Field Monitoring of Erosion and Sediment Control Practices and Development of Additional Iowa DOT Design Manual Guidance

Final Report
April 2020

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16. Abstract

The National Pollutant Discharge Elimination System General Permit No. 2 requires the Iowa Department of Transportation (DOT) to develop a stormwater pollution prevention plan for all construction activities that are covered by the permit. The Stormwater Pollution Prevention Plan includes the design, installation, and maintenance of erosion and sediment control (E&SC) practices to minimize downstream impact from stormwater discharges. The Iowa DOT has specifications, standard drawings, and guidance for the design of E&SC practices, but these practices had not been formally evaluated for field performance.

This research aimed to understand the performance of current E&SC practices and enhance the design guidance available to the Iowa DOT. Silt fence ditch checks, wattle ditch protection, silt fence perimeter control, and temporary sediment control basins were monitored for performance on US 30 in Tama County, Iowa. Two modified silt fence ditch check installations had an average of 2.5 and 4 times as much sediment accumulation as a standard silt fence, the modified wattle ditch protection had 13.15 times the sediment retention of a standard wattle installation, and silt fence perimeter control modifications led to less T-post deflection and failures observed than with the standard installation.

A temporary sediment control basin was monitored as a single basin and as basins in series. In the single basin, turbidity increased by an average 92 nephelometric turbidity units (NTUs) after residence in the basin, whereas the basins in series provided a turbidity reduction of 215 NTUs in the first basin and 870 NTUs in the second basin. However, the system of basins provides negligible turbidity reduction.

In addition to field monitoring, laboratory flume testing was conducted to compare the hydraulic performance of wattles. Average depth and length ratios were calculated for each tested wattle in addition to the percent difference between the wattle and an impervious weir and were classified from Class 1–4 with Class 1 being the least effective and Class 4 being the most effective at reducing supercritical flows. From flume testing, straw wattles meet Class 2; coconut coir, wood chips, and synthetic fiber wattles fall into Class 3; and miscanthus fiber would qualify as Class 4.

This field study provided researchers insight on the performance of standard and several trial modified E&SC practices. Controlled testing should continue to verify results observed in the field.

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NOMENCLATURE

AU-ESCTF	Auburn University - Erosion and Sediment Control Test Facility
BMP	best management practice
BOD	biological oxygen demand
CBMPP	Construction Best Management Practice Plan
CWA	Clean Water Act
DOT	Department of Transportation
DNR	Department of Natural Resources
ELG	effluent limitation guidelines
E&SC	erosion and sediment control
EX	excelsior
NAHB	National Association of Home Builders
NPDES	National Pollutant Discharge Elimination System
NPS	non-point source
NRDC	National Resources Defense Council
NTU	nephelometric turbidity unit
S	straw
SG	switch grass
SWPPP	Stormwater Pollution Prevention Plan
TAC	technical advisory committee
TSS	total suspended solids
US EPA	United States Environmental Protection Agency
WC	wood chip

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EXECUTIVE SUMMARY

Stormwater management has become an increasingly important aspect of construction activities in the state of Iowa. The National Pollutant Discharge Elimination System General Permit No. 2 requires the Iowa Department of Transportation (DOT) develop a stormwater pollution prevention plan for all construction activities that are covered by the permit. The Stormwater Pollution Prevention Plan (SWPPP) includes the design, installation, and maintenance of erosion and sediment control (E&SC) practices to minimize downstream impact from stormwater discharges.

The Iowa DOT has specifications, standard drawings, and guidance for the design of E&SC practices. Many of the practices included in these documents had not been formally evaluated for field performance. Furthermore, recent research performed by other state highway agencies has led to the development of new and improved E&SC practices. Opportunities exist to better understand the performance of standard Iowa DOT E&SC practices, improve the design and performance of practices, and to develop additional design manual guidance for the proper selection and design of practices. The objective of this research project was to enhance the E&SC design guidance available to the Iowa DOT. The research team outlined three objectives to meet this goal including (1) compile and catalog E&SC practices that can be used on Iowa DOT construction projects, (2) install and evaluate selected practices on active Iowa DOT construction sites to determine their effectiveness in reducing erosion and capturing sediment, and (3) develop implementable improvements for Iowa DOT E&SC design guidance.

Researchers conducted a comprehensive literature review on E&SC practices used in highway construction from state agency manuals, performance-based research, and large-scale testing of non-proprietary products. In addition, an SWPPP review of several Iowa DOT projects and a number of other states' DOT projects were compared to identify potential deficiencies in design. Based on the findings from this review, researchers coordinated with an Iowa DOT advisory committee to identify E&SC practices to field monitor during active construction. Practice selection was based on frequency of use, agency interest, and potential for improved performance. Field evaluations included Iowa DOT standard practices and several trial modifications. Practices were evaluated for erosion reduction, sedimentation potential, structural integrity, and water quality improvements.

This final report outlines the five standard E&SC practices and modified installations included in the review and field monitoring. Practices included silt fence ditch checks, wattle ditch protection, rock check dams, silt fence perimeter control, and temporary sediment control basins. Field evaluations were conducted on the US 30 expansion project in Tama County, Iowa. Water quality of temporary sediment control basins began in the fall of 2018 and continued in the summer of 2019. Standard and modified ditch check and sediment barrier practices were installed in July 2019 and monitored through December 2019.

Three ditch check types were included in this project: (1) silt fence ditch checks, (2) wattle ditch protection, and (3) rock check dams; however, only silt fence ditch checks and standard and modified wattle ditch protection types were field tested. Recommendations based on the literature and SWPPP review were made to enhance the performance of rock check dams but were not evaluated due to subcontractor availability. Several modifications to the standard silt fence ditch checks and wattle ditch protection exhibited improved field performance based on the initial channel survey and measured channel sedimentation. The silt fence ditch check installation with the highest sediment retention had 4.0 times the sediment accumulation of the standard and included a V-shaped installation, wire reinforcement, dewatering weir, and geotextile trenched into ground. A second modification had 2.5 times the sediment accumulation of the standard and included the V-shaped installation, wire reinforcement, and dewatering weir, but had the geotextile sliced into ground.

Wood chip, excelsior, straw, and switch grass wattles were monitored in the field. Due to the late field installation, temporary seeding had overgrown in several of the monitored channels. The wood chip wattle channel had the least vegetation and the most visually obvious sediment accumulation patterns; therefore, this channel was used to compare installation techniques. The modified installation, which included a special ditch protection mat underlay sod stapled to the channel bottom and nondestructive teepee staking, captured 13.2 times the sediment of the standard installation. Site limitations required each wattle type to be installed in separate channels. These channels had varying geometries, slopes, drainage areas, and rainfall. The differences did not allow for comparisons between wattle fills to be made. To supplement the field evaluations, laboratory flume testing was conducted to compare the hydraulic performance of wattles. Average depth and length ratios were calculated for each tested wattle in addition to the percent difference between the wattle and an impervious weir. Four wattle classifications (i.e., Class 1, 2, 3, and 4) were identified from the ratios, with Class 1 being the least effective and Class 4 being the most effective at reducing supercritical flows. From flume testing, excelsior wattles were classified in Class 1; straw wattles were classified in Class 2; coconut coir, wood chips, and synthetic fiber wattles were classified in Class 3; and miscanthus fiber qualified as Class 4.

In total, three silt fence perimeter control installations were tested at both 8 ft (2.43 m) T-post spacing and 5 ft T-post spacing. The primary observed deficiency in the standard installation was T-post deflection leading to failure. The addition of a wire reinforcement backing or decreased T-post spacing minimized post deflection, aiding in sediment retention. Sediment barrier performance was based on weekly site inspections.

Temporary sediment control basins were evaluated for water quality improvements. A treatment ratio was created that compared turbidity at discharge to turbidity at inflow; values under 1.0 indicated water quality improvements and above 1.0 indicated decline. Two basin systems were monitored including a single basin and a series of basins. All monitored basins commonly had performance efficiencies above the threshold of 1.0, indicating a decline in water after residence in the basins. In the single basin, turbidity increased by an average 92 nephelometric turbidity units (NTUs) after residence in the basin; whereas, the basins in series provided a turbidity reduction of 215 NTUs in the first basin and 870 NTUs in the second basin. However, the system of basins provided an average reduction of just 9 NTUs. Comparisons of the individual basins had different monitored dewatering mechanisms. After monitoring the DOT’s standard temporary sediment control basin, suggested modifications included treatment features such as an upstream forebay, geotextile lining, baffles, and a floating surface skimmer for enhanced performance.

This project provided the research team a basis for E&SC practice improvements; however, data collection was subject to the variability of field conditions. Subsequent controlled testing should be completed to verify results and provide repeatability.

1 INTRODUCTION

1.1 PROBLEM STATEMENT

Construction activities typically involve heavy earthmoving activities that can disturb several acres of land at a time. According to the U.S. Environmental Protection Agency (US EPA), sediment is the predominant pollutant of concern during clearing and grading stages of construction, where large un-vegetated and un-stabilized land areas are exposed to erosive elements (US EPA 2005). The lack of ground cover during construction results in land areas being susceptible to increased rates of soil erosion. Sediment runoff rates from construction sites can be 10 to 20 times higher than those of agricultural lands and 1,000 to 2,000 times greater than those of forested lands (US EPA 2008). Construction sites have measured erosion rates of approximately 20 to 200 tons/ac/year (45 to 450 metric tons/ha/year) (Pitt et al. 2007). As stormwater runoff flows over unprotected areas on construction sites, it can suspend and transport pollutants, causing significant physical, chemical, and biological water quality impacts and impairments to nearby receiving waters. Furthermore, polluted surface waters can affect operations at water treatment plants, power stations, and other water-handling facilities.

Sediment resulting from slope and channel erosion are transported downstream through natural or existing stormwater conveyance systems. Other pollutants stemming from construction activities can also be introduced to the local environment through the improper use and disposal of chemicals and hydrocarbons. Erosion and the resulting sedimentation in waterways have become one of the nation's largest water pollution problems. The US EPA identifies sediment along with nutrients and heavy metals, which typically sorb to soil particles, as the most widespread pollutants affecting the beneficial uses of the nation's rivers and streams (US EPA 1998, 2016).

In addition to environmental implications, sedimentation can cause vast economic impact. The loss of aquatic habitat and diminished water quality is often difficult to quantify; however, some impacts (i.e., the cost of dredging and disposing of accumulated sediment) are easier to assess. In the US alone, the annual cost of soil erosion for on- and off-site effects are estimated at $44 billion (Pimentel et al. 1995). Furthermore, the cost of eroded soil replacement comes at a high price. Eroded sediments may include the loss of soil nutrients necessary for plant growth. This nutrient loss can lead to topsoil replacement actions to satisfy proper vegetative growth (Goldman et al. 1986). The creation of soil is a slow process; better methods and practices for controlling erosion, sedimentation, and other pollutants from construction sites are needed to forestall these problems and meet the demands of increasing growth and development.

To mitigate the downstream effects from construction, the National Pollutant Discharge Elimination System General Permit No. 2 (NPDES permit) requires construction operators with a site disturbance of more than 1 ac to develop a stormwater pollution prevention plan (SWPPP) for all construction activities that are covered by the permit (Iowa DNR 2017). Erosion and sediment control (E&SC) practices and the plan for implementation throughout construction phases must be included in the SWPPP. These practices are designed to reduce erosion and sediment pollution; however, there is a lack of performance data.

Many of the commonly implemented practices have not been formally evaluated for field performance and greatly vary in design from state to state. Kaufman (2000) and Chapman et al. (2014) acknowledged the lack of peer-reviewed research and highlighted the need for credible, scientific results when designing and implementing E&SC plans. Understanding and enhancing the performance of these practices is increasingly important as more stringent effluent guidelines and limitations are created locally, by state, and federally.

1.2 RESEARCH OBJECTIVES

The primary objective of this research was to enhance E&SC design guidance available to the Iowa Department of Transportation (DOT). To accomplish this goal, the research team established the following tasks:

1. Compile and catalog E&SC practices that could be used on Iowa DOT construction projects
2. Install and evaluate selected practices on active Iowa DOT construction sites to determine their effectiveness in reducing erosion and capturing sediment
3. Develop implementable improvements for Iowa DOT E&SC design guidance based on the results of field evaluations

1.3 SITE SELECTION

Researchers collaborated with the project technical advisory committee (TAC) to identify potential active construction projects to install and evaluate E&SC practices. The ideal site would have a cooperative contractor and be located within a two-hour driving range of Iowa State University for accessibility. The research team identified the Tama County US 30 expansion project (Tama US 30) as the ideal site to conduct field evaluations. Tama US 30, overseen by the Iowa DOT office in Marshalltown, was estimated to have 4.5 million yd^3 (3.44 million m^3) of grading spanning a three-year period beginning in the fall of 2017. The project location is shown in Figure 1.1

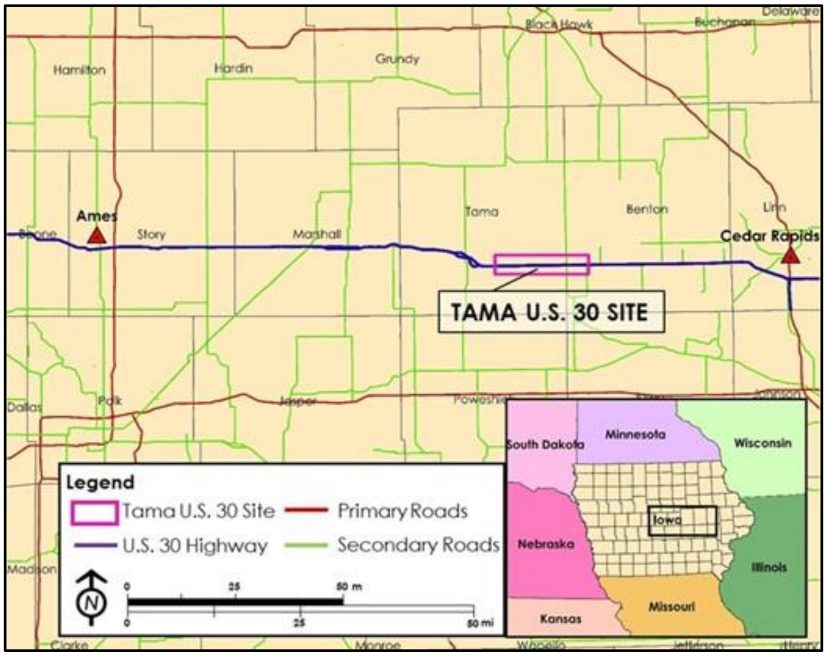


Figure 1.1. Tama US 30 expansion project location

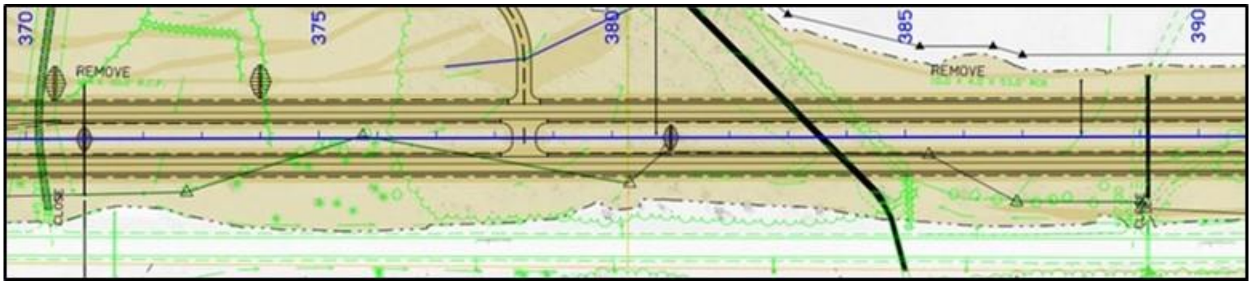
The roadway expansion project was motivated by increased traffic throughout the US 30 corridor between Ames and Cedar Rapids. Several segments of the corridor already have been expanded to four lanes due to increasing traffic, particularly large trucks. The Tama US 30 widening will increase the remaining two-lane segment from Tama-Toledo east to the junction of US 218 to four lanes. The existing US 30 is shown in Figure 1.2.

(a) Aerial view of existing Tama US 30

(b) Ground-level view of Tama US 30–July 25, 2018

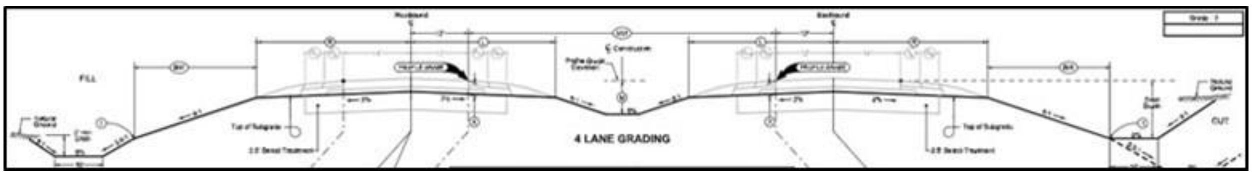
Figure 1.2. Tama US 30 existing roadway

The two current US 30 lanes will be abandoned and four lanes, a median, and two shoulders will be newly constructed. Figure 1.3 shows (a) a portion of the Tama US 30 grading site plan, (b) a typical Iowa DOT four-lane cross section, and (c) and (d) examples of previous US 30 expansions near the current site. The existing roadway is marked in green and the planned new construction is outlined in black. The project spans approximately 12 mi (19.3 km) of roadway with extensive grading, providing the research team plenty of areas for the installation of E&SC practices to monitor.

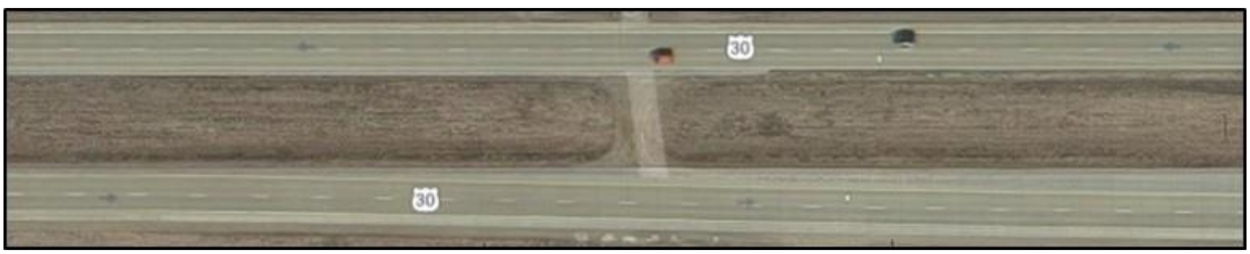


Johnson et al. 2017/Iowa DOT

(a) Site plan



(b) Typical four-lane cross section



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(c) Aerial view of expanded US 30

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(d) Completed four-lane segment of US 30, west of Tama US 30 project site

Figure 1.3. Tama US 30 proposed plan and cross section

1.4 RESEARCH SIGNIFICANCE

Development of updated E&SC design guidance will allow Iowa DOT designers to incorporate the latest technology in construction stormwater management. The developed guidance is geared toward ease of implementation with proposed specifications, design guidance language, and/or details. This research effort will allow the Iowa DOT to better understand the performance of current standard practices and enhance the construction stormwater management program with state-of-the-art E&SC practices. Enhanced practices will protect water quality downstream of construction activities, reduce regulatory compliance issues, and improve overall public perception.

1.5 ORGANIZATION OF REPORT

This report is divided into eight chapters beginning with Chapter 1, which includes an introduction to the topic.

Chapter 2 provides an overview of E&SC requirements and practices through a brief literature and SWPPP review.

Chapter 3 describes the means and methods that were used for data collection and report compilation.

Chapters 4, 5, and 6 focus on singular types of E&SC practices including ditch checks, sediment barriers, and detention practices, respectively. Each of the chapters encompasses an individual literature review for all practices covered in the section. Literature reviews were conducted for (1) silt fence ditch checks, (2) wattle ditch protection, (3) rock check dams, (4) silt fence perimeter control, and (5) temporary sediment control practices. These chapters also include Iowa DOT standard practices, design modifications accepted for evaluation, cost analyses, installation and evaluation criteria, and field monitoring results and discussion.

Chapter 7 includes the complete record of laboratory testing the hydraulic performance of various wattle types.

Chapter 8 outlines the main conclusions, limitations, and suggestions for future research.

Supporting materials are included in the appendices.

2 BACKGROUND

This chapter provides background on the need for construction stormwater management, regulatory requirements, and the history of E&SC requirements. In addition, this chapter includes an overview and review of SWPPPs prepared by the Iowa DOT.

2.1 EROSION AND SEDIMENT CONTROL

The Iowa Department of Natural Resources (DNR) lists more than 75% of Iowa's assessed waterbodies as impaired or potentially impaired (Iowa DNR 2016). Impairment indicates limitations of the waterbodies' designated uses for recreation, supporting aquatic life, human consumption, or navigation (Iowa DNR 2018). Poorly managed construction activities are one major contributor of nonpoint source (NPS) pollutants that lead to water quality degradation. Earthwork construction activities (clearing, grading, soil compaction, etc.) typically disturb large areas and can increase sediment yield by up to 10,000 times that of stabilized land (Yeri et al. 2005). These activities leave sites susceptible to rainfall- and runoff-induced soil erosion and an increased risk of degrading the quality of downstream receiving waterbodies. Landphair et al. (1997) estimated that 3.5 billion metric tons (3.86 billion tons) of sediment are discharged into US waterways annually from construction sites. Sediment-laden runoff increases turbidity, decreases flow capacity, and provides a mode of transport for other pollutants, including heavy metals, nutrients, fertilizers, petrochemicals, construction chemicals, wash water, and sanitary waste. Pollutants have subsequent consequences that affect the aquatic health of nearby areas (Bugg et al. 2017a).

Due to the effect of sediment-laden stormwater on the nation's water resources, the US EPA created the National Pollutant Discharge Elimination System (NPDES) program in 1972 under the authority of the Clean Water Act (CWA). The NPDES aimed to regulate pollutant discharge to restore the chemical, physical, and biological integrity in waters of the US. Originally, NPDES regulated point sources of pollution. Point source pollution is considered as pollution stemming from a single point, such as a factory or sewage treatment plant, whereas NPS pollution is caused by runoff suspending pollutants from one of many diffuse sources. In 1999, the second phase of the NPDES program was adopted, in which the US EPA included the regulation of NPS including construction sites greater than 5 ac, large and medium municipal sewers, and industrial discharges.

In 2002, the US EPA was required to propose effluent limitation guidelines (ELGs), national regulatory standards for stormwater and wastewater discharged to surface water and municipal sewage treatment plants, which included parameters such as biological oxygen demand (BOD), total suspended solids (TSS), fecal coliforms, pH, and turbidity limits for the construction and development category, as well as the inclusion of best management practices (BMPs) for construction pollutants. In 2004, the US EPA published a determination stating that ELGs would not be an effective means to control construction pollutants. This publication was met with a lawsuit from the Natural Resources Defense Council (NRDC) Waterkeeper Alliance, the state of New York, and the state of Connecticut declaring the US EPA was not meeting the requirements of the CWA. In 2008, the US EPA was required to publish proposed regulations for the construction and development category.

The US EPA established ELGs for the construction development industry, which set a turbidity limit of 280 NTUs in 2009 that would apply to the reissuance of a Construction General Permit. However, the 2012 reissuance did not include a turbidity limit due to the need to "collect more industry data" (AGC 2019). The Wisconsin Builders Association, National Association of Home Builders (NAHB), and Utility Water Act Group petitioned the US EPA to review the calculations and data, from which the 280 NTU turbidity limit was derived. As a result, the US EPA revoked the turbidity limit. Although no turbidity limit was placed, the 2012 reissuance required developers to employ SWPPPs under NPDES for any construction activities larger than 1 ac in disturbance to minimize downstream impacts (AGC 2019, US EPA 2019). An SWPPP is a comprehensive plan developed at the design phase for the location, installation, and maintenance of BMPs or E&SC practices.

E&SC practices are implemented throughout construction phasing to reduce erosion and capture sediment prior to off-site discharge. These practices are designed to minimize soil loss and sediment transport. E&SC practices may be structural or non-structural. Structural practices are either permanently or temporarily constructed practices to prevent sediment discharges off-site. Structural E&SC practices include practices such as silt fences, rock check dams, or wattles. Non-structural practices are methods or procedures that can reduce erosion and sediment transport. These practices include minimizing exposed soil, surface roughening, and seeding.

This project focused on structural, non-proprietary E&SC practices. Common non-proprietary practices include silt fence, wattles, rock check dams, and sediment basins. Over the last several years, there have been many advances to traditional E&SC practices employed on construction sites. Manufactured products have also emerged and are becoming popular within the construction field. As innovative and manufactured E&SC products are released into the construction industry, there are limited performance data available. Kaufman (2000) and Chapman et al. (2014) acknowledged the lack of peer-reviewed research and highlighted the need for credible, scientific results when designing and implementing E&SC plans. This is increasingly important as the US EPA imposes more stringent effluent guidelines and limitations. In addition to field monitoring and evaluations on active construction sites, a significant amount of performance-based research has been conducted through large-scale testing of E&SC practices. Large-scale research has the advantage of testing in a controlled environment, eliminating unknown or estimated factors such as rainfall, drainage area, and sediment load.

2.2 STORMWATER POLLUTION PREVENTION PLAN REVIEW

Although the NPDES program was established in 1972, stormwater discharges were not required to be permitted until 1992. To receive a permit, dischargers have to develop an SWPPP, which is a site/source specific plan that identifies the existing quality of stormwater and potential pollutants and describes a plan to ensure compliance with the NPDES program, including implementation and maintenance. SWPPPs are intended to reduce pollution before an environmental impact is made. Permits are required for (1) industrial and commercial activities that may affect the quality of stormwater or outstanding state and national resource waters, (2) construction activities greater than 1 ac, and (3) cities and universities with municipal separate storm sewer systems (MS4). Federal regulations require SWPPPs pertaining to construction activities to include site information, an explanation of major activities planned, and an E&SC plan, outlining BMPs that will be used to mitigate erosion and control stormwater to obtain a permit. Permits must be obtained by site operators and may last up to five years (US EPA 2007). While the US EPA provides a framework for creating an SWPPP, documentation and enforcement is delegated to the states. In the state of Iowa, the Iowa DNR was appointed to administer NPDES permits in 1978, and Construction Stormwater Discharge Permits became effective in 2003 (Iowa DNR 2019).

Most Iowa DOT construction projects are required by the NPDES permit to apply for an Iowa DNR Construction General Permit No. 2 (CGP). The CGP is centered on construction phases and E&SC practices. Due to grading associated with construction, ground stabilization is often compromised. Erosion is likely to occur without ground cover and contributes to the sediment loading in stormwater runoff. Sediment and other pollutants may become suspended in overland flows during storm events. The CGP requires a plan to minimize erosion and the impacts of construction site pollutants (primarily sediment). The SWPPP has six sections including (1) site evaluation and design development, (2) assessment, (3) control selection and plan design, (4) certification and notification, (5) construction/implementation, and (6) final stabilization and discontinuation (Iowa DNR 2019).

The first section, site evaluation and design development, requires applicants to record site information including soil types, current water quality, identification of surface waters on or nearby the site, and receiving waters of site runoff in addition to areas of disturbance and preservation. The project and construction activities must also be described in this section with an accompanying site map. Site map elements should include disturbed areas, slopes, stockpiles, and existing drainage patterns. The assessment section of an SWPPP should include descriptions of the site area, disturbed area, drainage areas, and runoff coefficient. With this information, the control selection and plan design section can be developed. In this section, applicants must develop an E&SC plan with consideration of federal, state, and local requirements. Iowa DNR requires stabilization methods, such as seeding; structural measures, namely, silt fence and check dams, among others; post-construction stormwater quantity controls, such as bioswales and retention ponds; and pollutant disposal, in particular concrete washout stations, to be covered in the control selection and plan design.

In addition to the SWPPP, applicants must describe the sequence of activities or planned construction phasing. The fourth section, certification and notification, identifies the permittee (typically the project owner) and contractor or subcontractors responsible for upholding and maintaining the plan presented in the third section. If the SWPPP receives certification, a notice of intent (NOI) must be filed prior to start of the project for the permit to be valid. The next section requires permittees to implement the E&SC plan, maintain practices, update the plan with practice adaptations and hazardous materials on-site, and file inspections at least once weekly, and recommends inspections within 24 hours of a storm event with 0.5 in. (1.25 cm) or more of rain. Once the project reaches final stabilization, a notice of discontinuation (NOD) can be filed. Until a NOD is filed and approved, the SWPPP must be maintained. Figure 2.1 illustrates the SWPPP life cycle. Applicants can apply for a CGP for up to five years; however, accompanying fees are based on the duration of the permit (Iowa DNR 2019).

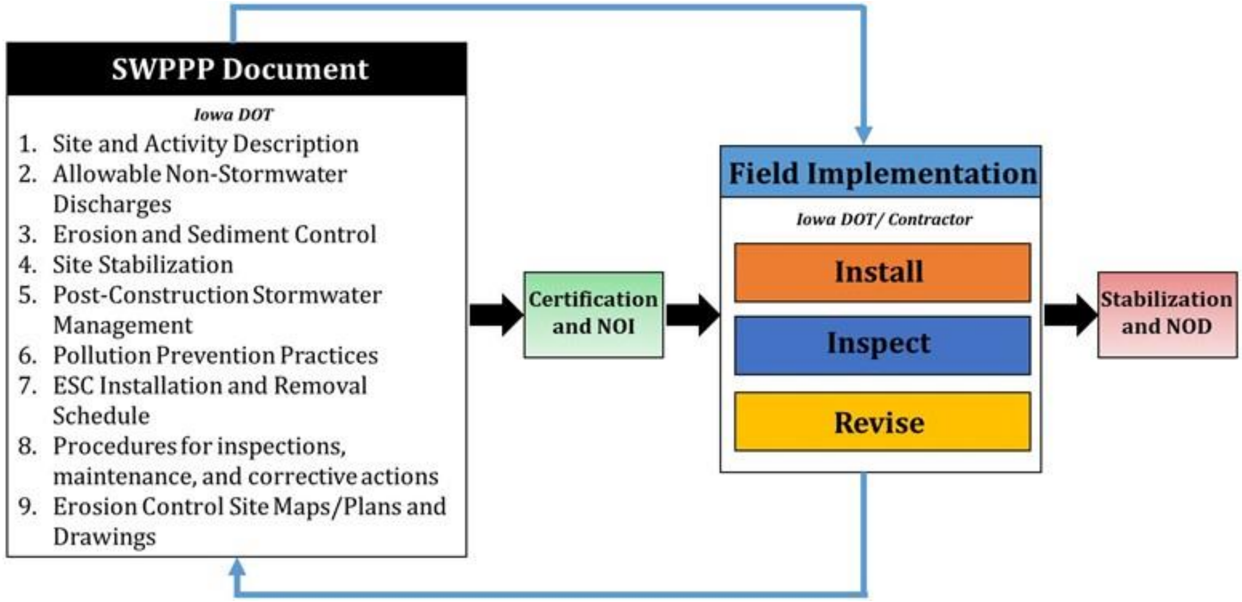

Figure 2.1. Typical SWPPP life cycle

Most Iowa DOT projects obtain permit coverage under a CGP No. 2; however, if the project is located in an Outstanding Iowa Waters (OIW) watershed, it is required to be permitted under an individual NPDES permit, which may have individual requirements. For the projects covered under the CGP No. 2, stormwater discharge permit applications include (1) notice of intent for stormwater discharges associated with industrial activity for construction activities, (2) public notice of stormwater discharge, and (3) pollution prevention plan (PPP). The PPP must be included in project plans that involve the most earth disturbance and also referenced in any other plan set. According to Stormwater Discharge Permits in Chapter 10 of the Iowa DOT Design Manual, much of the information in the PPP is routine and given in a sample PPP. However, some sections require individual attention, for example, project site description. The manual prescribes the project site description to be kept general and all inclusive. Both total acres and disturbed acres must be calculated. The total acres are calculated by multiplying the average right-of-way width by the length of the permit limits plus extra acres for interchanges or borrow sites. The disturbed acres are areas where protective ground cover is removed and results in exposed soil. In addition to areas, location of stormwater patterns, receiving waterways, soil associations, and runoff coefficients must be included in the site description section. General soil associations and runoff coefficients, as well as routine PPP material, can be found in Stormwater Discharge Permits (Iowa DOT 2019a).

The Tama US 30 project included the developed SWPPP within in the grading plans. Figure 2.2 and Figure 2.3 show the first two pages of the plan, which include the SWPPP narrative.

110-12A
10-17-17

POLLUTION PREVENTION PLAN

This project is regulated by the requirements of the Iowa Department of Natural Resources (DNR) National Pollutant Discharge Elimination System (NPDES) General Permit No. 2 OR an Iowa Department of Natural Resources (DNR) National Pollutant Discharge Elimination System (NPDES) individual storm water permit. The Contractor shall carry out the terms and conditions of this permit and the Pollution Prevention Plan (PPP).

This Base PPP includes information on Roles and Responsibilities, Project Site Description, Controls, Maintenance Procedures, Inspection Requirements, Non-Storm Water Controls, Potential Sources of Off Right-of-Way Pollution, and Definitions. This plan references other documents rather than repeating the information contained in the documents. A copy of this Base Pollution Prevention Plan, amended as needed per plan revisions or by contract modification, will be readily available for review.

All contractors shall conduct their operations in a manner that controls pollutants, minimizes erosion, and prevents sediments from entering waters of the state and leaving the highway right-of-way. The prime contractor shall be responsible for compliance and implementation of the PPP for their entire contract. This responsibility shall be further shared with subcontractors whose work is a source of potential pollution as defined in this PPP.

I. ROLES AND RESPONSIBILITES
- A. Designer:
  1. Prepares Base PPP included in the project plan.
  2. Prepares Notice of Intent (NOI) submitted to Iowa DNR.
  3. Signature authority on the Base PPP and NOI.
- B. Contractor/Subcontractor:
  1. Affected contractors/subcontractors are co-permittees with the IDOT and will sign a certification statement adhering to the requirements of the NPDES permit and this PPP plan. Affected contractors/subcontractors are anyone responsible for sediment or erosion controls or involved in land disturbing activities. All co-permittees are legally required under the Clean Water Act and the Iowa Administrative Code to ensure compliance with the terms and conditions of this PPP.
  2. Submit an Erosion Control Implementation Plan (ECIP) according to Specifications Section 2602 and any additional plan notes.
  3. Install and maintain appropriate controls.
  4. Supervise and implement good housekeeping practices.
  5. Conduct joint required inspections of the site with inspection staff.
  6. Comply with training and certification requirements of Specifications Section 2602.
  7. Signature authority on Co-Permittee Certification Statements and storm water inspection reports.
- C. RCE/Inspector:
  1. Update PPP whenever there is a change in design, construction, operation or maintenance, which has a significant effect on the discharge of pollutants from the project.
  2. Maintain an up-to-date record that identifies contractors and subcontractors as co-permittees.
  3. Make these plans available to the DNR upon their request.
  4. Conduct joint required inspections of the site with the contractor/subcontractor.
  5. Complete an inspection report after each inspection.
  6. Signature authority on storm water inspection reports and Notice of Discontinuation (NOD).

II. PROJECT SITE DESCRIPTION
- A. This Pollution Prevention Plan (PPP) is for the construction of a new four lane divided highway on relocated US 30 in Tama County from 1.3 miles east of Tama east to the bridge over Salt Creek.
- B. This PPP covers approximately 772 acres with an estimated 614 acres being disturbed. The portion of the PPP covered by this contract has 433 acres disturbed.
- C. The PPP is located in an area of one soil association (Tama - Muscatine - Downs). The estimated weighted average runoff coefficient number for this PPP after completion will be 0.30.
- D. Storm Water Site Map - Multiple sources of information comprise the base storm water site map including:
  1. Drainage patterns - Plan and Profile sheets and Situation plans.
  2. Proposed Slopes - Cross Sections.
  3. Areas of Soil Disturbance - construction limits shown on Plan and Profile sheets.
  4. Location of Structural Controls - Tabulations on C sheets.
  5. Locations of Non-structural Controls - Tabulations on C sheets.
  6. Locations of Stabilization Practices - generally within construction limits shown on Plan and Profile sheets.
  7. Surface Waters (including wetlands) - Project Location Map and Plan and Profile sheets.
  8. Locations where storm water is discharged - Plan and Profile sheets.
- E. The base site map is amended by contract modifications and progress payments (fieldbook entries) of completed erosion control work. Also, due to project phasing, erosion and sediment controls shown on project plans may not be installed until needed, based on site conditions. For example, silt fence ditch checks will typically not be installed until the ditch has been installed. Installed locations may also be modified from tabulation locations by field staff. Installed locations will be documented by fieldbook entries.
- F. Runoff from this work will flow into roadway ditches to: Otter Creek to Iowa River to Mississippi River and Salt Creek to Iowa River to Mississippi River.

III. CONTROLS
- A. The contractor's ECIP specified in Article 2602.03 for accomplishment of storm water controls should clearly describe the intended sequence of major activities and for each activity define the control measure and the timing during the construction process that the measure will be implemented.
- B. Preserve vegetation in areas not needed for construction.
- C. Sections 2601 and 2602 of the Standard Specifications define requirements to implement erosion and sediment control measures. Actual quantities used and installed locations may vary from the Base PPP and amendment of the plan will be documented via fieldbook entries or by contract modification. Additional erosion and sediment control items may be required as determined by the inspector and/or contractor during storm water monitoring inspections. If the work involved is not applicable to any contract items, the work will be paid for according to Article 1109.03 paragraph B.
  1. EROSION AND SEDIMENT CONTROLS
     - a. Stabilization Practices
       - 1) Site plans will ensure that existing vegetation or natural buffers are preserved where attainable and disturbed portions of the site will be stabilized.
       - 2) Initialize stabilization of disturbed areas immediately after clearing, grading, excavating, or other earth disturbing activities have:
         - a) Permanently ceased on any portion of the site, or
         - b) Temporarily ceased on any portion of the site and will not resume for a period exceeding 14 calendar days.
       - 3) Staged permanent and/or temporary stabilizing seeding and mulching shall be completed as the disturbed areas are completed. Incomplete areas shall be stabilized according to paragraph III, C, 1, a, 2, b above.
       - 4) Permanent and Temporary Stabilization practices to be used for this project are located in the Estimated Project

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POLLUTION PREVENTION PLAN

Quantities (100-0A, 100-1A, or 100-1C) and Estimate Reference Information (100-4A) located on the C sheets of the plan. Typical drawings detailing construction of the practices to be used on this project are referenced in the Standard Road Plans Tabulation.
- 5) Preservation of existing vegetation within right-of-way or easements will act as vegetative buffer strips.
- 6) Preservation of topsoil: Bid items to be used for this project are located in the Estimated Project Quantities (100-0A, 100-1A, or 100-1C) and Estimate Reference Information (100-4A) located on the C sheets of the plan. Additional information may be found in Tabulations in the C or T sheets of the plans or is referenced in Standard Specifications Section 2105.

- b. Structural Practices
  - 1) Structural practices will be implemented to divert flows from exposed soils and detain or otherwise limit runoff and the discharge of pollutants from exposed areas of the site. Additionally, structural practices may include: silt basins that provide 3600 cubic feet of storage per acre drained or equivalent sediment controls, outlet structures that withdraw water from surface when discharging basins, and controls to direct storm water to vegetated areas.
  - 2) Structural practices to be used for this project are located in the Estimated Project Quantities (100-0A, 100-1A, or 100-1C) and Estimate Reference Information (100-4A) located on the C sheets of the plan, as well as all other item specific Tabulations. Typical drawings detailing construction of the devices to be used on this project can be found on the B sheets of the plans or are referenced in the Standard Road Plans Tabulation.
- c. Storm Water Management
  - 1) Measures shall be installed during the construction process to control pollutants in storm water discharges that will occur after construction operations have been completed. This may include velocity dissipation devices at discharge locations and along length of outfall channel as necessary to provide a non-erosion velocity flow from structure to water course. If included with this project, these items are located in the Estimated Project Quantities (100-0A, 100-1A, or 100-1C) and Estimate Reference Information (100-4A) located on the C sheets of the plan, as well as all other item specific Tabulations. Typical drawings detailing construction of the practices to be used on this project are referenced in the Standard Road Plans Tabulation. The installation of these devices may be subject to Section 404 of the Clean Water Act.

2. OTHER CONTROLS
   - a. Contractor disposal of unused construction materials and construction material wastes shall comply with applicable state and local waste disposal, sanitary sewer, or septic system regulations. In the event of a conflict with other governmental laws, rules and regulations, the more restrictive laws, rules or regulations shall apply.
     - 1) Vehicle Entrances and Exits - Construct and maintain entrances and exits to prevent tracking of sediments onto roadways.
     - 2) Material Delivery, Storage and Use - Implement practices to prevent discharge of construction materials during delivery, storage, and use.
     - 3) Stockpile Management - Install controls to reduce or eliminate pollution of storm water from stockpiles of soil and paving.
     - 4) Waste Disposal - Do not discharge any materials, including building materials, into waters of the state, except as authorized by a Section 404 permit.
     - 5) Spill Prevention and Control - Implement procedures to contain and clean-up spills and prevent material discharges to the storm drain system and waters of the state.
     - 6) Concrete Residuals and Washout Wastes - Designate temporary concrete washout facilities for rinsing out concrete trucks. Provide directions to truck drivers where designated washout facilities are located. Designated washout areas should be located at least 50 feet away from storm drains, streams or other water bodies. Care should be taken to ensure these facilities do not overflow during storm events.
     - 7) Concrete Grooving/Grinding Slurry - Do not discharge slurry to a waterbody or storm drain. Slurry may be applied on foreslopes or removed from the project.
     - 8) Vehicle and Equipment Storage and Maintenance Areas - Perform on site fueling and maintenance in accordance with all environment laws such as proper storage of onside fuels and proper disposal of used engine oil or other fluids on site. Employ washing practices that prevent contamination of surface and ground water from wash water.
     - 9) Litter Management - Ensure employees properly dispose of litter.
     - 10) Dewatering - Properly treat water to remove suspended sediment before it re-enters a waterbody or discharges off-site. Measures are also to be taken to prevent scour erosion at dewatering discharge point.
3. APPROVED STATE OR LOCAL PLANS
   During the course of this construction, it is possible that situations will arise where unknown materials will be encountered. When such situations are encountered, they will be handled according to all federal, state, and local regulations in effect at the time.

IV. MAINTENANCE PROCEDURES
The contractor is required to maintain all temporary erosion and sediment control measures in proper working order, including cleaning, repairing, or replacing them throughout the contract period. This shall begin when the features have lost 50% of their capacity.

V. INSPECTION REQUIREMENTS
- A. Inspections shall be made jointly by the contractor and the contracting authority at least once every seven calendar days. Storm water monitoring inspections will include:
  1. Date of the inspection.
  2. Summary of the scope of the inspection.
  3. Name and qualifications of the personnel making the inspection.
  5. Review erosion and sediment control measures within disturbed areas for the effectiveness in preventing impacts to receiving waters.
  6. Major observations related to the implementation of the PPP.
  7. Identify corrective actions required to maintain or modify erosion and sediment control measures.
- B. Include storm water monitoring inspection reports in the Amended PPP. Incorporate any additional erosion and sediment control measures determined as a result of the inspection. Immediately begin corrective actions on all deficiencies found within 3 calendar days of the inspection.

VI. NON-STORM WATER DISCHARGES
This includes subsurface drains (i.e. longitudinal and standard subdrains) and slope drains. The velocity of the discharge from these features may be controlled by the use of patio blocks, Class A stone, erosion stone or other appropriate materials. This also includes uncontaminated groundwater from dewatering operations, which will be controlled as discussed in Section III of the PPP.

VII. POTENTIAL SOURCES OF OFF RIGHT-OF-WAY (ROW) POLLUTION
Silts, sediment, and other forms of pollution may be transported onto highway right-of-way (ROW) as a result of a storm event. Potential sources of pollution located outside highway ROW are beyond the control of this PPP. Pollution within highway ROW will be conveyed and controlled per this PPP.

VIII. DEFINITIONS

TAMA COUNTY | PROJECT NUMBER **NHSX-030-6(189)--3H-86** | SHEET NUMBER **CE.1**

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Figure 2.2. Tama US 30 SWPPP, CE.1

110-12A
10-17-17

POLLUTION PREVENTION PLAN

A. Base PPP - Initial Pollution Prevention Plan.
B. Amended PPP - May include Plan Revisions or Contract Modifications for new items, storm water monitoring inspection reports, and fieldbook entries made by the inspector.
C. IDR - Inspector's Daily Report - this contains the inspector's daily diary and bid item postings.
D. Controls - Methods, practices, or measures to minimize or prevent erosion, control sedimentation, control storm water, or minimize contaminants from other types of waste or materials. Also called Best Management Practices (BMPs).
E. Signature Authority - Representative from Designer, Contractor/Subcontractor, or RCE/Inspector authorized to sign various storm water documents.

CERTIFICATION STATEMENT

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Signature

Paul W. Flattery
Print Name

111-25
10-18-11

INDEX OF TABULATIONS

Tabulation	Tabulation Title	Sheet No.
C Sheets		
100-14M	SILT BASINS	CE.6 - CE.8
100-17M	TABULATION OF SILT FENCES	CE.8
100-18M	SILT FENCES FOR DITCH CHECKS	CE.9 - CE.23
100-19	PERIMETER AND SLOPE SEDIMENT CONTROL DEVICE	CE.24
100-22	ROLLED EROSION CONTROL	CE.25
100-23	ROCK EROSION CONTROL	CE.26 - CE.27
100-32	ROCK CHECK DAM	CE.28 - CE.43
100-33	TEMPORARY SEDIMENT CONTROL BASIN	CE.44
100-34	STORMWATER DRAINAGE BASIN AND STORAGE	CE.2 - CE.5
110-12A	POLLUTION PREVENTION PLAN	CE.1 - CE.2

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STORMWATER DRAINAGE BASIN AND STORAGE

Refer to EC Standards and 570s Details.

