analysis of bed soil (Sample 2)

Sieve No.	Grain Size (mm)	m_{sieve} (g)	$m_{sieve+soil}$ (g)	m_{soil} (g)	$P_{retained}$ (%)	Cum. $P_{retained}$ (%)	P_{Finer} (%)
4	4.75	765	845	80	8	8	92
8	2.36	490	595	105	10.5	18.5	81.5
20	0.85	425	740	315	31.5	50.0	50.0
30	0.60	480	590	110	11.0	61.0	39.0
40	0.30	560	735	175	17.5	78.5	21.5
60	0.250	550	580	30	3.0	81.5	18.5
80	0.180	510	545	35	3.5	85.0	15.0
100	0.150	490	530	40	4.0	89.0	11.0
200	0.075	520	585	65	6.5	95.5	4.5
Pan	-	275	320	45	4.5	100.0	0.0
				1000			

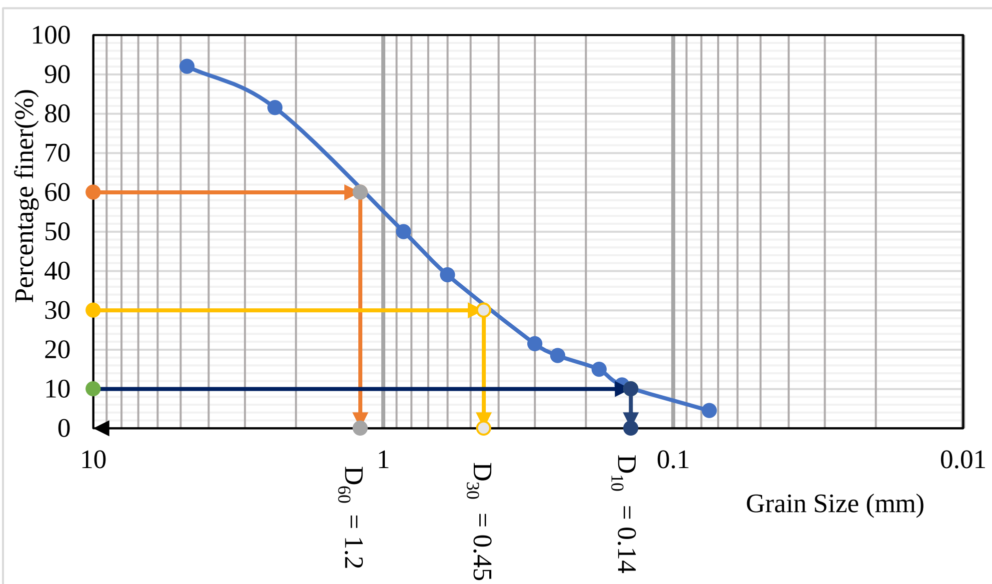

Figure C 2 Gradation analysis curve bed soil (Sample 2)

Table C 4 Calculation of Cc and Cu, identification of soil type (Sample 2)

%Gravel= 8%	
%Sand= 87.5%	
% Fines=4.5%	
D_{60} = 1.2	
D_{30}=0.45	Since F_{200}<5
D_{10}=0.14	C_u>6, 1<C_c<3
	Gravel< 15%
$C_u = D_{60}/D_{10}$ = 8.57	**Soil:**
$C_c=(D_{30}^2)/(D_{60}*D_{10})$ =1.2	Well-graded sand

Sample: 3

Soil taken: Just below the bridge (near left bank)

Sample weight: 1000 gram

Table C 5 Sieve analysis of bed soil (Sample 3)

Sieve No.	Grain Size (mm)	m_{sieve} (g)	$m_{sieve+soil}$ (g)	m_{soil} (g)	$P_{retained}$ (%)	Cum. $P_{retained}$ (%)	P_{Finer} (%)
4	4.75	765.70	1135.50	369.80	36.99	36.99	63.01
8	2.36	489.80	753.00	263.20	26.33	63.33	36.67
20	0.85	423.70	615.10	191.40	19.15	82.47	17.53
30	0.60	478.60	539.10	60.50	6.05	88.53	11.47
40	0.30	552.90	591.80	38.90	3.89	92.42	7.58
60	0.25	549.70	557.00	7.30	0.73	93.15	6.85
80	0.18	524.00	535.30	11.30	1.13	94.28	5.72
100	0.15	348.70	355.60	6.90	0.69	94.97	5.03
200	0.08	514.30	533.50	19.20	1.92	96.89	3.11
Pan	-	273.4	304.5	31.1	3.1	100.0	0.00
				999.6			

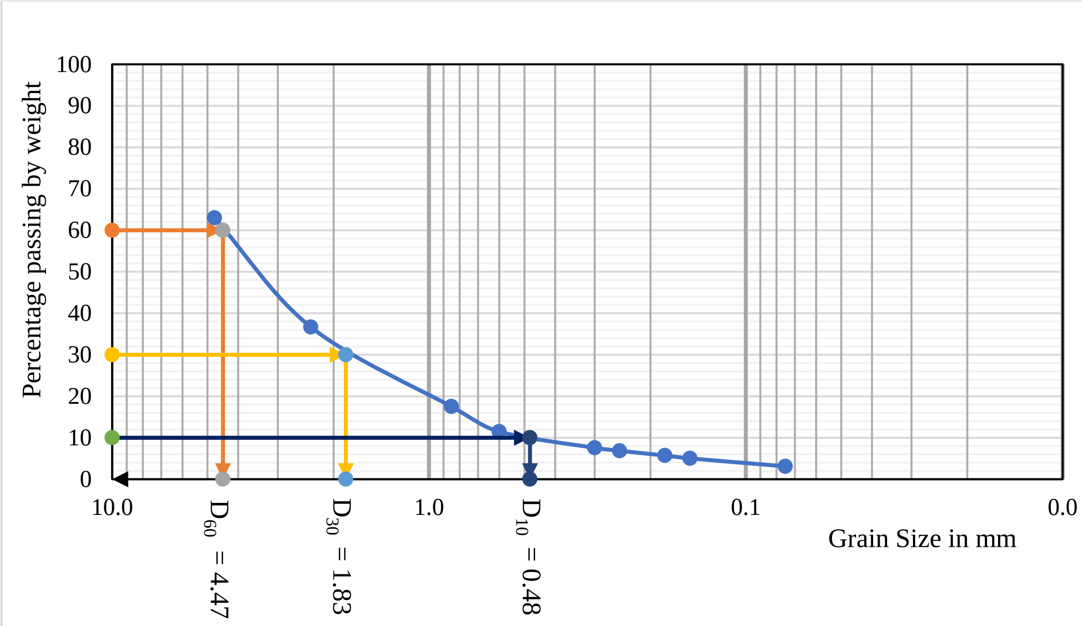

Figure C 3 Gradation analysis of bed soil (Sample 3)

Table C 6 Calculation of C_c and C_u, identification of soil type (Sample 3)

%Gravel= 36.99	
%Sand=59.9	
% Fines=3.11	
D_{60} =4.47mm	Since, F_{200}<5
D_{30}= 1.83mm	C_u>6, 1<C_c<3
D_{10}= 0.48mm	Gravel> 15%
	Soil:
Cu = D_{60}/D_{10} = 9.31	Well-graded sand with gravel
Cc= $(D_{30}^2)/(D_{60}*D_{10})$ = 1.56	

Plot 1: Sample collection 03/02/2021

Sample size: 1000 gram

Table C 7 Sieve analysis of sediment sample (Plot 1)

Sieve No.	Grain Size (mm)	m_{sieve} (g)	$m_{sieve+soil}$ (g)	m_{soil} (g)	$P_{retained}$ (%)	Cum. $P_{retained}$ (%)	P_{Finer} (%)
4	4.75	514.3	546.5	32.2	3.2270996	3.227099619	96.77290038
8	2.36	527.9	606.4	78.5	7.9	11.1	88.9
20	0.85	426.2	665.3	239.1	24.0	35.1	64.9
30	0.60	431.3	558.6	127.3	12.8	47.8	52.2
50	0.30	377.1	602	224.9	22.5	70.4	29.6
60	0.250	365.9	434.4	68.5	6.9	77.2	22.8
80	0.180	524.3	671.6	147.3	14.8	92.0	8.0
100	0.150	422.6	435	12.4	1.2	93.2	6.8
200	0.075	516.5	569	52.5	5.3	98.5	1.5
Pan	-	273.5	288.6	15.4	1.5	100.0	0.0
				998.3			