Drainage Basin Location						Summary of Stormwater Storage							
Basin No.	Station to Station		Side	Discharge Point		Total Disturbed Area	Disturbed Area with Storage Provided	Disturbed Area without Storage Provided	Best Management Practice	Total Storage Volume Provided	Total Storage Volume Required	Storage Volume Met?	Remarks
				Station	Side	Acres	Acres	Acres		CF	CF	Yes/No	
1	111+30.57	138+00.00	All	111+30.57	Right	18.2	29.0	-10.8	Total	104448.2	65567.1	Yes	
									Silt Fence for Ditch Check (EC-201)	69311.3			
									Silt Basin (EW-403)	8527.8			
									Rock Check Dam (570-2)	26609.2			
2	133+00.00	146+50.00	Both	144+25.00	Right	4.8	15.9	-11.1	Total	57222.1	17298.6	Yes	
									Silt Fence for Ditch Check (EC-201)	7330.9			
									Silt Basin (EW-403)	2841.9			
									Temporary Sediment Control Basin (570-3)	23757.5			
									Rock Check Dam (570-2)	23291.8			
3	138+00.00	169+75.00	All	159+25.00	Right	18.8	32.3	-13.5	Total	116366.9	67797.4	Yes	
									Silt Fence for Ditch Check (EC-201)	88496.3			
									Silt Basin (EW-403)	9344.8			
									Temporary Sediment Control Basin (570-3)	8661.9			
									Rock Check Dam (570-2)	9864.0			
4	169+75.00	176+00.00	Both	175+00.00	Right	4.2	11.8	-7.5	Total	42335.4	15254.6	Yes	
									Silt Fence for Ditch Check (EC-201)	24767.9			
									Silt Basin (EW-403)	3560.1			
									Temporary Sediment Control Basin (570-3)	14007.4			
5	169+75.00	186+50.00	All	183+00.00	Right	8.7	10.9	-2.2	Total	39262.2	31183.9	Yes	
									Silt Fence for Ditch Check (EC-201)	27304.3			
									Silt Basin (EW-403)	9959.0			
									Temporary Sediment Control Basin (570-3)	1998.9			
7	182+75.00	222+25.00	All	221+50.00	Right	28.7	183.3	-154.6	Total	659902.3	103422.8	Yes	
									Silt Fence for Ditch Check (EC-201)	90481.8			
									Silt Basin (EW-403)	19088.8			
									Temporary Sediment Control Basin (570-3)	522108.9			
									Rock Check Dam (570-2)	28222.9			
8	194+50.00	196+00.00	Lt	195+50.00	Left	0.3	0.8	-0.5	Total	2771.0	1102.1	Yes	
									Silt Fence for Ditch Check (EC-201)	1742.8			
									Silt Basin (EW-403)	0.0			
									Temporary Sediment Control Basin (570-3)	1028.2			
9	196+00.00	197+00.00	Lt	196+50.00	Left	0.2	1.3	-1.0	Total	4525.8	850.7	Yes	
									Silt Fence for Ditch Check (EC-201)	376.8			
									Temporary Sediment Control Basin (570-3)	822.6			
									Rock Check Dam (570-2)	3326.4			

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Figure 2.3. Tama US 30 SWPPP, CE.2

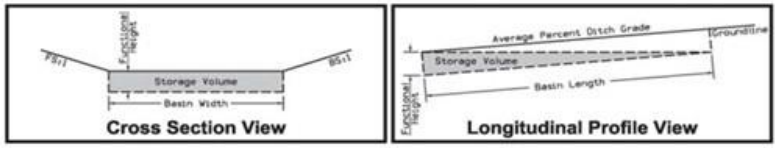
These pages outline the roles and responsibilities of designers, contractors, and inspector; site description covering project type, area, soils, and stormwater drainage patterns; BMPs including stabilization, structural, and stormwater management practices; inspection and inspection documentation requirements such as date of inspection, summary, major observations, and necessary corrective action; maintenance requirements; non-stormwater discharges; potential site pollutants; and definitions. An index of BMP tabulations and information on the site drainage basins directly followed the PPP.

In subsequent sheets within the plan set, E&SC practices are tabulated and include general information such as location by site station number, dimensions, storage volume, project side, and application or material, where applicable. Tabs include information for silt basins, silt fences, ditch checks, rolled erosion control products, erosion stone, and temporary sediment control basins. An example tabulation is shown in Figure 2.4.

100-14M
Modified

SILT BASINS

Possible Standard: EW-403



* The functional height used in the volume equation is 95% of effective height. Effective height is 3 feet as shown in EW-403.
* Volume equation: (0.5*Length*(Width*Height+Width*(Height-Length*Avg%DitchGrade))

Basin No.	Location: Station	Location: Side	Installation (Tab Total) EACH	Bid Items: Installation 2*Tab Total EACH	Bid Items: Removal 0.5*Bid Qty. EACH	Basin Width FT	Basin Length FT	Functional Height FT	Avg. % Ditch Grade	Volume* CF	Remarks
	US 30										
1	111+55.00	Med	1	2	1	10.0	50.0	2.85	0.8%	1424.0	Inlet
1	111+55.00	Lt.	1	2	1	10.0	50.0	2.85	1.0%	1423.8	Outlet
1	121+05.00	Med	1	2	1	10.0	50.0	2.85	4.0%	1420.0	Inlet
1	121+05.00	Lt.	1	2	1	10.0	50.0	2.85	4.0%	1420.0	Outlet
1	134+05.00	Med	1	2	1	10.0	50.0	2.85	4.0%	1420.0	Inlet
1	134+05.00	Lt.	1	2	1	10.0	50.0	2.85	4.0%	1420.0	Outlet
2	144+25.00	Lt.	1	2	1	10.0	50.0	2.85	2.8%	1421.5	Inlet
2	144+35.00	Lt.	1	2	1	10.0	50.0	2.85	3.7%	1420.4	Inlet
3	149+95.00	Med	1	2	1	10.0	50.0	2.85	2.8%	1421.5	Inlet
3	149+95.00	Lt.	1	2	1	10.0	50.0	2.85	2.8%	1421.5	Outlet
3	150+05.00	Lt.	2	4	2	10.0	50.0	2.85	2.8%	1421.5	Outlet
3	155+40.00	Lt.	1	2	1	10.0	50.0	2.85	3.0%	1421.3	Outlet
3	159+00.00	Rt.	1	2	1	10.0	50.0	2.85	2.7%	1421.6	Outlet
3	160+05.00	Med	1	2	1	10.0	50.0	2.85	0.1%	1424.9	Inlet
4	174+10.00	Lt.	1	2	1	10.0	50.0	2.85	1.3%	1423.4	Inlet
4	175+20.00	Rt.	1	2	1	10.0	50.0	2.85	0.6%	1424.3	Outlet
5	177+95.00	Med	1	2	1	10.0	50.0	2.85	1.5%	1423.1	Inlet
5	177+95.00	Lt.	1	2	1	10.0	50.0	2.85	1.8%	1422.8	Inlet
5	178+05.00	Lt.	1	2	1	10.0	50.0	2.85	1.8%	1422.8	Inlet
5	181+45.00	Lt.	1	2	1	10.0	50.0	2.85	1.8%	1422.8	Outlet
5	184+70.00	Rt.	1	2	1	10.0	50.0	2.85	3.6%	1420.5	Outlet
5	185+00.00	Lt.	1	2	1	10.0	50.0	2.85	1.7%	1422.9	Inlet
5	185+10.00	Rt.	1	2	1	10.0	50.0	2.85	0.6%	1424.3	Inlet
7	191+95.00	Med	1	2	1	10.0	50.0	2.85	1.5%	1423.1	Inlet
7	191+95.00	Lt.	1	2	1	10.0	50.0	2.85	1.5%	1423.1	Outlet
7	192+05.00	Lt.	1	2	1	10.0	50.0	2.85	1.5%	1423.1	Outlet
7	194+95.00	Lt.	1	2	1	10.0	50.0	2.85	1.5%	1423.1	Inlet
7	195+05.00	Lt.	1	2	1	10.0	50.0	2.85	1.5%	1423.1	Outlet
7	212+20.00	Lt.	1	2	1	10.0	50.0	2.85	0.0%	1425.0	Inlet
7	212+30.00	Lt.	1	2	1	10.0	50.0	2.85	0.0%	1425.0	Inlet
7	217+95.00	Med	1	2	1	10.0	50.0	2.85	1.5%	1423.1	Inlet
7	217+95.00	Lt.	1	2	1	10.0	50.0	2.85	0.0%	1425.0	Outlet
7	218+05.00	Lt.	1	2	1	10.0	50.0	2.85	0.0%	1425.0	Outlet
7	221+05.00	Lt.	1	2	1	10.0	50.0	2.85	0.0%	1425.0	Inlet
11	233+95.00	Med	1	2	1	10.0	50.0	2.85	0.4%	1424.6	Inlet
11	234+35.00	Lt.	1	2	1	10.0	50.0	2.85	0.2%	1424.8	Inlet
12	245+90.00	Med	1	2	1	10.0	50.0	2.85	0.0%	1425.0	Inlet
12	246+10.00	Lt.	1	2	1	10.0	50.0	2.85	0.2%	1424.8	Outlet
12	245+90.00	Med	1	2	1	10.0	50.0	2.85	0.0%	1425.0	Inlet
12	246+10.00	Lt.	1	2	1	10.0	50.0	2.85	0.2%	1424.8	Outlet
12	257+95.00	Lt.	1	2	1	10.0	50.0	2.85	0.2%	1424.8	Outlet
12	258+05.00	Med	1	2	1	10.0	50.0	2.85	0.5%	1424.4	Inlet
12	258+05.00	Lt.	1	2	1	10.0	50.0	2.85	0.2%	1424.8	Outlet
12	263+20.00	Lt.	1	2	1	10.0	50.0	2.85	0.2%	1424.8	Outlet
12	263+30.00	Lt.	1	2	1	10.0	50.0	2.85	0.2%	1424.8	Outlet
12	264+35.00	Lt.	1	2	1	10.0	50.0	2.85	0.2%	1424.8	Inlet
12	277+95.00	Lt.	1	2	1	10.0	50.0	2.85	0.2%	1424.8	Outlet
12	278+05.00	Lt.	1	2	1	10.0	50.0	2.85	0.2%	1424.8	Outlet
12	280+35.00	Lt.	1	2	1	10.0	50.0	2.85	0.2%	1424.8	Outlet
12	283+95.00	Lt.	1	2	1	10.0	50.0	2.85	0.3%	1424.6	Outlet
12	284+05.00	Lt.	1	2	1	10.0	50.0	2.85	0.3%	1424.6	Outlet
12	285+05.00	Med	1	2	1	10.0	50.0	2.85	0.2%	1424.8	Inlet
12	289+05.00	Lt.	1	2	1	10.0	50.0	2.85	0.5%	1424.4	Inlet
12	289+30.00	Med	1	2	1	10.0	50.0	2.85	0.5%	1424.4	Inlet
15	302+60.00	Lt.	1	2	1	10.0	50.0	2.85	0.5%	1424.4	Inlet
15	303+05.00	Med	1	2	1	10.0	50.0	2.85	2.2%	1422.3	Inlet
15	306+95.00	Lt.	1	2	1	10.0	50.0	2.85	4.0%	1420.0	Outlet

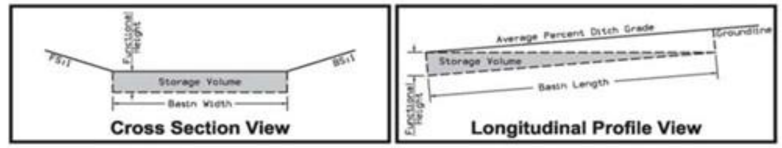
FILE NO.	ENGLISH	DESIGN TEAM Flattery\Johnson

9/29/2017 11:53:03 AM ajohns1 c:\pw_work\pwmain\ajohns1\d0569206\86030189_CE1.xlsm

100-14M
Modified

SILT BASINS

Possible Standard: EW-403



* The functional height used in the volume equation is 95% of effective height. Effective height is 3 feet as shown in EW-403.
* Volume equation: (0.5*Length*(Width*Height+Width*(Height-Length*Avg%DitchGrade))

Basin No.	Location: Station	Location: Side	Installation (Tab Total) EACH	Bid Items: Installation 2*Tab Total EACH	Bid Items: Removal 0.5*Bid Qty. EACH	Basin Width FT	Basin Length FT	Functional Height FT	Avg. % Ditch Grade	Volume* CF	Remarks
15	307+05.00	Med.	1	2	1	10.0	50.0	2.85	2.9%	1421.4	Inlet
15	307+05.00	Lt.	1	2	1	10.0	50.0	2.85	4.0%	1420.0	Outlet
15	313+00.00	Lt.	1	2	1	10.0	50.0	2.85	4.0%	1420.0	Inlet
15	315+00.00	Lt.	1	2	1	10.0	50.0	2.85	1.6%	1423.0	Outlet
15	315+65.00	Lt.	1	2	1	10.0	50.0	2.85	2.8%	1421.5	Outlet
15	318+45.00	Lt.	1	2	1	10.0	50.0	2.85	2.8%	1421.5	Outlet
15	318+55.00	Med.	1	2	1	10.0	50.0	2.85	4.0%	1420.0	Inlet
15	318+55.00	Lt.	1	2	1	10.0	50.0	2.85	2.8%	1421.5	Outlet
20	337+95.00	Med.	1	2	1	10.0	50.0	2.85	2.0%	1422.5	Inlet
20	337+95.00	Lt.	1	2	1	10.0	50.0	2.85	0.5%	1424.4	Outlet
20	339+00.00	Lt.	1	2	1	10.0	50.0	2.85	3.0%	1421.3	Inlet
21	345+20.00	Med.	1	2	1	10.0	50.0	2.85	2.0%	1422.5	Inlet
21	345+20.00	Lt.	1	2	1	10.0	50.0	2.85	1.8%	1422.8	Outlet
21	345+60.00	Lt.	1	2	1	10.0	50.0	2.85	1.8%	1422.8	Inlet
21	347+95.00	Lt.	1	2	1	10.0	50.0	2.85	1.4%	1423.3	Inlet
21	348+05.00	Lt.	1	2	1	10.0	50.0	2.85	1.3%	1423.4	Inlet
22	354+45.00	Med.	1	2	1	10.0	50.0	2.85	0.1%	1424.9	Inlet
22	354+45.00	Lt.	1	2	1	10.0	50.0	2.85	3.0%	1421.3	Outlet
22	354+55.00	Med.	1	2	1	10.0	50.0	2.85	0.1%	1424.9	Inlet
22	355+10.00	Lt.	1	2	1	10.0	50.0	2.85	0.6%	1424.3	Outlet
23	364+95.00	Lt.	1	2	1	10.0	50.0	2.85	3.0%	1421.3	Inlet
23	365+10.00	Lt.	1	2	1	10.0	50.0	2.85	5.9%	1417.6	Inlet
23	366+45.00	Lt.	1	2	1	10.0	50.0	2.85	2.8%	1421.5	Outlet
23	368+20.00	Lt.	1	2	1	10.0	50.0	2.85	2.7%	1421.6	Outlet
23	368+30.00	Lt.	1	2	1	10.0	50.0	2.85	2.9%	1421.4	Outlet
25	370+95.00	Lt.	1	2	1	10.0	50.0	2.85	0.1%	1424.9	Inlet
25	371+00.00	Lt.	1	2	1	10.0	50.0	2.85	0.2%	1424.8	Inlet
26	375+35.00	Lt.	1	2	1	10.0	50.0	2.85	4.4%	1419.5	Ditch
26	375+70.00	Lt.	1	2	1	10.0	50.0	2.85	4.4%	1419.5	Ditch
26	376+05.00	Lt.	1	2	1	10.0	50.0	2.85	4.4%	1419.5	Ditch
26	376+40.00	Lt.	1	2	1	10.0	50.0	2.85	4.4%	1419.5	Ditch
26	376+75.00	Lt.	1	2	1	10.0	50.0	2.85	4.4%	1419.5	Ditch
26	377+10.00	Lt.	1	2	1	10.0	50.0	2.85	4.4%	1419.5	Ditch
26	377+45.00	Lt.	1	2	1	10.0	50.0	2.85	4.4%	1419.5	Ditch
26	377+80.00	Lt.	1	2	1	10.0	50.0	2.85	4.4%	1419.5	Ditch
26	378+15.00	Lt.	1	2	1	10.0	50.0	2.85	4.4%	1419.5	Ditch
26	378+50.00	Lt.	1	2	1	10.0	50.0	2.85	4.4%	1419.5	Ditch
26	380+70.00	Med.	1	2	1	10.0	50.0	2.85	2.4%	1422.0	Inlet
26	381+25.00	Lt.	1	2	1	10.0	50.0	2.85	5.2%	1418.5	Ditch
26	381+55.00	Lt.	1	2	1	10.0	50.0	2.85	5.2%	1418.5	Ditch
26	381+85.00	Lt.	1	2	1	10.0	50.0	2.85	5.2%	1418.5	Ditch
26	382+15.00	Lt.	1	2	1	10.0	50.0	2.85	5.2%	1418.5	Ditch
26	382+45.00	Lt.	1	2	1	10.0	50.0	2.85	5.2%	1418.5	Ditch
26	382+75.00	Lt.	1	2	1	10.0	50.0	2.85	5.2%	1418.5	Ditch
26	383+05.00	Lt.	1	2	1	10.0	50.0	2.85	5.2%	1418.5	Ditch
26	383+35.00	Lt.	1	2	1	10.0	50.0	2.85	5.2%	775.0	Ditch
27	387+95.00	Med.	1	2	1	10.0	50.0	2.85	0.3%	1387.5	Inlet
27	387+95.00	Lt.	1	2	1	10.0	50.0	2.85	0.8%	1325.0	Outlet
27	388+05.00	Lt.	1	2	1	10.0	50.0	2.85	0.1%	1412.5	Outlet
27	393+45.00	Lt.	1	2	1	10.0	50.0	2.85	0.4%	1375.0	Inlet
27	393+55.00	Med.	1	2	1	10.0	50.0	2.85	3.3%	1012.5	Inlet
27	398+90.00	Lt.	1	2	1	10.0	50.0	2.85	3.8%	950.0	Inlet
27	400+95.00	Lt.	1	2	1	10.0	50.0	2.85	3.9%	937.5	Outlet
27	401+05.00	Med.	1	2	1	10.0	50.0	2.85	4.0%	925.0	Inlet
27	401+05.00	Lt.	1	2	1	10.0	50.0	2.85	3.9%	937.5	Outlet
27	402+95.00	Lt.	1	2	1	10.0	50.0	2.85	3.9%	937.5	Inlet
27	408+95.00	Lt.	1	2	1	10.0	50.0	2.85	3.0%	1050.0	Outlet

TAMA COUNTY	PROJECT NUMBER NHSX-030-6(189)--3H-86	SHEET NUMBER CE.6

Johnson et al. 2017/Iowa DOT

Figure 2.4. Silt fence ditch check tabulation

Following the individual practice tabulations, the drainage basins are delineated, and the staging plan is included.

E&SC installation drawing details are not included in the SWPPP portion of the plan sheets but can be found separately as special design details. These details include the required components and dimensions for installation of the individual practices but do not provide context or function of the practices. These details are essential for designers, field personnel, and contractors for estimating project quantities and understanding the proper installation of the practices. Iowa DOT E&SC details can be found in Appendix A.

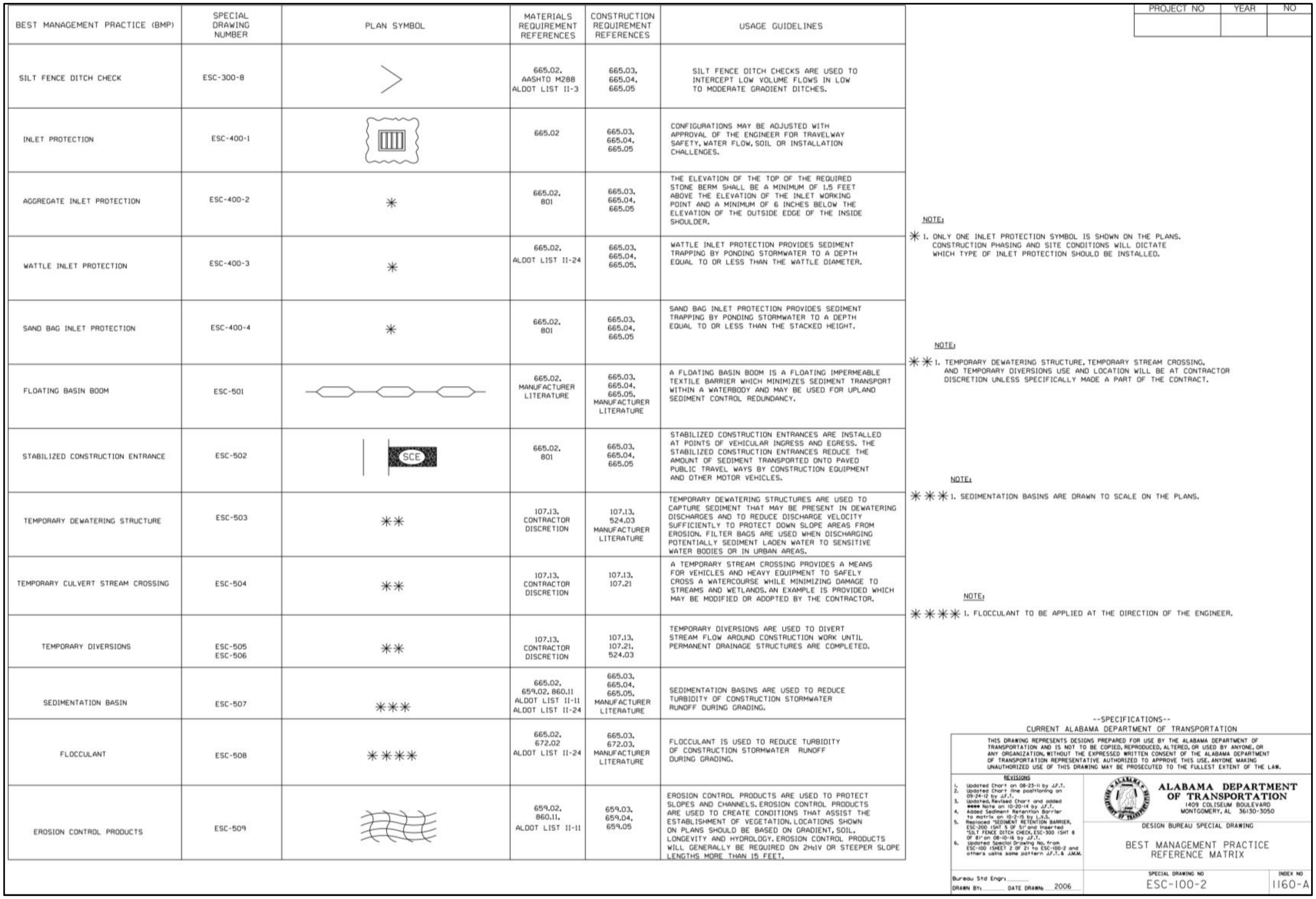
In addition to the standard details, the Iowa DOT provides a design manual to aid in the creation of the SWPPP. This manual provides guidance to designers to assist in E&SC plans for primary highways. The manual contains typical designs and recommended ranges for sizing of the practices but should be tailored from site to site. Equations to calculate material and maintenance bid quantities are included but are overly generalized with suggestions such as "assume 3 cleanouts per (temporary sediment control) basin" or "rock check dams are used to replace failed silt fence ditch checks." In Section 10C-6, Erosion Control Devices, the guide states to prioritize sizing and placement practices in the following order: silt basins, rock ditches, rock check dams, turf reinforcement, silt fence ditch checks, silt fence, temporary sediment control basin, slope protection, perimeter protection, and inlets (Iowa DOT 2019b). The manual provides general ideology and quick tips for implementation on the practices, but primarily focuses on the tabulations and bid quantities. For more information on the function of the practices, the manual refers to the Iowa DOT E&SC Field Guide.

The field guide is an extensive guide that provides general background on SWPPPs and compliance. This guide is broken into eight sections including introduction, compliance, function of E&SCs, SWPPPs, examples of proper and failed installations, frequently asked questions, troubleshooting, and resources available. This guide is tailored to compliance inspections for field personnel; however, it benefits designers by breaking down the ideology of each E&SC practice. It provides information on how, where, and why E&SCs should be implemented, despite the linear, pre-calculated SWPPP design outlined in the design manual. The field guide has an immense amount of information but would not be a quick reference when installing practices or conducting routine, weekly inspections. This guide may be better in smaller, segmented pocket guides, distributed to installers or inspectors.

Aside from guidance available through the DOT, stormwater professionals and SWPPPs designers may reference the Iowa Statewide Urban Design and Specifications (SUDAS) Design Manual. Chapter 7 of the SUDAS manual covers E&SC and provides background and permitting processes in construction applications. Prior to presenting practices, the chapter explains the erosion and sedimentation process followed by design criteria. Design criteria includes description/uses, design considerations, application, maintenance and design examples, time of year, and regional considerations, where applicable. This chapter is more than 180 pages and includes the background, function, design, and examples of E&SCs used in construction. This resource is applicable for designers and field personnel as a comprehensive E&SC guide.

For reference, researchers compared the Iowa DOT SWPPPs to several other states, including the Minnesota DOT (MnDOT), Alabama DOT (ALDOT), and Pennsylvania DOT (PennDOT). Similar to Iowa DOT, MnDOT provides an SWPPP narrative and an index for supplemental designs and tabulations. The design details and location of a BMP is found in tables following the SWPPP; however, the MnDOT SWPPP narrative is more comprehensive than Iowa's. Along with the site description, BMPs, maintenance and inspection requirements, non-stormwater discharges, potential site pollutants, and definitions included in the Iowa DOT SWPPP, MnDOT outlines areas of environmental sensitivity, land feature changes, BMP implementation timeline, project personnel and training, project contacts, and requires a signature from the design engineer and water resources engineer.

ALDOT's Stormwater Management Plan (SWMP) is a component of the Construction Best Management Practice Plan (CBMPP). The SWMP documents site description, stormwater inspection personnel, operations, temporary encroachments on water resources, potential pollutants, off-site areas, modifications to contract documents, on-site stormwater meetings, environmental submittals, and ALDOT approval certification. In addition to the SWMP, the CMBPP must encompass soil properties, hydrology, environmental concerns and commitments, outline structural and chemical BMPs, and provide a project map with BMP locations. An example of the ALDOT E&SC symbology and project map are shown in Figure 2.5 and Figure 2.6, respectively.



BEST MANAGEMENT PRACTICE (BMP)	SPECIAL DRAWING NUMBER	PLAN SYMBOL	MATERIALS REQUIREMENT REFERENCES	CONSTRUCTION REQUIREMENT REFERENCES	USAGE GUIDELINES
SILT FENCE DITCH CHECK	ESC-300-8		665.02, AASHTO M288 ALDOT LIST II-3	665.03, 665.04, 665.05	SILT FENCE DITCH CHECKS ARE USED TO INTERCEPT LOW VOLUME FLOWS IN LOW TO MODERATE GRADIENT DITCHES.
INLET PROTECTION	ESC-400-1		665.02	665.03, 665.04, 665.05	CONFIGURATIONS MAY BE ADJUSTED WITH APPROVAL OF THE ENGINEER FOR TRAVELWAY SAFETY, WATER FLOW, SOIL OR INSTALLATION CHALLENGES.
AGGREGATE INLET PROTECTION	ESC-400-2	*	665.02, 801	665.03, 665.04, 665.05	THE ELEVATION OF THE TOP OF THE REQUIRED STONE BERM SHALL BE A MINIMUM OF 1.5 FEET ABOVE THE ELEVATION OF THE INLET WORKING POINT AND A MINIMUM OF 6 INCHES BELOW THE ELEVATION OF THE OUTSIDE EDGE OF THE INSIDE SHOULDER.
WATTLE INLET PROTECTION	ESC-400-3	*	665.02, ALDOT LIST II-24	665.03, 665.04, 665.05.	WATTLE INLET PROTECTION PROVIDES SEDIMENT TRAPPING BY PONDING STORMWATER TO A DEPTH EQUAL TO OR LESS THAN THE WATTLE DIAMETER.
SAND BAG INLET PROTECTION	ESC-400-4	*	665.02, 801	665.03, 665.04, 665.05	SAND BAG INLET PROTECTION PROVIDES SEDIMENT TRAPPING BY PONDING STORMWATER TO A DEPTH EQUAL TO OR LESS THAN THE STACKED HEIGHT.
FLOATING BASIN BOOM	ESC-501		665.02, MANUFACTURER LITERATURE	665.03, 665.04, 665.05, MANUFACTURER LITERATURE	A FLOATING BASIN BOOM IS A FLOATING IMPERMEABLE TEXTILE BARRIER WHICH MINIMIZES SEDIMENT TRANSPORT WITHIN A WATERBODY AND MAY BE USED FOR UPLAND SEDIMENT CONTROL REDUNDANCY.
STABILIZED CONSTRUCTION ENTRANCE	ESC-502	SCE	665.02, 801	665.03, 665.04, 665.05	STABILIZED CONSTRUCTION ENTRANCES ARE INSTALLED AT POINTS OF VEHICULAR INGRESS AND EGRESS. THE STABILIZED CONSTRUCTION ENTRANCES REDUCE THE AMOUNT OF SEDIMENT TRANSPORTED ONTO PAVED PUBLIC TRAVEL WAYS BY CONSTRUCTION EQUIPMENT AND OTHER MOTOR VEHICLES.
TEMPORARY DEWATERING STRUCTURE	ESC-503	**	107.13, CONTRACTOR DISCRETION	107.13, 524.03 MANUFACTURER LITERATURE	TEMPORARY DEWATERING STRUCTURES ARE USED TO CAPTURE SEDIMENT THAT MAY BE PRESENT IN DEWATERING DISCHARGES AND TO REDUCE DISCHARGE VELOCITY SUFFICIENTLY TO PROTECT DOWN SLOPE AREAS FROM EROSION. FILTER BAGS ARE USED WHEN DISCHARGING POTENTIALLY SEDIMENT LADEN WATER TO SENSITIVE WATER BODIES OR IN URBAN AREAS.
TEMPORARY CULVERT STREAM CROSSING	ESC-504	**	107.13, CONTRACTOR DISCRETION	107.13, 107.21	A TEMPORARY STREAM CROSSING PROVIDES A MEANS FOR VEHICLES AND HEAVY EQUIPMENT TO SAFELY CROSS A WATERCOURSE WHILE MINIMIZING DAMAGE TO STREAMS AND WETLANDS. AN EXAMPLE IS PROVIDED WHICH MAY BE MODIFIED OR ADOPTED BY THE CONTRACTOR.
TEMPORARY DIVERSIONS	ESC-505 ESC-506	**	107.13, CONTRACTOR DISCRETION	107.13, 107.21, 524.03	TEMPORARY DIVERSIONS ARE USED TO DIVERT STREAM FLOW AROUND CONSTRUCTION WORK UNTIL PERMANENT DRAINAGE STRUCTURES ARE COMPLETED.
SEDIMENTATION BASIN	ESC-507	***	665.02, 659.02, 860.11 ALDOT LIST II-11 ALDOT LIST II-24	665.03, 665.04, 665.05, MANUFACTURER LITERATURE	SEDIMENTATION BASINS ARE USED TO REDUCE TURBIDITY OF CONSTRUCTION STORMWATER RUNOFF DURING GRADING.
FLOCCULANT	ESC-508	****	665.02, 672.02 ALDOT LIST II-24	665.03, 672.03, MANUFACTURER LITERATURE	FLOCCULANT IS USED TO REDUCE TURBIDITY OF CONSTRUCTION STORMWATER RUNOFF DURING GRADING.
EROSION CONTROL PRODUCTS	ESC-509		659.02, 860.11, ALDOT LIST II-11	659.03, 659.04, 659.05	EROSION CONTROL PRODUCTS ARE USED TO PROTECT SLOPES AND CHANNELS. EROSION CONTROL PRODUCTS ARE USED TO CREATE CONDITIONS THAT ASSIST THE ESTABLISHMENT OF VEGETATION. LOCATIONS SHOWN ON PLANS SHOULD BE BASED ON GRADIENT, SOIL, LONGEVITY AND HYDROLOGY. EROSION CONTROL PRODUCTS WILL GENERALLY BE REQUIRED ON 2H:1V OR STEEPER SLOPE LENGTHS MORE THAN 15 FEET.

PROJECT NO	YEAR	NO

NOTE:

* 1. ONLY ONE INLET PROTECTION SYMBOL IS SHOWN ON THE PLANS. CONSTRUCTION PHASING AND SITE CONDITIONS WILL DICTATE WHICH TYPE OF INLET PROTECTION SHOULD BE INSTALLED.

NOTE:

** 1. TEMPORARY DEWATERING STRUCTURE, TEMPORARY STREAM CROSSING, AND TEMPORARY DIVERSIONS USE AND LOCATION WILL BE AT CONTRACTOR DISCRETION UNLESS SPECIFICALLY MADE A PART OF THE CONTRACT.

NOTE:

*** 1. SEDIMENTATION BASINS ARE DRAWN TO SCALE ON THE PLANS.

NOTE:

**** 1. FLOCCULANT TO BE APPLIED AT THE DIRECTION OF THE ENGINEER.

--SPECIFICATIONS--
CURRENT ALABAMA DEPARTMENT OF TRANSPORTATION

REVISIONS

1. Updated Chart on 08-23-11 by J.F.T.
2. Updated Chart line positioning on 09-24-12 by J.F.T.
3. Updated, Revised Chart and added **** Note on 10-20-14 by J.F.T.
4. Added Sediment Retention Barrier to matrix on 10-2-15 by L.V.S.
5. Replaced "SEDIMENT RETENTION BARRIER, ESC-200 (SHT 5 OF 5)" and Inserted "SILT FENCE DITCH CHECK, ESC-300 (SHT 8 OF 8)" on 08-10-16 by J.F.T.
6. Updated Special Drawing No. from ESC-100 (SHEET 2 OF 2) to ESC-100-2 and others using same pattern J.F.T. & J.M.M.

ALABAMA DEPARTMENT OF TRANSPORTATION
1409 COLISEUM BOULEVARD
MONTGOMERY, AL 36130-3050

DESIGN BUREAU SPECIAL DRAWING

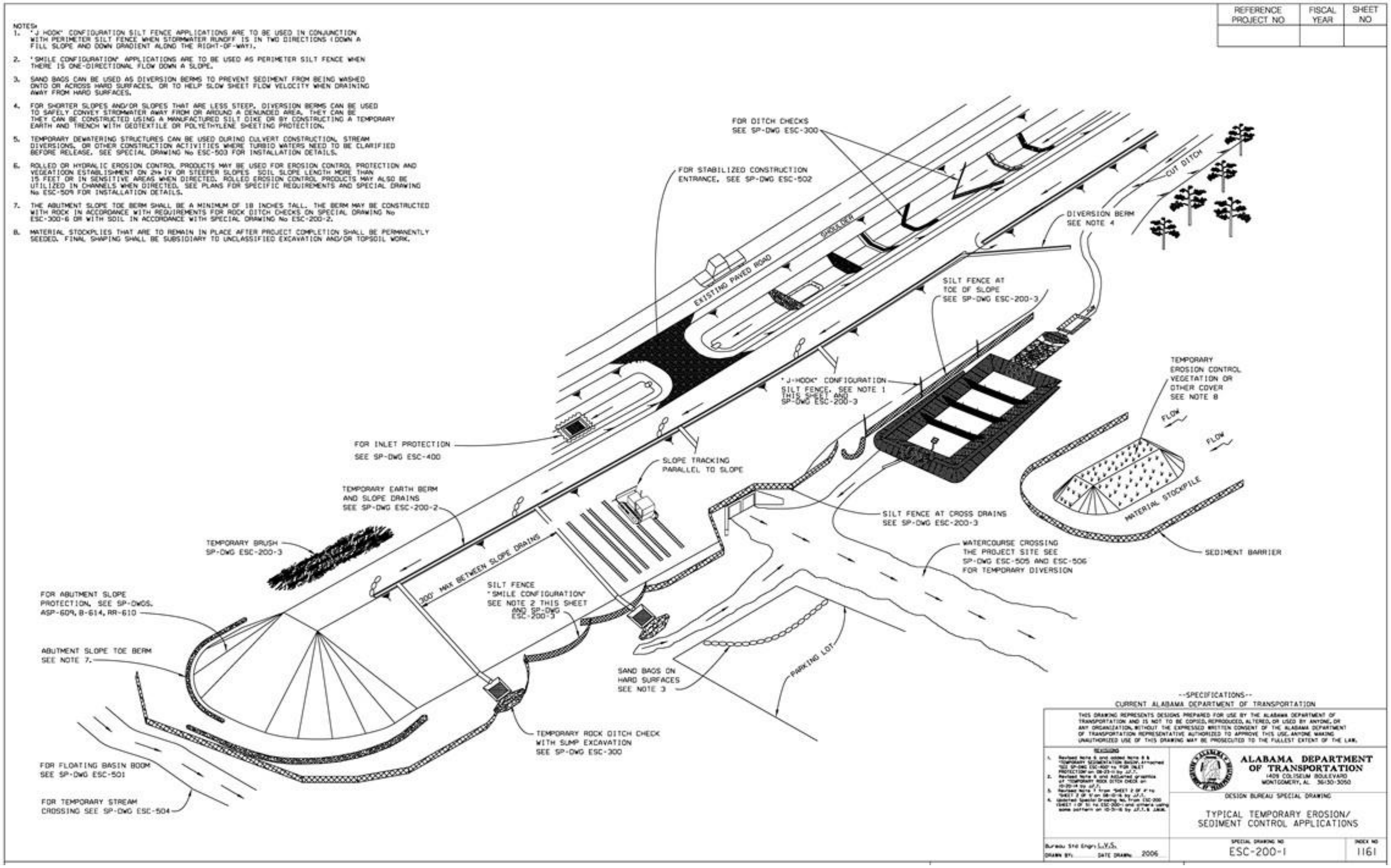
BEST MANAGEMENT PRACTICE REFERENCE MATRIX

Bureau Std Engr: ______
DRAWN BY: ______ DATE DRAWN: 2006

SPECIAL DRAWING NO: ESC-100-2
INDEX NO: 1160-A

ALDOT 2020

Figure 2.5. Alabama DOT E&SC symbology



ALDOT 2020

Figure 2.6. Alabama DOT E&SC applications

Similarly, PennDOT requires SWPPPs to have site plans that encompass existing contours, slope lines delineating cut and fills, drainage divides, grading areas, and symbolic E&SC features.

By providing a map with E&SC practices represented, practitioners can easily reference location of practice, identify missing or lacking practices, and inspect and maintain practices more easily. By requiring a site map with marked practices, closer attention and details would be required by designers. This provides an opportunity for closer consideration of site slopes, drainage areas, soil and cover types, and E&SC practices in a system for treatment. In addition to a site map with practices, adopting a comprehensive SWPPP with less routine information would require designers and engineers to work more closely with the site features and challenges, while identifying the most appropriate staging, BMPs, and opportunities to preserve soil and downstream water quality.

Within all of the SWPPPs reviewed, several practices were reoccurring including, but not limited to silt fence in perimeter control and ditch check applications; wattles in perimeter control, ditch check, and inlet protection applications; rock check dams; sediment control basins; and rolled erosion control products. The literature and SWPPP review provided the research team with a comprehensive catalog of existing and emerging non-proprietary E&SC practices. From this catalog, researchers and the TAC selected several E&SC practices to evaluate during active DOT construction. Field evaluations included both current Iowa DOT-approved practices and trial modifications of improved practices. The selection of practices was based on potential for success, frequency of use on Iowa DOT projects, and specific TAC interests. Materials, equipment, and labor for E&SC installations were provided by the site contractors and/or Iowa DOT.

3 MEANS AND METHODS

3.1 INTRODUCTION

E&SC practice selection for this study was based on frequency of use, agency interest, and potential for improved performance. Based on the E&SC practices selected by the DOT technical advisory committee and research team, field monitoring was selected as the most appropriate means for performance evaluation.

E&SC practices were installed during active construction. Areas for installation and monitoring were recommended by the site team including the grading and E&SC subcontractors and Iowa DOT field team. These areas were recommended on the basis of grading activities and proximity to each other for accessibility in monitoring. Under the project contract, subcontractors were responsible for installation of all standard and modified E&SC practices. Installations were supervised by the researchers. The schematics of the standard and modified E&SC practices are found in Appendix A and Appendix B, respectively.

E&SC practices evaluated in this research study are categorized in one of the following (1) ditch checks, (2) sediment barriers, or (3) detention practices. Figure 3.1 illustrates all installed practice types.

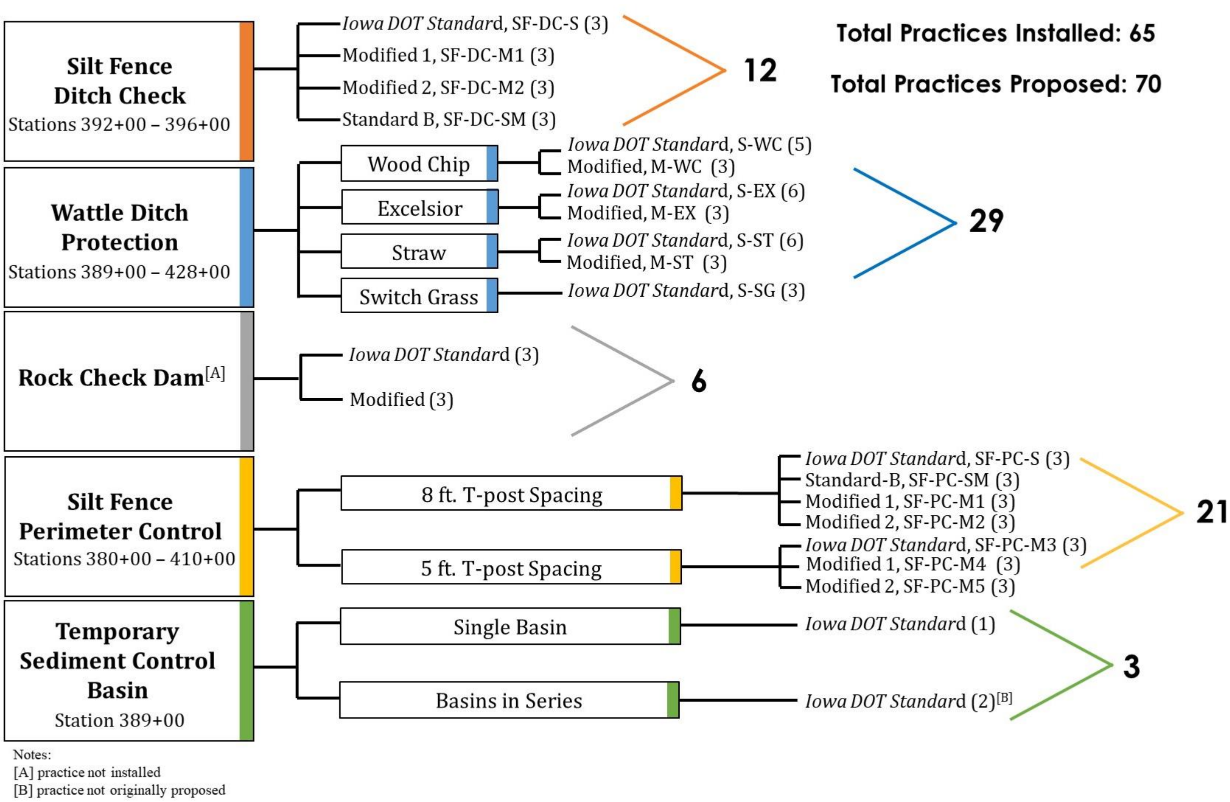


Figure 3.1. Installed E&SC practices on Tama US 30

Monitoring of E&SC practices occurred during the fall of 2018 and summer/fall of 2019. Water quality monitoring of the single basin took place from September 25, 2018 through October 16, 2018. Monitoring continued on basins in a series system from May 17, 2019 through September 3, 2019. Ditch checks and perimeter controls were installed July 26, 2019 and monitored through December 10, 2019. Installation and field monitoring were coordinated around the normal grading and work operations of the site contractor. Sampling equipment installation and removal was based on the site accessibility and need of the contractor. A timeline of activities is shown in Figure 3.2.

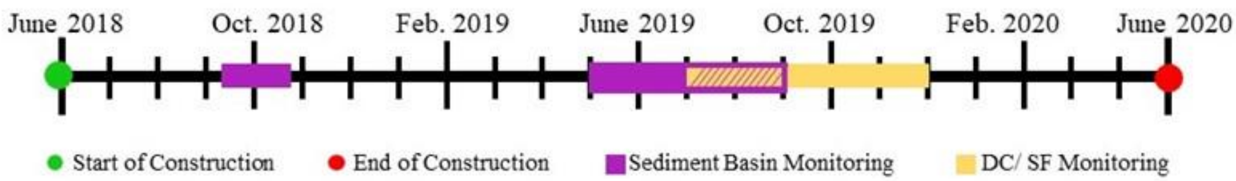
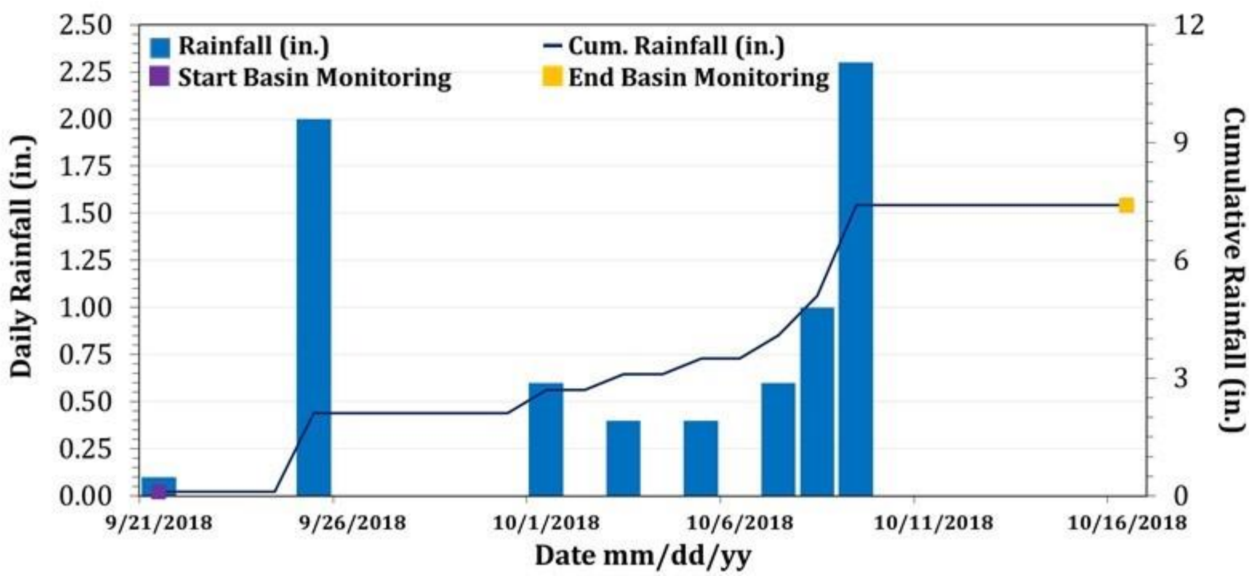
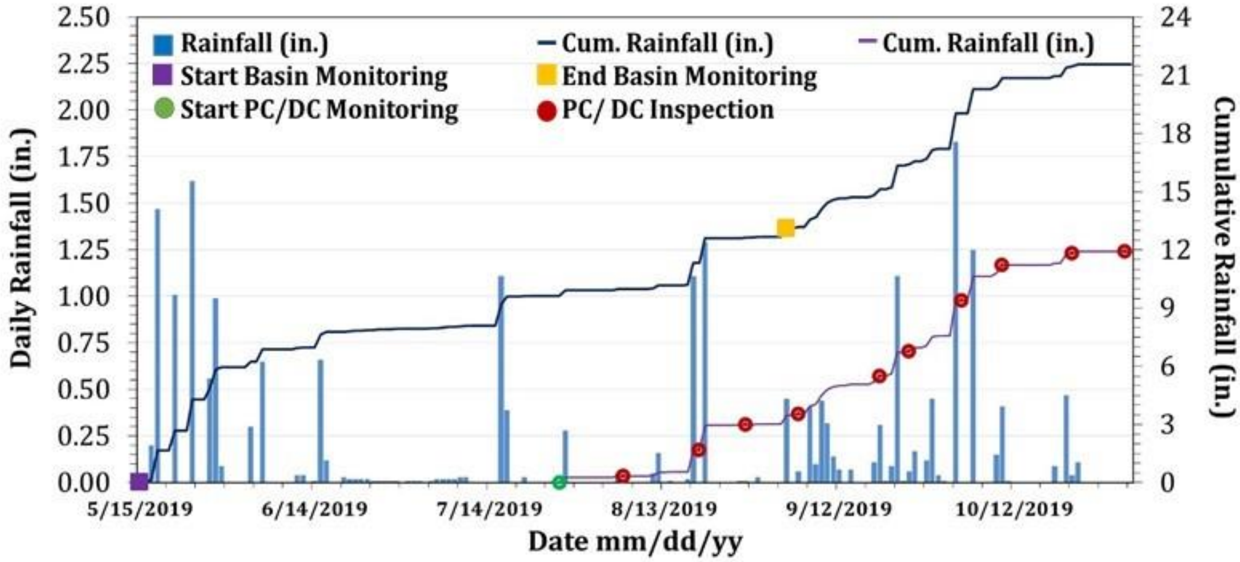


Figure 3.2. Activity timeline on Tama US 30

Figure 3.3 provides the total rainfall and dates of monitoring activities.



(a) Monitoring period, fall 2018



(b) Monitoring period, summer and fall 2019

Figure 3.3. Rainfall on Tama US 30 research site

Rainfall in 2017 and 2018 was 30.06 in. (76.35 cm) and 46.61 in. (118.39 cm), respectively, according the Iowa Department of Agriculture and Land Stewardship annual weather summary reports (Naig and Glisan 2018, Naig and Hillaker 2017). For comparison, the design rainfall depths on the Tama US 30 project are shown in Table 3.1.

Table 3.1. Design 24 hour rainfall depths in Tama County, Iowa

Frequency, years	Rainfall depth, in. (cm)
2	3.1 (7.9)
5	4.0 (10.2)
10	4.6 (11.7)
25	5.3 (13.5)
50	5.9 (15.0)
100	6.6 (16.8)

Source: Natural Resources Conservation Service 2007

In addition to monitoring, soil testing was completed to classify soils on-site. Soils were classified as a lean clay with sand (CL-SC) according to the Unified Soil Classification System (USCS). Soil samples were taken from deposited material in the basin and site prior to grading and produced plasticity indices of 18.7 and 19, respectively. Basin materials had a liquid limit of 46.3, whereas site materials had a liquid limit of 35.6. The gradation plot is shown in Figure 3.4.

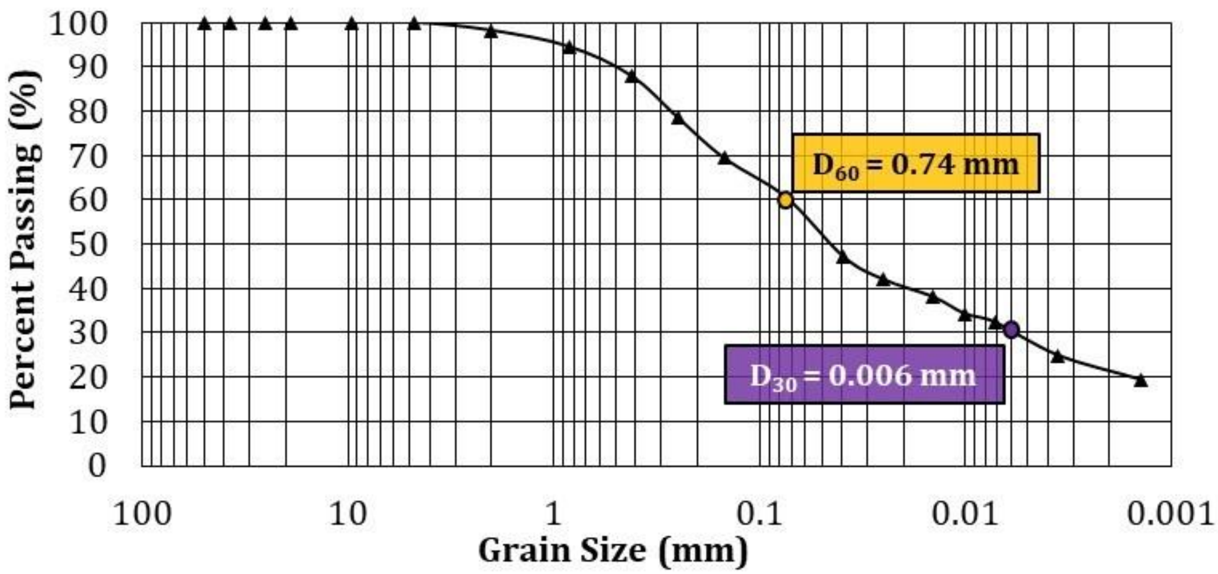


Figure 3.4. Tama US 30 soil gradation

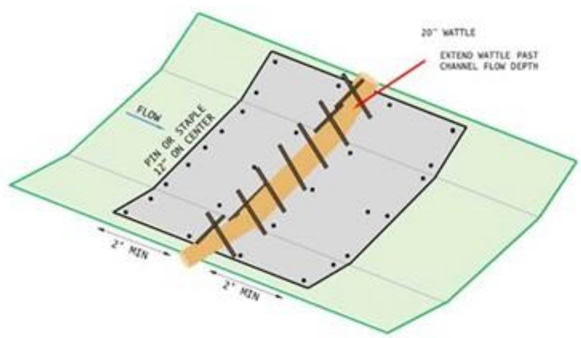
During monitoring, weekly inspections were conducted. Researchers used a number of methods to collect performance data including water sampling, surveying, visual forensic inspections (a weekly regimen of photographs at same views), and drone analysis. Weekly inspections reports were completed for each individual practice and included inspection date, cumulative rainfall, rainfall since last inspection, drainage area, and general comments. After the inspection, the second page provided an area to organize weekly photographs. An example of a weekly inspection report is shown in Figure 3.5 and accompanying weekly photograph regimen are shown in Figure 3.6. A complete record of inspection reports was provided as supporting material to this final report.

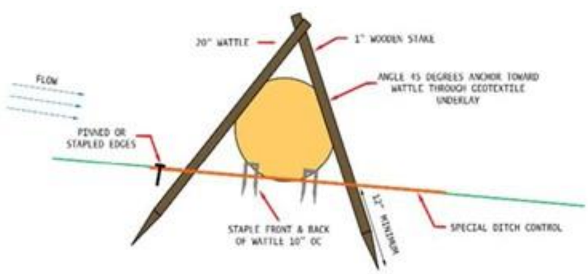
WATTLE DITCH CHECK

Inspection Date:	10/22/2019
Inspector(s):	J.S./B.K.
Installation Configuration:	Modified WC Wattle
Label:	WC-M-1
Installation Date:	7/26/2019
Previous Inspection Date:	10/10/2019
Drainage Area:	4.75
Rainfall Observed (to date):	11.82
Since last inspection:	0.61
LiDAR Scans taken?	No.

Wattle Ditch Check Installation (07/26/19)

Installation Detail





Observations/Notes:

Upstream Sediment Deposition? Yes.

Upstream/ Downstream Scour? Not observed.

Flow Bypass? Flow bypass on right side of wattle due to upstream sediment deposition.

Evidence of Overtopping? Yes at midpoint. Starting to exhibit flow bypass.

Other:

WC-M-1 1 10/22/2019

Figure 3.5. Inspection form

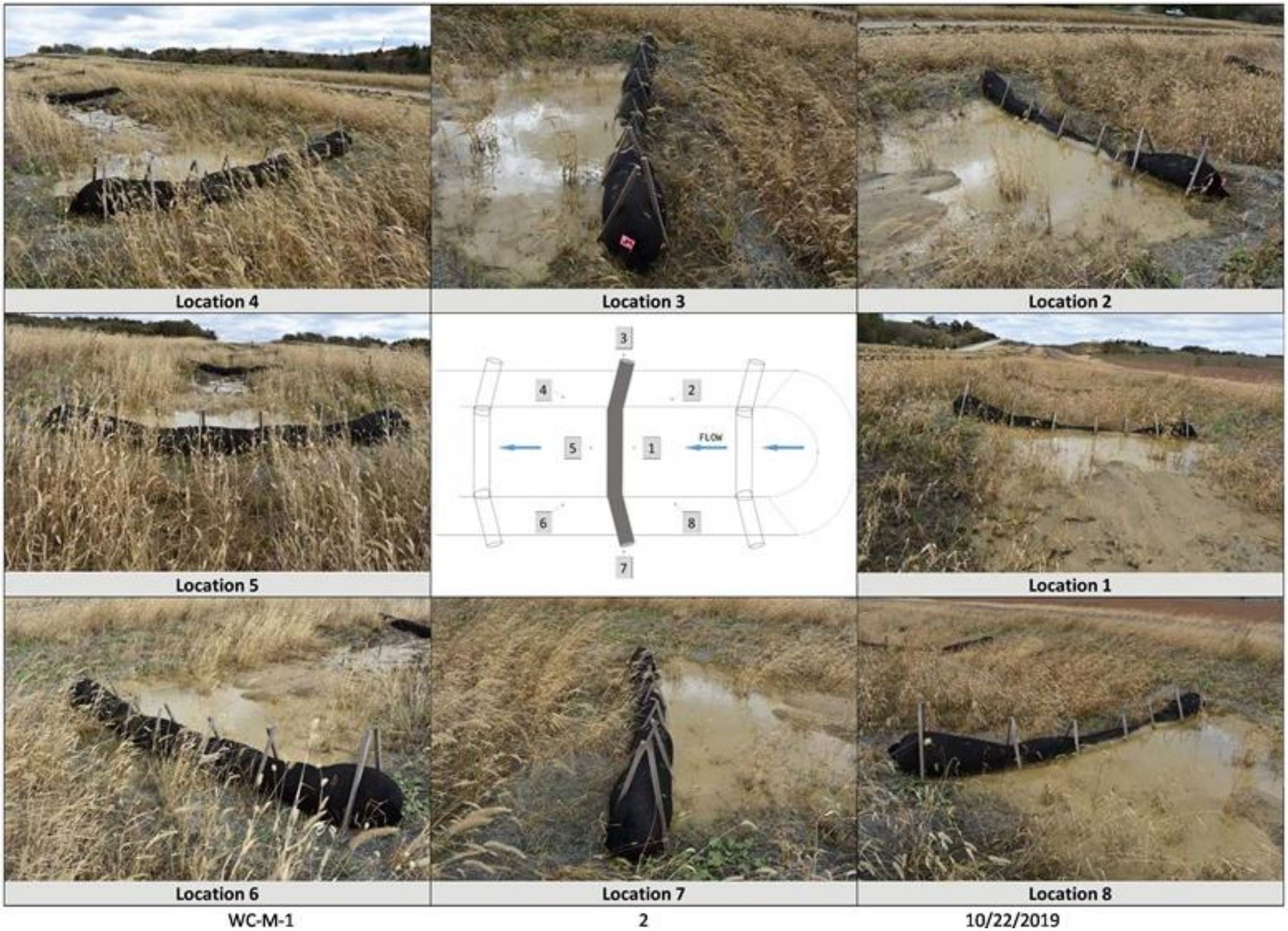


Figure 3.6. Weekly inspection photographs

3.2 FIELD MONITORING OF DITCH CHECKS

Ditch check practices were installed on July 26, 2019 and evaluated for sedimentation potential, structural integrity, and common failure modes through December 10, 2019. Alike practices were installed in the same channels or perimeters to ensure similar drainage areas, slopes, soil types, ground cover, and precipitation. Installation configurations are shown in the following sections. A Trimble TX5 LiDAR scanner was used to scan practices at the beginning, middle, and end of the sampling season. Global Positioning System (GPS) points were taken on each practice using a Trimble R8 GNSS. Autodesk ReCap was used to associate GPS points with the scans and then convert scans into point clouds compatible with AutoCAD Civil 3D. In Civil 3D, surfaces were created from the LiDAR point clouds, and surface subtraction was used to quantify sediment accumulation or erosion. In addition to the scans, stakes were spaced every 10 ft (3.05 m) upstream of ditch check practices and surveyed at installation. Stakes were installed to expose 12 in. (31 cm). At the end of the sampling season, hand measurements were taken from the top of the stake down to measure sediment accumulation in the channel. A profile view of the channel was created for the day of installation using the original survey points. A post-monitoring profile was created by plotting modified elevation points that account for sediment accumulation with the original northing and easting points. Profile views were compared to estimate the total volume of accumulation.

3.3 LABORATORY TESTING OF WATTLE DITCH PROTECTION PRODUCTS

In addition to field monitoring wattle ditch protection, laboratory testing experiments were conducted to further compare the performance of practices across various wattle fill media. A series of flume experiments were performed to evaluate eight wattle types that varied in fill material, containment material, and density. For each wattle type, three replicable test series were performed. Each series of tests were performed by introducing flow at 4 incremental flow rates at 3 incremental channel slopes, resulting in a total of 36 tests per wattle type.

Wattle evaluations were conducted using a tiered slope and flow regime that introduced clean water at 0.25, 0.75, 1.25, and 2.00 ft^3/s (0.007, 0.021, 0.035, and 0.057 m^3/s) at slope grades of 3.50%, 4.25%, and 5.00%. Flow duration for each tier was approximately 3.5 minutes or until flow equilibrium (i.e., constant ponding length from wattle to hydraulic jump) was achieved within the flume. This evaluation process was selected so that the wattles' performance could be analyzed with respect to slope and flow rate. The eight wattles tested were evaluated against the results of the control test that maximized upstream subcritical flow lengths and minimized channelized flow velocity. The criteria used for evaluation were: (1) impoundment depth ratio, (2) subcritical length ratio, (3) independent performance analyses of each wattle evaluated using analysis of variance (ANOVA), and (4) statistical relevance between each wattle tested and the control test of an impermeable weir.

3.4 FIELD MONITORING OF SEDIMENT BARRIERS

Practices categorized as sediment barriers were installed in the last week of July 2019 and evaluated for sedimentation potential, structural integrity, and common failure modes. Weekly forensic and aerial inspections were conducted.

3.5 FIELD MONITORING OF TEMPORARY SEDIMENT CONTROL BASINS

A single temporary sediment control basin and two basins in series were evaluated for performance efficiency in the fall of 2018 and summer of 2019, respectively. For the purpose of evaluating performance degradation over the course of the monitoring period, dredging was not conducted on the basin. Water samples were analyzed for turbidity and total solids at inflow and discharge of the basins and compared to find performance efficiency. Water samples were collected every 12 hours using a Teledyne ISCO 6712 automated sampler. Rainfall was collected using a Teledyne ISCO 674 rain gauge, connected to the sampler. The automated sampler was powered using a 12V marine battery with solar panel charging system. Rainfall data collected during field evaluations is shown in Figure 3.3.

Water quality sampling was used to evaluate samples for turbidity and total solids. Turbidity was analyzed to provide an indication of water clarity. Elevated turbidity indicates low levels of water quality resulting from the suspension of fine particulates. Total solids is another measure of water quality that provides a complete measure of particulates by weight. Total solid concentrations were used to quantify all settled solids present in samples. Laboratory procedures can be found in Appendix C.

Turbidity was determined using a Hach 2100Q portable turbidimeter. Total solids testing was conducted in accordance with ASTM Standard D3977-97 (ASTM Standard D3977-97 2015). Sediment concentrations were expected to be above 200 ppm; therefore, the evaporation test method (Test Method A, ASTM D3977-97) was selected.

3.6 AERIAL INSPECTIONS

A DJI Inspire 2 unmanned aerial system (UAS) and a DJI Zenmuse X5S camera were used to conduct aerial inspections for a comprehensive view of site conditions. This system is shown in Figure 3.7.

© 2019 DJI

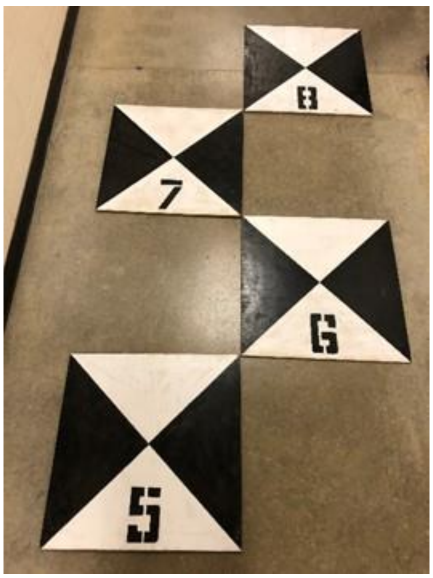
(a) DJI Inspire 2 UAS components

© 2019 DJI

(b) Assembled system withZenmuse X5S camera

Figure 3.7. DJI Inspire 2

During the 2019 construction season, over 15 flights were conducted on the site at different locations, taking georeferenced images for photogrammetric applications. Each automated flight captured over 700 images that were used for developing two-dimensional (2D) maps and three-dimensional (3D) models of the Tama US 30 site. Ground Control Points (GCP) contributed the photogrammetry development by correcting uncertainties in the image geolocation. Eight GCPs were prepared for this study by creating 2 ft by 2 ft (0.61 m by 0.61 m) plywood markers and painting with black and white triangles. Numbers were assigned and painted on each GCP marking for matching surveying results with the initial model. GCP markers were spread across the flight path, and a real-time kinematic (RTK) unit was used to obtain northing, easting, and elevation information of the GCP markers. The RTK unit and GCPs are shown in Figure 3.8.



(a) GCP


(b) RTK unit

Figure 3.8. GCP and RTK unit

In addition to automated, pre-programmed flights, manual flights were also conducted to focus on failures or deficiencies on-site. Photographs captured from aerial flights were used to create the site plan shown in Figure 3.9.

(a) STA 375+00 to 387+00


(b) STA 389+00 to 400+00


(c) STA 423+00 to 433+00

Figure 3.9. Site plan

The site plan highlights the areas of the site where standard and modified practices were monitored. Channels are outlined based on the ditch check practice installed within the channel. Station numbers are included on the site plan for reference.

3.7 LIST OF MATERIALS

In addition to a general toolbox and personal protective equipment, the following materials were used for site visits:

(A) Ditch check practices
   a. Trimble TX5 LiDAR scanner
   b. Measuring tape
   c. Nikon D7200 camera
   d. AccuMASTER digital angle finder
   e. Inspection sheets

(B) Silt fence perimeter control
   a. Nikon D7200 camera
   b. AccuMASTER digital angle finder
   c. Inspection sheets

(C) Sediment basin
   a. Laptop with Teledyne ISCO Flowlink 5.1 Software
   b. Connect cable for external 12 VDC source
   c. Replacement 33.8 oz (1.0 L) sample bottles
   d. Sample bottle caps

(D) Aerial inspections
   a. DJI Inspire 2 UAS and Zenmuse X5S camera
   b. 8 propellers (including 4 spare propellers)
   c. 12 batteries
   d. Remote controller
   e. iPad Pro 10 tablet
   f. Trimble R8 RTK unit
   g. GCPs

4 DITCH CHECKS

4.1 INTRODUCTION

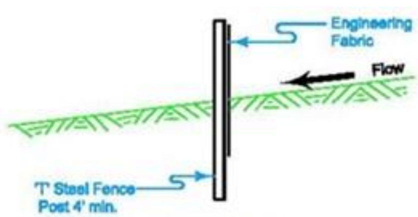
Ditch checks, or check dams, are temporary erosion control structures constructed across stormwater conveyance channels to interrupt flow and impound runoff. Impoundments reduce the length of supercritical flows and create areas of subcritical flow, reducing erosion potential and promoting sedimentation. Typically, ditch check spacing is dependent on the height of the practice and channel slope. Ditch checks are the most efficient when the impoundment or subcritical flow length extends the full distance between ditch check practices. Ditch checks are common in a variety of materials including variations of silt fence, fiber logs, rock, sandbags, and several varieties of manufactured devices. This section focuses on (1) silt fence, (2) wattles, and (3) rock check dams, as these were the three types of ditch checks available for testing on Tama US 30.

4.2 SILT FENCE DITCH CHECK

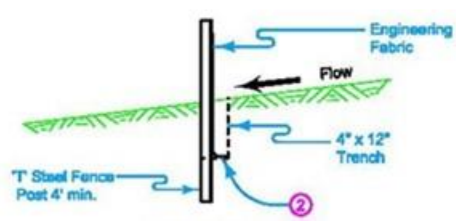
Silt fence ditch checks function primarily to reduce kinetic energy and flow velocity within a conveyance channel. A benefit of reduced velocities is that conditions favorable for the deposition of suspended sediment are created. Silt fence ditch checks are installed perpendicular to flow in conveyance channels and typically consist of a geotextile material attached to a steel T-post. The geotextile material is secured to the ground either by manually trenching or slicing into the ground. Some DOTs have adopted a wire reinforcement behind the geotextile material to enhance structural integrity.

4.2.1 Iowa DOT Standard

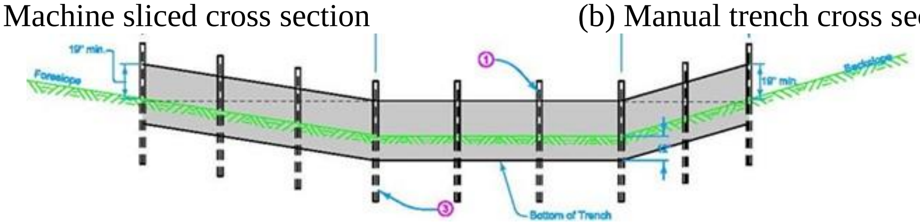
The Iowa DOT standard silt fence ditch check (SF-DC-S) specifies 4 ft (1.2 m) steel T-posts, driven at least 28 in. (71 cm) into the ground (Figure 4.1).



(a) Machine sliced cross section



(b) Manual trench cross section



(c) Elevation view

Iowa DOT 2018

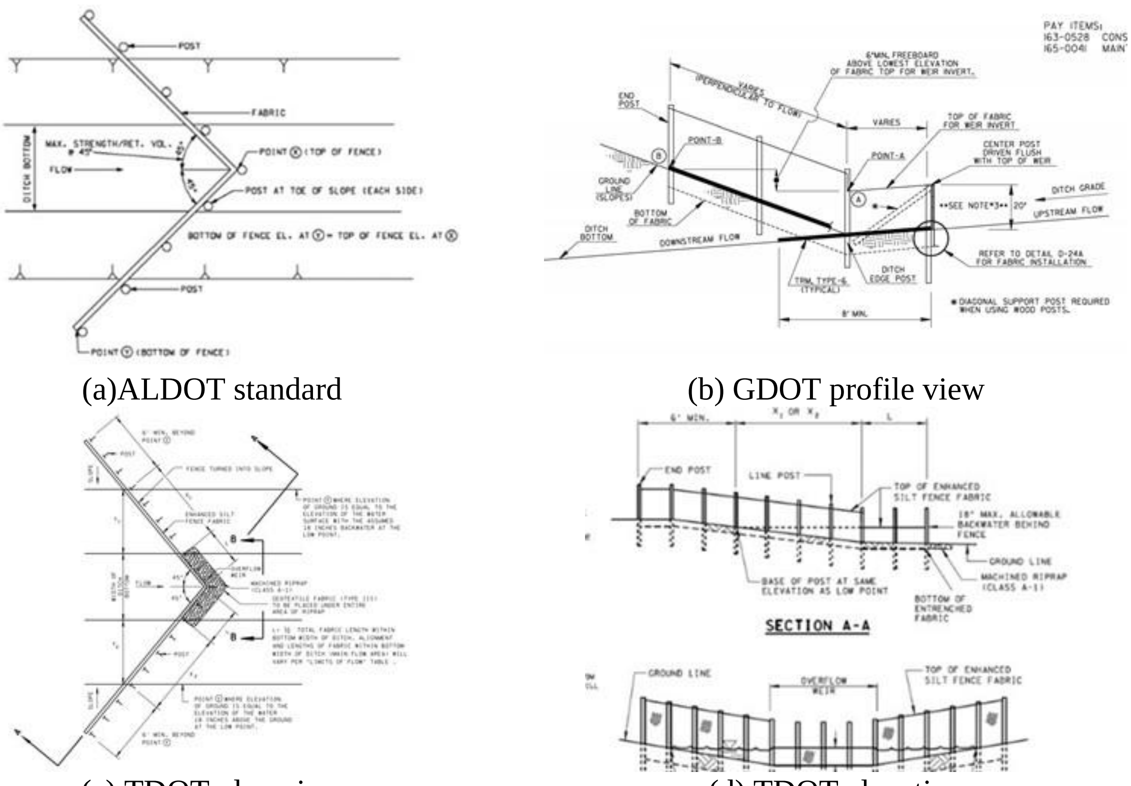
Figure 4.1. Iowa DOT silt fence ditch check detail EC-201

Posts are to be installed in a perpendicular line across the flow channel, spaced no more than 4 ft (1.2 m) apart. Geotextile silt fence material is to extend at least 19 in. (48 cm) above the ground line and is wire- or cable- tied to the post through the top, middle, and bottom of the material. Ties should be angled, with the highest point on the back of the post. Material can either be trenched 4 in. by 12 in. (10 cm by 30 cm) or sliced 12 in. (30.24 cm) into the ground.

4.2.2 Literature Review

Silt fence is a widely known and industry-accepted E&SC practice. The use of silt fence across areas of concentrated flow is typically discouraged. However, a handful of DOTs have provided enhanced silt fence guidance specific for ditch check applications. In addition, silt fence ditch check installations have been evaluated through large-scale testing to optimize the design and installation of silt fence used in areas of concentrated flow.

Compared to traditional silt fence installations for perimeter controls, ditch check applications include shorter post spacing and include the use of a weir spillway. Figure 4.2 shows silt fence ditch check equivalents from (a) ALDOT, (b) the Georgia DOT (GDOT), and (c and d) the Tennessee DOT (TDOT).



(a)ALDOT standard

(b) GDOT profile view

(c) TDOT plan view

(d) TDOT elevation

Figure 4.2. Silt fence ditch check installations

The ALDOT standard implements a V-line installation with dewatering weir at the vertex. The geotextile is reinforced with wire backing. The silt fence geotextile and underlay are sod stapled to the channel bottom every 6 in. (15 cm) on-center (OC). Posts are spaced 3 ft (0.9 m). TDOT employs a similar ditch check installation, implementing a V-line with dewatering weir; however, a riprap at the vertex replaces the geotextile underlay of the silt fence. Rather than sod stapled, the geotextile is trenched in (TDOT 2020). Figure 4.2b illustrates a GDOT silt fence ditch check, which also incorporates a dewatering weir but is installed perpendicular to flow. The GDOT detail requires that diagonal wooden posts be installed if wooden posts are being used to support the fence. A turf reinforcement mat is used at the dewatering weir to control energy dissipation (GDOT 2015).

Donald et al. (2015) evaluated the performance of five different wire-backed, nonwoven silt fence ditch check installation techniques. Silt fence ditch checks were subjected to flows ranging from 0.56 to 1.68 ft^3/s (0.016 to 0.048 m^3/s). The evaluations included the ALDOT silt fence ditch check standard, which consisted of a V-shaped installation at a 45 degree angle, pointed downstream, concave to the flow path. T-posts were to be installed at the center of the V and on either side. The detail then referenced to follow the silt fence perimeter control installation, which called out 10 ft (3 m) post spacing, 6 in. by 6 in. (15.2 cm by 15.2 cm) trench, wire backing reinforcement, and 32 in. (81.3 cm) silt fence height above ground. The ALDOT detail was compared to four other modified installations, which included the ALDOT standard with hay bale dissipater, ALDOT standard with #4 stone dissipater, TDOT standard, and an enhanced ALDOT installation. The installations included the following:

- Standard ALDOT V: Center post is placed in the channel centerline, posts spaced approximately 3 ft (1 m) OC. Fabric and wire backing are inserted in a 6 in. by 6 in. (15.2 cm by 15.2 cm) trench. Overall fence height is 32 in. (81.3 cm).

- V-installation w/hay bale dissipater: ALDOT V-installation with hay bales abutted downstream of silt fence.

- V-installation w/modified #4 stone dissipater: ALDOT V-installation with #4 stone abutted downstream of silt fence on top of geotextile.

- TDOT enhanced silt fence ditch check: ALDOT V-installation with an 18 in. (45.7 cm) weir is cut into the fabric that extends across the width of the channel bottom. Filter fabric (FF) splash apron is installed directly downstream of the weir. Apron is covered with ALDOT Class I riprap to dissipate energy of water overtopping the weir. The schematics are shown in Figure 4.2c and d.

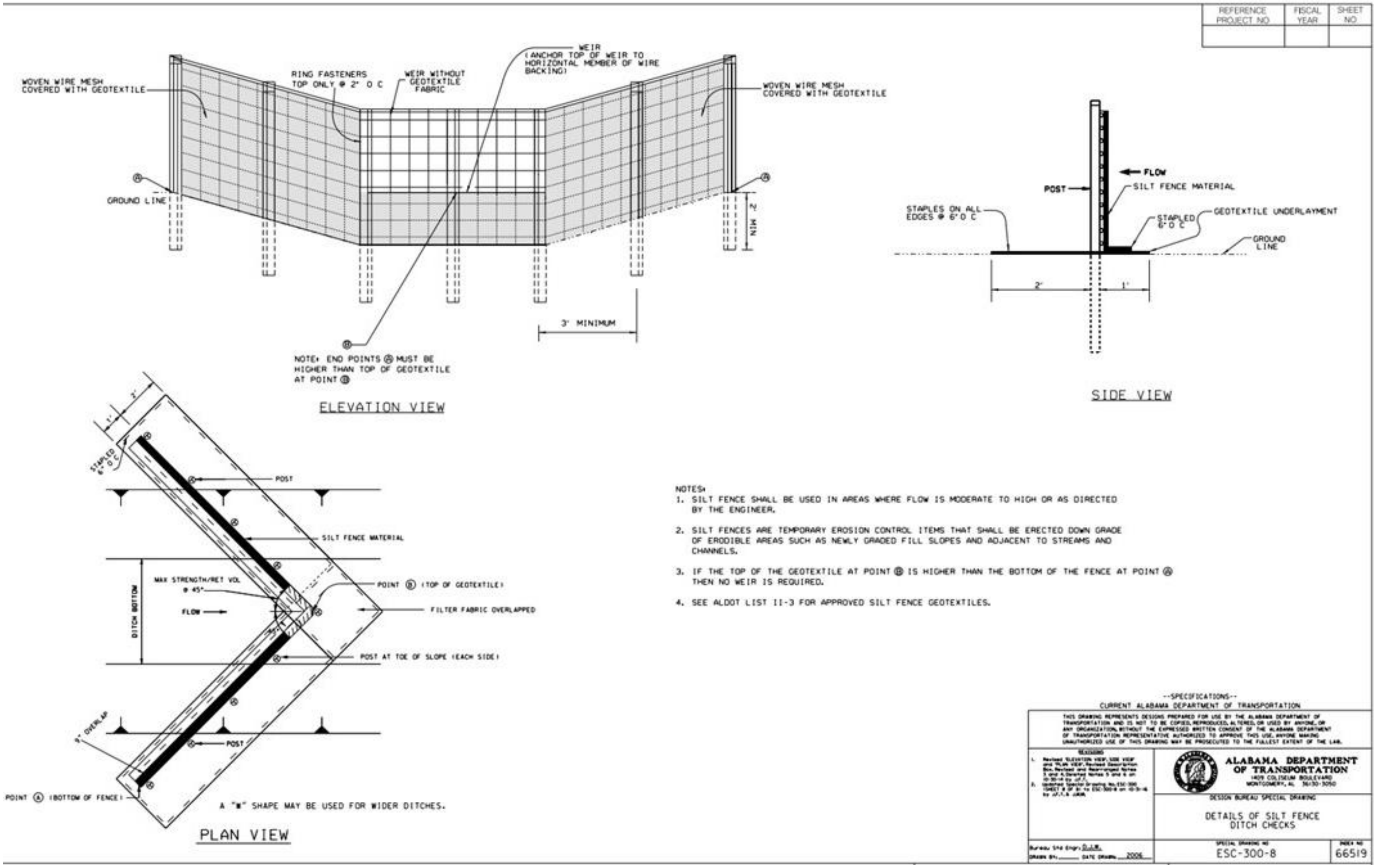
- Enhanced ALDOT pinned installation: Silt fence is not trenched in. Follows the TDOT enhanced installation. FF underlay is installed as a splash pad to protect channel bottom directly upstream and downstream of the silt fence using round top sod pins spaced 5 in. (12.7 cm) on-center. Silt fence FF is also stapled to the channel bottom on top of underlay using sod pins spaced 10 in. (25.4 cm) OC.

The ALDOT standard exhibited scour at the middle post in low flow conditions and was therefore not evaluated in the higher-tiered flow conditions. Testing indicated that the dissipaters did not aid in structural performance of the ALDOT standard and experienced similar failure; however, the #4 stone dissipater delayed erosion patterns and forced them to occur farther downstream. The TDOT enhanced silt fence ditch check reached full-channel length impoundment without failure but exhibited the need for a downstream splash pad. The enhanced ALDOT pinned installation was configured to minimize undercutting of the splash pad, exhibited by the TDOT installation. The enhanced ALDOT pinned installation performed best in large-scale testing and was installed in field for longevity testing. Over the course of six tests, the installation retained 90% of the sediment introduced with no obvious failures (Donald et al. 2015). The enhanced ALDOT pinned installation is shown in Figure 4.3a and b.

(a) Impoundment (b) Sediment retention

Figure 4.3. Longevity evaluation of pinned silt fence ditch check

The increased height of silt fence ditch checks, when compared to wattles, sandbags, or riprap in the same application, impounds greater depths and lengths of stormwater. The advantage in this is that longer segments of a channel can be protected, while minimizing the total amount of ditch checks required along the channel. The increased impoundment increases hydrostatic pressure on the silt fence and creates concern of structural failure. The addition of a dewatering weir relieves some of the hydrostatic pressure, while still creating impoundments and favorable conditions for sedimentation and decreased channel erosion. The addition of a weir and splash pad allows the silt fence to operate as an effective ditch check for a longer period of time. As a result of this research, ALDOT modified its standard silt fence ditch check detail, shown in Figure 4.4, to reflect the modified configuration developed through testing.



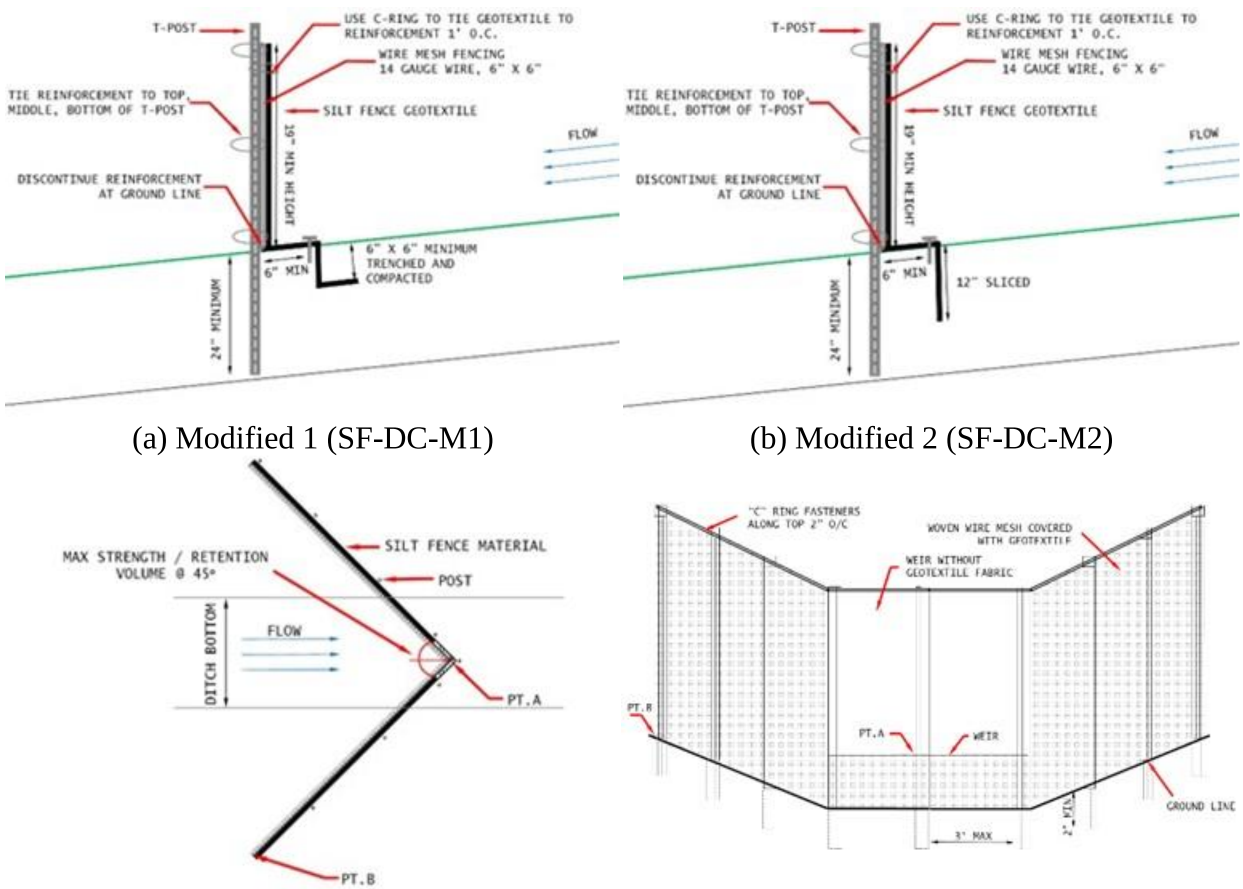
ALDOT 2020

Figure 4.4. ALDOT enhanced silt fence ditch check

4.2.3 Evaluated Design Modifications

Two modified silt fence ditch check details were developed. Modifications to the DOT standards included the addition of wire reinforcement, weir for dewatering, and a V-shaped installation. For both modified designs, T-posts were specified to be driven at least 24 in. (61 cm) into the ground. Reinforcement (geogrid, wire mesh, etc.) was to be tied to the T-posts at the top, middle, and bottom and terminated at the ground line. The geotextile silt fence material was to be tied to the top of the reinforcement every 2 in. (5 cm) OC, using C-ring type fasteners. Silt fence ditch check Modified 1 (SF-DC-M1) called for the geotextile to be trenched 6 in. by 6 in. (15.2 cm by 15.2 cm) into the ground, whereas the silt fence ditch check Modified 2 (SF-DC-M2) was to be offset 6 in. (15.2 cm) and sliced into the ground 12 in. (30 cm).

SF-DC-M1 included decreased T-post spacing to 3 ft, a wire reinforcement, 6 in. (15.2 cm) offset with staple, and a 6 in. by 6 in. (15.2 cm by 15.2 cm) trench as shown in Figure 4.5a.



(a) Modified 1 (SF-DC-M1) (b) Modified 2 (SF-DC-M2)

(c) V-installation configuration, plan view (d) Dewatering weir detail

Figure 4.5. Modified silt fence details

SF-DC-M2 included decreased T-post spacing to 3 ft (0.9 m), a wire reinforcement, 6 in. (15.2 cm) offset with staple, and 12 in. (30 cm) sliced as shown in Figure 4.5b. Both modifications were designed in a V-shape, with the tip of the V pointing downstream or in the direction of the flow, Figure 4.5c. Posts were designed to be spaced no more than 3 ft (0.9 m) apart and driven at least 2 ft (0.6 m) in the ground. A weir was designed to be cut into the geotextile material at the vertex of the V. The lowest point on the weir at the vertex, Point A, should be below the bottom of the silt fence at the outermost edges, Point B, in Figure 4.5d. The modified silt fence ditch check designs are shown in Figure 4.5.

The Iowa DOT standard silt fence ditch check detail (EC-201) was followed for the installation of SF-DC-S and SF-DC-SM. SF-DC-SM implemented the proprietary product Silt Saver Woven Belted Silt Fence (WBSF). The Iowa DOT silt fence ditch check EC-201 is shown in Figure 4.1 (Iowa DOT 2018). A summary of installed ditch checks is shown in Table 4.1.

Table 4.1. Summary of evaluated silt fence ditch check modifications

Description	Code	Installation
Iowa DOT standard	SF-DC-S	EC-201
Modified 1	SF-DC-M1	V-shaped with offset trench
Modified 2	SF-DC-M2	V-shaped with offset slice
Silt Saver WBSF	SF-DC-SM	EC-201

4.2.4 Cost Analysis

A cost analysis was conducted to compare the standard installation detail to the modified installation recommendations. Request for pricing was sent to E&SC product suppliers and distributors from across the US. Four suppliers, including two from Iowa, quoted material cost. The average cost per component was calculated and used for material cost estimates. Iowa DOT provided typical practice costs, which included materials and labor.

To more closely compare the cost of the standard and modified practices, a labor cost correction was added to material cost. The correction factor was calculated with several considerations including the cost difference between the raw material cost estimated and DOT material and installation cost, $/ft (m), productivity, ft/min (m/min), and labor costs, $/min.

To estimate cost, a typical Iowa DOT highway median was used for channel dimensions and consisted of a 10 ft (3.05 m) channel bottom, 4 ft (1.22 m) depth, with 6:1 side slopes. The standard silt fence material cost was estimated to be $1.15/ft ($3.94/m). A complete tabulation for the design can be found in Table 4.2.

Table 4.2. Iowa DOT standard silt fence (SF-DC-S) cost estimate

Component	Qty.	Unit	Unit cost	Total
SF engineering fabric, 36 in. (91 cm)	29 (8.8)	ft (m)	$0.08 ($0.26)	$2.34
Studded T-post, 4 ft (1.2 m)	9	ea	$3.40	$30.60
Cable ties, 50 lb (23 kg)	27	ea	$0.02	$0.49
Total cost per ditch check				**$33.43**
Total cost per ft (m)				**$1.15 ($3.77) [A]**
Estimated unit installation cost per ft (m)				**$0.10 ($0.33)**
Total estimated installed cost per ditch check				**$36.25**

Note: [A] Iowa DOT provided cost of $1.25/ft ($3.94/m), installed

The Iowa DOT provided a typical cost of $1.25/ft ($4.10/m), which includes installation cost, resulting in an installation cost of $0.10/ft ($0.33/m). Based on video footage captured during installation, a contractor crew of three workers installed approximately 3.2 ft/min (0.98 m/min) of the standard silt fence ditch check. Multiplying the per foot labor cost and productivity results in a labor cost of $0.31/min. The labor cost was then used to back-calculate the difference in raw material and material with installation costs for the modified designs, using the installation productivity. The labor correction factor calculation is shown in Table 4.3. A complete table of materials and cost can be found in Appendix D.

Table 4.3. Iowa DOT standard silt fence labor cost estimate

Component	Qty.	Unit
Estimated labor cost (**Δ**)	0.10 (0.33)	$/ft ($/m)
Installation productivity (IP)	3.2 (0.98)	ft/min (m/min)
Labor (Δ × IP)	**0.31**	**$/min**

The cost analysis is specific to the channel geometry described. A Microsoft Excel spreadsheet-based tool was created, which considers user-input channel geometries, for cost comparison. This tool has ditch check options including standard and modified silt fence ditch checks, standard and modified wattle ditch protection, and standard and modified rock check dams. The tool provides users with appropriate ditch check spacing and channel profile based on input and practice selected.

The costs for the standard installation with the Silt Saver WBSF geotextile is shown in Table 4.4.

Table 4.4. Iowa DOT standard silt fence with WBSF material (SF-DC-SM) cost estimate

Component	Qty.	Unit	Unit cost	Total
SF engineering fabric, 36 in. (91 cm)	29 (8.8)	ft (m)	$0.70	$20.23
Studded T-post, 4 ft (1.2 m)	9	ea	$3.40	$30.60
Cable ties, 50 lb (22.7 kg)	27	ea	$0.02	$0.49
Material cost per ditch check				**$51.31**
Material cost per ft (m)				**$1.77 ($5.81)**
Estimated installation cost per ft (m)				**$0.10 ($0.33)**
Total estimated installed cost per ditch check				**$54.23**

The only difference in costs is the manufactured fabric. Since the installation productivity remains the same, the Δ is consistent with the standard installation cost estimate of $0.10/ft ($0.33/m).

Both modified installations included the addition of wire reinforcement, C-rings, sod staples, and a decrease in T-post spacing. The cost for the modified designs was estimated to be $2.83/ft ($9.29/m). A cost of $7.15/ft ($23.46/m) was provided to the DOT by a subcontractor for the installation of a handful of practices. A tabulation of material cost is provided in Table 4.5.