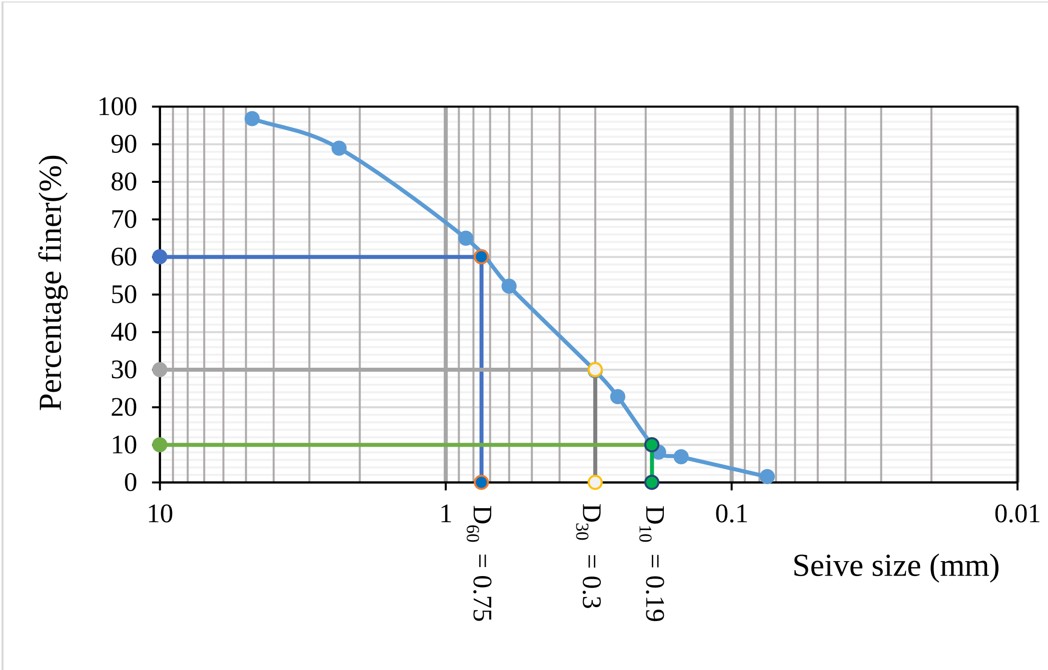

Figure C 4 Gradation analysis of sediment sample (Plot 1)

Table C 8 Calculation of C_c and C_u, identification of soil type (Plot 1)

%Gravel= 3.23	
%Sand= 95.27	
% Fines=1.5	
D_{60} =0.75 mm	Since F_{200}<5
D_{30}= 0.3 mm	C_u<6, 1>C_c
D_{10}= 0.19 mm	Gravel <15%
	Soil:
$C_u = D_{60}/D_{10} = 3.94$	
$C_c=(D_{30}^2)/(D_{60}*D_{10}) = 0.63$	Poorly graded sand

Soil sample: plot 2 (Sample collection: May)

Weight taken: 760.3 gram

Table C 9 Sieve analysis of soil sample (Plot 2)

Sieve No.	Grain Size (mm)	m_{sieve} (g)	$m_{sieve+soil}$ (g)	m_{soil} (g)	$P_{retained}$ (%)	Cum. $P_{retained}$ (%)	P_{Finer} (%)
4	4.75	765.7	765.7	0	0	0	100
8	2.36	528.1	620.5	92.4	12.2	12.2	87.8
20	0.85	426.1	525.4	99.3	13.1	25.3	74.7
30	0.60	469.4	550.5	81.1	10.7	36.0	64.0
50	0.30	452.3	560.4	108.1	14.3	50.3	49.7
60	0.250	366	413.5	47.5	6.3	56.6	43.4
80	0.180	507.2	613.2	106	14.0	70.6	29.4
100	0.150	422.6	501.2	78.6	10.4	80.9	19.1
200	0.075	514.4	586.7	72.3	9.5	90.5	9.5
Pan	-	273.4	345.4	72	9.5	100.0	0.0
				757.3			