Table 4.5. Modified 1 silt fence (SF-DC-M1) cost estimate

Component	Qty.	Unit	Unit cost	Total
SF engineering fabric, 36 in. (91 cm)	14 (4.3)	ft (m)	$0.08 ($0.26)	$1.14
Studded T-post, 4 ft (1.2 m)	7	ea	$3.40	$23.80
Cable ties, 50 lb (23 kg)	21	ea	$0.02	$0.38
Sod staples, 6 in. (15.2 cm)	28	ea	$0.03	$0.97
Welded wire fence, 18 in. (45.7 cm)	14 (4.3)	ft (m)	$0.89 ($2.92)	$12.58
C-ring ties, 1 in. (2.5 cm)	15	ea	$0.03	$0.45
Total cost per ditch check				**$39.32**
Total cost per ft (m)				**$2.78 ($8.47) [A]**
Estimated unit installation cost per ft (m)				**$0.17 ($0.56)**
Total estimated installed cost per ditch check				**$41.80**

Note: [A] Iowa DOT provided cost of $7.15/ft ($23.46/m), installed

Modified 2 incorporated the same material cost as Modified 1, but slicing was used to key the silt fence material into the ground. Slicing slightly decreased the time required for installation, increasing productivity. Due to the angle specified for the modified installation, there was trouble maneuvering the slicing machine and required hand repairs in several areas. The cost estimate for Modified 2 is shown in Table 4.6.

Table 4.6. Modified 2 silt fence (SF-DC-M2) cost estimate

Component	Qty.	Unit	Unit cost	Total
SF engineering fabric, 36 in. (91 cm)	14 (4.3)	ft (m)	$0.08 ($0.26)	$1.14
Studded T-post, 4 ft (1.2 m)	7	ea	$3.40	$23.80
Cable ties, 50 lb (23 kg)	21	ea	$0.02	$0.38
Sod staples, 6 in. (15.2 cm)	28	ea	$0.03	$0.97
Welded wire fence, 18 in. (45.7 cm)	14 (4.3)	ft (m)	$0.89 ($2.92)	$12.58
C-ring ties, 1 in. (2.5 cm)	15	ea	$0.03	$0.45
Total cost per ditch check				**$39.32**
Total cost per ft (m)				**$2.78 ($8.47)** [A]
Estimated unit installation cost per ft (m)				**$0.15 ($0.46)**
Total estimated installed cost per ditch check				**$41.38**

Note: [A] Iowa DOT provided cost of $7.15/ft ($23.46/m), installed

To compare the total cost (material and installation) to the standard practice, the labor cost of $0.31/min was maintained and applied to the reduced installation productivity of 1.78 ft/min (0.54 m/min) for Modified 1 and 2.14 ft/min (0.70 m/min) for Modified 2. The resulting installation cost rate is $0.17/ft ($0.56/m) and $0.15/ft ($0.46/m), respectively. Modified 1 and Modified 2 cost 15% and 14%, respectively, more than the standard silt fence installation.

4.2.5 Installation Criteria, Evaluation, and Limitations

Each of the four silt fence ditch check designs were installed three times, for a total of 12 installations. To minimize differences in contributing area, channel characteristics, soil type, and vegetation, silt fence ditch checks were installed in a single median channel. The channel is outlined in green on the site plan shown in Figure 3.9. The installation pattern of the silt fence ditch checks can be seen in Figure 4.6.

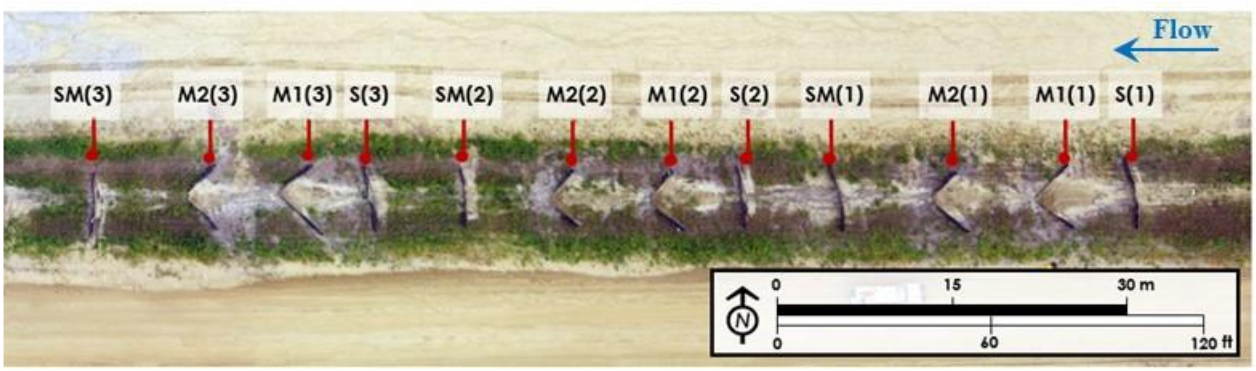


Figure 4.6. Installation configuration of silt fence ditch check channel

Installations techniques alternated within the channel to randomize their placement. The drainage areas were determined by delineating contributing areas from contour maps in a geographic information system (GIS). The drainage areas for each practice are displayed in Table 4.7.

Table 4.7. Silt fence ditch check drainage areas

Practice	Drainage area, ac (ha)
SF-DC-S-1	3.97 (1.61)
SF-DC-M1-1	4.02 (1.63)
SF-DC-M2-1	4.10 (1.66)
SF-DC-SM-1	4.13 (1.67)
SF-DC-S-2	4.21 (1.71)
SF-DC-M1-2	4.26 (1.72)
SF-DC-M2-2	4.33 (1.75)
SF-DC-SM-2	4.37 (1.77)
SF-DC-S-3	4.42 (1.79)
SF-DC-M1-3	4.46 (1.81)
SF-DC-M2-3	4.52 (1.83)
SF-DC-SM-3	4.57 (1.85)

Evaluation of the silt fence ditch checks included structural integrity, sedimentation, and impoundment. The structural integrity was visually monitored through weekly photo inspections and channel surveying. Sedimentation was measured using channel surveying and LiDAR scanning at the beginning, mid-term, and end of monitoring period. 3D surface models were created from the LiDAR scans; however, due to the growth in the channel and capture of vegetation, soil surface models comparing installation and post-monitoring periods could not be created. Instead, sedimentation was measured through comparison of the original channel survey of stakes at the middle point of the channel. Aerial inspections were used to monitor sedimentation and impoundment. Installations were performed by GreenTech. Maneuvering the slicing machine in the channel at 45 degree angles was a challenge in installation. Several areas along the slice had to be repaired using hand tools.

4.2.6 Inspection Results

Visual inspections on each silt fence ditch check were performed and documented through a photo journal weekly. Photographs were organized per inspection date and per practice. A complete archive of inspection logs is available as supporting material to this report. The figures in this section display a set of inspection photos for each installation (SF-DC-S, SF-DC-M1, SF-DC-M2, SF-DC-SM) at monthly intervals (July 26, 2019; August 27, 2019; September 24, 2019; and October 22, 2019). Rainfall accumulation was 2.99 in. (7.59 cm), 6.78 in. (17.22 cm), and 11.82 in. (30.02 cm) by August 27, 2019; September 24, 2019; and October 22, 2019, respectively.

Two of the Iowa DOT standard silt fence ditch checks, SF-DC-S-1, started to experience post deflection within a month of installation after 2.99 in. (7.59 cm) of rainfall, Figure 4.7 (SF-DC-S-2 and S-3), and the third exhibited undercutting and downstream scour after 5.5 in. (13.97 cm) of rain.

(a) 7/26/2019, installation - upstream

(b) 7/26/2019, installation - downstream

(c) 8/27/2019 - upstream

(d) 8/27/2019 - downstream

(e) 9/24/2019 - upstream

(f) 9/24/2019 - downstream

(g) 10/22/2019 - upstream

(h) 10/22/2019 - downstream

Figure 4.7. Silt fence ditch check- standard (SF-DC-S)

Lack of sedimentation upstream and erosion patterns in the channel indicated undercutting on all of the three monitored standard installations. After nearly two months and 11.82 in. (30.02 cm) of rain, there was still no evidence of sedimentation and further channel erosion; however, the posts did not seem to deflect much further.

All of the Modified 1 installations, SF-DC-M1, exhibited sedimentation and signs of impoundment after 2.99 in. (7.59 cm) of rainfall (Figure 4.8).


(a) 7/26/2019, installation - upstream | (b) 7/26/2019, installation - downstream


(c) 8/27/2019 - upstream | (d) 8/27/2019 - downstream


(e) 9/24/2019 - upstream | (f) 9/24/2019 - downstream


(g) 10/22/2019 - upstream | (h) 10/22/2019 - downstream

Figure 4.8. Silt fence ditch check - Modified 1, SF-DC-M1

There was no evidence of channel erosion or post deflection. SF-DC-M1-1 had accumulation reach 50% height after 9.4 in. (23.88 cm) of rain, requiring sediment removal. SF-DC-M1-2 and SF-DC-M1-3 had accumulation up to full height after 11.21 in. (28.47 cm) of rainfall. By the third and fourth inspections shown in Figure 4.8c and d, there was evidence of channel flow overtopping the weir on the first two installations (SF-DC-M1-1 and SF-DC-M1-2), particularly on SF-DC-M1-2. The downstream photo on the fourth inspection, Figure 4.8h, displays erosion just downstream of the weir, indicating overtopping flows scoured the earthen channel. While a special ditch control mat was intended to reduce the occurrence of scour at the weir discharge, a higher level of armoring may be needed in future installations. A geotextile pinned to the channel bottom may provide adequate scour resistance. Without proper armoring, the scour point may extend toward the upstream face of the ditch check, eventually compromising the integrity of the installation.

Similar to SF-DC-M1, all SF-DC-M2 installations exhibited sedimentation and impoundment after 2.99 in. (7.59 cm) of rainfall. There was also evidence of flow overtopping the weir causing erosion of the channel immediately downstream. Erosion downstream of the weir increased in the third and fourth inspections but did not seem to compromise structural integrity. Photographs are shown in Figure 4.9.

(a) 7/26/2019, installation - upstream

(b) 7/26/2019, installation - downstream

(c) 8/27/2019 - upstream

(d) 8/27/2019 - downstream

(e) 9/24/2019 - upstream

(f) 9/24/2019 - downstream

(g) 10/22/2019 - upstream

(h) 10/22/2019 - downstream

Figure 4.9. Silt fence ditch check - Modified 2, SF-DC-M2

The SF-DC-SM employed a standard installation technique with the SiltSaver WBSF material. Inspection photographs are shown in Figure 4.10.

(a) 7/26/2019, installation - upstream

(b) 7/26/2019, installation - downstream

(c) 8/27/2019 - upstream

(d) 8/27/2019 - downstream

(e) 9/24/2019 - upstream

(f) 9/24/2019 - downstream

(g) 10/22/2019 - upstream

(h) 10/22/2019 - downstream

Figure 4.10. Silt fence ditch check – Silt Saver WBSF, SF-DC-SM

In the Figure 4.10e and f, captured during the third inspection, there is evidence of some sedimentation with high water markings on the fence. SF-DC-SM-1 and -2 exhibited a high water mark by the second inspection but did not show signs of sedimentation upstream. This could be due to the apparent opening size, allowing quicker dewatering and less sedimentation. However, flow patterns indicate scour upstream of the practice, leading to undercutting. This was less obvious than undercutting observed on SF-DC-SM-3. Although the installation did not exhibit post deflection until the fourth inspection, there was obvious undercutting by the third inspection. Runoff had eroded a significant portion of the channel directly upstream the ditch check. The geotextile was dislodged from its original slice. By the fourth inspection, the silt fence had failed and overtopped due to post deflection. This material has much larger apparent opening sizes than the DOT standard geotextile (US sieve #30), allowing runoff to pass through more quickly and easily. Due to the flow velocity within the channel, there was evidence of erosion with little evidence of upstream sediment deposition.

4.2.7 Sedimentation Results

To quantify the performance of all installed silt fence ditch checks, stakes were placed at 10 ft (3.0 m) intervals along the midpoint of the channel and set at an exposed height of 12 in. (30.5 cm), protruding from the channel surface. Stakes were surveyed using the RTK unit on the day of installation and sedimentation amounts were measured on December 10, 2019, the final date of inspection. A surface profile, shown in Figure 4.11, was plotted showing the difference in channel grade along the silt fence test channel.

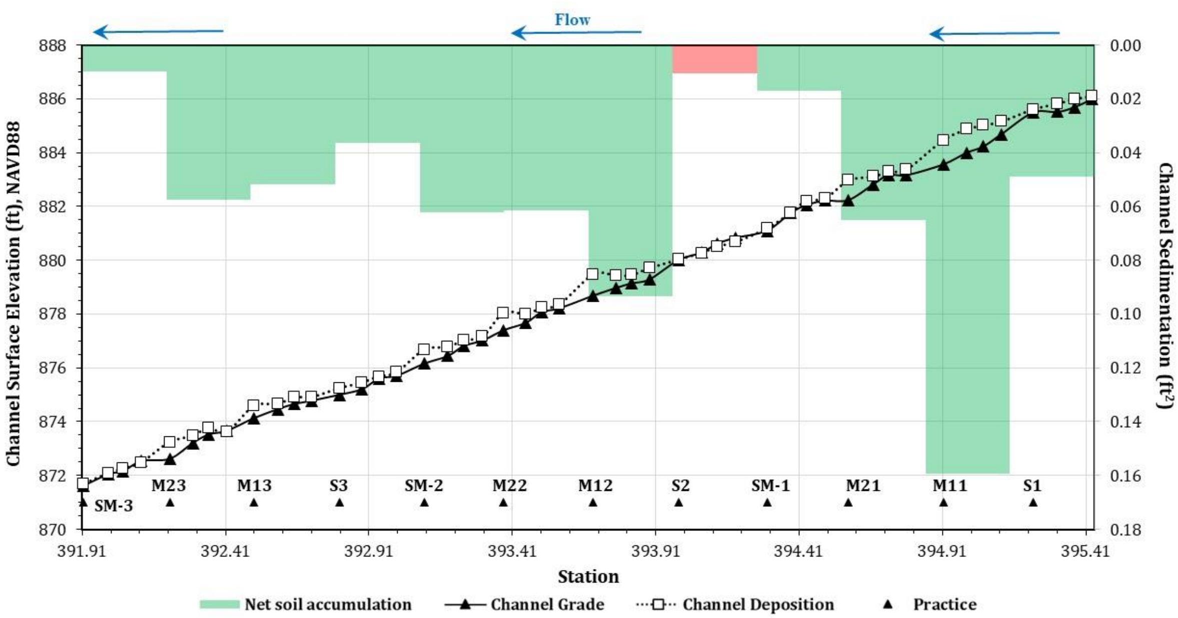


Figure 4.11. Silt fence ditch check channel grade profile

The x-axis represents the station numbers of the project site at which the practice was installed, and the y-axis is the ground elevation. Measured channel sedimentation is on the secondary y-axis in square feet. Red bars indicate negative sedimentation, or channel erosion.

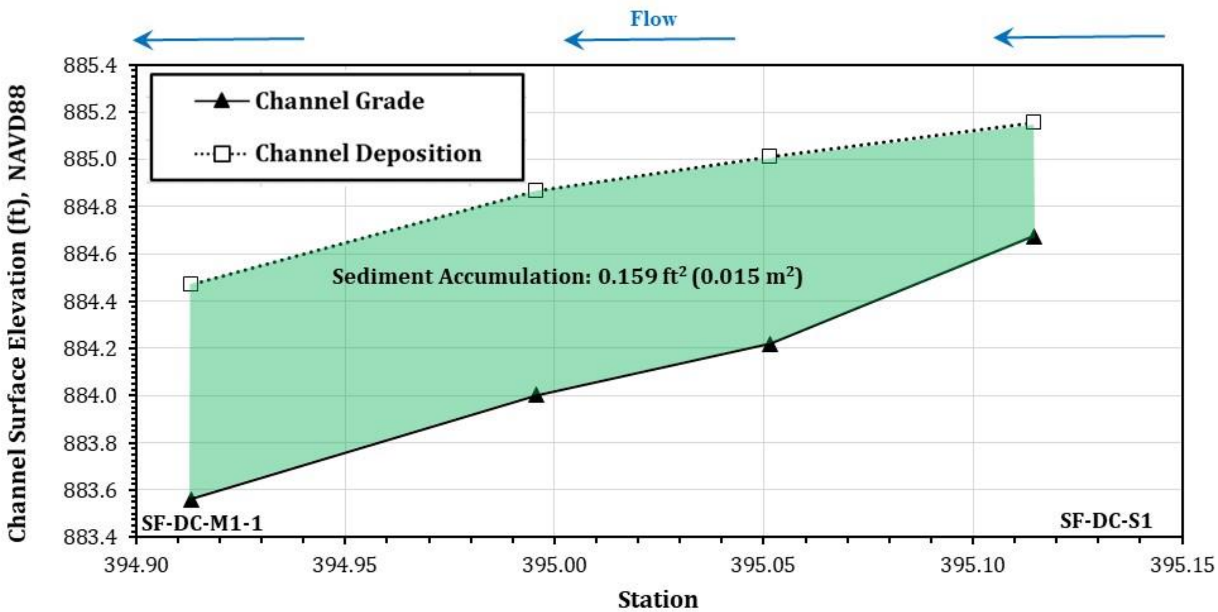
These surface profiles provided a 2D view of sedimentation patterns. To estimate a sediment volume retained by each practice, the area between the profiles were multiplied by the average channel width, assuming that sediment accumulation was evenly distributed. Channel widths were found by importing aerial images into GIS and using the measure tool. The average channel width was determined to be 20.3 ft (6.19 m) for the silt fence ditch checks. Table 4.8 provides the practice name, cumulative drainage area, and volume of sediment retained in the order of installation.

Table 4.8. Silt fence ditch check drainage areas

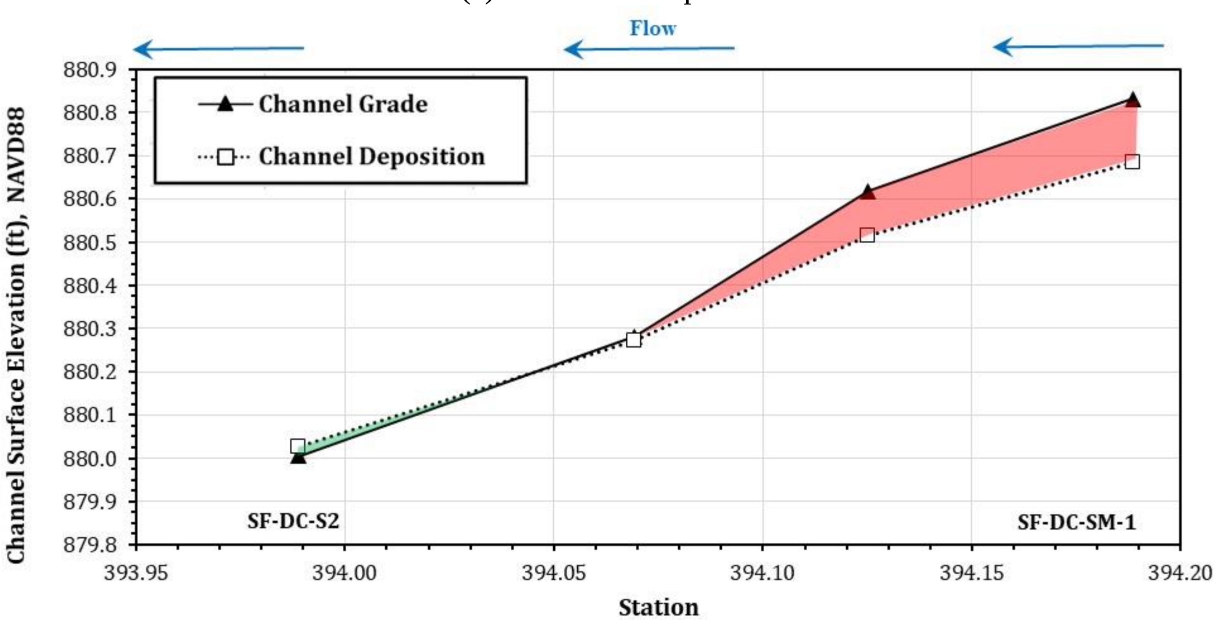
Station	Practice	Drainage area, ac (ha)	Upstream sedimentation, ft^3 (m^3)
395+23	SF-DC-S-1	3.97 (1.61)	1.00 (0.03)
394+91	SF-DC-M1-1	4.02 (1.63)	3.24 (0.09
394+58	SF-DC-M2-1	4.10 (1.66)	1.33 (0.04)
394+30	SF-DC-SM-1	4.13 (1.67)	0.35 (0.01)
393+99	SF-DC-S-2	4.21 (1.71)	-0.22 (-0.01)
393+69	SF-DC-M1-2	4.26 (1.72)	1.90 (0.05)
393+38	SF-DC-M2-2	4.33 (1.75)	1.25 (0.04)
393+10	SF-DC-SM-2	4.37 (1.77)	1.26 (0.04)
392+81	SF-DC-S-3	4.42 (1.79)	0.74 (0.02)
392+51	SF-DC-M1-3	4.46 (1.81)	1.06 (0.03)
392+21	SF-DC-M2-3	4.52 (1.83)	1.17 (0.03)
391+92	SF-DC-SM-3	4.57 (1.85)	0.20 (0.01)

Negative values indicate erosion in the channel upstream of the installed practice. Drainage areas to each ditch check were delineated on GIS using contours derived from digital surface models (DSMs) created from aerial UAS-acquired imagery.

The surface profiles of SF-DC-M1-1, which exhibited the most sediment accumulation, and SF-DC-S-2, which exhibited the most channel erosion, are shown in Figure 4.12a and b, respectively. Surface profiles for each individual practice can be found in Appendix E.



(a) SF-DC-M1-1 profile



(b) SF-DC-S-2 profile

Figure 4.12. Profiles for silt fence ditch checks with (a) max. and (b) min. sedimentation

The average sediment retention of SF-DC-S was 0.51 ft^3 (0.014 m^3). SF-DC-M1 and SF-DC-M2 exhibited 4 and 2.5 times more sediment accumulation with 2.06 ft^3 (0.058 m^3) and 1.29 ft^3 (0.037 m^3), respectively. Table 4.9 summarizes the performance of each installation technique with average volume accumulation and standard deviation. In addition, the table provides a cost/benefit comparison based on the installed cost and captured sediment directly upstream of the practice.

Table 4.9. Performance summary of silt fence ditch check installations

Installation	Avg. sedimentation, ft^3 (m^3)	Std. dev., ft^3 (m^3)	Installed cost	Cost/ Accumulation, $/$ft^3$ ($/$m^3$)
SF-DC-S	0.51 (0.014)	0.52 (0.015)	$9.03	17.71 (625.42)
SF-DC-M1	2.06 (0.058)	0.90 (0.025)	$41.80	20.29 (716.53)
SF-DC-M2	1.29 (0.037)	0.06 (0.037)	$41.38	32.08 (1,144.20)
SF-DC-SM	0.60 (0.017)	0.47 (0.013)	$32.40	90.23 (3,186.44)

4.2.8 Discussion and Recommendations

SF-DC-M1 exhibited the largest average sediment accumulation, with the largest standard deviation. The first installed M1 practice had a sediment accumulation of 0.16 ft^2 (0.01 m^2) at the midpoint, with an estimated volume of 3.24 ft^3 (0.09 m^3) between the day of installation and last inspection. However, the modified installation farthest downstream, SF-DC-M1-3, captured 0.05 ft^2 (0.01 m^2) at the midpoint, or an estimated 1.06 ft^3 (0.03 m^3) total accumulation.SF-DC-M2 captured 47% less sediment than SF-DC-M1, despite the only difference in installation being a sliced versus trenched method.

Of the standard installations, SF-DC-SM (manufactured fabric) captured 16% more sediment then SF-DC-S (standard), but still exhibited T-post deflection and scour. Both modified installations captured more than twice the sediment when compared to the standard installation and would be recommended for future installations. While the cost/accumulation for SF-DC-M1 is slightly higher than SF-DC-S, SF-DC-M1 had a greater longevity in the field. In addition, it is likely that the cost for SF-DC-S would greatly increase if maintenance and replacement costs were considered. The life-cycle cost and cost/accumulation for SF-DC-M1 would be the best option if field longevity was considered.

Common silt fence ditch check failures observed on-site included T-post deflection, leading to overtopping, undercutting, and flow bypass. These failures can be seen in Figure 4.13 and Figure 4.14. These failures were not observed when monitoring the modified practices.

Figure 4.13. Silt fence ditch check overtopping due to T-post deflection

(a) Overtopping and T-post deflection

(b) Overtopping

(c) Flow bypass of silt fence ditch check

Figure 4.14. Silt fence ditch check failures

Based on field monitoring and results, Modified 1 would be recommended to adopt with the addition of a geotextile splash pad at the vertex to avoid downstream scouring during dewatering. While field results provide a basis for practice adoption, it would be advantageous to test and compare the installations in a controlled setting to compare performance using controlled flow and sediment rates descriptive of expected field drainage areas, flow conditions, and sediment loading.

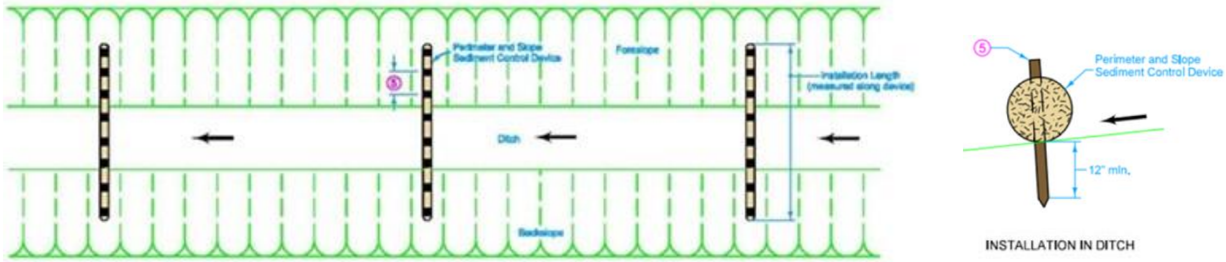
4.3 WATTLE DITCH PROTECTION

Wattles are cylindrical tubes filled with a media to create a 3D barrier that can be used for a variety of E&SC applications including sediment barriers, ditch checks, inlet protection, and slope interrupters. In erosion prevention applications, wattles are installed to create upstream impoundments, which reduce flow velocity and effective shear stress along the ground surface, preventing erosion from occurring. A secondary benefit is the deposition of rapidly settable solids within impoundment pools due to reduced flow velocity. Contrary to many marketing claims, the filtration capability of wattles is relatively low compared to their capability in sediment retention through impoundment and velocity reduction (Donald et al. 2015).

Wattles are manufactured within a factory environment by filling a tubular containment mesh with natural or synthetic material to form a matrix media that is intended to provide water quality improvements. Wattles are commonly manufactured in a variety of dimensions, encasement nettings, fill density, and fill media including wheat straw, pine straw, wood excelsior fiber, grass fiber, coconut fiber, chipped wood, compost, recycled carpet, and recycled rubber chips. This wide range of availability allows wattles to be adapted to site-specific conditions and applications. Wattle implementation has become popular across the industry due to relatively low cost and ease of installation. The porous nature of wattles allows water to flow through the device, allowing for dewatering of a channel or upstream impoundment, which is advantageous to reduce flooding concerns and allow vegetation to grow. In addition, biodegradable wattles can be left in-place to naturally decompose without requiring removal at the termination of a project.

4.3.1 Iowa DOT Standard

The Iowa DOT standard wattle ditch check installation specifies a wattle placed perpendicular to the flow direction channel, extending up the foreslope and backslope. The wattle is staked through the netting and fill material every 2 ft (0.61 m). Stakes are driven into the ground a minimum of 12 in. (30.48 cm). The Iowa DOT standard wattle installation EC-204 was used for four wattle types including straw (S-S), excelsior (EX-S), wood chip (WC-S), and switch grass (SG-S) and is shown in Figure 4.15 (Iowa DOT 2018).



Iowa DOT 2018

Figure 4.15. Iowa DOT wattle ditch protection detail EC-204

4.3.2 Literature Review

Limited peer reviewed literature exists evaluating in-field performance characteristics of wattle practices; however, several large-scale performance evaluations have been conducted to identify and improve the effectiveness of wattles used in E&SC applications, including ditch checks.

McLaughlin et al.'s (2009) foundational field study compared natural fiber wattles filled with coir and straw to riprap ditch checks. Researchers found that to optimize ditch check performance, impoundment pools formed by ditch checks should reach upslope to the downstream side of the preceding ditch check (McLaughlin et al. 2009). These finding suggest that the spacing between consecutive ditch checks in a channel is a function of the practice installed height and channel slope. Donald et al. (2013) conducted wattle performance evaluations on the standard ALDOT wattle installation detail, as well as six modified installation enhancement strategies. Evaluations were conducted using a large-scale testing apparatus with a flow rate of 0.56 ft^3/s (0.016 m^3/s) in a 39.5 ft (12 m) long trapezoidal channel with an earthen section designed to mimic a highway median. The trapezoidal cross section had a top width of 13 ft (4m), bottom width of 4 ft (1.2 m), and 3H:1V side slopes. The standard installation consisted of a wattle installed in a U-shape, concave upstream, and secured by installing wooden stakes on the downstream side of the wattle, piercing the netting. Modifications made to the standard installation were intended to increase impoundment capabilities. Alterations to the standard installation included (1) an alternative staking configuration, (2) incorporating a geotextile underlay to minimize undermining and scour, (3) including sod staples to facilitate ground contact, and (4) trenching wattles into the earthen soil. Performance was determined through the evaluation of the hydraulic and energy grade lines created by the wattles. Measured subcritical flow lengths obtained during testing suggest that teepee staking, inclusion of a geotextile underlay, and sod stapling improve performance by 99% when compared to the standard installation (Donald et al. 2013).

In a subsequent study, Donald et al. (2015) evaluated the effects on hydraulic performance based on wattle fill material, fill density, and dimensions. This large-scale study analyzed the performance five wheat straw, two excelsior fibers, and one synthetic fiber at low (0.565 ft^3/s [0.016 m^3/s]), medium (1.13 ft^3/s [0.032 m^3/s]), and high (1.70 ft^3/s [0.048 m^3/s]) flows. Wheat straw and excelsior wattles performed similarly when comparing density and depth impoundment ratios. Impoundment depths created by the synthetic fiber wattles were 23%, 31%, and 32% greater than wheat straw wattles at low, medium, and high flow rates, despite being

147% less dense. Similarly, impoundment depths created by the synthetic fiber wattles were 153%, 112%, and 87% greater than excelsior fiber impoundments at low, medium, and high flow rates, and 66.4% less dense. The study concluded that fill density, rather than material, was the greatest mitigating factor for controlling runoff depth at medium and high flow conditions (Donald et al. 2015).

Bhattarai et al. (2016) evaluated sediment retention capabilities of five ditch checks for the Illinois DOT. Sediment reduction was determined by comparing the change in sediment concentration as flow passed through/over the ditch check practices at low (0.18 ft^3/s [0.005 m^3/s]) and high (0.35 ft^3/s [0.010 m^3/s]) flow conditions. Products evaluated included Triangular Silt Dike, GeoRidge, excelsior sediment log, straw wattle, and Siltworm. Results from the experiments indicated that the Triangular Silt Dike and GeoRidge ditch checks were the only practices to achieve sediment reduction. Triangular Silt Dike was able to reduce sediment concentration by 1.99% and 1.85% under low and high flow conditions, respectively, while GeoRidge had a reduction of 3.92% under the low flow condition. The remaining ditch checks had increased sediment concentrations downstream of the practice. Enhanced installation methodologies, including trenching or addition of an underlay, were recommended to facilitate intimate contact between wattles and the channel bottom, but these proposed installation modifications were not evaluated in this study (Bhattarai et al. 2016).

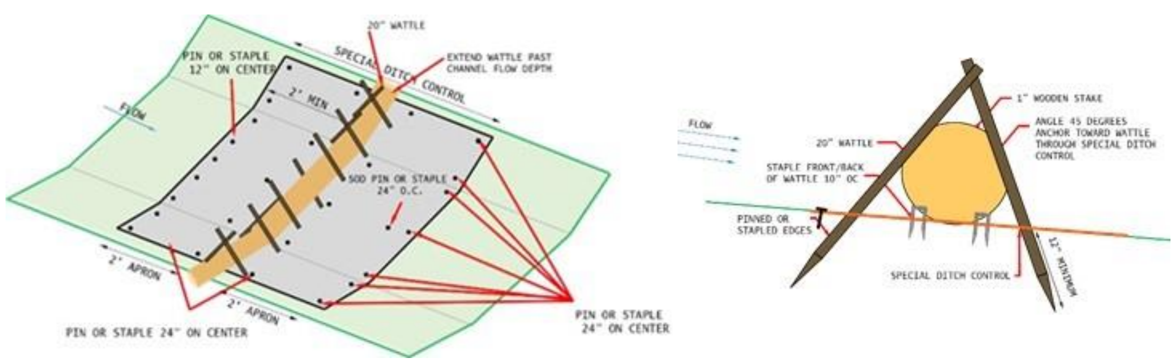
Due to difficulty in comparative performance analysis of ditch checks across varying channel and flow parameters, Donald et al. (2016) developed a hydraulic performance criterion to objectively analyze wattle efficiency that was directly related to supercritical and subcritical flows. Supercritical flows are characterized by high kinetic energy and low potential energy, typical of shallow depth flowing at high velocity. Subcritical flows have greater potential energy than kinetic energy, typical of greater depth flowing at low velocity. The hydraulic performance model plotted theoretical Froude numbers (F) versus water depth (y) to specific energy (E) ratios (i.e., y/E). By plotting model data, a third-order polynomial relationship was generated. An inflection point was identified on the curve that correlated to y/E = 0.75 and an F value of approximately 0.8. This inflection point represented a change in flow behavior that facilitated subcritical flow conditions, improved impoundment, and increased sedimentation potential. Experimental data gathered during large-scale experiments was used to calculate y/E ratios for each wattle tested and plotted along the curve for evaluation. These criteria allowed ditch checks testing data to be normalized and compared in a standardized method across a variety of flow conditions (Donald et al. 2016).

Whitman et al. (2019) evaluated innovative and manufactured sediment barriers used in perimeter control applications, including a straw-filled and compost-filled wattle. Structural, sediment retention, and water quality results were compared to a wire-backed nonwoven silt fence configuration, referred to as a heavy-duty silt fence (HDSF) from Whitman's 2018 study (Whitman et al. 2018). During evaluations, each of the tubular practices experienced extensive undermining, which ultimately resulted in flow bypass. The sediment capture rates of the straw wattle and compost log were 12% and 14% less than the HDSF, respectively. While not evaluated during the study, recommendations were made to include sod pins during the installation of wattles and to install geotextile underlays for all tubular sediment barriers. The study concluded that an impoundment depth between 1.0 and 1.5 ft (0.31 and 0.46 m) was optimal for capturing sediment, with retention rates of at least 90%. Troxel (2013) also evaluated compost-filled wattles used on perimeter control applications. Results indicated that 18 in. (45 cm) and 12 in. (30 cm) wattles had removal efficiencies of 92.9% and 88.2%, respectively (Troxel 2013, Whitman et al. 2019).

As outlined, several recent studies have focused on identifying wattle performance when installed as ditch checks. Shared goals among these studies were to evaluate wattles installed using commonly accepted installation methodologies and develop alternative installation strategies that improve overall performance. These studies provided valuable insight regarding wattle performance as a function of installation methodology; however, there are limited findings and observations from in-field studies.

4.3.3 Evaluated Design Modifications

Modifications to the wattle ditch protection included the addition of special ditch protection underlay and teepee staking pattern. The wattle was laid perpendicular to the channel and extended past the high-water mark on either channel side. The underlay was to be pinned using a 6 in. (15.2 cm) sod pin on the face of inflow on the back side at 5 in. (12.7 cm) on-center. The center and sides perpendicular to the wattle were to be pinned at 12 in. (30.5 cm) on-center. The 20 in. (508 cm) wattle was to be stapled to the underlay. The wattle was to be secured using a non-destructive teepee staking configuration with stakes every 2 ft (0.61 m). Stakes were to be angled at 45 degrees and driven at least 12 in. (30.48 cm) into the ground. This installation was completed for three wattle types including straw (S-M), excelsior (EX-M), and wood chip (WC-M). The modified wattle design is shown in Figure 4.16.



(a) Isometric view (b) Profile view

Figure 4.16. Modified wattle ditch protection detail

Table 4.10 summarizes the components of each wattle installation. The far-left column lists all the elements included in the wattle analysis. The “x” indicates the presence of the design element or component.

Table 4.10. Wattle ditch protection summary

Design element	EX-S	EX-M	S-S	S-M	WC-S	WC-M
Excelsior log	x	x				
Straw wattle			x	x		
Wood chip filter sock					x	x
Special ditch control		x		x		x
Teepee staking		x		x		x

4.3.4 Cost Analysis

A cost analysis was conducted to compare the standard installation detail to the modified installation recommendation. Request for pricing was sent to E&SC product suppliers nationwide. Four suppliers quoted material cost. The average cost per item was calculated and used in the cost estimates of the installation. A complete table of materials and cost can be found in Appendix D.

To estimate cost, a typical Iowa DOT highway median was used for channel dimensions and consisted of a 10 ft (3.05 m) channel bottom, 4 ft (1.22 m) depth, with 6:1 side slopes. The standard wattle ditch protection was estimated using an excelsior wattle and calculated to be $4.39/linear ft (14.40/m), as compared to $3.30/ft ($10.83/m) provided by the Iowa DOT, which included installation. This gave a difference (Δ) of $0.56/ft ($1.84/m). A complete material cost tabulation for the design can be found in Table 4.11.

Table 4.11. Standard wattle ditch protection cost estimate, excelsior fill

Component	Qty.	Unit	Unit cost	Total
Wooden stakes, 36 in.	15	ea	$0.62	$9.33
Excelsior wattle, 10 ft	30 (9.14)	ft (m)	$4.08 ($13.39)	$122.25
Total cost per ditch check				**$131.58**
Total cost per ft (m)				**$4.39 ($14.40)** [A]
Estimated unit installation cost per ft (m)				**$0.56 ($1.69)**
Total estimated installed cost per ditch check				**$137.36**

Note: [A] Iowa DOT provided cost of $3.30/ft ($10.83/m), installed

Similar to the silt fence ditch checks, an installation cost correction factor was found using the difference in installed and material cost and productivity. Video footage from installation provided a productivity rate of 8.24 ft/min (2.51 m/min) of the standard wattle ditch protection. Multiplying the difference per foot and productivity resulted in a labor cost of $4.58/min. The labor cost was then used to back-calculate the difference in raw material and material and installation cost for the modified designs, using the installation productivity. The labor correction factor calculation is shown in Table 4.11.

Modified installation design included the addition of special ditch protection mat, sod staples, and an increase in wooden stakes. Cost for the modified designs was estimated to be $4.03/linear ft ($13.22/m), as opposed to the quoted cost to the DOT of $20.35/linear ft ($66.77/m) for limited installation by the subcontractor. A tabulation of cost is shown in Table 4.12.

Table 4.12. Modified wattle ditch protection cost estimate, excelsior fill

Component	Qty.	Unit	Unit cost	Total
Wooden stakes, 36 in.	30	ea	$0.62	$18.66
Excelsior wattle, 10 ft	30 (9.14)	ft (m)	$2.43 ($7.97)	$73.00
Special ditch protection, 8 ft	0.54	roll	$48.63	$26.53
Sod staples, 6 in.	75	ea	$0.03	$2.60
Total cost per ditch check				**$120.79**
Total cost per ft (m)				**$4.03 ($13.22)** [A]
Estimated unit installation cost per ft (m)				**$1.66 ($5.07)**
Total estimated installed cost per ditch check				**$170.74**

Note: [A] Iowa DOT provided cost of $20.35/ft ($66.77/m), installed

To compare the total cost (material and installation) to the standard practice, the labor cost of $4.58/min was maintained and applied to the productivity 2.75 ft/min (0.84 m/min).

The standard and modified wattle ditch protection installations were calculated using an excelsior-filled wattle. Table 4.13 shows the cost of varying wattle products.

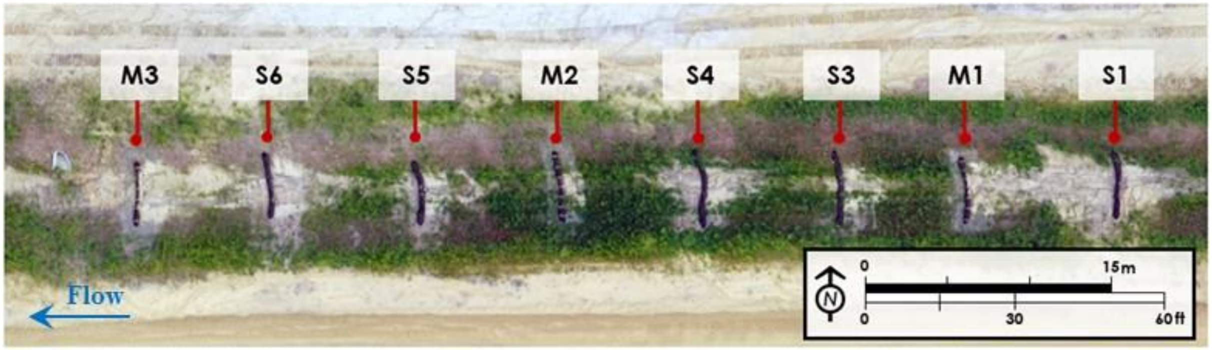
Table 4.13. Varying wattle type cost

Fill	Nominal diameter, in. (cm)	Cost, ft (m)
Excelsior	20 (50)	$2.65 ($8.69)
Wheat straw w/ netting	20 (50)	$2.30 ($7.55)
Wood chip w/ sock	20 (50)	$6.00 ($19.69)
Coconut coir	12 (30)	$6.27 ($20.57)
Premium coconut coir	12 (30)	$7.04 ($23.10)
Recycled carpet	12 (30)	$4.13 ($13.55)

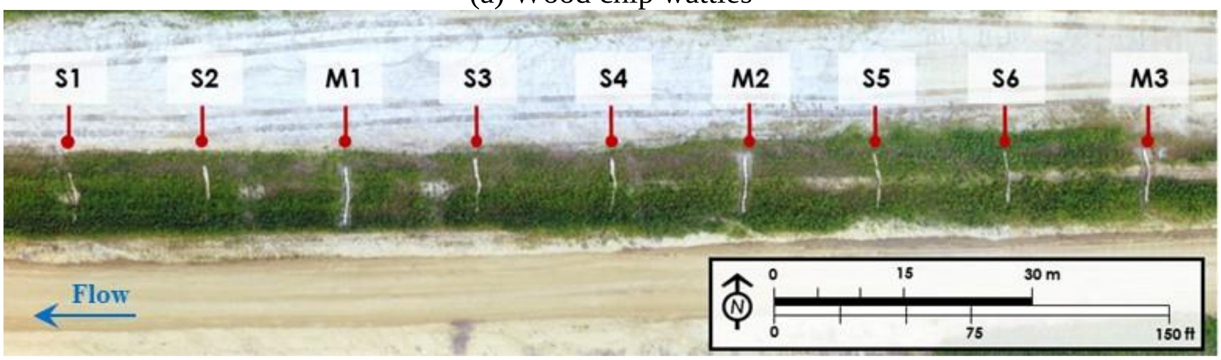
These products have proven to have different hydraulic performances, which are discussed in Chapter 7. Values presented in Table 4.13 solely reflect the cost of the wattle and do not include other installation components.

4.3.5 Installation Criteria, Evaluation, and Limitations

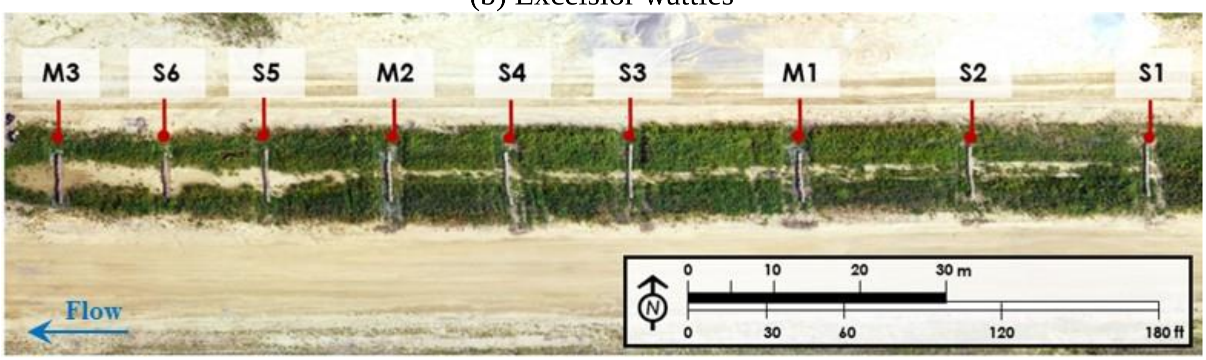
Wattles were installed using a pattern of two standard to one modified installation (S-S-M-S-S-M-S-S-M) in a single channel. Wattles filled with alike material were installed in an individual channel, with a total of three monitored channels (excelsior [EX], straw [S], and wood chip [WC]). Switch grass (SG) wattles were offered by SoilTek in Grimes, Iowa, but had limited availability. Three standard switch grass wattles were installed in a single channel. With leftover material, a fourth wattle was installed using an alternating staking pattern. Similar to the silt fence ditch check installations, wattles were installed in a single channel to encounter similar flows and sediment loads. The wattle channels are outlined on the site plan shown in Figure 3.9. The installation pattern in each of the wattle channels is shown in Figure 4.17.



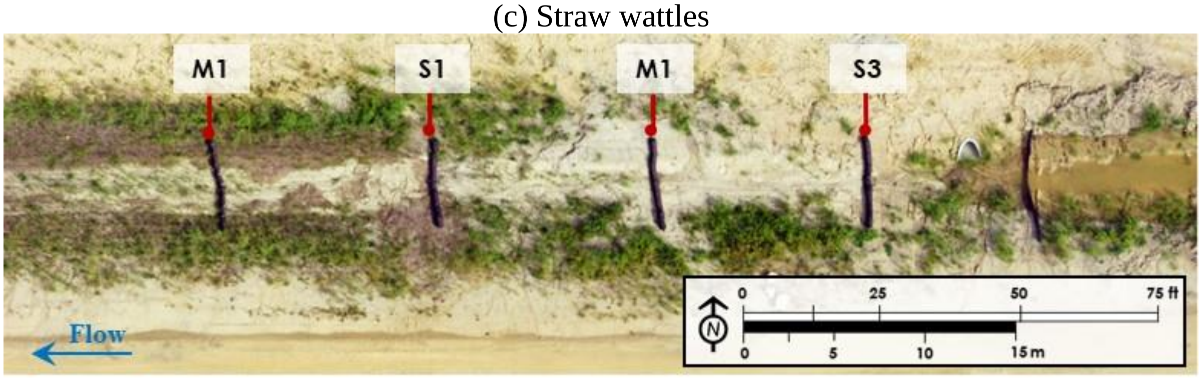
(a) Wood chip wattles



(b) Excelsior wattles



(c) Straw wattles



(d) Switch grass wattles

Figure 4.17. Installation configuration of wattle ditch protection

Wattle performance was evaluated on structural integrity, sedimentation, and impoundment. Similar to the SF-DC, structural integrity was visually monitored through weekly photo inspections. Sedimentation was measured using LiDAR scanning at the beginning, middle, and end of monitoring. Surface models were created from LiDAR point clouds and compared. However, several of the channels experienced extreme vegetation growth throughout monitoring, which impeded the function of the scanner. This was particularly challenging in the excelsior and straw wattle channels. Impoundment was measured using channel surveying and upstream staking to investigate high water marking.

4.3.6 Inspections

Visual inspections were completed for each installation of wattle ditch protection practice and documented through a photo journal weekly. Photographs were organized per inspection date, per practice. A complete archive of inspection photos is available digitally. The figures included in this section display a set of inspection photos for each installation and fill media at monthly intervals (July 26, 2019; August 27, 2019; September 24, 2019; and October 22, 2019). Rainfall accumulation was 2.99 in. (7.59 cm), 6.78 in. (17.22 cm), and 11.82 in. (30.02 cm) by August 27, 2019; September 24, 2019; and October 22, 2019, respectively.

Figure 4.18 and Figure 4.19 include inspection photos from the wood chip wattle channel.

(a) 7/26/2019, installation - upstream

(b) 7/26/2019, installation - downstream

(c) 8/27/2019 - upstream

(d) 8/27/2019 - downstream

(e) 9/24/2019 - upstream

(f) 9/24/2019 - downstream

(g) 10/22/2019 - upstream

(h) 10/22/2019 - downstream

Figure 4.18. Wood chip wattle standard installation, S6


(a) 7/26/2019, installation - upstream


(b) 7/26/2019, installation - downstream


(c) 8/27/2019 - upstream


(d) 8/27/2019 - downstream


(e) 9/24/2019 - upstream


(f) 9/24/2019 - downstream


(g) 10/22/2019 - upstream


(h) 10/22/2019 - downstream

Figure 4.19. Wood chip wattle modified installation, M3

Within the first month, there was evidence of undercutting for the standard installed wattle. When compared to the modified installation, there was no evidence of impoundment or high-water mark on the wattle netting. By the fourth inspection, there was deep channel erosion under the standard wattles, whereas the modified wattle exhibited sedimentation within the channel and runoff reaching the full wattle height and overtopping. All five standard wattles exhibited significant undercutting and had no signs of overtopping or upstream sedimentation. By the final inspection in December, all of the standard installations had experienced undercutting. Of the five standard installations, three of the wattles exhibited undercutting after 1.68 in. (4.27 cm) of rain, and two exhibited undercutting after 2.99 in. (7.59 cm) of rain. Two of the modified installations had evidence of scour downstream of the wattle and flow bypass starting due to the high sedimentation and impoundment. Of the modified installations,WC-M1 exhibited flow bypass after 11.21 in. (28.47 cm) of rain and WC-M3 had evidence of downstream scour after 5.5 in. (13.97 cm) of rain. Researchers would recommend extending the wattle further up the side slopes of the channel. In addition, it would be expected that the channel and wattle be maintained. Sedimentation patterns started to cause flow bypass on the first and third modified installation.

Figure 4.20 and Figure 4.21 include inspection photos of the standard and modified installations of the straw wattles, whereas Figure 4.22 and Figure 4.23 include the excelsior-filled wattles.

(a) 7/26/2019, installation - upstream

(b) 7/26/2019, installation - downstream

(c) 8/27/2019 - upstream

(d) 8/27/2019 - downstream

(e) 9/24/2019 - upstream

(f) 9/24/2019 - downstream

(g) 10/22/2019 - upstream

(h) 10/22/2019 - downstream

Figure 4.20. Straw wattle standard installation, S4


(a) 7/26/2019, installation - upstream


(b) 7/26/2019, installation - downstream


(c) 8/27/2019 - upstream


(d) 8/27/2019 - downstream


(e) 9/24/2019 - upstream


(f) 9/24/2019 - downstream


(g) 10/22/2019 - upstream


(h) 10/22/2019 - downstream

Figure 4.21. Straw wattle modified installation, M2

(a) 7/26/2019, installation - upstream

(b) 7/26/2019, installation - downstream

(c) 8/27/2019 - upstream

(d) 8/27/2019 - downstream

(e) 9/24/2019 - upstream

(f) 9/24/2019 - downstream

(g) 10/22/2019 - upstream

(h) 10/22/2019 - downstream

Figure 4.22. Excelsior wattle standard installation, S4


(a) 7/26/2019, installation - upstream   (b) 7/26/2019, installation - downstream


(c) 8/27/2019 - upstream   (d) 8/27/2019 - downstream


(e) 9/24/2019 - upstream   (f) 9/24/2019 - downstream


(g) 10/22/2019 - upstream   (h) 10/22/2019 - downstream

Figure 4.23. Excelsior wattle modified installation, M2

Figure 4.24 shows the standard installation of the switch grass wattles. The modified installation including the teepee staking, underlay, and sod staples was not completed for the switch grass wattles.

(a) 7/26/2019, installation - upstream

(b) 7/26/2019, installation - downstream

(c) 8/27/2019 - upstream

(d) 8/27/2019 - downstream

(e) 9/24/2019 - upstream

(f) 9/24/2019 - downstream

(g) 10/22/2019 - upstream

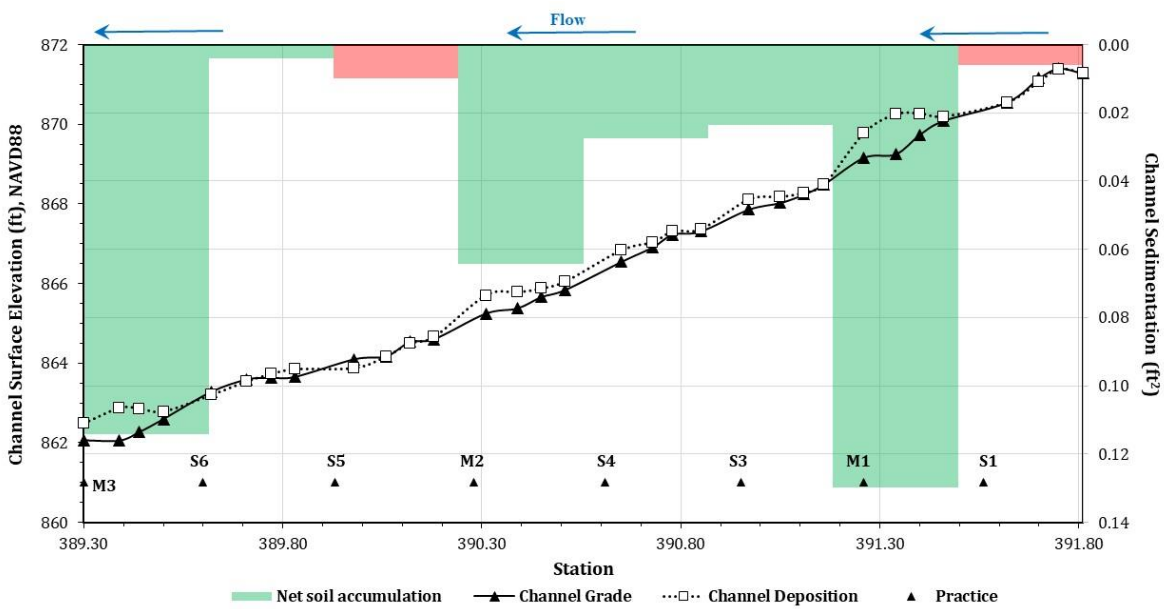
(h) 10/22/2019 - downstream

Figure 4.24. Switch grass wattle standard installation, S1

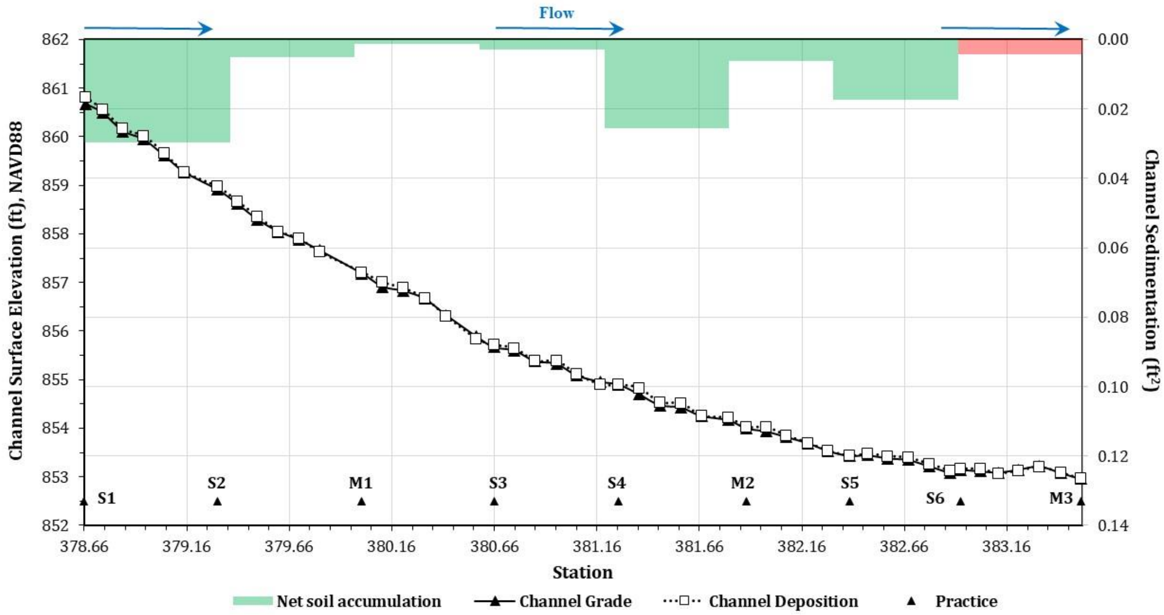
Figure 4.24d starts to show evidence of undercutting, which is continually exhibited in Figure 4.24e through h. Due to extreme vegetation in both the straw and excelsior channels, it is difficult to view differences in inspection photos. There is some evidence of impoundment by the fourth inspection; however, there is little to no shown sedimentation. From field observations, researchers conclude that both wattle channels are following similar patterns as the wood chip shown in Figure 4.18 and Figure 4.19. The modified installation of each product has evidence of high water marking and upstream sedimentation. Due to the vegetation, LiDAR scans could not accurately capture the channel surface; however, researchers measured sedimentation on the upstream stakes of each practice.

4.3.7 Sedimentation Results

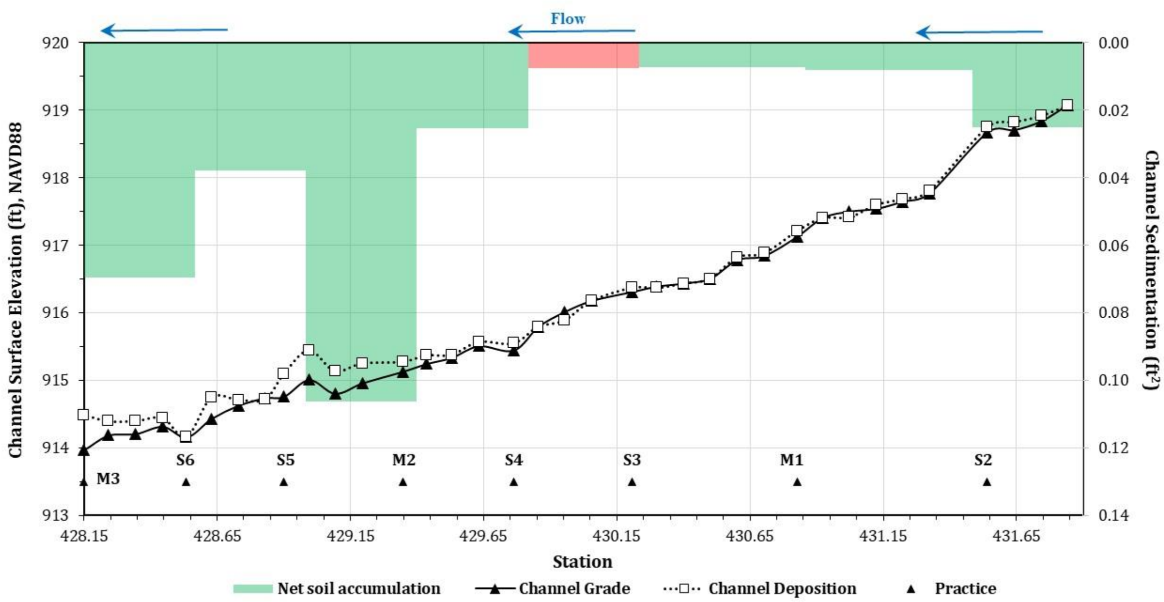
To quantify the performance of all installed wattle ditch protection practices, stakes were placed every 10 ft at the midpoint of the channel and set at an exposed height of 12 in. Stakes were surveyed on the day of installation and sedimentation was measured on December 10, 2019, the final date of inspection. A surface profile for each wattle type was plotted and can be found in Figure 4.25. The x-axis represents the station numbers of the project site at which the practice was installed, and the y-axis is the ground elevation. Measured channel sedimentation is on the secondary y-axis in square feet. Red bars indicate negative sedimentation, or channel erosion.



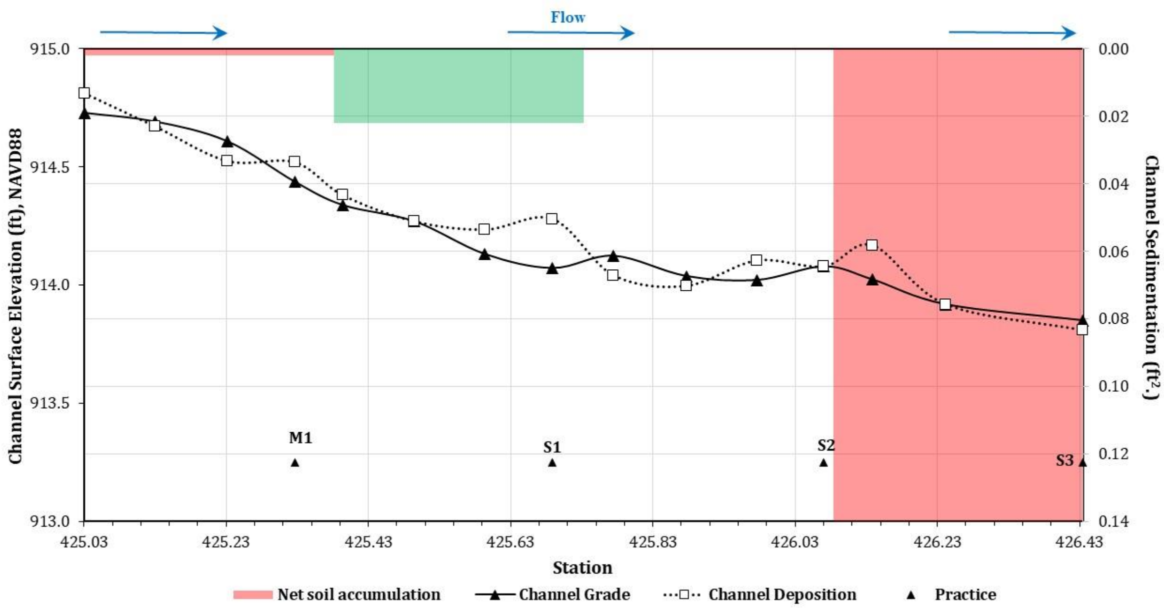
(a) Wood chip wattle with sock



(b) Excelsior wattle with net



(c) Straw wattle with net



(d) Switch grass wattle with sock

Figure 4.25. Wattle ditch protection channel grade profiles

Surface profiles provided a 2D view of sedimentation patterns. To estimate a sediment volume retained by each practice, the area between the profiles were multiplied by the average channel width, assuming that sediment accumulation was evenly distributed. Channel widths were found by importing aerial images into GIS and using the measure tool. The average channel width for the channel with wood chip, excelsior, straw, and switch grass wattles were 14.7 ft (4.5 m), 21.9 ft (6.7 m), 20.6 ft (6.3 m), and 17.5 ft (5.3 m), respectively. Table 4.14, Table 4.15, Table 4.16, and Table 4.17 provide the practice name, cumulative drainage area, and volume of sediment retained for each straw, wood chip, excelsior, and switch grass wattles, respectively. Negative values indicate erosion in the channel upstream of the installed practice. Drainage areas to each ditch check were delineated using a digital surface model created by drone analysis.

Table 4.14. Drainage area and sediment accumulation of straw wattle ditch protection

Practice	Drainage area, ac (ha)	Sediment accumulation, ft^3 (m^3)
S1	2.03 (0.82)	NA
S2	2.20 (0.89)	0.52 (0.02)
M1	2.32 (0.94)	0.17 (0.00)
S3	2.43 (0.98)	0.15 (0.00)
S4	2.53 (1.02)	-0.16 (0.00)
M2	2.61 (1.06)	0.52 (0.02)
S5	2.73 (1.1)	2.19 (0.06)
S6	2.79 (1.13)	0.78 (0.02)
M3	2.88 (1.17)	1.43 (0.04)

Table 4.15. Drainage area and sediment accumulation of wood chip wattle ditch protection

Practice	Drainage area, ac (ha)	Sediment accumulation, ft^3 (m^3)
S1	4.65 (1.88)	-0.09 (0.00)
M1	4.75 (1.92)	1.91 (0.05)
S3[a]	4.83 (1.95)	0.35 (0.01)
S4	4.92 (1.99)	0.40 (0.01)
M2	4.99 (2.02)	0.95 (0.03)
S5	5.05 (2.04)	-0.15 (0.00)
S6	5.13 (2.08)	0.06 (0.00)
M3	5.20 (2.10)	1.68 (0.05)

[a] S2 not installed due to material availability

Table 4.16. Drainage area and sediment accumulation of excelsior wattle ditch protection

Practice	Drainage area, ac (ha)	Sediment accumulation, ft^3 (m^3)
S1	0.23 (0.093)	NA
S2	0.36 (0.15)	0.65 (0.02)
M1	0.47 (0.18)	0.11 (0.00)
S3	0.59 (0.24)	0.03 (0.00)
S4	0.74 (0.30)	0.06 (0.00)
M2	0.85 (0.34)	0.56 (0.02)
S5	0.94 (0.38)	0.14 (0.00)
S6	1.04 (0.42)	0.38 (0.01)
M3	1.10 (0.45)	-0.09 (0.00)

Table 4.17. Drainage area and sediment accumulation of switch grass wattle ditch protection

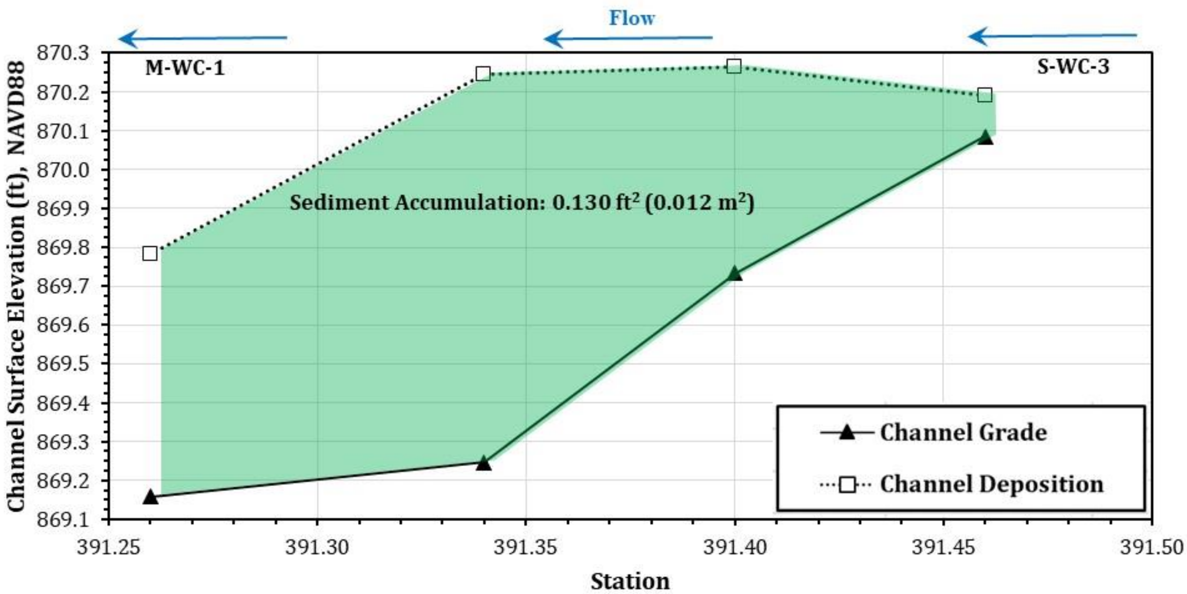
Practice	Drainage area, ac (ha)	Sediment accumulation, ft^3 (m^3)
M1	0.96 (0.39)	-0.04 (0.00)
S1	0.99 (0.4)	0.39 (0.01)
S2	1.05 (0.42)	-0.01 (0.00)
S3	1.15 (0.47)	-11.65 (-0.3)

A performance summary of installation type for each fill media can be found in Table 4.18.

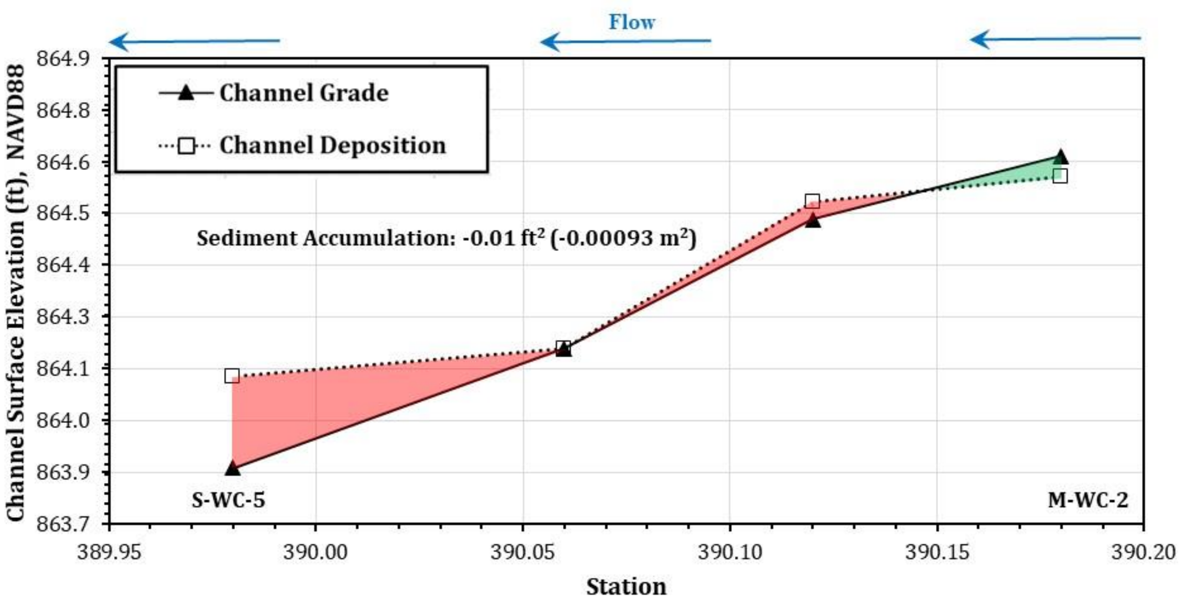
Table 4.18. Performance summary of wattle ditch protection

Installation	Avg. sedimentation, ft^3 (m^3)	Std. dev., ft^3 (m^3)	Cost/ Accumulation, $\$/ft^3$ ($\$/m^3$)
WC-S	0.12 (0.0034)	0.22 (0.01)	1,144.67 (40,423)
WC-M	1.51 (0.043)	0.41 (0.01)	113.07 (3,993)
EX-S	0.25 (0.0071)	0.23 (0.01)	549.44 (19,403)
EX-M	0.19 (0.0054)	0.27 (0.01)	898.61 (31,734)
S-S	0.70 (0.020)	0.81 (0.02)	196.23 (6,930)
S-M	0.71 (0.020)	0.53 (0.02)	240.41 (8,490)
SG-S	-3.76 (0.017)	5.85 (0.17)	--

Due to the time of practice installation and seeding coinciding, the wattle channels had rapid vegetation growth. As shown in the inspection photos, the straw and excelsior wattles channel had the thickest vegetative growth and impeded monitoring of the practices. The wood chip wattles were installed directly downstream of the silt fence ditch checks and had the least growth of all the monitored channels. Researchers considered the wood chip channel closest to representing a channel during heavy grading and primarily used this channel for comparing installation techniques. Figure 4.26 shows the wood chip wattle practice with the (a) most and (b) least sediment accumulation. A complete record of wattle ditch protection practice profiles can be found in Appendix F.



(a) WC-M-1 profile



(b) WC-S-5 profile

Figure 4.26. Surface profiles for wattle ditch protection with (a) max. and (b) min. sedimentation

4.3.8 Discussion and Recommendations

Wood chip, excelsior, straw, and switch grass wattles were monitored in the field. Due to overgrowth in the other installation channels, wood chip wattles were used for installation comparisons. The modified installation, which included a special ditch protection mat underlay sod stapled to the channel bottom and nondestructive teepee staking, captured 13.15 times the sediment of the standard installation.

Similar to the silt fence ditch check results, Modified 1 was the farthest upstream installation of the three installed and exhibited the most sediment accumulation with 1.913 ft^3 (0.054 m^3). Based on inspection observations, Modified 1 started to experience flow bypass after sediment accumulation minimized storage capacity behind the practice and directed flow around. It is expected that if Modified 1 was extended farther up the side slopes of the channel, greater accumulation would have been accounted for. On average, the modified practice captured 13.15 times that of the standard installation. Two of the standard installations (S2 and S5) had negative accumulation, indicating channel erosion. Sediment volume is an estimated amount based on the average width of the channel.

When cross referencing the inspection reports, it was observed that all standard installations indicated undercutting in the channel by the final inspection date, whereas the modified installations had the three highest accumulation volumes. It is likely that the added special ditch protection aided in the increased performance; however, downstream scour was exhibited at the downstream end of the mat on Modified 1 and 3, potentially contributing to increased sediment load for the subsequent practices. Based on field monitoring observation and results, it would be recommended to adopt the modified installation and extend the underlay further downstream.

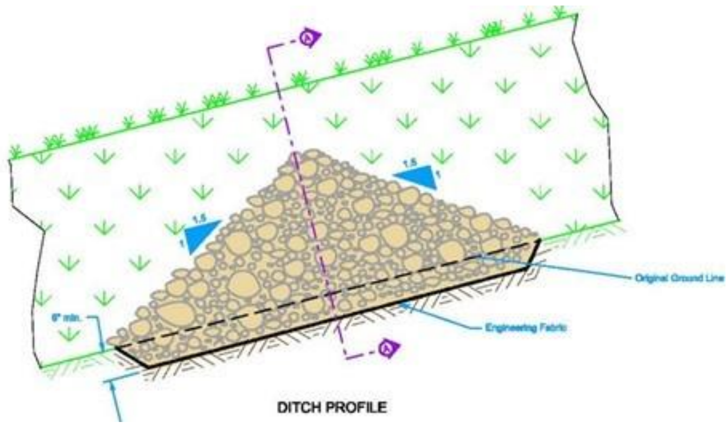
While field results provided a basis for practice adoption, it would be advantageous to test and compare the installations in a controlled setting to ensure similar drainage areas, flow conditions, and sediment loading. Due to the vast differences in channel geometry, drainage areas, and vegetation, wattle fill performance could not be compared. To supplement the findings from the field, laboratory testing of the hydraulic performance of wattle fill media was conducted. A complete record of this testing can be found in Chapter 7.

4.4 ROCK CHECK DAM

Rock check dams are a common industry-accepted practice due to their structural stability in concentrated flows. Rock check dams consist of one or more aggregate classes, which are typically selected based on expected flow velocities within a channel. Some agencies specify a geotextile underlay beneath the aggregate to prevent undercutting. Larger aggregates have larger pores and allow water to pass through easily. Some agencies suggest a choker stone or material to minimize the nozzle effect created by the larger pores. A rock check dam maximizes performance and minimizes erosion when the impoundment length reaches the check dam prior, promoting sedimentation and reducing erosion from supercritical flows.

4.4.1 Iowa DOT Standard

The Iowa DOT standard rock check dam specifies excavating the channel a minimum of 6 in. (15.2 cm) below the original ground line and installing an engineering fabric. A rock check dam has slopes of 1.5:1 on the front and back side. Riprap should be Class D revetment. Rock check dam standard EC-302 is shown in Figure 4.27 (Iowa DOT 2018).



Iowa DOT 2018

Figure 4.27. Iowa DOT rock check dam detail EC-302

4.4.2 Literature Review

A 2009 study by McLaughlin et al., funded by the North Carolina DOT (NCDOT), evaluated water quality in three roadway ditch systems. The first study area evaluated three channels with a different check dam practice in each. The practices evaluated included (1) standard rock check dam, (2) fiber check dams (straw or coir logs), and (3) fiber check dams with the addition of polyacrylamide (PAM), a flocculating agent. The channel slopes were relatively even between 5% and 7%. In total, the test area experienced 23 storms with a total of 27 in. (672 mm) of precipitation. Turbidity values for each check dam was 3,813 NTUs, 202 NTUs, and 34 NTUs, respectively. Similarly, the practices lost an average of 944 lb (428 kg), 4.1 lb (2.1 kg), and 2 lb (0.9 kg) per storm, respectively. In another test area, two channels at 3% slopes were tested with (1) a standard rock check dam and (2) fiber check dams with PAM. This area experienced nine storms, totaling in 6 in. (141 mm) of rain. Turbidity values were 867 NTUs and 115 NTUs, with average sediment losses of 7.3 lb (3.3 kg) and 1.8 lb (0.8 kg) per storm, respectively. Check dams were installed per NCDOT details. This study concluded that fiber check dams outperformed rock dams, especially with the addition of a flocculating agent (McLaughlin et al. 2009).

To further investigate, Kang et al. (2013) evaluated the turbidity reduction in three check dam types with and without the addition of PAM including (1) standard rock check dam, (2) excelsior log, and (3) rock check dam rolled in an excelsior erosion control blanket. This large-scale test lined a 2.95 ft (0.9 m) wide by 2.95 ft (0.9 m) deep channel with a 5%–7% slope. Three check dams were spaced evenly and flows ranging from 0.5–2.01 ft^3/s (0.014–0.057 m^3/s) were introduced for 20 minutes. Overall, the addition of PAM decreased turbidity by greater than 75%; however, the rock check dam had the smallest effect on water quality. The excelsior wattle had the greatest amount of sediment deposition, followed by the rock check dam covered in the excelsior erosion control blanket. It was concluded that even with the addition of PAM, the rock check dam provided the smallest amount of surface area for the suspended particles to mix with the flocculant (Kang et al. 2013).

Large-scale testing at Auburn University E&SC Testing Facility (AU-ESCTF) was conducted to evaluate rock check dams with and without chokers. Three riprap ditch checks were tested in 30 ft (9.144) long, 18 in. (45.72 cm) deep test channel with a 5% slope. The first installation followed the ALDOT detail, which included an 18 in. (46 cm) high check dam, 9 ft (2.7 m) wide, 3H:1V sloped sides, and a filter fabric underlay 3 ft (1 m) upstream and downstream of the check dam. The second installation followed the ALDOT detail but added a #4 choker aggregate on the upstream side of the rock check dam. The third and final installation followed the ALDOT standard but implemented an extra 8 ft (2 m) of filter fabric to wrap around the check dam, acting as a choker on the upstream side. Installation configurations are shown in Figure 4.28.

(a) Riprap ditch check w/o choker (b) Riprap ditch check w/ #4

(c) Riprap ditch check w/ 8 oz FF choker (d) 8 oz FF choker secured w/ riprap

Figure 4.28. Riprap ditch check installations

Impoundment lengths were measured to evaluate the performance of the check dams. The impoundment lengths were 14.5 ft (4.42 m), 20.5 ft (6.25 m), and 29.1 ft (8.87 m), respectively. The installation recommended to the ALDOT to adopt, was the third installation, which employed a filter fabric choker, reaching 100% increase in impoundment length from standard installation and a 97% impoundment efficiency (Zech et al. 2014).

Due to their structural stability in concentrated flows, rock check dams remain popular in the construction industry; however, little peer-reviewed literature is available. Continued large-scale testing will provide insight on the best installation techniques and aggregate selection, but field observations are necessary to understand the longevity and maintenance of rock check dams.

4.4.3 Design Modifications

Modifications to the rock check dam were meant to include the addition of a geotextile underlay and overlay. The rock slope was to employ slopes of 3:1 with at least a 2 ft (0.61 m) level section between slopes. The front of the underlay was to be trenched 6 in. by 6 in. (15.2 cm by 15.2 cm) and compacted. The geotextile underlay was to extend 3 ft (0.91 m) beyond the toe of the rock slope on each side, and to be secured to the channel bottom using 6 in. (15.2 cm) sod pins every 5 in. (12.7 cm) on-center. The overlay was to be pinned at the front and to wrap the front slope face and top of the check dam. Riprap was to be used on the top of the check dam to aid in securing the overlay. The type and size of rock used for check dam construction was to be selected considering expected site flows. The modified rock check dam design is shown in Figure 4.29.

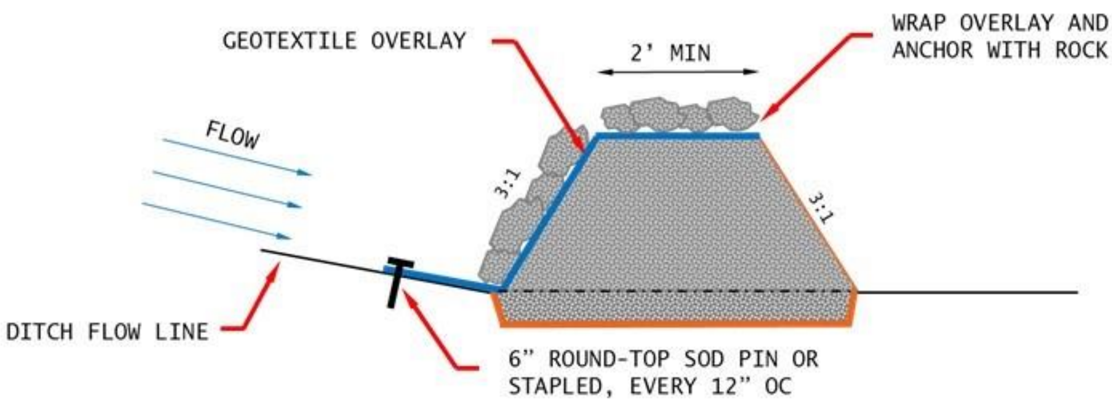


Figure 4.29. Modified rock check dam detail

4.4.4 Cost Analysis

A cost analysis was conducted to compare the standard installation detail to the modified installation recommendation. Request for pricing was sent to E&SC product suppliers nationwide. Four suppliers quoted material cost. The average cost per item was calculated and used in the cost estimates of the installation. A complete table of materials and cost can be found in Appendix D.

To estimate cost, a typical DOT highway median was used for channel dimensions and consisted of a 10 ft (3.048 m) channel bottom, 4 ft (1.22 m) depth, with 6:1 side slopes. The standard rock check dam was estimated to be \$21.94/ft (\$66.88/m), as compared to \$31.90/linear ft (\$104.66/m) provided by the Iowa DOT. Due to the rock check dams not getting installed, the labor estimate was based on the difference (Δ) of DOT value to estimated material cost. A complete tabulation for the design can be found in Table 4.19.

Table 4.19. Iowa DOT standard rock check dam material cost estimate

Component	Qty.	Unit	Unit cost	Total
Riprap, Class D	13.2 (10.1)	yd^3 (m^3)	\$56.03 (\$73.05)	\$737.85
SF engineering fabric, 36 in. (91 cm)	102 (31.1)	ft (m)	\$0.08 (\$0.26)	\$8.24
Material cost per check dam				**\$746.08**
Material cost per ft (m)				**\$21.94 (\$66.88) [A]**

Note: [A] Iowa DOT provided bid amount of \$31.90/ft (\$104.66/m) installed, Δ of \$9.96/ft (\$30.35/m)

Modified installation design included the addition of a geotextile overlay and underlay and side slopes of 3H:1V. Material cost for the modified designs was estimated to be \$37.99/linear ft (\$115.79/m), as opposed to installed bid amount presented to the DOT of \$39.80 (\$130.58/m) for limited installation by the subcontractor. A corrected cost was calculated to include labor. A tabulation of cost is shown in Table 4.20.

Table 4.20. Modified rock check dam material cost estimate

Component	Qty.	Unit	Unit cost	Total
Riprap, Class D	22.7 (17.4)	yd^3 (m^3)	\$56.03 (\$73.05)	\$1,274
SF engineering fabric, 36 in. (91 cm)	204 (62.2)	ft (m)	\$0.08 (\$0.26)	\$16.47
Sod staples, 6 in. (15 cm)	34	ea	\$0.03	\$1.18
Material cost per check dam				**\$1,292**
Material cost per ft (m)				**\$37.99 (\$115.79) [A]**
Estimated installation cost per ft (m)				**\$47.95 (\$146.14)**
Total estimated installed cost per ditch check				**\$1,630.17**

Note: [A] Iowa DOT provided bid amount of \$39.80/ft (\$130.58/m), installed

With the suggested modified cost nearly doubling that of the standard, researchers proposed to keep the standard installation but add a geotextile overlay. This increased cost from \$21.94 to \$22.22/linear ft (\$66.88 to \$98.07/m). Estimated cost can be seen in Table 4.21.

Table 4.21. Standard rock check dam with added overlay cost estimate

Component	Qty.	Unit	Unit cost	Total
Riprap, Class D	13.2 (10.1)	yd^3 (m^3)	\$56.03 (\$73.05)	\$737.99
SF engineering fabric, 36 in. (91 cm)	204 (62.2)	ft (m)	\$0.08 (\$0.26)	\$16.32
Sod staples, 6 in. (15 cm)	34	ea	\$0.03	\$1.18
Total cost per ditch check				**\$755.49**
Total cost per ft (m)				**\$22.22 (\$67.73)**
Estimated installation cost per ft (m)				**\$32.18 (\$98.07)**
Total estimated installed cost per ditch check				**\$1,094.00**

4.4.5 Installation Criteria, Evaluation, and Limitations

Rock check dams were planned to be installed in an alternating pattern of standard and modified design (S-M-S-M-S-M). Three of each design were supposed to be installed in a single channel for similar flow and sediment loading comparisons. The proposed rock check dam monitoring area is outlined in orange in Figure 3.9a.

Rock check dam performance was intended to be evaluated on structural integrity, sedimentation, and impoundment, similar to the other ditch protection types. However, due to grading and subcontractor activities, the rock check dams were not installed for evaluation in the 2019 construction season. It would be recommended to test the performance of varied rock check dam installations in a controlled setting to ensure comparable flows, channel geometries, and sediment loads.

4.4.6 Discussion and Recommendations

Although rock check dams were not installed for field monitoring, several previously installed rock check dams were observed and photographed during site visits, such as the one shown in Figure 4.30.

Figure 4.30. Rock check dam undercutting

The main observed deficiency was piping, leading to channel erosion and undercutting. In addition, rock check dams reached full height sedimentation without maintenance. The addition of a geotextile overlay would aid in slowing concentrated channel flow and eliminate the piping effect but also aid in maintenance to prolong the life of the check dams on-site. The geotextile overlay could easily be picked up for sediment removal and kicked off. In severe cases, the overlay could be replaced with new material. It would be advantageous to test and compare the standard and modified installations in a controlled setting to ensure similar drainage areas, flow conditions, and sediment loading.

5 SEDIMENT BARRIERS

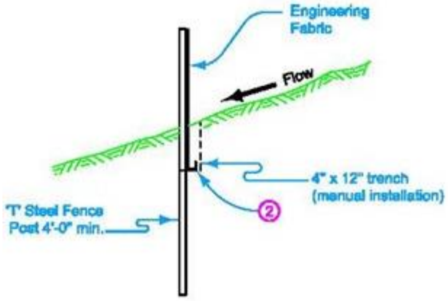
Sediment barriers, commonly referred to as perimeter controls, envelope disturbed areas as a last-line defense before flows discharge from a construction site. Sediment barriers vary between sites, but common perimeter control practices include silt fence, wattles, sandbags, vegetated buffers, and sediment retention devices. Of these practices, silt fence is the most commonly used.

5.1 SILT FENCE PERIMETER CONTROL

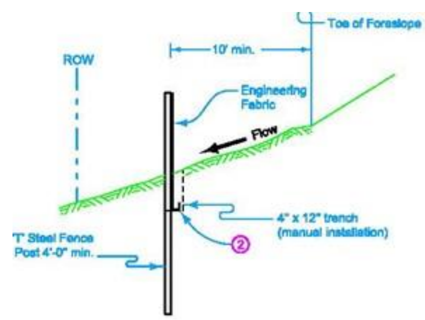
Silt fence typically consists of a geosynthetic fabric installed as a vertical barrier to create impoundments and decrease runoff velocity, which promotes favorable conditions for sedimentation. The geotextile is tied to either a T-post or reinforcement backing, which is then connected to a T-post. When implemented as a perimeter control, silt fence intercepts and treats sheet flow prior to off-site discharge.

5.1.1 Iowa DOT Standard

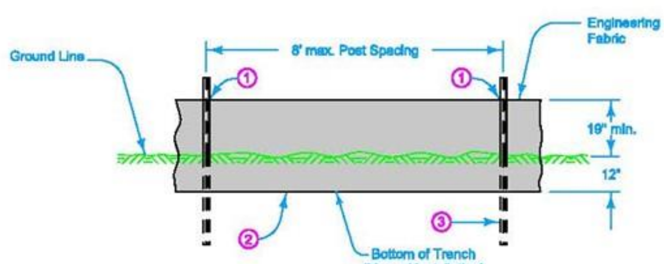
The Iowa DOT silt fence perimeter control standard, SF-PC-S, (EC-201) specifies a 4 ft (1.2 m) T-post driven at least 24 in. (60 cm) into the ground. A woven geotextile is trenched and compacted 6 in. by 6 in. (15.2 cm by 15.2 cm) or sliced 12 in. (30 cm) below ground line. The material is either wire- or cable-tied through the top, middle, and bottom of geotextile to the T-post at an angle, with the highest point on the back of the T-post. A profile and back view of EC-201 is shown in Figure 5.1.



(a) Profile



(b) On slope



(c) T-post spacing

Iowa DOT 2018

Figure 5.1. Iowa DOT silt fence perimeter control detail EC-201

This installation was also used for SF-PC-SM; however, Silt Saver material was used in replacement of the woven geotextile (Iowa DOT 2018).

5.1.2 Literature Review

Silt fence remains a favored practice due to its versatility for site-specific needs, low cost, and ease of installation and removal. Silt fence does not require as wide of an area as sediment basins or vegetated buffers, and its install does not disturb off-site land, aiding in its popularity of use.

Silt fence primarily treats flows through the promotion of gravitational settling; however, there may be some filtering benefit. Filtration properties are a function of the geotextile's apparent opening size (AOS) and size of the suspended sediment particles. Geotextiles used for filtration of stormwater runoff are prone to blinding and degradation, limiting capabilities over their lifetime (Bugg et al. 2017b); however, blinding of openings improves impoundment property. Permittivity, defined as the volumetric flow of water per unit area of the geotextile, should not be used as an indicator of a geotextile's filter efficiency. Permittivity is a lab-tested property of the geotextile determined by either a constant or falling head test. This test does not consider sediment-laden conditions and therefore does not consider clogging potential of the geotextile, providing a biased flow-through rate (Gogo-Abite and Chopra 2013).

According to the Oklahoma State publication on the Failure Avoidance and Effective Silt Fence Technology (FAEST), it can take a particle 0.1–0.2 days to settle out of a 0.16–0.32 ft (0.05–0.1 m) depth; it's essential for stormwater to be retained at least this long to allow sedimentation to occur, making structural success and impoundment capability significant in silt fence design and implementation (Yeri et al. 2005). A majority of retained sediment is a product of the fence's ability to impound stormwater, which is largely dependent on the structural integrity of the silt fence. Silt fence often faces two modes of failure, either undercutting or overtopping. Undercutting allows stormwater to flow under the fence, which typically originates from piping, whereas in overtopping the impoundment flows over the practice due to increased hydrostatic pressure from either lack of maintenance and sediment accumulation or T-post failure.

Several factors may affect the structural proficiency of silt fence, including sediment load, receiving flow rates, and installation technique. When using silt fence, there are several design parameters to consider, including geotextile material, installation height, entrenchment, reinforcement, among others (Bugg et al. 2017a). There are limited design criteria available through the US EPA pertaining to silt fence; however, installation guidance is available from state highway and environmental agencies. According to the Iowa SUDAS, the maximum contributing drainage area cannot exceed 0.25 ac (0.10 ha) per 100 linear ft (30.5 m) of silt fence, a standard commonly adopted across the US. If the area exceeds these parameters, it should be split into several storage containments (Iowa SUDAS 2020). Other design guidance, including ALDOT, allows 0.5 ac (0.2 ha) per 100 ft (30.5 m) of silt fence, providing that the silt fence is wire reinforced (Bugg et al. 2017a).