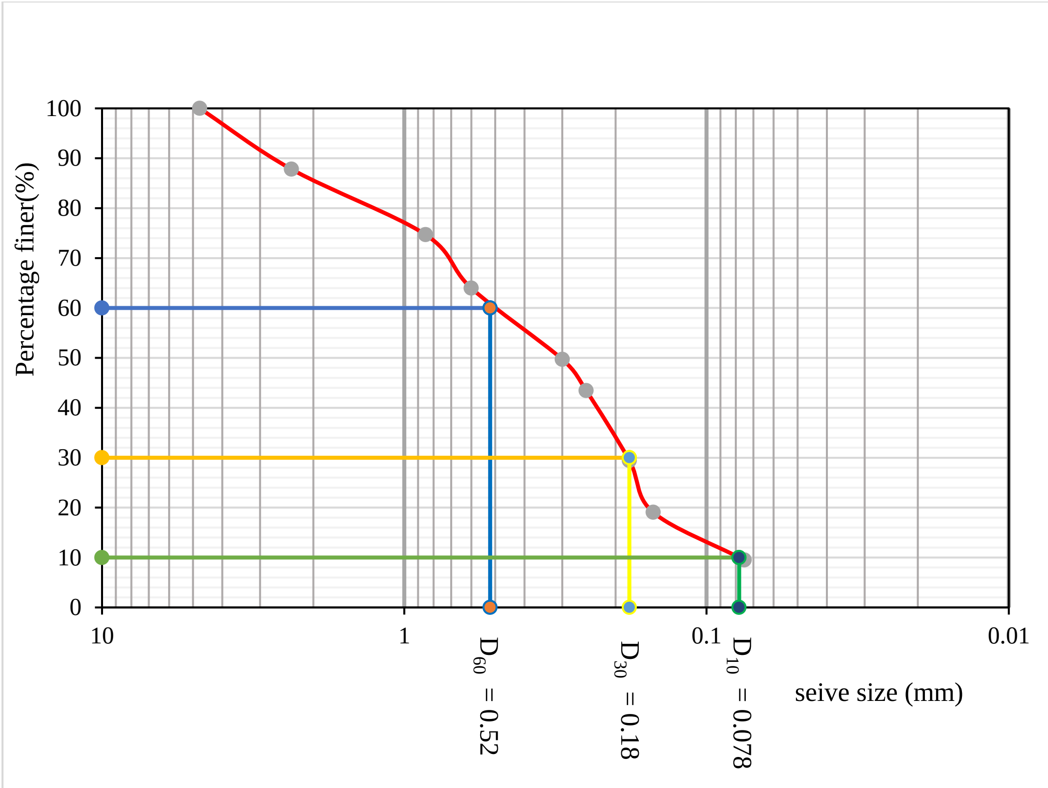

Figure C 5 Gradation curve of soil sample (Plot 2)

Table C 10 Calculation of C_c and C_u, identification of soil type (Plot 1)

%Gravel= 0	
%Sand= 98.5	
% Fines=9.5	
D_{60} =0.52 mm	Since F_{200}<5
D_{30}= 0.18 mm	C_u>6, 1>C_c, Meets PI of SC
D_{10}= 0.078 mm	Gravel <15%
	Soil:
$C_u = D_{60}/D_{10} = 6.67$	
$C_c= (D_{30}^2)/(D_{60}*D_{10}) = 0.8$	Poorly graded sand with clay

Soil sample: Plot 3

Sediment weight: 563.3 gram

Table C 11 Sieve analysis of plot soil sample (Plot 3)

Sieve No.	Grain Size (mm)	m_{sieve} (g)	$m_{sieve+soil}$ (g)	m_{soil} (g)	$P_{retained}$ (%)	Cum. $P_{retained}$ (%)	P_{Finer} (%)
4	4.75	765.7	765.7	0	0	0	100
8	2.36	528.1	586.7	58.6	9.0	9.0	91.0
20	0.85	426.1	525.4	99.3	15.3	24.3	75.7
30	0.60	469.4	575.6	106.2	16.3	40.6	59.4
50	0.30	452.3	560.7	108.4	16.7	57.3	42.7
60	0.250	366	418.7	52.7	8.1	65.4	34.6
80	0.180	507.2	563.4	56.2	8.6	74.0	26.0
100	0.150	422.6	463.5	40.9	6.3	80.3	19.7
200	0.075	514.4	565.3	50.9	7.8	88.1	11.9
Pan	-	273.4	350.7	77.3	11.9	100.0	0.0
				650.5			