Silt fence installation is highly variable on construction sites. The US EPA dictates little criteria, leaving implementation open to jurisdictions for local needs. Requirements by the US EPA include silt fence placement on contour lines; sufficient amount of silt fence per contributing area; use of a heavy, porous fabric; mounting posts to be driven at least 24 in. (0.6 m) with appropriate spacing; and compacted soil around the silt fence (US EPA 2004). Complications on-site may include broken or bent supports, damaged fabric, loose soils, and vandalism; Cooke et al. (2015) highlight the importance of training and educating construction crews on the required installation and maintenance. Timely removal is also important to avoid unintended flow paths, ponding, and off-site pollution. With limited research behind silt fence, installation becomes subjective, facing several issues.

Large-scale testing on silt fence sediment barriers have been conducted at Oklahoma State University, the University of Central Florida, and largely at the AU-ESCTF. In response to the US EPA 2002 conference on sediment total maximum daily loads (TMDLs) and linear construction, researchers at Oklahoma State University considered silt fence's conflicting laboratory and field data pertaining to sediment retention. Oklahoma State researchers designed a new silt fence design, the FAEST, which aimed to solve common failure modes of a traditional silt fence. This included low strength and flow at low points along the fence, typically resulting in undercutting or overtopping. Their design included using metal posts, implementation of a geotextile apron, and lateral barriers. The tested design had an 18 in. (45.7 cm) apron, 12 in. (30.5 cm) fence height, and 36 in. (91 cm) spacing between posts. Lateral barriers were installed 120 degrees to the silt fence, baffling the flow and increasing detention time.

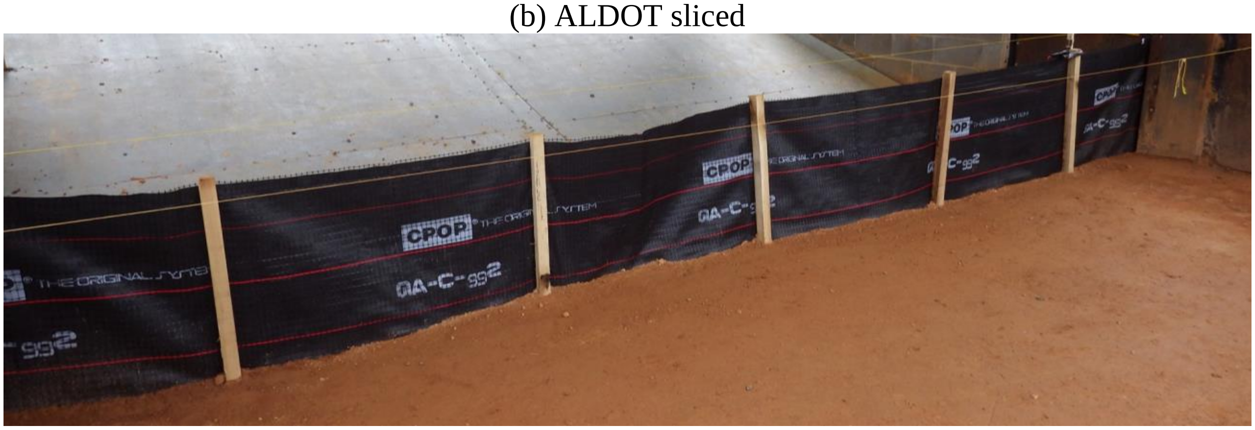
The test ran six simulations of 2.5 in./hr (63.5 mm/hr) rainfall events on a combination of three different soil types (sandy loam, silty clay, and loam) and two slope gradients (10% and 13%). The trapping efficiency averaged 86%, with a toe failure in one of the trials skewing the results. In four of six simulations, trapping efficiency exceeded 90%. The FAEST installation eliminated toe undercutting; however, scouring occurred. The test showed that fence performance was dependent on the soil type; silty clay had the highest trapping efficiency. Despite smaller particles potentially flowing through the openings, performance was highest. Improved performance likely occurred due to increased impoundment time with the addition of lateral barriers.

Gogo-Abite and Chopra's 2013 study at the University of Central Florida tested the performance efficiencies of silt fence materials in turbidity and solids concentration removal. A woven and nonwoven geotextile was subjected to varying rainfall intensities and slopes, using a tilting test bed. Influent and effluent runoff were analyzed for sediment concentration and turbidity in three rainfall events, on two different gradients. Rainfall simulations included 1 in./hr (25 mm/hr), 3 in./hr (76 mm/hr), and 5 in./hr (127 mm/hr) on both a 10% and 25% gradient. When cumulatively analyzed across rainfall events and slope gradient, the nonwoven geotextile provided a 52% reduction in turbidity and 25% removal of sediment concentration; the woven geotextile, however, provided an 18% reduction in turbidity and 10% removal of sediment concentration. The upstream slope had no effect on the sediment concentration reduction for the nonwoven but varied the results for the woven geotextile (Gogo-Abite and Chopra 2013). This study would indicate that a nonwoven geotextile should be used for the silt fence; however, different soil types may alter the performance efficiency. A woven geotextile may be applicable for a soil type with a higher proportion of sand compared to silts and clays. In this study, the nonwoven material had a smaller apparent opening size than the woven, which may have affected the filtering capacity of the geotextile. As the primary function of the silt fence is to contain flow and promote sedimentation and high clogging potential, it is assumed the varying opening size would not greatly contribute to the cumulative performance efficiency (Gogo-Abite and Chopra 2013).

Bugg et. al (2017b) conducted large-scale performance-based evaluations at the AU-ESCTF on ALDOT silt fence installations, including a manually trenched and sliced installation of a wire-reinforced geotextile. In addition, an Alabama Soil and Water Conservation Committee (AL-SWCC) detail was tested, which included a woven, polypropylene-reinforced silt fence. The study at AU-ESCTF aimed to test the structural integrity and sediment retention of each design's installation. ALDOT details, for trenched and sliced installation, include a 5 ft (1.5 m) tall steel post, spaced 10 ft (3.05 m) on-center. A nonwoven geotextile with a weight of 3.98 oz/yd^2 (135 g/m^2) is specified. For the trenched installation, a 6 in. (15.2 cm) wide by 6 in. (15.2 cm) deep trench is dug to bury the wire reinforcement and fabric, fulfilling the requirement of placing the reinforcement and fabric at least 6 in. (15.2 cm) below the ground surface. In the sliced detail, reinforcement was shown to be buried at least 8 in. (20.3 cm) under the ground surface. The AL-SWCC describes a 2 in. (5.1 cm) by 2 in. (5.1 cm) hardwood stake configuration, spaced 4 ft on-center. The stakes should be buried at least 12 in. (30.5 cm), while maintaining a height of 24 in. (61 cm) above surface. A woven geotextile is to be buried at least 4 in. (10.2 cm) deep and attach to the mount between 18 in. (45.7 cm) and 24 in. (61 cm) above ground, with compacted soil in front of the trench (Bugg et al. 2017b). The configurations are shown in Figure 5.2.

(a) ALDOT trenched

(b) ALDOT sliced



(c) AL-SWCC

Figure 5.2. Alabama silt fence configurations

Both ALDOT's details experienced structural failure during simulated rain events. The trenched installation experienced structural failure in the second of three simulated storm events. In each failure episode, the center post deflected, causing overtopping of the impounded stormwater. The deflection in the steel post hindered the impoundment time, thus limiting the settling availability. When compared to the AL-SWCC trenched silt fence, the hardwood posts did not indicate any deflection. In addition to post material, the AL-SWCC installation had post placement at 4 ft (1.2 m) on-center, compared to ALDOT's 10 ft (3 m), which may have also aided in maintaining the structural integrity. The ALDOT sliced installation experienced undermining at several locations in each of the trials. This indicates the sliced installation would not last in a single 2 year, 24 hour storm event.

The sediment retention rate was considered for the three tested practices. This compared known introduced sediment to the sediment captured after dewatering. The AL-SWCC had a retention rate of 90.5%, compared to the ALDOT trenched and sliced methods at 82.7% and 66.9%, respectively (Bugg et al. 2017b). The improved sediment retention rate of the AL-SWCC trenched design stems from its structural success in the design storm event. The maintained structure allowed longer ponding times for sediment to settle out of suspension. Several factors or combinations could have improved the structural performance, including hardwood post material, post placement, and polypropylene net reinforcement. Additionally, geotextile type may have affected retention rates; a woven geotextile, used in the AL-SWCC installation, has a lower flow through value, which may aid impoundment. However, with a lower flow through rate, hydrostatic forces acting on the silt fence would increase, making the structural performance increasingly important. Added hydrostatic pressure could cause T-post failure. Further studies would need to be conducted to show which, if any, factor primarily aided in the structural integrity of the silt fence.

Continued large-scale testing was conducted at AU-ESCTF, evaluating eight modifications of wired-backed, nonwoven silt fence installations (Whitman et al. 2018). The ALDOT standard included a 32 in. (81.3 cm) tall 3.5 oz/yd^2 (118 g/m^2) geotextile was trenched 6 in. by 6 in. (15.2 cm by 15.2 cm) into the ground and connected to a 17 gauge steel woven wire reinforcement with 11/16 in., 16 gauge galvanized C-rings. The wire backing was attached to 0.95 lb/ft studded T-posts with 11 gauge aluminum wire ties. Posts were spaced 10 ft (3 m) on-center. The performance of the ALDOT standard evaluated by Bugg et al. (2017b) was used as the performance baseline. Variations to the standard included decreasing geotextile height to 24 in. (61 cm), increasing T-post weight to 1.25 lb/ft, decrease post space to 5 ft (1.5 m) on-center, and adding a trench offset.

The installations were subjected to three, 30 minute rain events, simulated to match that of the 2 year, 24 hour design storm at 0.22 ft^3/s (0.03 m^3/s). Water was released through a weir, mixed with native Alabama soils (USCS well-graded sand), and distributed across a 20 ft long galvanized 3H:1V slope to represent sheet flow. A 12 ft by 20 ft (3.7 m by 6.1 m) earthen section was just upstream of the installed practice to represent field-like conditions. Performance evaluations were conducted across four areas including (1) structural performance, (2) sediment retention, (3) water quality, and (4) statistical relevance. Of the modifications, M8 performed best, retaining 93% of sediment with 0.18 ft (0.004 m) post deflection. Whitman et al. (2018) concluded that increasing T-post weight and decreasing spacing increased the performance of the silt fence. Whitman et al. (2018) used M8, naming it heavy-duty silt fence (HDSF) for a 2019 comparison study of sediment barriers.

Whitman et al.'s 2019 study evaluated innovative and manufactured sediment barrier practices including two manufactured silt fence systems, three sediment retention barrier installations, and three manufactured sediment retention barriers, in a field-like environment to identify performance capabilities and limitations. Testing was conducted using the same apparatus as

Whitman et al. 2018. Performance evaluations were based on (1) sediment retention, (2) maximum impoundment depths, (3) effluent flow rates (4) treatment efficiency, and (5) longevity of performance over several storms. The two manufactured silt fence systems included the Georgia DOT Type C and Silt Saver Stage Release Silt Fence (SRSF). The HDSF from Whitman et al. 2018 was used as the baseline. When compared to the HDSF, impoundment depths were decreased by 25% and 55% for the GDOT Type C and SRSF, respectively, and flow increased by 27% and 45%, respectively. Sediment retention from the Whitman et al. 2018 study was 93% for the HDSF. GDOT Type C and SRSF sediment retention was 90% and 85%, respectively (Whitman et al. 2019)

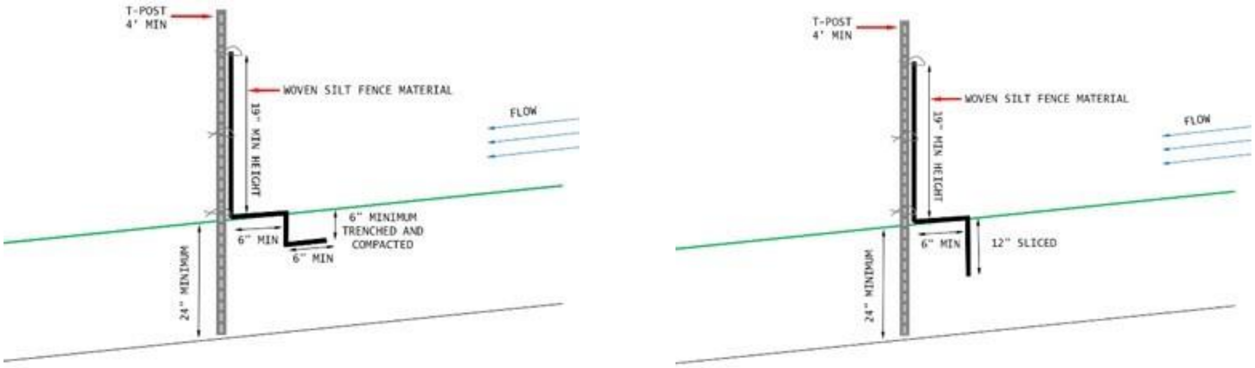
When comparing all of the sediment barriers tested, including two manufactured silt fence systems, three sediment retention barriers, and three manufactured sediment barriers, Whitman et al. (2019) concluded that impoundment depths of 1 ft or greater consistently retained 90% of sediment. Impoundment depths of greater than 1.5 ft had no increase in sediment retention capability, making impoundment depths of 1–1.5 ft the target. When depths were between 1 and 1.5 ft, surface turbidity was decreased up to 60%. Of the observed practices, only sediment retention barriers improved water quality. Major failure modes included undermining and flow bypass (Whitman et al. 2019).

Several large-scale tests have been conducted to evaluate and improve sediment barrier products and their installations; however, innovative approaches and products continue to be released. While large-scale testing is beneficial for controlled evaluations and reproducible results, there is limited peer-reviewed literature available for field observation and testing.

5.1.3 Evaluated Design Modifications

Modifications to the silt fence as perimeter control included reinforcement, offset trenching, and varying post spacing. All modified designs included the standard woven geotextile and T-posts being driven 24 in. (60.96 cm) into the ground for all installations. The silt fence geotextiles were either to be offset, trenched, and compacted 6 in. by 6 in. (15.24 by 15.24 cm) or sliced 12 in. (30.48 cm).

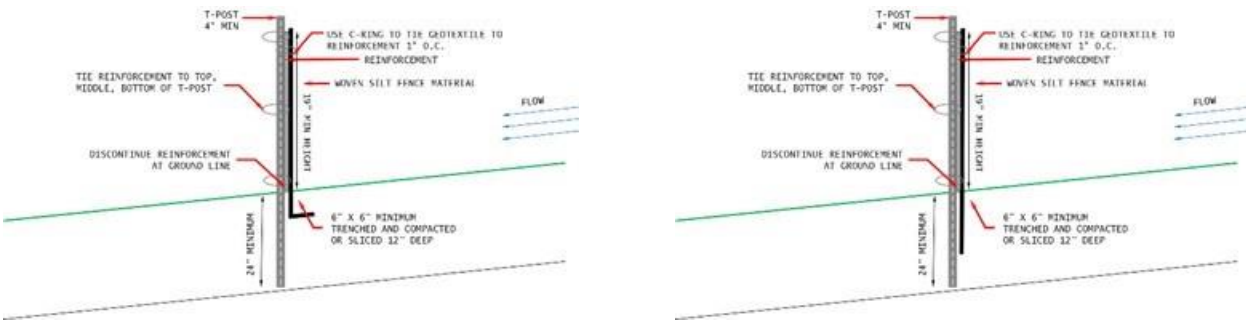
For the silt fence perimeter control Modified 1 (SF-PC-M1) and Modified 4 (SF-PC-M4) installations, silt fence material was to be offset from the T-post 6 in. (15.2 cm) and trenched and compacted 6 in. by 6 in. (15.2 cm by 15.2 cm) or sliced 12 in. (30 cm). The silt fence material was to extend at least 19 in. (48 cm) above ground and be tied at the top, middle, and bottom of the T-post. SF-PC-M1 specified T-post spacing at 8 ft (2.4 m) whereas SF-PC-M4 specified spacing at 5 ft (1.5 m). The profile view for SF-PC-M1 and SF-PC-M4 is shown in Figure 5.3.



(a) Trenched and compacted (b) Sliced

Figure 5.3. SF-PC-M1 and SF-PC-M4 modification

For the silt fence perimeter control Modified 2 (SF-PC-M2) and Modified 5 (SF-PC-M5), reinforcement (geogrid, wire mesh, etc.) was to be tied to T-posts at the top, middle, and bottom and terminated at the ground line. The silt fence geotextile material was to be tied to the top of the reinforcement every 1 ft (30 cm) on-center. Geotextile was to be offset from the T-post 6 in. (15.2 cm) and trenched and compacted 6 in. by 6 in. (15.2 cm by 15.2 cm) or sliced 12 in. (30 cm). The silt fence material was to extend least 19 in. (48.3 cm) above ground. SF-PC-M2 specified T-posts at 8 ft (2.4 m), whereas SF-PC-M5 specified 5 ft (1.5 m) post spacing. The profile view of SF-PC-M2 and SF-PC-M5 is shown in Figure 5.4.

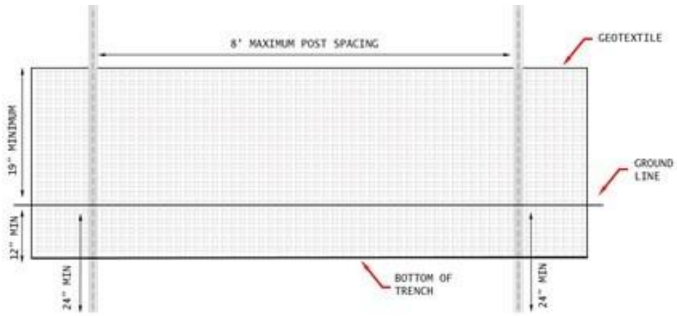


(a) Trenched and compacted (b) Sliced

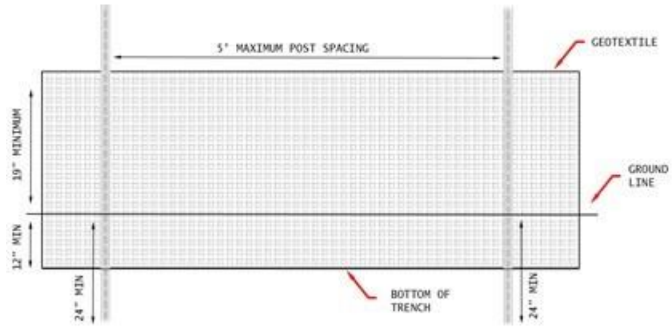
Figure 5.4. SF-PC-M2 and SF-PC-M5 modification

Installations for the standard silt fence perimeter control (SF-PC-S), silt fence perimeter control with Silt Saver manufactured material (SF-PC-SM), Modified 1 (SF-PC-M1), and Modified 2 (SF-PC-M2) were installed at the standard 8 ft (2.4 m) T-post spacing.

Silt fence perimeter control Modified 3 (SF-PC-M3) followed the Iowa DOT standard install but specified T-post spacing to be 5 ft (1.5 m). Refer to Figure 5.1 for the profile view of SF-PC-M3. Similarly, Modified 4 (SF-PC-M4) and Modified 5 (SF-PC-M5) followed the installation techniques of SF-PC-M1 and SF-PC-M2, respectively. T-post spacing and associated installations can be seen in Figure 5.5. at (a) 8 ft (2.4 m) and (b) 5 ft (1.4 m).



(a) Standard T-post spacing (SF-PC-S, SF-PC-SM, SF-PC-M1, SF-PC-M2)



(b) Modified 5 ft T-post spacing (SF-PC-M3, SF-PC-M4, SF-PC-M5)

Figure 5.5. T-post spacing for silt fence perimeter control

A summary table, Table 5.1 outlines the components of each installation.

Table 5.1. Silt fence perimeter control summary

Design element	S	SM	M1	M2	M3	M4	M5
Standard material	x		x	x	x	x	x
Multi-belt material		x					
8 ft (2.44 m) T-post spacing	x	x	x	x			
5 ft (1.524) T-post spacing					x	x	x
Wire reinforcement				x			x
Sliced	x	x	x	x	x	x	x
Offset			x	x		x	x

5.1.4 Cost Analysis

A cost analysis was conducted to compare the standard installation detail to the modified installation recommendations. Request for pricing was sent to E&SC product suppliers nationwide. Four suppliers quoted material cost. The average cost per item was calculated and used in the cost estimates of the installation. Costs are inclusive of materials, but a labor correction factor was calculated following the procedure from the ditch check section. A complete table of materials and cost can be found in Appendix D.

To estimate cost, the maximum length of a silt fence perimeter control was used at 200 ft (60.96 m) in length. The standard installation and Modified 1 had the same cost, due to the same materials; however, Modified 1 had an offset at installation. Likewise, Modified 3 and 4 had the same cost, as they were the same installations as the standard and Modified 1, but with 5 ft (1.5 m) T-post spacing. A complete tabulation of material costs and labor corrections can be found in Table 5.2 through Table 5.9.

Table 5.2. Standard silt fence perimeter control material cost estimate

Component	Qty.	Unit	Unit cost	Total
SF engineering fabric, 36 in.	200 (61)	ft (m)	$0.08 ($0.26)	$16.15
Studded T-post, 4 ft	26	ea	$3.40	$88.40
Cable ties, 50 lb	78	ea	$0.02	$1.40
Total cost per perimeter control segment				**$105.95**
Total cost per ft (m)				**$0.53 ($1.61)**
Estimated unit installation cost per ft (m)				**$0.72 ($2.36)**
Total estimated installed cost per 200 ft (61 m) segment				**$250.00**

Note: [A] Iowa DOT provided cost of $1.25/ft ($3.94/m), installed

Table 5.3. Standard silt fence with manufactured material cost estimate

Component	Qty.	Unit	Unit cost	Total
Silt Saver WBSF	200 (61)	ft (m)	$0.70 ($2.30)	$139.50
Studded T-post, 4 ft	26	ea	$3.40	$88.40
Cable ties, 50 lb	78	ea	$ 0.02	$1.40
Total cost per perimeter control segment				**$229.39**
Total cost per ft (m)				**$1.15 ($3.77)**
Estimated installation cost per ft (m)				**$0.72 ($2.36)**
Total estimated installed cost per 200 ft (61 m) segment				**$373.35**

Table 5.4. Modified 1 silt fence perimeter control material cost estimate

Component	Qty.	Unit	Unit cost	Total
SF engineering fabric, 36 in.	200 (61)	ft (m)	$0.08 ($0.26)	$16.15
Studded T-post, 4 ft	26	ea	$3.40	$88.40
Cable ties, 50 lb	78	ea	$0.02	$1.40
Total cost per perimeter control segment				**$105.95**
Total cost per ft (m)				**$0.53 ($1.61)**
Estimated unit installation cost per ft (m)				**$0.72 ($2.36)**
Total estimated installed cost per 200 ft (61 m) segment				**$250.00**

Note: [A] Iowa DOT provided cost estimate of $1.25/ft ($3.94/m), installed
Same cost as standard installation. Only design change is 6 in. (15 cm) offset.

Table 5.5. Modified 2 silt fence perimeter control material cost estimate

Component	Qty.	Unit	Unit cost	Total
SF engineering fabric, 36 in.	200 (61)	ft (m)	$0.08 ($0.26)	$16.15
Studded T-post, 4 ft	26	ea	$3.40	$88.40
Cable ties, 50 lb	78	ea	$0.02	$1.40
Welded wire fence, 18 in.	200 (61)	ft (m)	$0.89 ($2.92)	$178.00
C-ring ties, 1 in.	200	ea	$0.03	$6.00
Total cost per perimeter control segment				**$289.95**
Total cost per ft (m)				**$1.45 ($4.42)**
Estimated installation cost per ft (m)				**$1.36 ($4.16)**
Total estimated installed cost per 200 ft (61 m) segment				**$562.72**

Note: [A] Iowa DOT provided cost of $7.70/ft ($25.26/m), installed

Table 5.6. Modified 3 silt fence perimeter control material cost estimate

Component	Qty.	Unit	Unit cost	Total
SF engineering fabric, 36 in.	200 (61)	ft (m)	$0.08 ($0.26)	$16.15
Studded T-post, 4 ft	41	ea	$3.40	139.40
Cable ties, 50 lb	123	ea	$0.02	$2.21
Total cost per perimeter control segment				**$157.76**
Total cost per ft (m)				**$0.79 ($2.40)**
Estimated installation cost per ft (m)				**$0.46 ($1.40)**
Total estimated installed cost per 200 ft (61 m) segment				**$240.00**

Note: [A] Iowa DOT provided cost of $1.25/ft ($3.94/m), installed

Table 5.7. Modified 3 silt fence perimeter control labor correction

Unit	Qty.	Unit
Δ (DOT cost-material estimate)	0.46 (1.40)	$/ft ($/m)
Installation productivity (IP)	2.61 (0.86)	ft/min (m/min)
Labor (Δ × IP)	**1.20**	**$/min**

Table 5.8. Modified 4 silt fence perimeter control material cost estimate

Component	Qty.	Unit	Unit cost	Total
SF engineering fabric, 36 in.	200 (61)	ft (m)	$0.08 ($0.26)	$16.15
Studded T-post, 4 ft	41	ea	$3.40	$139.40
Cable ties, 50 lb	123	ea	$0.02	$2.21
Total cost per perimeter control segment				**$167.73**
Total cost per ft (m)				**$0.84 ($2.76)**
Estimated installation cost per ft (m)				**$0.46 ($1.40)**
Total estimated installed cost per 200 ft (61 m) segment				**$240.00**

Note: [A] Iowa DOT provided cost of $4.40/ft ($13.25/m), installed
Same cost as Modified 3 installation. Only design change is 6 in. (15 cm) offset.

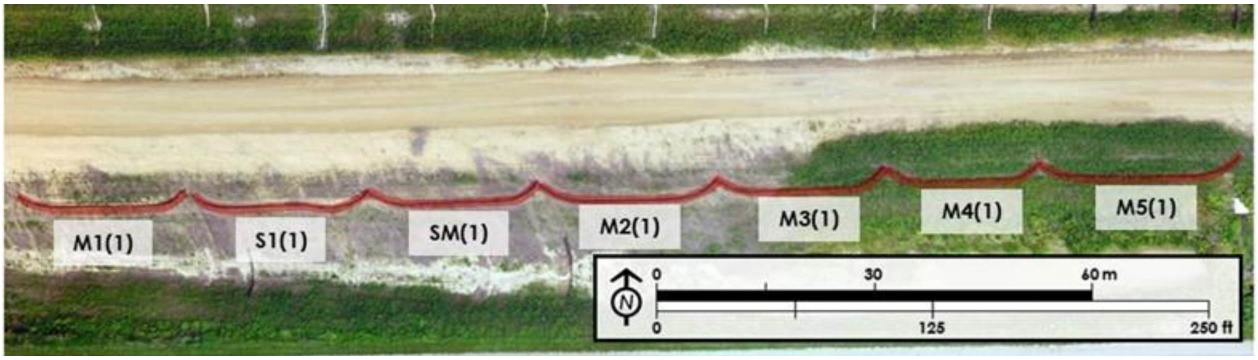
Table 5.9. Modified 5 silt fence perimeter control material cost estimate

Component	Qty.	Unit	Unit cost	Total
SF engineering fabric, 36 in.	200 (61)	ft (m)	$0.08 ($0.26)	$16.15
Studded T-post, 4 ft	41	ea	$3.40	$139.40
Cable ties, 50 lb	123	ea	$0.02	$2.21
Welded wire fence, 18 in.	200 (61)	ft (m)	$0.89 ($2.92)	$178.00
C-ring ties, 1 in.	200	ea	$0.03	$6.00
Total cost per perimeter control segment				**$341.76**
Total cost per ft (m)				**$1.71 ($5.21)**
Estimated installation cost per ft (m)				**$0.76 ($2.32)**
Total estimated installed cost per 200 ft (61 m) segment				**$494.13**

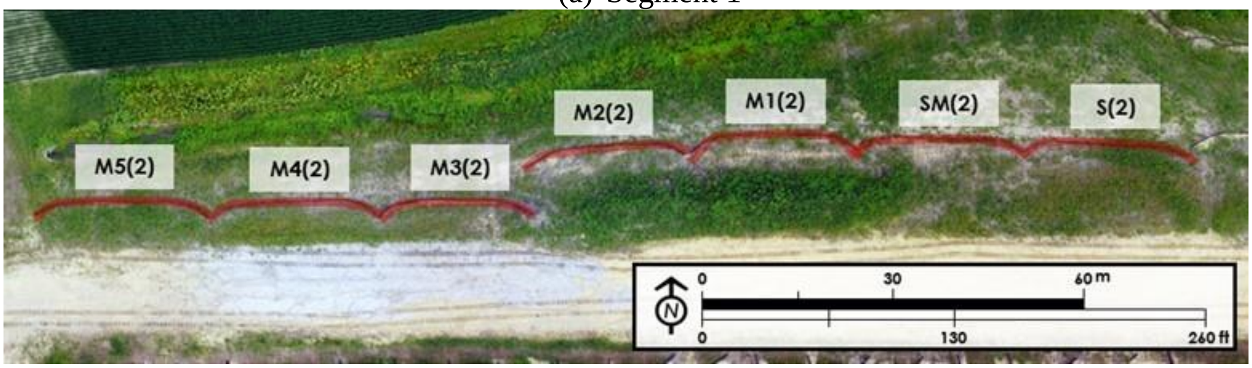
Note: [A] Iowa DOT provided cost of $7.70/ft ($25.26/m), installed

5.1.5 Installation Criteria, Evaluation, and Limitations

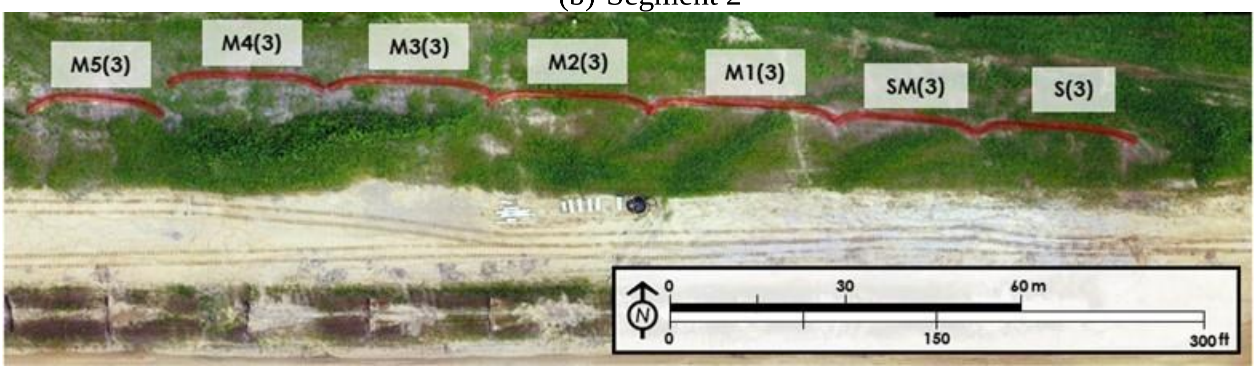
Each silt fence perimeter control design (7 total) was installed 3 times, totaling in 21 runs of monitored silt fence. A single run of each SF-PC design was installed in three separate areas, alternating installations evenly. By alternating installations on a single perimeter line, the fences were the most likely to encounter similar rain events, soil types, and drainage areas, allowing the designs to be compared. The silt fence segments are shown in the site plan in Figure 3.9. The installation pattern of the silt fence perimeter controls can be seen in Figure 5.6.



(a) Segment 1



(b) Segment 2



(c) Segment 3

Figure 5.6. Silt fence perimeter control configuration installation

Performance evaluations of the silt fence perimeter controls included structural integrity, sedimentation, and impoundment. The structural integrity was visually monitored through weekly photo inspections and measuring T-post deflections with an angle finder. Sedimentation was measured using LiDAR; however, due to the length of the silt fence runs, representative sections were scanned. During monitoring, it was found that the original scanned sections were not the low point for most of the silt fence runs. This could have been caused by changing grading patterns during active construction or changing flow patterns due to sedimentation. Maximum sedimentation often occurred behind other sections of the silt fence. Due to sediment capture in various sections along the runs of silt fence and thick vegetation impeding the function of the LiDAR scanner sedimentation, findings were largely based on weekly standard and aerial inspections. Photographs and inspection commentary are provided in the following section.

5.1.6 Inspections

Weekly inspections were conducted to understand the performance of the standard and trial modifications of silt fence perimeter control. Inspections were conducted with UAS and documented with photographs. The aerial inspections provided the full view of the silt fence run to illustrate sedimentation patterns. The images in Figure 5.7 consist of periodic aerial photographs during field monitoring.

(a) Inspection 8/6/2019, 0.33 in. (0.84 cm) rainfall

(b) Inspection 9/5/2019, 3.53 in. (8.97 cm) rainfall

(c) Inspection 9/24/2019, 6.78 in. (17.22 cm) rainfall

Figure 5.7. Standard silt fence perimeter control aerial inspection photos

The initial aerial inspection was conducted the week after installation on August 6, 2019, after 0.33 in. (0.84 cm) of rain. Little change was observed from the installation date. The second inspection shown was flown on September 5, 2019, after 3.53 in. (8.97 cm). The final drone flight, due to weather, was flown on September 24, 2019, after 6.78 in. (17.22 cm) of rain.

Similar to the silt fence ditch checks, silt fence perimeter control was installed late in the construction season due to subcontractor scheduling and grading. Grading in the area was ending and thick vegetation grew, aiding in stabilization. The second run of silt fence was downslope from a soil stockpile and had the most observed sedimentation of all the installed runs. The second run of silt fence installations are shown in the aerial images. While changes can be tracked looking at aerial images, there are close-up photographs provided of observed silt fence deficiencies from all monitored runs.

Figure 5.8 shows the post deflection on two of the three standard installations after 3.53 in. (8.97 cm) of rain.

(a) Post deflection on SF-PC-S1 (9/5/2019)

(b) Post deflection on SF-PC-S2 (9/5/2019)

Figure 5.8. Standard silt fence perimeter control deficiencies

Figure 5.9 and Figure 5.10 show periodic aerial photos during field monitoring for the SF-PC-SM and SF-PC-M1 sites.

(a) Inspection 8/6/2019, 0.33 in. (0.84 cm) rainfall

(b) Inspection 9/5/2019, 3.53 in. (8.97 cm) rainfall

(c) Inspection 9/24/2019, 6.78 in. (17.22 cm) rainfall

Figure 5.9. SF-PC-SM aerial inspection photos

(a) Inspection 8/6/2019, 0.33 in. (0.84 cm) rainfall

(b) Inspection 9/5/2019, 3.53 in. (8.97 cm) rainfall

(c) Inspection 9/24/2019, 6.78 in. (17.22 cm) rainfall

Figure 5.10. SF-PC-M1 aerial inspection photos

Figure 5.11 shows the overtopping of the third run of the SF-PC-M3 installation. Overtopping occurred due to sedimentation to full height of silt fence. No T-post deflection was observed.

Figure 5.11. SF-PC-M1 overtopping

Figure 5.12 and 5.13 show periodic aerial photos during field monitoring and the sedimentation, respectively, at the SF-PC-M2 site.

(a) Inspection 8/6/2019, 0.33 in. (0.84 cm) rainfall

(b) Inspection 9/5/2019, 3.53 in. (8.97 cm) rainfall

(c) Inspection 9/24/2019, 6.78 in. (17.22 cm) rainfall

Figure 5.12. SF-PC-M2 aerial inspection photos

(a) Full sedimentation, no deflection (9/5/2019)

(b) Overtopping due to full height sedimentation (9/24/2019)

Figure 5.13. SF-PC-M2 sedimentation

Figure 5.14 through Figure 5.16 show periodic aerial photos during field monitoring of the SF-PC-M3, SF-PC-M4, and SF-PC-M5 sites.

(a) Inspection 8/6/2019, 0.33 in. (0.84 cm) rainfall

(b) Inspection 9/5/2019, 3.53 in. (8.97 cm) rainfall

(c) Inspection 9/24/2019, 6.78 in. (17.22 cm) rainfall

Figure 5.14. SF-PC-M3 aerial inspection photos

(a) Inspection 8/6/2019, 0.33 in. (0.84 cm) rainfall

(b) Inspection 9/5/2019, 3.53 in. (8.97 cm) rainfall

(c) Inspection 9/24/2019, 6.78 in. (17.22 cm) rainfall

Figure 5.15. SF-PC-M4 aerial inspection photos

(a) Inspection 8/6/2019, 0.33 in. (0.84 cm) rainfall

(b) Inspection 9/5/2019, 3.53 in. (8.97 cm) rainfall

(c) Inspection 9/24/2019, 6.78 in. (17.22 cm) rainfall

Figure 5.16. SF-PC-M5 aerial inspection photos

Figure 5.17 illustrates the full height sedimentation encountered by the second installation of the Modified 5 and sustained structural integrity.

(a) Full height sedimentation (9/5/2019)

(b) Sedimentation (9/24/2019)

Figure 5.17. SF-PC-M5 sedimentation

5.1.7 Discussion and Recommendations

Due to the length of the silt fence perimeter control, which captured large areas, each installation technique encountered different flow patterns, slopes, vegetation, and potentially rainfall, dependent on location. In addition, the long spans made it difficult to collect sedimentation data. The monitored practices were installed late in the construction season due to subcontractor scheduling and grading. Grading in the area was ending and thick vegetation grew, aiding in stabilization; however, weekly inspections were conducted to collect observational data. Aerial images provided insight on flow and sedimentation patterns created by the silt fence perimeter control.

By the second inspection, two of the three standard silt fence installations had failed due to T-post deflection causing overtopping. Similarly, the standard installation with manufactured, belted material had two of the three installations fail due to post-deflection. One of the failures led to undercutting and the other led to overtopping and downslope erosion. Modified 2 and 5 held back a large quantity of sediment with no observed structural change. The difference in the two installations was the T-post spacing. Modified 1 and 4 did not have any observed failures, but more sediment was observed behind Modified 4. It is believed that the closer spacing aided in maintaining the structural integrity.

Based on these observations, it would be recommended that adopting either the wire reinforcement at 8 ft (2.4 m) spacing or decreasing spacing to 5 ft (1.5 m) aids in the structural integrity. Both of these practices had an offset. Since the offset is no additional cost to the DOT and seems to aid in structural integrity, it is recommended to adopt the offset. Based on cost comparison and observed performance, decreasing post spacing is recommended. In addition to the recommendations from this field study, researchers suggest testing the performance of a wooden stake system to replace the steel T-posts to decrease cost. However, it would be advantageous to test representative runs of the standard and modified installations in a controlled environment to ensure similar conditions for comparison. In addition to these modifications, it is recommended to decrease the length of the silt fence segments and implement J-hooks or C-configurations to reduce the load on low points of the silt fence.

6 TEMPORARY SEDIMENT CONTROL BASIN

6.1 INTRODUCTION

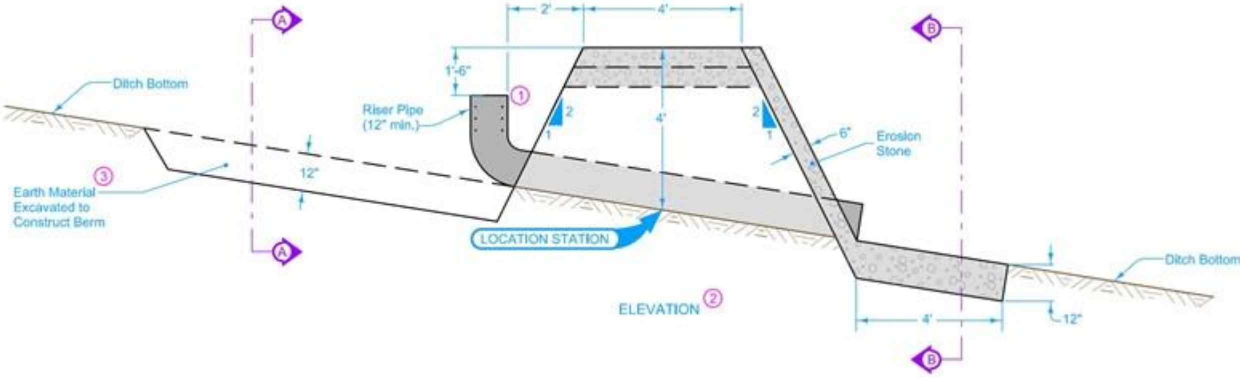
Detention-based practices are designed to temporarily detain construction site stormwater to facilitate the gravitational settling of suspended soil particles. Detention can be achieved through several Iowa DOT standard practices including silt basins and temporary sediment control basins.

6.1.1 Temporary Sediment Control Basin

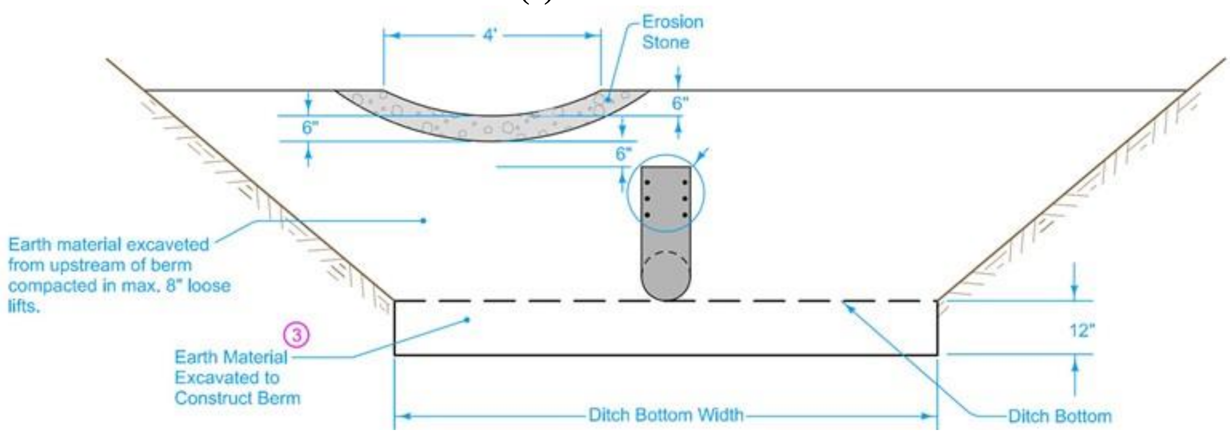
Sediment basins are a sediment-control practice that capture suspended solids by providing residence time for captured runoff, promoting sedimentation. The design of a temporary sediment basin includes considerations of inflow channel, volumetric storage, geometry, dewatering, and emergency/auxiliary overflow or spillway. Additional components such as baffles and floating surface skimmers have been shown to enhance the capture of sediment within the basin.

6.1.2 Iowa DOT Standard

The Iowa DOT standard sediment basin detail is designed to create temporary detention within the typical channel environment. The basin is constructed by excavating an additional 12 in. (30 cm) and using the material to create an earthen berm. The berm has a 4 ft (1.2 m) top width and is 4 ft (1.2 m) high at the midpoint of the berm. Side slopes are 1:2 (H:V). Situated along the berm, a 4 ft (1.2 m) wide by 6 in. (15 cm) deep spillway allows for runoff to bypass the sediment basin when the volume capacity is exceeded. The spillway is armored with erosion stone to prevent scour during overtopping events. A 4 ft (1.2 m) erosion stone apron extends beyond the toe of the berm along the downstream face of the sediment basin. A 12 in. (30 cm) diameter corrugated riser pipe is installed through the berm. The upstream face of the dewatering pipe is turned upward at a 90 degree bend to create a riser structure at the end of the sediment basin. The top of the riser pipe is drilled with three 1.0 in. (2.5 cm) holes spaced 2.0 in. (5 cm) along the top of the pipe. Typically, a riser structure has about 12 perforations. The Iowa DOT temporary sediment control basin detail EC-601 is represented from profile and cross-section views in Figure 6.1a and b, respectively (Iowa DOT 2018).



(a) Profile view



(b) Upstream cross section A-A

Iowa DOT 2018

Figure 6.1. Iowa DOT temporary sediment control basin detail, EC- 601

Photographs from field-installed sediment basins are provided in Figure 6.2.

(a) Basin (downstream perspective)

(b) Riser pipe structure (c) Spillway

Figure 6.2. Typical sediment basin installed in Tama US 30

6.1.3 Literature Review

Sediment basins are a sediment-control practice that are often employed on the edge of disturbed watersheds to capture suspended solids by providing residence time for captured runoff, promoting sedimentation (Thaxton et al. 2004). Sediment basins are used to provide volumetric storage and promote gravitational settling, and they have been shown to trap up to 75% of suspended solids, heavy metals, and other organic compounds. Stormwater residence time within a basin is dependent on their design and construction. Sediment basin design includes volumetric sizing and geometries, inflow channel, dewatering mechanism, and emergency overflow or spillway. A one-size-fits-all approach is not applicable for sediment basin design due to varying hydrologic and soil conditions across construction sites (Perez et al. 2016a). Additional components such as baffles and dewatering skimmers have been investigated through large-scale testing and proved to enhance the performance of sediment basins; however, evaluations of the performance of sediment basins in situ conditions are limited.

6.1.3.1 Sizing and Geometry

Size and geometry are arguably the most essential components to the efficiency of a sediment basin due to influencing the residence time and thus trapping efficiency. In a pioneering study by Hazen in 1904, pond trapping efficiency was proportional to sediment basin surface area; however, it was independent of the basin depth (Thaxton et al. 2004). Sufficient volume is required to ensure stormwater will not overtop the basin, allowing untreated, sediment-laden water to exit the site. To optimize settling, sediment basins should be designed long and narrow. This was identified as early as 1975 (Thaxton et al. 2004) and is still used in several state agencies. AL-SWCC and North Carolina Department of Environmental Quality (NC-DEQ) recommends a minimum length to width ratio of 2:1, which is commonly accepted; however, maximum settling efficiency is reached with a 5:1 ratio. Early volumetric design guidance by the US EPA recommended designing storage to accommodate runoff from a 10 year, 24 hour storm event (US EPA 1976). Guidance has evolved since, with several environmental agencies using sizing guidance of 1,800 ft^3 of storage per contributing acre (125 m^3 of storage per hectare) of drainage. Currently, the US EPA CGP allows for sizing sediment basins using one of two methods: (1) the calculated volume of runoff from a 2 year, 24 hour storm, or (2) 3,600 ft^3/ac (252 m^3/ha) drained into the basin (US EPA 2019).

Despite the importance of the size and shape of the basin, sediment characteristics should be considered during design. Colloidals, clays, and silts are discharged from the basins more readily, due to their slower settling times (Thaxton et al. 2004). Fine particles, including silt and clay, have the greatest effect on turbidity and require longer residence time for sedimentation. Settling time is dependent on the terminal velocity of each individual particle, which is affected by shape factors, specific gravity, and also the viscosity, which fluctuates due to temperature changes. Construction activities create fine sediment particles that may not follow typical settling behavior; they also re-suspend easily due to their size, mass, and position relative to the deposition (Fang et al. 2015).

6.1.3.2 Flow Dissipation

In design, Stokes' Law is used to provide the required flow length for a given particle size to settle. This is a simplified approach that considers laminar flow and unhindered settling conditions. Under most situations, a sediment basin may be assumed to have laminar flow; however, turbulence may occur during intense rainfall events causing re-suspension of previously deposited sediment (Perez et al. 2016b). The addition of the baffles dissipates the turbulent flow that may suspend already settled solids. Baffles reduce flow energy and turbulence potential to aid in avoidance of resuspension of the finer particles. The hydraulically effective width, defined as where flow is uniformly distributed, is increased with baffles.

Typically, three rows of baffles are installed perpendicular to the inflow, reducing the velocity of flow. It is recommended that the baffles meet or exceed the full depth of the sediment basin to ensure dissipation even during conditions where flow is passing through the spillway (Perez et al. 2016b).

In Thaxton's sediment retention pond study at North Carolina State University, the smallest grain size captured was between 2.7×10^{-3} to 3.4×10^{-3} in. (68–86 μm); however, the addition of baffles allowed the capture of particles with a grain size of 1.2×10^{-3} to 1.7×10^{-3} in. (30–42 μm), demonstrating the importance energy dissipation and avoidance of turbulence to capture the smaller gradation (Thaxton et al. 2004). Thaxton's research references a design suggestion from a Goldman study in 1986 that any sediment basin with a ratio smaller than 10:1 should employ baffles within the pond (Goldman et al. 1986). In Thaxton's study, three materials were tested across three different flow velocities. Overall, the evenly distributed jute/coir baffle performed the best by most effectively absorbing inflow momentum, diffusing energy, and damping the turbulent density; their installation substantially reduced the average flow velocities and fluctuation when compared to the control, an open flow basin (Thaxton et al. 2004).

Several DOTs have adopted flow baffles or energy dissipaters including the Alabama and North Carolina DOTs (ALDOT 2020, NCDOT 2015).

Figure 6.3a shows a sample of coconut coir typically used as a sediment basin baffle. Figure 6.3b shows a series of baffles installed within a sediment basin.

(a) Coconut coir (b) Baffles installed in basin

Figure 6.3. Sediment basin baffles

6.1.3.3 Dewatering

In addition to basin geometry and sediment behavior considerations, a form of dewatering is necessary for treated stormwater to exit the basin in avoidance of permanent ponding (Thaxton et al. 2004). Dewatering is a slow and controlled practice allowing treated water to flow out of the basin to receiving water bodies. Dewatering is typically achieved through several mechanisms, including riser structures, floating surface skimmers, and spillways. Traditionally, effluent has been discharged through perforated riser pipes, which pull water from across the entire depth of the basin. The disadvantage to this approach is that water is removed from profiles within the basin where a high amount of sediment is present, allowing effluent to be discharged without always achieving the adequate detention time. More recently, skimmers are being implemented in sediment basins, so discharge is being pulled from the topmost layer of the detained water, which is presumably the least turbid, most treated water. Dewatering then occurs across the entire depth, compared to a localized point of the riser pipe. Albert (2001) showed that sediment loss from a basin equipped with a perforated riser principal spillway was 1.8 times greater than when a skimmer principal spillway was used. The US EPA Construction General Permit and the Iowa DNR NPDES General Permit No. 2 both require the use of surface dewatering (US EPA 2019, Iowa DNR 2017). Residence time can vary greatly across sites and basins; however, 2–5 days is typical for influent detention. This allows adequate settling time for the suspended solids before exiting the basin (Perez et al. 2016b).

A sediment basin was designed at AU-ESCTF to evaluate several design factors including baffles, surface dewatering skimmer, and excavated sump. The basin was 56 ft (17.1 m) in length and 28 ft (8.5 m) in width, with a volume of 2,790 ft^3 (79.0 m^3). Three rows of wire coir baffles were installed, creating a system of four bays. Coir netting was secured on the bottom of the basin as well as up the sides using U-shaped anchors. Baffles were all at the same elevation, extending beyond the flow depth of the auxiliary spillway. A 1.5 in. (3.8 cm) diameter floating surface skimmer was connected to a 4 in. (10 cm) diameter polyvinyl chloride (PVC) pipe outlet in the fourth bay. Upstream of the basin, a forebay consisting of an excavated sump and riprap ditch check was installed 20 ft (6.1 m) upstream of the basin to capture rapidly settable solid particles. The basin was designed for evaluation of sumps, baffles, and lamella technology (a series of inclined parallel plates to create favorable settling conditions) based on data collection and analysis of water quality, flow rate, basin storage, sediment deposition, and sediment sampling for particle characterization. Inflow would occur for the first 30 minutes of testing, where water and sediment were introduced. Hours 1–25 served as the polishing period, absent of turbulent inflow.

Testing results indicated the use of the excavated sump upstream of the basin had no significant effect on the performance of the capture efficiency of the basin. However, this area allows for capture and storage of sediment within the channel where dredging and maintenance activities may be easier to perform. The use of a modified coir baffle system consisting of a reduced percent open area (POA) (10.9% versus 21.8% POA) was shown to be less effective in treating turbidity within the basin. Testing of high-rate lamella settlers within the third and fourth bays of the basin provided a turbidity reduction enhancement of up to 29%. The research provided recommendations on including a permanent wet storage zone within the basin to provide dilution and dissipating kinetic energy of highly turbid first flushes from runoff events (Perez et al. 2016b, 2019).

6.1.3.4 Chemical Treatment

Several state DOTs use chemical treatment in sediment basins to improve water quality, especially in states where discharge limits are in place. For example, the Alabama Department of Environmental Management requires discharged water to be less than 50 NTUs higher than receiving background turbidity levels; if turbidity levels are higher than that, water remediation is compulsory, or discharge is prohibited. Chemical flocculant can drastically decrease turbidity levels and is particularly helpful in sediment basin efficiency (Fang et al. 2015). Sediment basin efficiency can be improved in two main practices: increasing detention time with larger storage or implementing chemical flocculant. Chemical flocculant, generally PAM due to its common environmental and land management applications, is often added into sediment basins through either an active process or passive process. PAM is a water-soluble synthetic polymer that easily dissolves when in contact with stormwater runoff. Flocculant implementation drastically increases settling velocity of suspended sediment within the basin, reducing the settling time from several hours to just minutes. In a study at North Carolina State University, the use of flocculant reduced turbidity of the influent at 291 NTUs to less than 100 NTUs at the basin discharge (Kang et al. 2014).

Despite slower settling velocities of finer particles, there is aggregate potential through natural or artificial flocculation (Thaxton et al. 2004). It is common in southern states to add a flocculant within a sediment, promoting aggregation to larger particles and yielding faster settling velocities and higher trapping efficiencies. A sediment basin using flocculant dosing was constructed and monitored on a highway construction project in Franklin County, Alabama. The basin had a storage potential of 18,091 ft^3 (512.3 m^3) and used a skimmer and three coir baffles. In addition, PAM was added to the first bay of the basin to evaluate the increased settling potential. Samples were collected using an automated ISCO sampler routed to a collection point 1.5 ft (0.45 m) from the bottom of the basin and at the point of discharge. Sampling was triggered based on flow rate measured through the use of a bubbler flow module attached to the ISCO sampler. Collected samples were evaluated for turbidity and TSS and compared to determine treatment efficiency.

Results indicated sediment removal ranging between 83% and 97.9% across separate rainfall events. Lower removal efficiencies were attributed to events where runoff overtopped the basin, emphasizing the importance of providing adequate storage volume. After dewatering the basin, 1,700 ft^3 (48.1 m^3) of sediment was collected after seven months of basin use; this volume occupied 65% of the basin's 2,620 ft^3 (74.2 m^3) dead storage capacity. Of the sediment, 25% was classified as coarse particles, with a diameter greater than 0.02 in. (0.5 mm); the settling velocity of these particles could occur in 15–20 ft/min (4.5–6.0 m/min). A total of 47% of the sediment was fine or medium, with diameters ranging from 0.003–0.5 in. (0.08–0.5 mm). Their settling velocities ranged from 0.5–1.0 ft/min (0.15–3.0 m/min), which allowed them to settle through the entire basin depth within 15 min. Only 15% of the sediment collected was silt with diameters of 0.00008–0.002 in. (2.032–50.8 µm); these particles took up to 6.5 hours to settle the entire basin depth. After seven hours of settling, only clay particles were suspended, affecting the turbidity of the basin (Fang et al. 2015).

Appropriate chemical treatment applications are not limited to sediment basins. There has been research when applying chemical flocculant to check dams, liners, and slope drains either actively or passively (Kang et al. 2014). An active process may resemble a small-scale water treatment center on an active site, but this is commonly associated with a higher installation cost. If a chemical treatment is selected as an additional E&SC practice, it is often implemented through a passive process; a passive process involves adding flocculant in either granular or block form to installed E&SC practices. Selecting the appropriate chemical treatment process should consider precipitation, volume of flow, volume requiring treatment, turbidity, pH of receiving waters, and amount of flocculant required (McLaughlin and Zimmerman 2009).

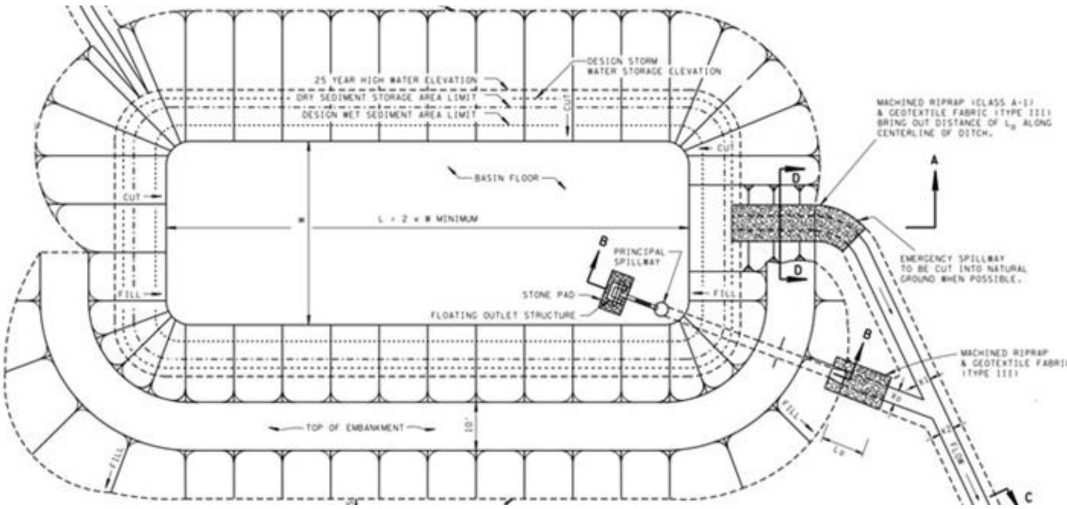
Kang's flocculant study also evaluated the performance of using PAM on a series of six wattles. The series included wattles with and without jute nets, with no flocculant, with block flocculant (BPAM), or with granular flocculant (GPAM). Influent and effluent water quality data were collected; water quality was analyzed for turbidity reduction and particle size. Only those wattles with PAM showed a turbidity reduction, ranging from 58%–67%. The average particle size increased from 9.4×10^{-4} to 8.3×10^{-3} in. (24 to 211 μm) by adding PAM; increasing particle size yields a faster settling time in impoundment and may improve sediment capture of E&SC practices (Kang et al. 2014). The addition of GPAM on jute netting produced the greatest turbidity reduction at 67%; TSS was decreased by nearly 75%, when comparing influent and effluent. GPAM outperformed BPAM, increasing surface area for interaction. The effectiveness of a flocculant is dependent on mixing energy, contact time, and impoundment time (Kang et al. 2014).

The E&SC Practices for Chemical Treatment Systems for Construction Stormwater and Dewatering technology deployment report by the Federal Highway Administration (FHWA) identifies several potential flocculants including PAM, diallydimethyl ammonium chloride (DADMAC), chitosan, gypsum, alum, and aluminum and iron chlorides. There is criticism in adding chemicals to sediment controls, considering the intended purpose is to remove any pollutant potential; however, polymers almost immediately bind to sediment in runoff, decreasing adverse effects on surrounding habitats. Projects in Washington, including DOT sites, have employed the use of polymer flocculants with no record of harm to the environment (McLaughlin and Zimmerman 2009).

The FHWA outlines a cost analysis for active and passive treatment; however, cost is extremely site dependent. Active treatment is typically costly to employ. These systems can require larger areas for installation, greater amounts of earthwork, and costly pumping and monitoring systems (McLaughlin and Zimmerman 2009). Where active treatment is implemented, the cost of equipment run time must be considered. Passive treatment cost analysis is simpler, considering the chemical cost in addition to the conventional E&SC practices and continuous maintenance. By promoting particle settlement, sediment controls using flocculation may require more regular maintenance, removing sedimentation to prevent an increase of hydrostatic pressure and ultimately avoiding failure. Flocculation has been used in several state DOTs, including Alabama, California, Florida, Washington, and North Carolina.

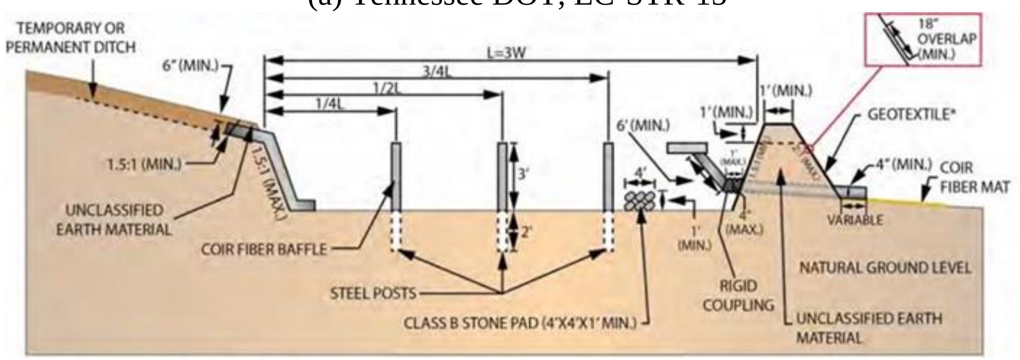
6.1.4 Alternative Sediment Basin Designs

Three standard sediment basin designs used by peer state DOTs were reviewed. These standards were included in this review as they provide advanced sediment basin design components. The TDOT standard basin, Figure 6.4a, provides for an inflow and discharge channel on opposite ends of the basin.



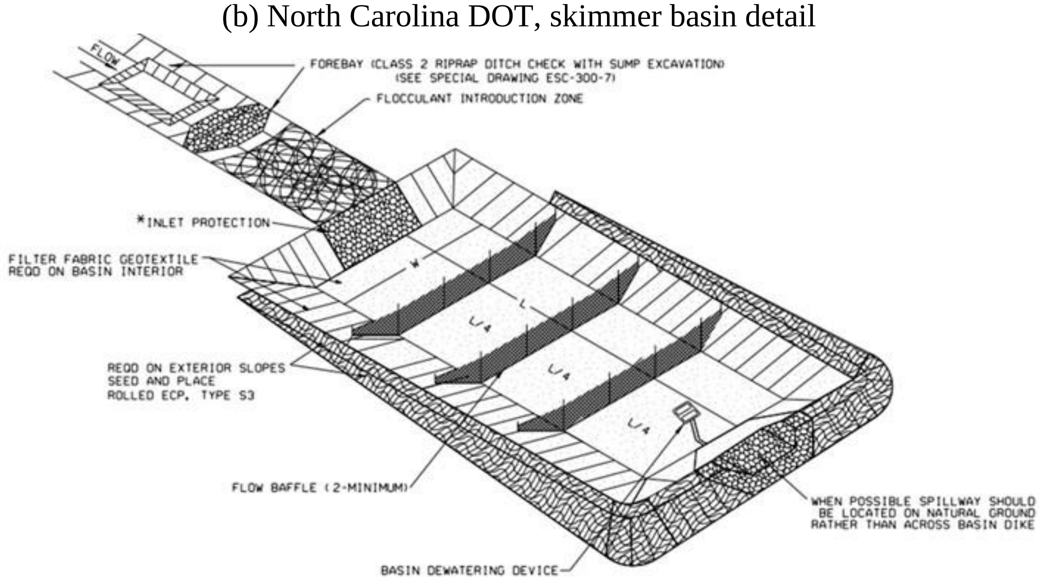
TDOT 2020

(a) Tennessee DOT, EC-STR-15



NCDOT 2015

(b) North Carolina DOT, skimmer basin detail



ALDOT 2020

(c) Alabama DOT, temporary sediment basin detail

Figure 6.4. Sediment basin details from peer DOTs

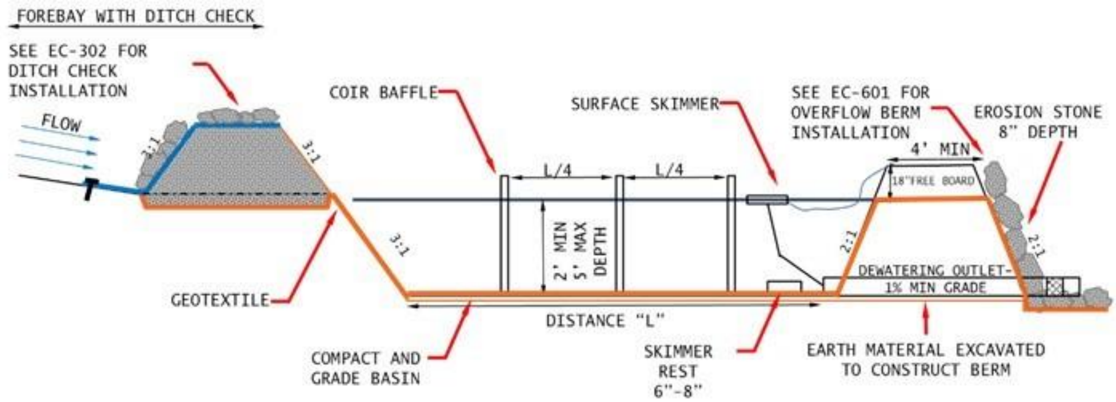
Primary dewatering is achieved through a floating surface skimmer attached to pipe that runs through the berm. The same discharge pipe has a 90 degree elbow downstream of the skimmer and extends up to allow for flow to pass through at higher impoundment stages. This is considered the primary spillway. The skimmer, primary spillway, and auxiliary spillway are routed to a stabilized channel prior to discharging downstream (TDOT 2020).

Figure 6.4b shows a profile of the NCDOT sediment basin. The basin uses a length-to-width ratio of 3:1. The length of the basin is divided into four equal bays through the use of three rows of coir fiber baffles. Baffles dissipate flow energy by allowing water to uniformly flow across the width of the basin. This reduces short-circuiting by preventing inflow from moving directly to the outlet (Chen 1975, Millen et al. 1997). A 4 in. (10.16 cm) minimum diameter pipe extends through the berm and is connected to a floating surface skimmer in the fourth bay of the basin. Similar to the TDOT standard, a stone pad is provided for the skimmer to rest during low or empty storage conditions. This provides for a depth of dead storage, while also preventing the skimmer from getting stuck in deposited sediment (NCDOT 2015).

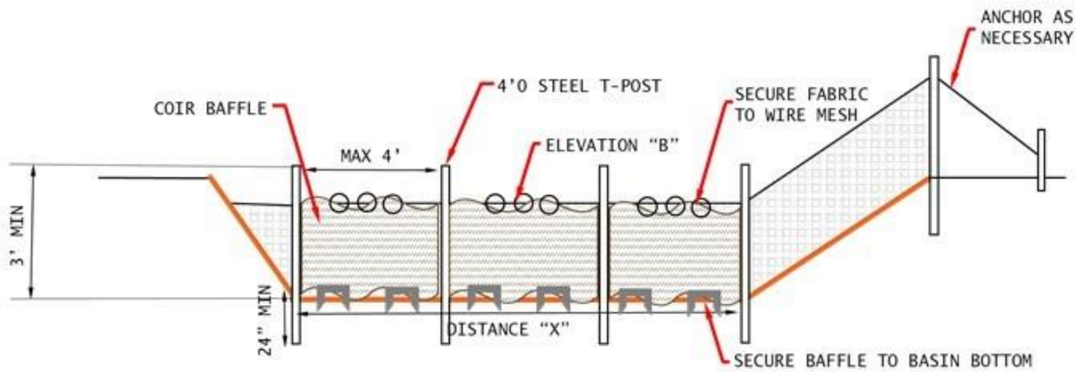
The ALDOT sediment basin detail, Figure 6.4c, includes details on the design of the upstream channel leading into the basin. The inflow channel includes an excavated forebay, which consists of an excavated sump and riprap ditch check. A forebay is a section upstream of a sediment basin that is designed to capture rapidly settable solids. Typical forebays consist of a series of riprap check dams and an excavated sump to provide for additional storage area of capture sediment. Forebays have the potential to improve the overall capture effectiveness of a sediment basin system, while allowing the basin itself to only receive smaller grain-sized particles. This decreases the frequency of dredging requirements and provides for additional stormwater storage. Downstream of the forebay, ALDOT has a dedicated flocculant introduction zone. Inlet protection in the form of channel armoring protects the inlet of the basin from eroding. The entire basin is wrapped in a geotextile to prevent scour from occurring within the basin. Providing a lining to sediment basins allows for the stabilization of the basin floor and sidewalls. In addition, this stabilization procedure eliminates the basin itself from contributing to suspension of soil. Similar to the NCDOT standard basin, baffles separate the basin into four bays. A skimmer within the fourth bay of the basin provides dewatering (ALDOT 2020).

6.1.5 Design Modifications

Modifications to the sediment control basin were meant to include the addition of an upstream rock check dam, coir baffles, geotextile lining, and surface skinner for dewatering. The basin was to be graded and compacted with a geotextile liner. A rock check dam was to be installed before the inflow slope. The inflow slope was to employ riprap armoring. Coir baffles were to be installed every quarter-length of the basin. T-posts were to be driven at least 24 in. (61 cm) into the ground and extend at least 36 in. (91 cm) above the ground line. Wire mesh reinforcement was to be tied to the posts with the coir baffle attached to the reinforcement. The baffle was to be secured to the bottom of the basin using staples. A surface skimmer was to be installed based on the expected basin volume, calculated from the design storm and drainage area. The auxiliary spillway was to have at least 18 in. (46 cm) freeboard. The modified sediment basin design is shown in Figure 6.5.



(a) Profile view of modified sediment basin



(b) Cross-sectional view of baffle

Figure 6.5. Modified temporary sediment control basin design

6.1.6 Cost Analysis

A cost analysis was conducted to compare the standard installation detail to the modified installation recommendations. Requests for pricing were sent to E&SC product suppliers nationwide. Four suppliers quoted material cost. The average cost per item was calculated and used in the cost estimates of the installation. Costs are inclusive of materials but do not reflect the cost of labor. A complete table of materials and cost can be found in Appendix D.

The Iowa DOT provided a unit cost of $3,200 per temporary sediment control basin (TSCB) installation. Table 6.1 summarizes the cost of added components including upstream rock dam, coir baffles every quarter-length, geotextile liner, and dewatering skimmer to a basin with a 4 ft (1.22 m) earthen berm (maximum depth), 5% channel grade, 10 ft (3.048 m) channel bottom with 2:1 side slopes. The total material cost for the modified basin is estimated at $2,418.

Table 6.1. Iowa DOT standard TSCB material cost estimate

Component	Qty.	Unit	Unit cost	Total
Rock check dam	1	ea	$755.49	$755.49/ea
Coir baffle system[B]	78 (23.8)	ft (m)	$4.30 ($14.10)	$335.38
Dewatering skimmer	1	ea	$1,328	$1,328/ea
Geotextile liner	247.8 (207.2)	yd^2 (m^2)	$0.24 ($0.29)	$60.03
Total estimated cost				**$2,418**

Note: [A] Iowa DOT provided typical cost of $3,200/basin installed
[B] Baffle system inclusive of coir, wire reinforcement, and T-posts

6.1.7 Installation Criteria, Evaluation, and Limitations

Temporary sediment control basins were evaluated for performance efficiency in the fall of 2018 and summer of 2019. Water quality monitoring of the single basin took place from September 25, 2018 through October 16, 2018. Monitoring continued on the basins in series system from May 17, 2019 through September 3, 2019. The location of these basins is shown in Figure 6.6.

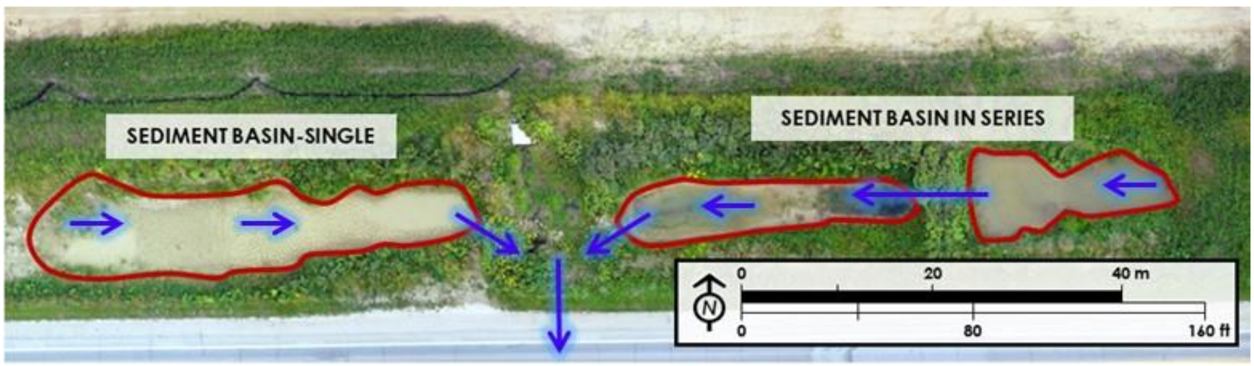


Figure 6.6. Modified temporary sediment control basin design

To evaluate water quality performance of the monitored sediment basins, automated water samplers were deployed to collect samples at the inflow and discharge of sediment basins. Teledyne ISCO 6712 full-size portable samplers were selected for sampling the basins. This sampler could be programmed based on several parameters such as time, flow, level, or rainfall, with the necessary attachments. A Teledyne ISCO 674 rain gauge was connected to one of the samplers, measuring the depth of rainfall observed on-site. An ISCO sampler is shown in Figure 6.7a.

(a) Sampler system

(b) Secured lock boxes w/ solar panel and rain gauge

(c) 12V marine battery

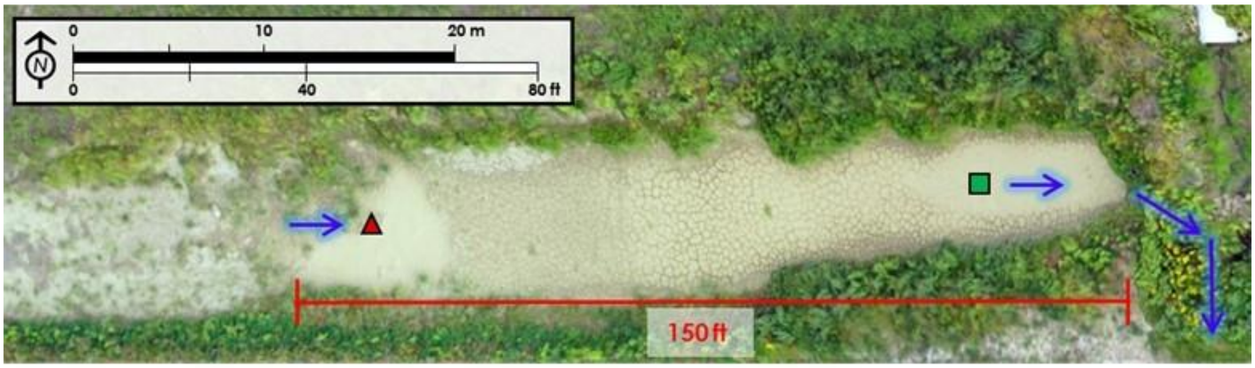
(d) Sample bottle array

Figure 6.7. Automated sampler apparatus on Tama US 30

To protect the samplers from theft and vandalism, samplers were housed in a constructed 5 ft long by 2 ft wide by 4 ft high (1.52 m long by 0.61 m wide by 1.22 m high) plywood lock box. The lock box was secured to a ground anchor with chain and locked with a pad lock as shown in Figure 6.7b. A 12V deep cycle marine battery was placed inside the box and was used to power the ISCO sampler. To keep the battery charged, a 36 cell, 50 watt solar panel (32.69 in. high by 21.13 in. wide by 1.97 in. diameter [32.69 cm high by 53.66 cm wide by 5.00 cm diameter]) was mounted to the top of the lock box housing, Figure 6.7c. Samplers were programmed to take 25 oz (0.75 L) samples from the basin at 12 hour sampling intervals. Each sample was collected in a single ISCO 33.8 oz (1.0 L) pie-shaped bottle. The ISCO 6712 auto samplers can hold a total of 24 pie bottles at a time, as shown in Figure 6.7d.

6.1.7.1 Water Quality Testing

Treatment efficiency of the basin was determined by comparing samples from inflow (Sampler A) and discharge (Sampler B) for turbidity and total solids. Total solids testing was conducted in accordance with ASTM standards D3977-97 (ASTM Standard D3977-97 2015). Sediment concentrations were expected to be above 200 mg/L; therefore, the evaporation test method (Test Method A, ASTM D3977-97) was selected. There was a total of 34 viable samples from inflow and discharge that were used to calculate the average turbidity and total solids reduction and treatment ratios. Sampling locations of the single basin are shown in Figure 6.8.



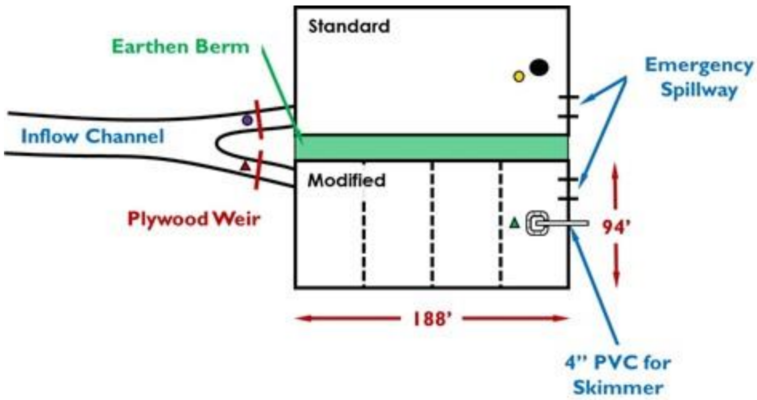
(a) Sample locations

(b) Sample float system at discharge

Figure 6.8. Single sediment basin sampling locations and dewatering system

The proposed modified basin was not evaluated through this study; however, the research team proposed a site-monitoring plan that could be used in the future to comparatively evaluate the performance of two parallel basins designed using the Iowa DOT standard basin and the proposed modifications. The modified basin installation was proposed between stations 670+00 and 675+00 and had a total drainage area of 4 ac (1.62 ha) or 2 ac (0.81 ha) per basin.

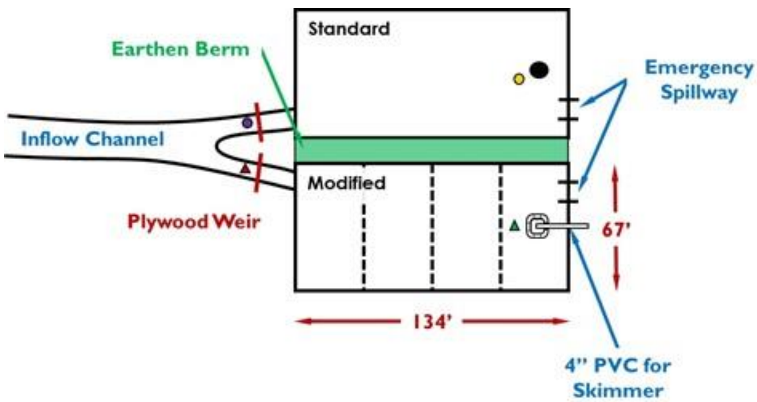
To limit variations in rainfall, contributing area, disturbed upstream area, and soil types, it was proposed that a single inflow channel be split to evenly introduce flow into two side-by-side basins. One basin would be constructed using the Iowa DOT standard sediment basin detail, and the second basin would be constructed using the developed modifications. The basins would each be sized to the (a) 2 year, 24 hour storm event, rather than (b) 3,600 ft^3/ac, as shown in Figure 6.9.



Design parameters (each basin):

- Top length: 188 ft (57.3 m)
- Top width: 94 ft (28.7 m)
- Bottom length: 164 ft (50 m)
- Bottom width: 70 ft (21.3 m)
- Side slopes: 3:1 (H:V)
- Depth: 4 ft (1.2 m) (at spillway)
- Volume: 57,682 ft^3 (1,633 m^3)
- Install skimmer at basin floor
- Skimmer:4 in. (10.2 cm) w/ 3.9 in. (9.9. cm) orifice
- Earthen berm width: 10 ft (3 m)

(a) Basin sized per 2 year, 24 hour storm



Design parameters (each basin):

- Top length: 134 ft (40.8 m)
- Top width: 67 ft (20.4 m)
- Bottom length: 110 ft (33.5 m)
- Bottom width: 43 ft (13.1 m)
- Side slopes: 3:1 (H:V)
- Depth: 4 ft (1.2 m) (at spillway)
- Volume: 27,000 ft^3 (765 m^3)
- Install skimmer at basin floor
- Skimmer: 3 in. (7.6 cm) w/ 2.9 in. (7.4 cm) orifice
- Earthen berm width: 10 ft (3 m)

(b) Basin sized per 3,600 ft^3/ac

Figure 6.9. Proposed modified basin sizing

6.1.8 Monitoring Results

Water quality sampling was used to evaluate samples for turbidity and total solids. Turbidity was analyzed to provide an indication of water clarity. Elevated turbidity indicates low levels of water quality resulting from the suspension of fine particulates. Total solids is another measure of water quality that provides a complete measure of particulates by weight. Total solid concentrations were used to quantify all settled solids present in samples.

To evaluate and compare water quality parameters measured in the basin, turbidity and total solids concentrations were plotted on a chart. Upstream and downstream measurements were plotted over time. In addition, a hyetograph cataloging 24 hour rainfall totals is provided to directly compare the performance of the basin across rainfall events. Due to variations in impoundment levels within the basin, there are several breaks in data points that represent dry basin conditions or beached sampling tubes due to sedimentation after dewatering. To quantify treatment efficiency, a treatment ratio measuring the discharge concentration to inflow concentration was calculated. Treatment ratio values less than 1.0 indicate lower turbidity values at discharge compared to inflow, while values greater than 1.0 indicate a higher discharge than inflow value.

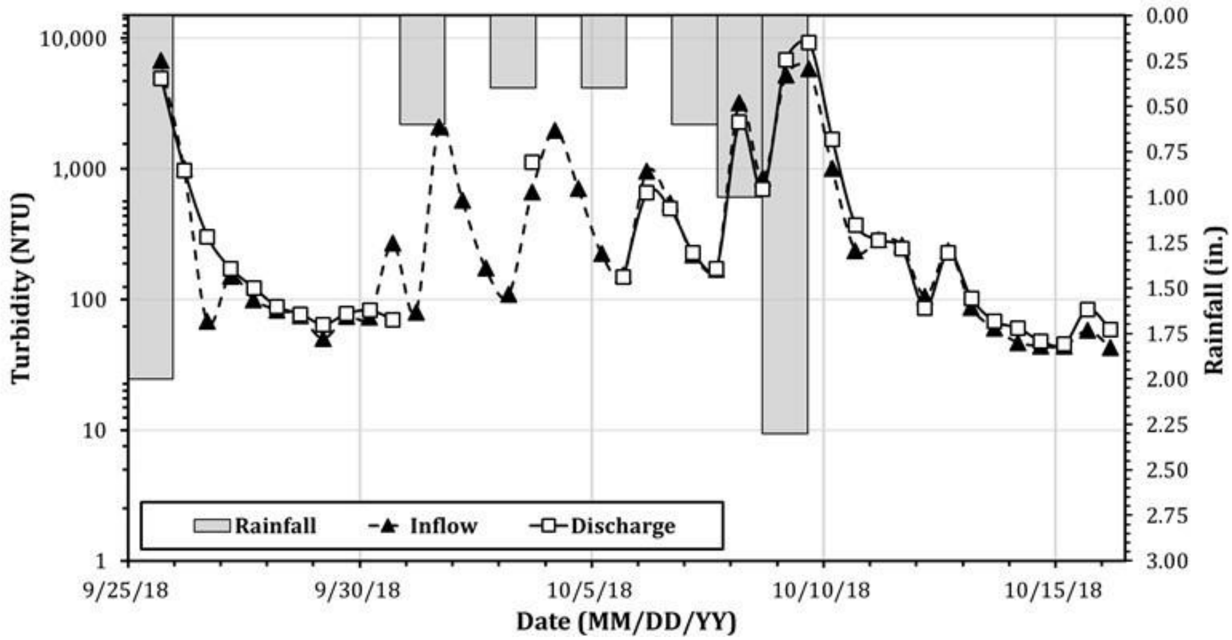
In addition to plotting the performance of the basin throughout sampling, basin performance was analyzed after individual storm events. For the purposes of comparison, storm events greater than or equal to 0.20 in. (0.51 cm) of rainfall in a 24 hour period was considered to be a qualifying storm event for analysis. Analysis was conducted from Day 0 (day of event) through Day 3 (~72 hours after event) to consider treatment during the dewatering period. Individual storm event plots can be found in Appendix G.

Summary plots were created and are included in the following sections. An average treatment ratio for each event was calculated and plotted with cumulative rainfall throughout the monitoring periods. Additionally, an average turbidity ratio was calculated for each 12 hour increment following the storm.

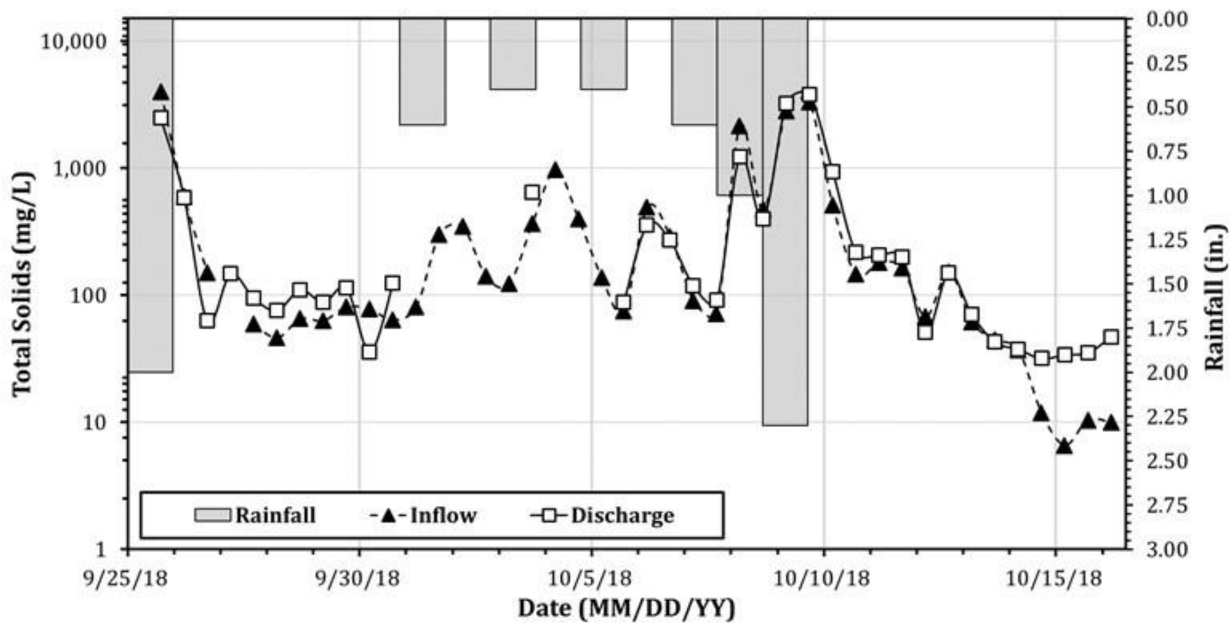
6.1.8.1 Single Basin Monitoring

Initial sampling occurred on a single basin for four weeks from September through October of 2018. The basin was located at station 389+00 and had a drainage area of 0.95 ac (0.38 ha). Over the course of sampling, a total of eighty-four 25.36 oz (0.75 L) water samples were collected (42 inflow samples, 42 discharge samples). Over the course of the monitoring period, rainfall was observed on seven days, with precipitation totaling 2.91 in. (7.40 cm). Despite several storms being captured during sampling, there were eight empty sample bottles from the discharge sampler due to dry basin conditions in sampling periods without rain events. In total, there were 68 comparable samples between inflow (34) and discharge (34).

Across all collected data, turbidity in the basin ranged from 43 to 6,781 NTUs at inflow and 45 to 9,236 NTUs at discharge. The average turbidity at the inflow and outflow sampling locations was 853 and 975 NTUs with a standard deviation of 1,563 and 2,016 NTUs, respectively. Total solids concentrations ranged from 2.0 to 4,007 mg/L at inflow and 32 to 3,794 mg/L at discharge. The average total solids concentrations at the inflow and outflow sampling locations was 469 and 490 mg/L with a standard deviation of 894 and 892 mg/L, respectively. Concentrations peaked on October 9, 2018 after receiving nearly 2.3 in. (5.84 cm) of rain across a three-day period. During this measurement, turbidity values at discharge were measured at 9,236 NTUs, more than 1.5 times greater than turbidity measured at inflow, 5,843 NTUs. On average, the basin increased turbidity by 92 NTUs prior to discharge, with a standard deviation of 760 NTUs. The basin decreased total solids concentrations by an average of 15.5 mg/L with a standard deviation of 345 mg/L. High standard deviations indicate a large range of turbidity and total solids values. Figure 6.10 represents turbidity and total solids data captured during sampling.



(a) Turbidity



(b) Total solids

Figure 6.10. Sediment basin water quality for 2018 single basin

To better illustrate treatment efficiency, a treatment ratio of discharge concentration to inflow concentration was calculated. Turbidity treatment efficiency is reflected on the plot in Figure 6.11.

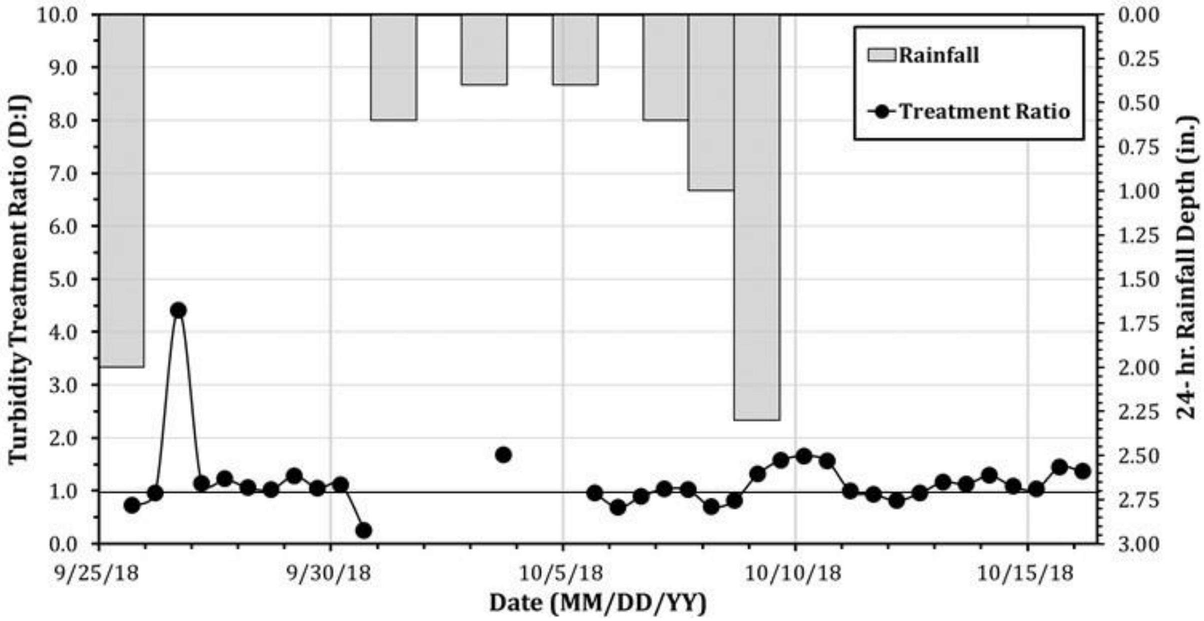


Figure 6.11. Sediment basin turbidity treatment ratio

Values less than 1.0 indicate improvement in water quality prior to discharge, whereas values greater than 1.0 indicate a decline in water quality after residence in the basin. As shown in Figure 6.11, the treatment ratio was commonly above 1.0, indicating turbidity and total solids were discharged from the basin at higher concentrations than what was measured at the inflow of the basin, particularly after consecutive rain events. Consecutive storm events likely caused the site to reach field saturation, thus increased runoff and erosive forces with each event. Increased sediment load and lacking maintenance likely caused sediment deposition to exceed the dead storage available in the basin. Increased flow velocities may have caused turbulence at inflow of the basin, resuspending and discharging previously settled material.

During fall 2018 monitoring period, there were seven storms that qualified as individual events. Qualified events are rainfall events producing more than 0.25 in. (0.64 cm) of rainfall within a 24 hour period according to the CGP (US EPA 2019). The qualifying storm events are displayed in Table 6.2.