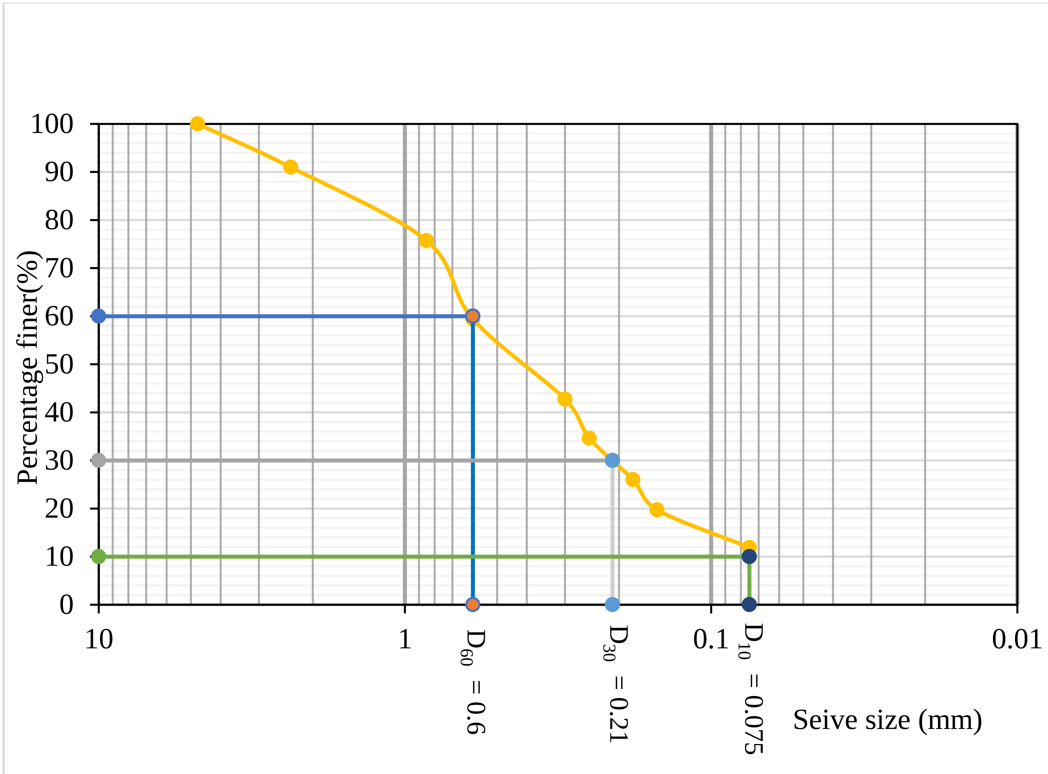

Figure C 6 Gradation curve of soil sample (Plot 3)

Table C 12 Calculation of C_c and C_u, identification of soil type (Plot 1)

%Gravel= 0	
%Sand= 88.1	
% Fines=11.9	
D_{60} =0.6 mm	Since $5<F_{200}<12$
D_{30}= 0.21 mm	$C_u>6$, $1<C_c<3$, meets PI of SC
D_{10}= 0.075 mm	Gravel <15%
	Soil:
$C_u = D_{60}/D_{10} = 8$	
$C_c= (D_{30}^2)/(D_{60}*D_{10}) = 1$	Poorly graded sand with clay

APPENDIX D

Calculation of plot sediment using MUSLE equation

Table D 1 Measurement of slope

Plot	Length (in.)	Height (in.)	Slope (%)
Plot 1	120	6.4	5.41
Plot 2	120	7	5.86
Plot 3	120	12.5	10.42
Plot 4	120	8.7	7.32

Calculation of CN correction

For newly graded areas, the average curve number value (CN) = 77, Based on the antecedent moisture content the CN value is changed by using formula below.

1. If the previous storm event was less than 5 days from measurement, $\mathrm{CN(I)} = \frac{4.2\mathrm{CN(II)}}{10-0.058\mathrm{CN(II)}}$

2. If the previous storm event is within 5 days $\mathrm{CN(III)} = \frac{23\mathrm{CN(II)}}{10+0.13\mathrm{CN(II)}}$

The CN value is calculated by above methods in the table below.

Calculation of q_p and Q

Plot:3

The calculations of all the components below were based on the slope length, slope percentage, area, and CN value.

$t_c = \frac{L^{0.8}(S+1)^{0.7}}{1140Y^{0\cdot 8}}$, tp=0.67×tc, $Pe = \frac{(P-0.2S)^2}{P+0.8S}$,$CN = \frac{1000}{10+S}$, $qp = \frac{484A\cdot Pe}{tp}$

Table D 2 Calculation table for Q and q_p

Date	Slope %(Y)	Slope length, L (ft)	P	CN	S	p_e	t_c	t_p	A	$q_{p(cfs)}$	Q (ft^3)	Q (Acre feet)
2/26/2021	5.41	10.01	2.6	63	5.87	0.26	0.009	0.006	0.00000356	0.07	2.18	0.0000500
3/23/2021	5.41	10.01	0.7	78	2.82	0.00	0.006	0.004	0.00000356	0.00	0.03	0.0000007
3/25/2021	5.41	10.01	1.4	76	3.16	0.17	0.006	0.004	0.00000356	0.07	1.40	0.0000321
4/29/2021	5.41	10.01	2.8	62	6.13	0.31	0.009	0.006	0.00000356	0.09	2.62	0.0000601
5/11/2021	5.41	10.01	2.5	64	5.63	0.28	0.009	0.006	0.00000356	0.08	2.37	0.0000544
5/17/2021	5.41	10.01	1.6	73	3.70	0.15	0.007	0.005	0.00000356	0.05	1.22	0.0000279
5/19/2021	5.41	10.01	0.6	77	2.99	0.00	0.006	0.004	0.00000356	0.00	0.00	0.0000000
6/1/2021	5.41	10.01	2.1	71	4.08	0.31	0.007	0.005	0.00000356	0.11	2.55	0.0000586
6/6/2021	5.41	10.01	1.1	77	2.99	0.07	0.006	0.004	0.00000356	0.03	0.56	0.0000128
6/8/2021	5.41	10.01	1.5	72	3.89	0.12	0.007	0.005	0.00000356	0.04	0.99	0.0000227
6/12/2021	5.41	10.01	1.4	77	2.99	0.15	0.006	0.004	0.00000356	0.06	1.26	0.0000290
6/29/2021	5.41	10.01	0.6	77	2.99	0.00	0.006	0.004	0.00000356	0.00	0.00	0.0000000
7/11/2021	5.41	10.01	0.8	77	2.99	0.02	0.006	0.004	0.00000356	0.01	0.14	0.0000032
7/20/2021	5.41	10.01	1.0	77	2.99	0.04	0.006	0.004	0.00000356	0.02	0.36	0.0000083
8/6/2021	5.41	10.01	0.6	77	2.99	0.00	0.006	0.004	0.00000356	0.00	0.00	0.0000001
8/15/2021	5.41	10.01	0.9	77	2.99	0.03	0.006	0.004	0.00000356	0.01	0.28	0.0000063
8/18/2021	5.41	10.01	1.1	77	2.99	0.08	0.006	0.004	0.00000356	0.03	0.70	0.0000161
8/19/2021	5.41	10.01	1.0	77	2.99	0.04	0.006	0.004	0.00000356	0.02	0.33	0.0000075

Estimation of sediment weight

$S=95(Q\times qp)^{0.56} K\times LS\times C\times P$

Table D 3 Estimation of sediment weight

Date	q_p(CFS)	Q (ft3)	K	LS	C	P	Total Sediment (Tons)	Sediment(grams)
2/26/2021	0.073	0.00005	0.29	0.19	1	1.00	0.005	4531
3/23/2021	0.002	0.00000	0.29	0.19	1	1.00	0.000	47
3/25/2021	0.067	0.00003	0.29	0.19	1	1.00	0.004	3183
4/29/2021	0.086	0.00006	0.29	0.19	1	1.00	0.006	5194
5/11/2021	0.082	0.00005	0.29	0.19	1	1.00	0.005	5037
5/17/2021	0.053	0.00003	0.29	0.19	1	1.00	0.003	2592
5/19/2021	0.000	0.00000	0.29	0.19	1	1.00	0.000	0
6/1/2021	0.106	0.00006	0.29	0.19	1	1.00	0.006	969
6/6/2021	0.027	0.00001	0.29	0.19	1	1.00	0.001	1152
6/8/2021	0.042	0.00002	0.29	0.19	1	1.00	0.002	2027
6/12/2021	0.062	0.00003	0.29	0.19	1	1.00	0.003	2884
6/29/2021	0.000	0.00000	0.29	0.19	1	1.00	0.000	0
7/11/2021	0.007	0.00000	0.29	0.19	1	1.00	0.000	247
7/20/2021	0.018	0.00001	0.29	0.19	1	1.00	0.001	713
8/6/2021	0.000	0.00000	0.29	0.19	1	1.00	0.000	3
8/15/2021	0.014	0.00001	0.29	0.19	1	1.00	0.001	526
8/18/2021	0.034	0.00002	0.29	0.19	1	1.00	0.002	1487
8/19/2021	0.016	0.00001	0.29	0.19	1	1.00	0.001	667

Table D 4 Calculation of sediment weight of three plots

Date	Plot 1	Plot 2	Plot 3	Plot 4
2/26/2021	4531	4898	13236	1611
3/23/2021	47	51	137	17
3/25/2021	3183	3441	9298	1132
4/29/2021	5194	5615	15174	1847
5/11/2021	5037	5445	14713	1791
5/17/2021	2592	2802	7572	922
5/19/2021	0	0	1	0
6/1/2021	969	1076	3416	416
6/6/2021	1152	1245	3364	410
6/8/2021	2027	2191	5922	721
6/12/2021	2884	3117	8424	1026
6/29/2021	0	0	1	0
7/11/2021	247	267	722	88
7/20/2021	713	770	2081	253
8/6/2021	3	3	9	1
8/15/2021	526	568	1535	187
8/18/2021	1487	1607	4343	529
8/19/2021	667	721	1948	237

APPENDIX E

TSS and Turbidity measurement

Table E 1 Average TSS for construction activities

Construction Activities	TSS (mg/l)				Average TSS (mg/l)
Temporary access road construction	38.29	3.02			20.66
Drilled shaft construction	3.83	3.58			3.71
Excavation of Foundation	9.03	9.48	7.9		8.80
Backfilling	22.6	30.33			26.47
Riverbank slope formation	70.51	46.5	64.59	12.45	48.51

Table E 2 TSS of sample in front of construction

Date of sampling	TSS (mg/l)	Sample taken
4/14/2021	38.29	Wilson Creek above rock trap from Dr. Habib
6/9/2021	7.90	Wilson Creek "just near at silt fence" (Dr. Habib sample)
6/9/2021	22.60	Just below drilled shaft; Dr. Habib
7/29/2021	46.50	In front of Silt Fence (Dr. Habib)
8/11/2021	64.59	Sample in front of drilled shaft (Dr. Habib)

Table E 3 TSS of sample upstream of construction

Date	TSS (mg/l)	Sample taken
4/22/2021	3.58	Wilson Creek just above rock trap from Dr. Habib
6/9/2021	9.48	Wilson Creek upstream ISCO (Dr. Habib sample)
6/9/2021	5.58	Upstream of autosampler; Dr. Habib
7/15/2021	4.85	Upstream ISCO (Dr. Habib)
7/29/2021	27.04	Upstream auto sampler (Dr. Habib)
8/11/2021	13.40	Upstream auto sampler (Dr. Habib)

Table E 4 TSS of sample downstream of construction

Date	TSS (mg/l)	Sample taken
4/22/2021	3.83	Wilson Creek d/s rock trap @11:50 from Dr. Habib
4/14/2021	3.02	Wilson Creek below rock trap from Dr. Habib
6/9/2021	9.03	Wilson Creek Downstream ISCO (Dr. Habib sample)
7/1/2021	30.33	Downstream of autosampler; Dr. Habib
7/15/2021	10.52	Downstream ISCO (Dr. Habib)
7/29/2021	70.51	Downstream autosampler (Dr. Habib)
8/11/2021	12.45	Sample downstream autosampler (Dr. Habib)

Table E 5 Turbidity of water sample

Date	In front of construction (NTU)	Downstream (NTU)	Upstream (NTU)
15-Jul	4.23	3.61	3.17
11-Aug	15.63	8.1	7.23
29-Jul	16.9	34.3	4.56
20-Aug	44.67	8.15	7.33

Table E 6 Comparison of TSS and turbidity in water samples

Date	Turbidity (NTU)	TSS (mg/l)
7/15/2021	3.33	4.85
7/15/2021	4.23	10.52
7/29/2021	4.56	27.04
7/29/2021	7.23	12.45
7/29/2021	8.15	13.40
8/11/2021	16.9	46.50
8/11/2021	34.3	70.51
8/11/2021	44.67	64.59