Table 6.2. Qualifying storm events 2018

Event	Date of event	24 hr rainfall depth, in. (cm)
1	9/25/2018	2.00 (5.08)
2	10/1/2018	0.60 (1.52)
3	10/3/2018	0.40 (1.02)
4	10/5/2018	0.40 (1.02)
5	10/7/2018	0.60 (1.52)
6	10/8/2018	1.00 (2.54)
7	10/9/2018	2.30 (2.65)

The maximum 24 hour rainfall depth was 2.30 in. (5.84 cm), with an average rainfall depth of 1.04 in. (2.65 cm) across the seven days. Associated plots can be found in Appendix G.

For each of the seven qualifying rainfall events, an average turbidity ratio was calculated from the day of event (0 hour) to three days after the event (72 hours). The turbidity ratio was plotted with cumulative rainfall throughout the season to reflect how accumulation of material or maintenance may affect the performance of the basin. Figure 6.12 reflects the average turbidity ratio during the 72 hour period for each qualifying event recorded during the season.

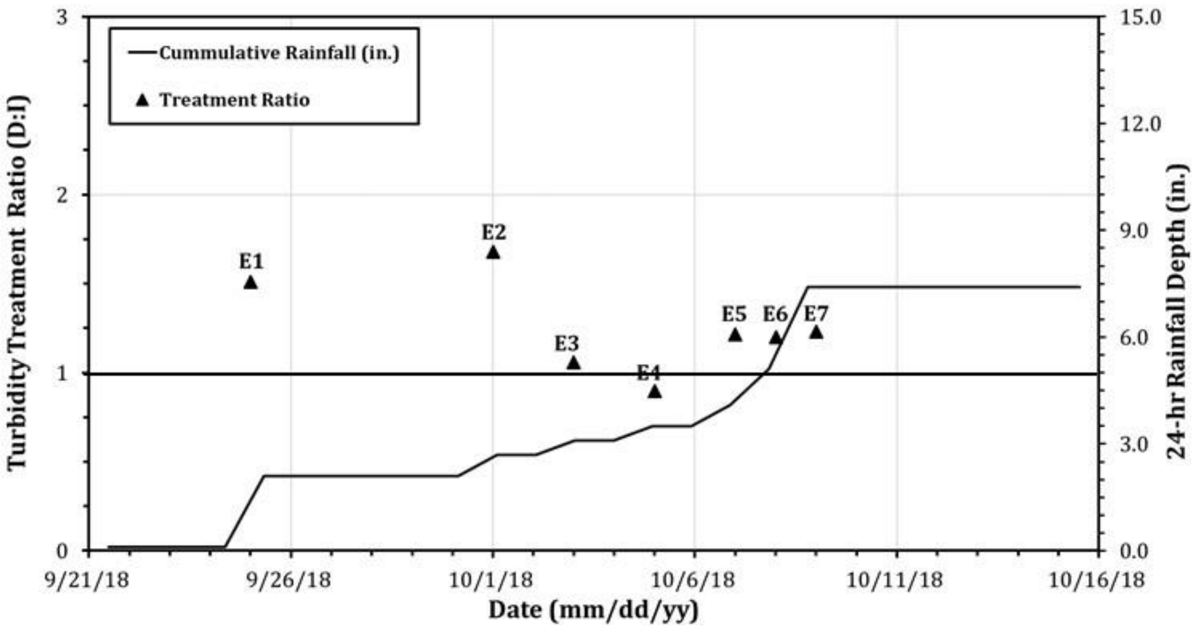


Figure 6.12. Turbidity treatment ratio of storm events 1–7

Figure 6.12 displays that all storm events, except event 4, had turbidity treatment ratios exceeding 1.0. The average turbidity treatment ratio was 1.19 with a standard deviation of 0.63. Event 3 produced the same depth of rainfall as event 4 and had a treatment ratio just above 1.0. Events 3 and 4 both produced 0.40 in. of rain, which was the lowest rainfall of the seven qualifying events. Events 5, 6, and 7, had rainfall depths of 0.60 in., 1.99 in., and 2.30 in., respectively; however, the differences in turbidity treatment ratio was negligible. Six of the seven events showed turbidity ratios above 1.0, indicating increased turbidity at discharge. When cross referencing Figure 6.10, turbidity values often reached magnitudes 10^3 NTUs and up to 10^4 NTUs during larger storm events. After detention in the basin, these values were even higher at discharge. The larger storm events presumably produced greater flow velocities, potentially causing resuspension of settled materials or increased erosion potential, which leads to an elevated sediment load.

To characterize the performance behavior of the basin during dewatering, the average turbidity ratio at 12 hour increments following the storm events was plotted, shown in Figure 6.13.

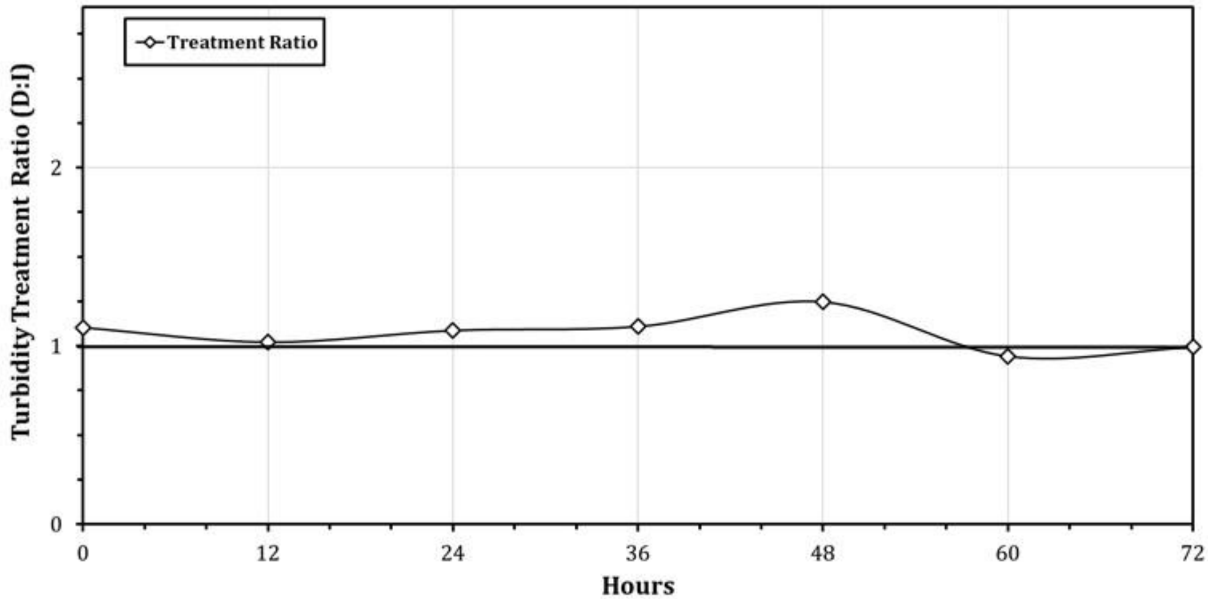


Figure 6.13. Average turbidity ratio at 0–72 hours

The turbidity ratio throughout the dewatering period remained relatively constant at 1.2, other than a spike at 0.0 hours (time of event) and 48 hours. Events 2 through 7 had additional rain events occur within 48 hours of the initial events. This likely contributed to the spike at hour 48.

6.1.8.2 Basins in Series Monitoring

A set of basins in series was identified and monitored between May and September of 2019. The basins were located at station 390+00 and had a drainage area of 6.56 ac (2.65 ha). The first basin had a flow length of approximately 75 ft (23 m) from inflow to discharge and served as pre-treatment. The second basin had a flow length of 100 ft (30.48 m). The riser pipe from Basin 1 inflows to Basin 2. Four automated samplers were deployed between the two basins. Samplers A and B were used to sample the first basin at inflow and discharge, respectively. Samplers C and D were used to sample the second basin at inflow and discharge, respectively. Sampler B collected at the discharge of the first basin, which then discharged to the inflow at Sampler C. All samples were collected from the surface of the water column using floating sampling devices as shown in Figure 6.8b. Sampling locations of the basins in series are shown in Figure 6.14.

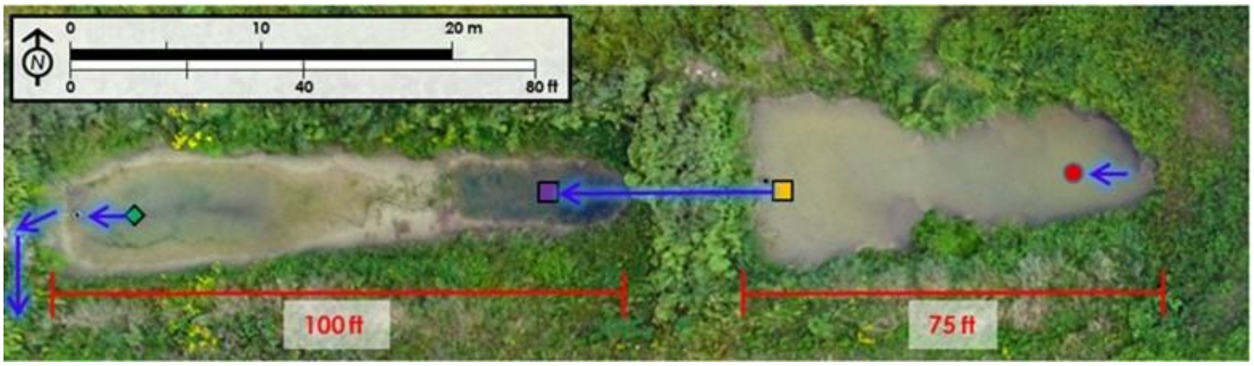


Figure 6.14. Sediment basins in series sampling locations

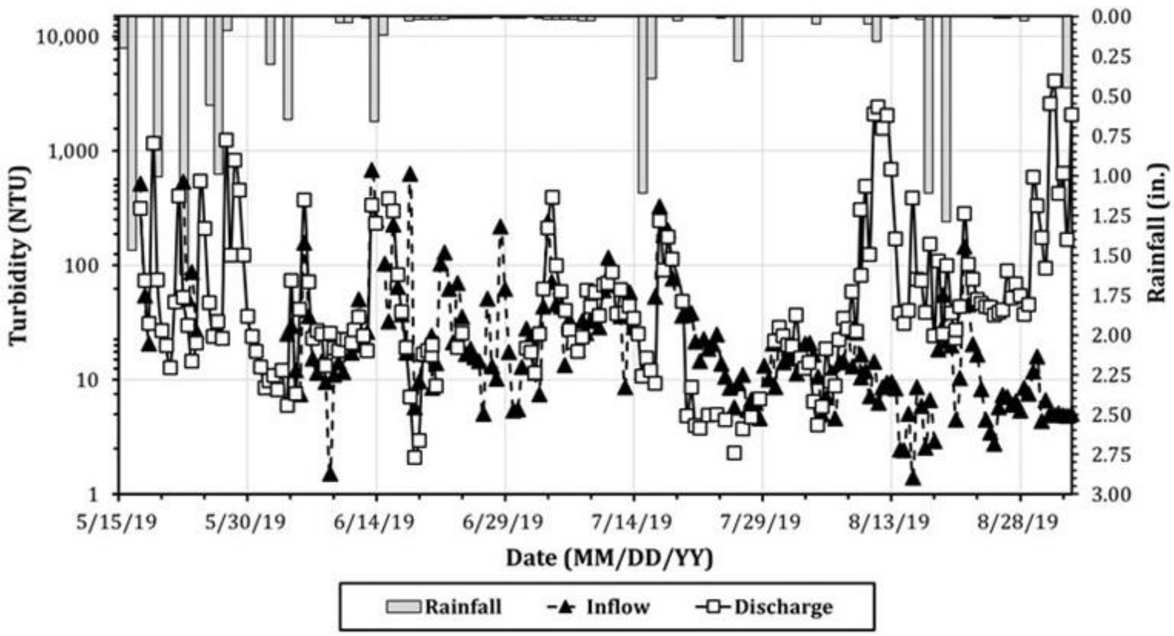
Sampling occurred in the two basins in series from May to September in 2019, where a total of 15.14 in. (38.46 cm) of rainfall was observed. Over the course of sampling, a total of 802 viable water samples were collected (190 A-inflow, 192 B-discharge, 214 C-inflow, and 206 D-discharge) for laboratory testing. Each basin experienced dry conditions after dewatering, causing the sampler to detect no liquid at several sampling times. Samplers A and B sampled the first basin in the series, which provided pre-treatment before the longer second basin. Presumably, the first basin should have allowed the heavier sediment particles (i.e., sand gradation) to quickly settle. Due to the accumulation of sediment at the inflow of the upstream basin, the sampling point for Sampler A was elevated above the water column, resulting in several periods without sample collection.

The sampling season had a high number of algae, plant materials, and gastropods contaminating samples as shown in Figure 6.15.

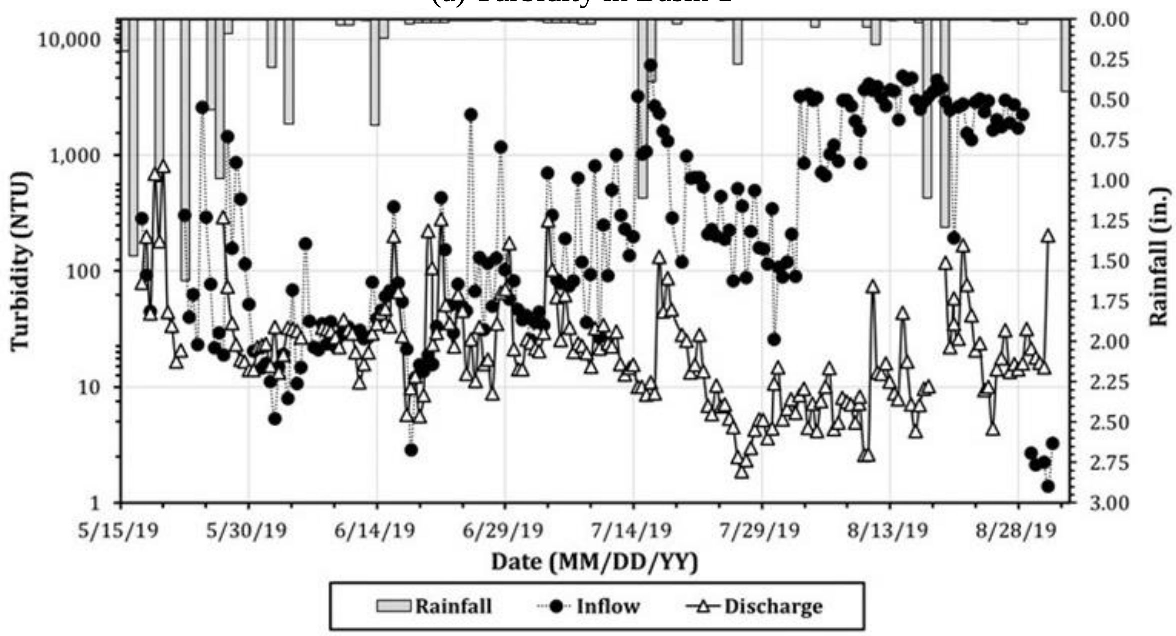
Figure 6.15. Algae growth in basin

This growth greatly affected the accuracy of total solids measurements. As a result, turbidity was the primary means used to quantify the performance efficiency of the basin.

The basin provided an average sediment reduction of 215 NTUs with a standard deviation of 511 NTUs. The second basin decreased turbidity by an average of 870 NTUs with a standard deviation of 1,282 NTUs. To characterize the treatment provided from the sediment basin series, samples collected from Sampler A (Basin 1 inflow) and from Sampler D (Basin 2 discharge) were compared. The system of basins provided an average turbidity reduction of only 9 NTUs with a standard deviation of 88 NTUs. Minimum turbidity measurements for samplers A, B, C, and D were 1.4, 2.1, 1.4, and 1.9 NTUs, respectively. The lowest measured turbidity from the series was at initial inflow and increased after flowing through the basin. Maximum turbidity measurements for samplers A, B, C, and D were 684, 4,068, 5,978, and 806 NTUs, respectively. Theoretically, data collected from Sampler B and Sampler C should have reflected similar turbidity values. However, a large increase in turbidity was observed between sample location C and sample location B. This suggests a large amount of sediment-laden stormwater was introduced to sampling point C through the riser structure that hydraulically connected the two basins. Samples collected at sample location B were pulled from the surface of the water column, while dewatering through the riser pipe was drawing water from the entire height of the column, likely transporting highly turbid water to the mouth of the second basin. The data collected from sample location B are representative of water quality that would be expected from a skimmer dewatering system. Figure 6.16 represents turbidity data collected (a) Basin 1 and (b) Basin 2.



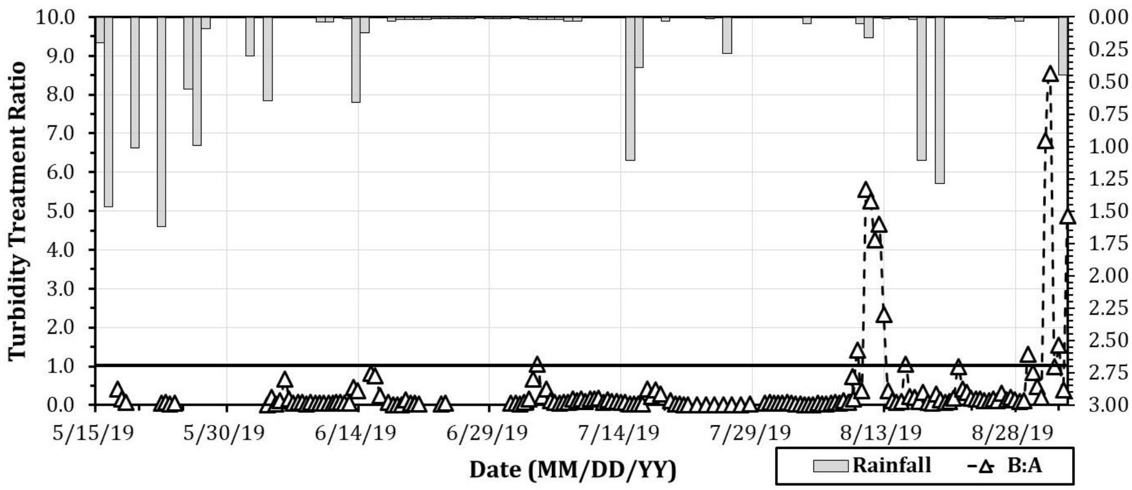
(a) Turbidity in Basin 1



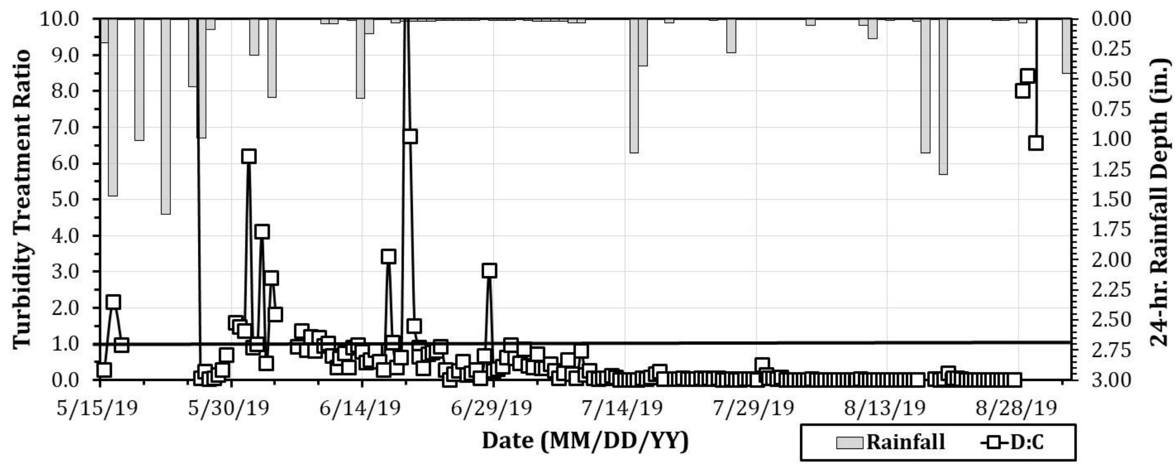
(b) Turbidity in Basin 2

Figure 6.16. Sediment basins in series performance data

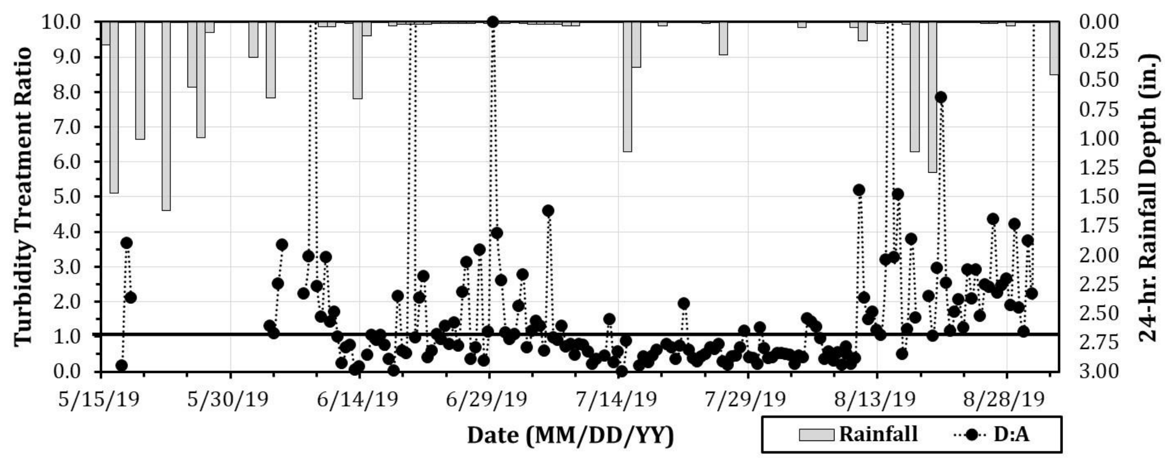
Treatment ratios were determined for the first basin, B:A; the second basin, D:C; and the entire series as a system, D:A. Plotted ratios shown in Figure 6.17a through c include treatment ratios from comparisons of sampling points: B:A, D:C, and D:A, respectively. Similar to the analysis for the single basin, values less than 1.0 indicate improvement in water quality prior to discharge, whereas values higher than 1.0 indicate a decline in water quality after residence in the basin.



(a) Turbidity ratio in Basin 1 (B:A)



(b) Turbidity ratio in Basin 2 (D:C)



(c) Turbidity ratio in series (D:A)

Figure 6.17. Sediment basins in series turbidity treatment ratios

Additionally, treatment ratios were compared between discharge from the first basin and entrance of the second basin, C:B. This ratio is shown in Figure 6.18.

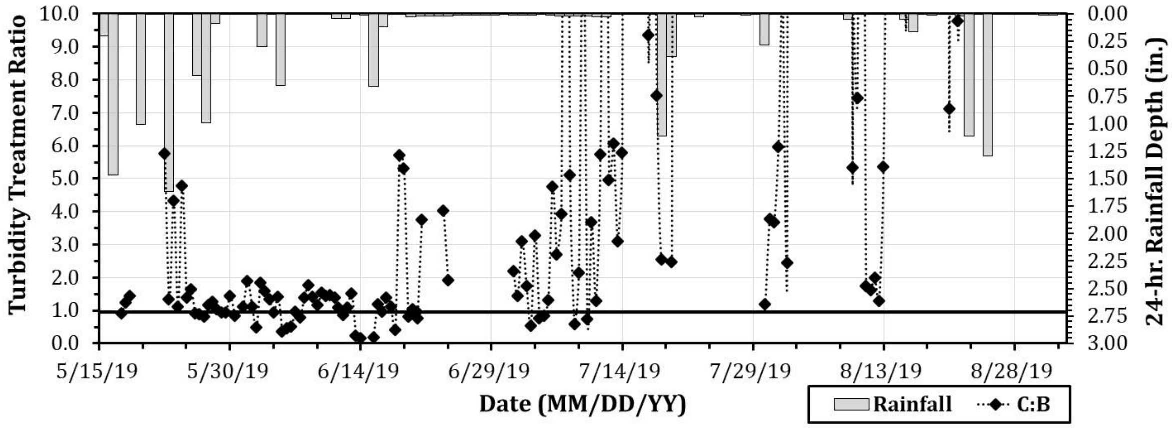


Figure 6.18. Second basin inflow vs. first basin discharge (C:B) turbidity treatment ratios

The first basin provided a reduction of 215 NTUs, and the second basin provided an average reduction of 870 NTUs, indicating treatment in each of the basins. However, the system of basins provided an average reduction of just 9 NTUs. When looking at the Figure 6.17a and b, the 151/163 and 166/189 data points, respectively, fall below the 1.0 threshold, whereas the turbidity ratios in Figure 6.18 and Figure 6.17c more consistently lie above 1.0.

Sampler C produced samples with the highest turbidity, reaching turbidity values on the magnitude of nearly 10^4. When compared to samples collected from location C, samples at location D consistently had lower turbidity values, with an average reduction of 870 NTUs in Basin 2. The length of the basin provided longer residence time and allowed smaller particles to settle out.

The two basins in series provided negligible turbidity reduction (9 NTUs). The turbidity reduction for the system was calculated by comparing samples collected from sample location D and location A.

In addition to analyzing the basins throughout the monitoring season, the series was analyzed for qualifying events above 0.2 in. (5.08 mm) of rainfall. In total, there were 15 qualifying events during monitoring between May and September of 2019. Events were numbered 8–23 to differentiate from 2018 events. Event details are summarized in Table 6.3. A complete record of individual events is provided in Appendix G.

Table 6.3. Qualifying storm events 2019

Event	Date of event	24 hr rainfall depth, in. (cm)
8	9/25/2018	2.00 (5.08)
9	5/17/2019	0.20 (0.51)
10	5/18/2019	1.67 (4.24)
11	5/21/2019	1.01 (2.57)
12	5/24/2019	1.62 (4.11)
13	5/27/2019	0.56 (1.42)
14	5/28/2019	0.99 (2.51)
15	6/3/2019	0.30 (0.76)
16	6/5/2019	0.65 (1.65)
17	6/15/2019	0.67 (1.70)
18	6/16/2019	0.79 (2.00)
19	7/16/2019	1.11 (2.82)
20	7/17/2019	0.39 (0.99)
21	7/27/2019	0.28 (0.71)
22	8/18/2019	1.11 (2.82)
23	8/20/2019	1.29 (3.28)

Average treatment ratios for each storm event were calculated and plotted with cumulative rainfall, Figure 6.19, to observe sediment resuspension, storage capacity, and maintenance effects on basin performance.

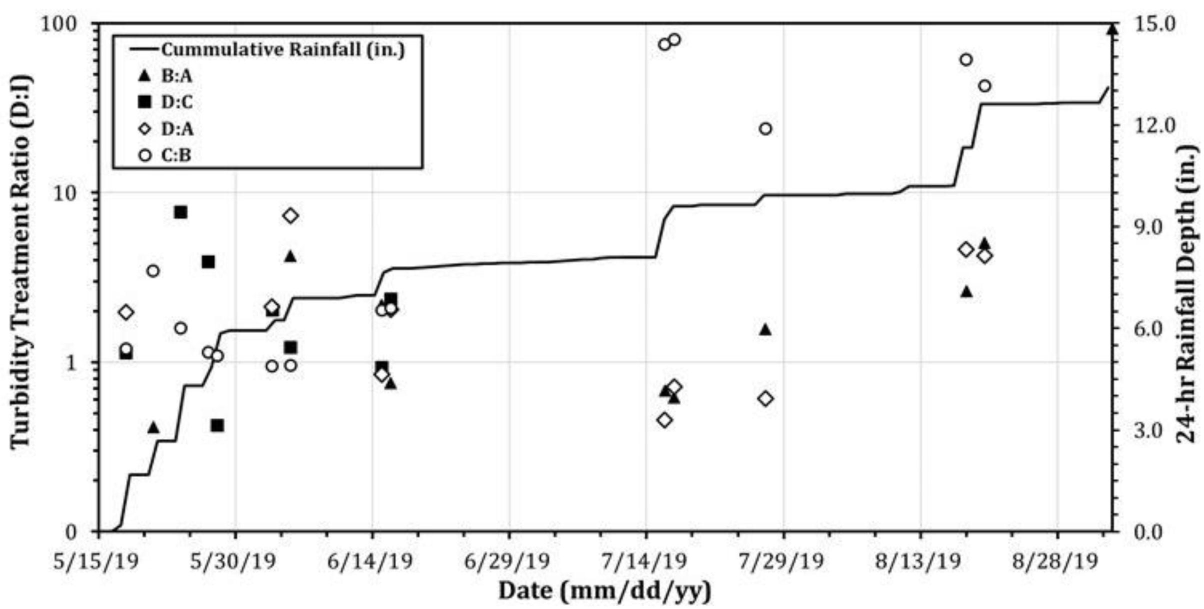


Figure 6.19. Average basin performance throughout 2019 monitoring season

As displayed in Figure 6.19, treatment ratios greatly increased as the monitoring period progressed for the middle comparison, which is calculated from Sampler C/Sampler B, as cumulative rainfall increased. As total rainfall and contributed sediment loads increase, it can be assumed storage capacity in the basins decreases. As sedimentation occurs on the basin floor, settled material is more proximal to the dewatering perforations on the riser pipe. This allows previously deposited material to flow into the second basin. Without maintenance, the riser pipe greatly increases turbidity of flow entering the second basin.

Comparing Figure 6.17a and b, Basin 1 treatment ratios also tended to increase over time, particularly after the August 13 rainfall, whereas Basin 2 values remained relatively constant until spiking after consecutive days of rainfall. This may be attributed to the sequence and geometries of the basins. Basin 1 had inflow with a higher concentration of larger diameter soil particles, which presumably settled before flowing to Basin 2. Particles suspended in the flows to Basin 2 were fine-grained but encountered nearly double the flow length of Basin 1, allowing for increased sedimentation. The deposition in the first basin rose more quickly due to its length decreasing dead storage available, whereas the second basin had more surface area for deposition to occur with lesser effect on storage capacity.

To observe treatment efficiencies throughout dewatering, the average turbidity ratios at 12 hour increments were plotted for the qualifying storm events (Figure 6.20).

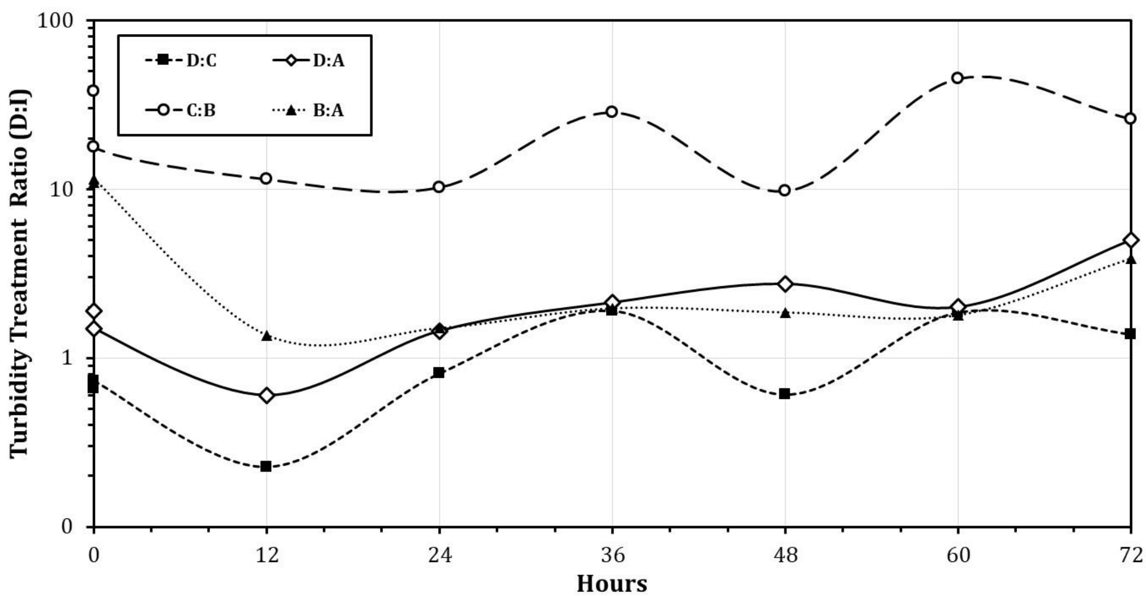


Figure 6.20. Treatment ratio during dewatering of series system

The basin turbidity treatment ratios at dewatering closely followed the patterns of the basins throughout monitoring. Treatment ratios were lowest in Basin 2 and highest when comparing the dewatering mechanisms. This emphasizes the improvement an installation with dewatering skimmer and length-to-width ratio increase would provide. Rather than install basins in series, it would be suggested to use the installation area to increase the length and use flow baffles to decrease turbulence and reduce resuspension.

6.1.9 Discussion and Recommendations

In both the single basin and basins in series, turbidity and total solids treatment ratios were commonly above 1.0, indicating a decline in water quality as water flowed through the basin. In the single basin, turbidity increased by an average 92 NTUs after residence in the basin, whereas the basins in series provided a turbidity decrease of 9 NTUs. Although the basins in series did not increase turbidity, water treatment was negligible. Turbidity values nearly reached 6,000 NTUs, providing less than a 0.5% reduction in turbidity when considering the average treatment. Prior to discharge from the site, turbidity values reached levels greater than 800 NTUs.

The basins did not have defined inflow channels and received sediment-laden flows from several directions due to lacking sediment barriers along the site perimeter. The channels that existed eroded with each storm, contributing to the incoming sediment load. As the basins dewatered, there was progressive widening due to sloughing of the basin walls and which minimized the length-to-width ratio of the basin. Additionally, materials from the sloughed walls would suspend with captured runoff. Due to lack of maintenance, there was accumulation of sediment in the basin, which exceeded the dead storage available, consequently decreasing the available live storage volume during subsequent storm events. In the single basin system, the riser pipe's buoyancy eventually caused the anchoring T-post to be dislodged from the basin ground. The basin was not dewatering via the riser pipe but overflowing and washing out the auxiliary spillway, shown in Figure 6.8b. Erosion stone was washed out, transferring flow shear stress to the earthen berm beneath it, causing erosion. Washout from the earthen berm was not captured, as discharge samples were taken proximal to the discharge pipe. It is likely turbidity and total solids concentrations were higher than captured by the sampler. Common sediment basin deficiencies captured on Tama US 30 are shown in Figure 6.21.

(a) Side wall sloughing and no defined inflow channel

(b) Erosion of overflow berm

(c) Buoyant riser pipe dislodged from basin bottom

(d) Washout of berm, riser pipe discharge elevation higher than inflow, sedimentation prior to dewatering

Figure 6.21. Sediment basin deficiencies, Tama US 30 site

6.1.10 Future Research Recommendations

This field-based sediment basin monitoring has highlighted the opportunity and potential to improve the performance of Iowa DOT's temporary sediment control basin design. There are future research opportunities to investigate performance enhancement of Iowa DOT basins used on active construction sites by evaluating the use of innovative treatment features within the basin, specifically quantifying performance enhancement provided by implementing an upstream forebay, geotextile lining, baffles, and a floating surface skimmer.

Large-scale testing of the modified basin components has been proposed to be conducted at the AU-ESCTF, a state-of-the-art research center dedicated to evaluating and improving the performance of E&SC practices used for highway construction applications. It is expected that performance evaluations will lead to additional design and implementation guidance to complement this study, which will provide for improved treatment of construction site stormwater runoff.

7 HYDRAULIC PERFORMANCE EVALUATION OF WATTLES

7.1 INTRODUCTION

The objective of this study was to evaluate the hydraulic performance of wattles used in E&SC applications using a state-of-the-art hydraulic flume and identify performance variations based on hydraulic loading, longitudinal slope, and wattle matrix media material. Identification of hydraulic performance properties provides practitioners and state agencies guidance when selecting wattle practices based on site-specific parameters and applications. This study provides insight on the ability of wattle practices of various fill materials to reduce erosion. Practices evaluated through this study were 12 in. (30.5 cm) diameter, commercially available wattles used as temporary E&SCs on active construction sites. The six types of matrix media material evaluated included (1) excelsior fiber, (2) wheat straw, (3) coconut coir, (4) wood chips, (5) synthetic fiber, and (6) miscanthus fiber. In addition, a 12 in. (30.5 cm) impermeable weir was evaluated and used as a base control from which comparisons were made.

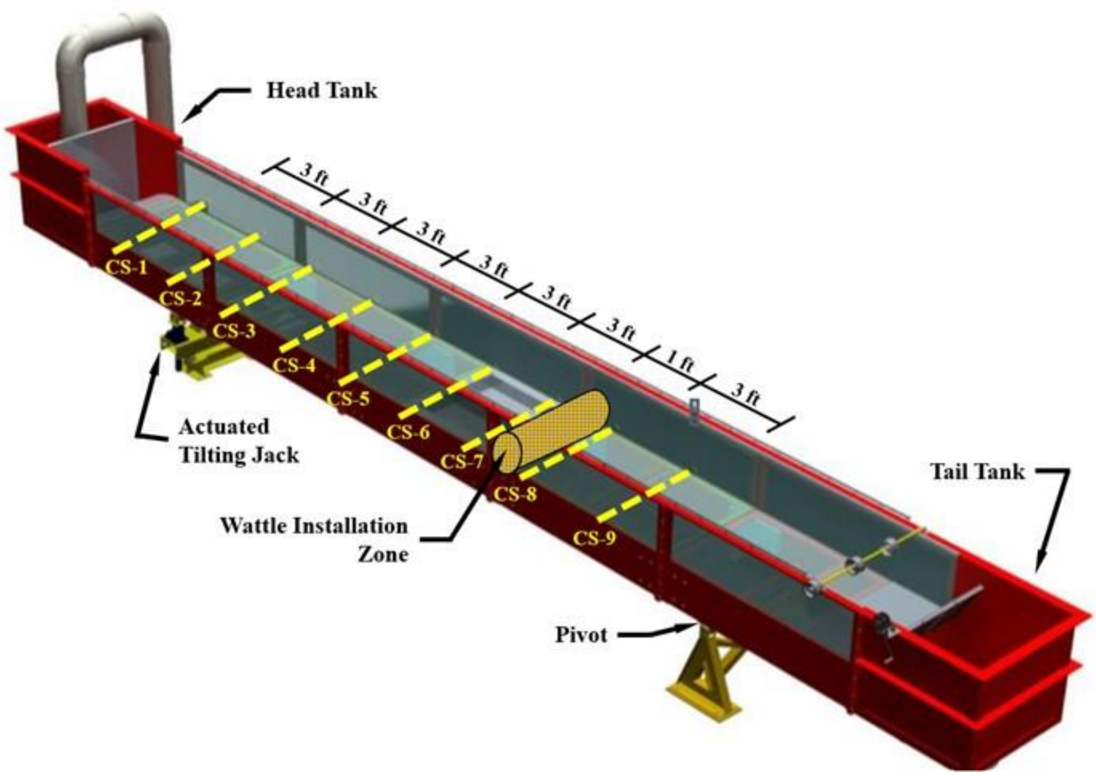
7.2 METHODOLOGY

This study used data collected at Iowa State University's Larry Buss Hydrology Laboratory to determine performance variations of wattle practices subjected to variable flow and slope tests. A series of flume experiments were performed to evaluate eight wattle types that included different matrix media material, containment mesh, and media density. For each wattle type, three replicable test series were performed. Each series of tests were performed by introducing flow at 4 incremental flow rates across 3 channel slopes, resulting in a total of 36 tests per wattle type.

7.2.1 Test Flume

The state-of-the-art flume system used during this study is shown in Figure 7.1a.

(a) Iowa State University flume



(b) Flume cross-sectional schematic

Figure 7.1. Test apparatus

The structural steel and tempered glass flume measures 38 ft (11.6 m) in length, with a uniform 4 ft (1.2 m) width by 2 ft (0.61 m) height cross-section. Flume slope can be adjusted between 0% and 5.0% through an actuated tilting jack mechanism. An adjustable tailgate allows for variable flow depths to be achieve based on user-defined discharge characteristics. Flow is introduced into the flume from a 9,906 gal (37,500 L) supply sump using a two-stage mixed vertical turbine pump powered by a 60 horsepower motor that has a peak flow capability of approximately 8.80 ft^3/s ($0.25\ m^3/s$). Flow is pumped through a 12 in. (300.5 cm) flow line that discharges into the flume's head tank. Flow rates are measured with an electromagnetic flow meter and additional manual flow rate control is provided by a variable frequency drive and electronically actuated butterfly valve.

7.2.2 Channelized Flow Tests

Wattle evaluations were conducted using a tiered slope and flow regime that introduced clean water at 0.25, 0.75, 1.25, and 2.00 ft^3/s (0.007, 0.021, 0.035, and 0.057 m^3/s) at slope grades of 3.50%, 4.25%, and 5.00%. Flow duration for each tier was approximately 3.5 minutes or until flow equilibrium (i.e., constant subcritical flow length measured from wattle center to hydraulic jump) was achieved within the flume. This evaluation process was selected to allow wattle performance to be analyzed with respect to slope and flow rate. As shown in Figure 7.1b, nine cross-sectional (CS) locations were established prior to testing for data collection, seven upstream and two downstream of the installed wattle. Cross sections were spaced 3 ft (1 m) apart, measuring from the upstream and downstream face of the installed wattle. These cross sections were used to obtain water depth measurements during testing.

7.2.3 Wattle Installation

The flume was designed to be adaptable to a wide assortment of testing scenarios that may arise within multiple engineering disciplines. A key design element that allows for such testing variations is the recessed sample tray located along the bottom of the flume approximately 20 ft (6.1 m) from the upstream head tank. Depending on specimen characteristics and dimensions, custom inserts can be constructed out of high density polypropylene sheeting and placed flush within the bottom of the flume to secure test specimens. For this study, a custom insert was constructed that allowed wattles to be installed using a staggered rope securement system that alternated from upstream to downstream of the installed wattle. This method of wattle securement mimicked field installations that provide intimate contact between the wattle and ground surface, thus minimizing flow bypass underneath the wattle during testing. Wattle specimens were cut slightly longer than the width of the flume so that sufficient fill material would be available within the ends of the wattle containment mesh to minimize flow bypass between the wattle and tempered glass side walls.

7.2.4 Control Test: Impermeable Barrier

Based on findings reported by Donald et al.(2013) that suggest wattle performance is optimized when upstream subcritical flow length is maximized and the energy grade line slope is minimized, a control test was conducted that analyzed the hydraulic performance of an impermeable weir installed in lieu of a wattle. The impermeable weir was constructed of 0.75 in. (30 cm) thick plywood material and was installed in the same manner as wattles and had an installation height of 0.75 ft (0.23 m), which was the average installation height of all wattles tested. Results obtained from the control experiments indicated the optimum hydraulic performance achievable for each wattle tested and provided a threshold from which wattle comparisons could be conducted.

7.2.5 Evaluated Wattles

Each wattle tested was installed using the rope securement system with three replicated tests conducted on each wattle. Eight wattles that were manufactured with five different fill material matrixes were evaluated as part of this study, which included excelsior wood fiber, wheat straw, recycled synthetic fiber, chipped wood, and miscanthus fiber. Four types of containment mesh were also evaluated to include natural netting, synthetic netting, synthetic socking, and polyester socking. The primary physical difference between netting and socking is that netting has a substantially larger apparent opening size (i.e., >0.5 in. [1.27 cm]) than socking (i.e., <0.1 in. [0.25 cm]). Table 7.1 provides a summary of the physical property descriptions for each of the eight wattles tested.

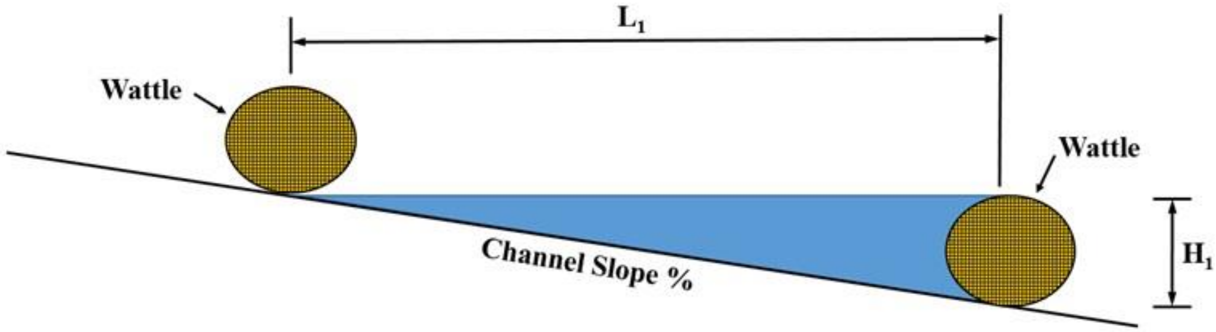
Table 7.1. Tested wattle properties

Wattle matrix media	Test	Containment mesh	Measured diameter, ft (m)	Installed height, ft (m)	Weight, lb (kg)	Installed density, lb/ft (kg/m)
Excelsior fiber	1	Natural netting	1.0 (0.30)	0.71 (0.22)	9.4 (4.26)	2.4 (3.57)
	2	Natural netting	0.9 (0.27)	0.70 (0.21)	8.8 (3.99)	2.2 (3.27)
	3	Natural netting	0.8 (0.24)	0.65 (0.20)	8.6 (3.90)	2.2 (3.27)
Wheat straw	1	HDPE netting	1.0 (0.30)	0.79 (0.24)	8.6 (3.90)	2.2 (3.27)
	2	HDPE netting	1.0 (0.30)	0.68 (0.21)	8.4 (3.81)	2.1 (3.13)
	3	HDPE netting	1.0 (0.30)	0.78 (0.24)	8.8 (3.99)	2.2 (3.27)
Wheat straw	1	HDPE sock	0.9 (0.27)	0.79 (0.24)	9.6 (4.35)	2.4 (3.57)
	2	HDPE sock	0.8 (0.24)	0.68 (0.21)	7.8 (3.54)	2.0 (2.98)
	3	HDPE sock	0.8 (0.24)	0.78 (0.24)	6.8 (3.08)	1.7 (2.53)
Standard coconut coir	1	Natural netting	1.0 (0.30)	0.85 (0.26)	22.0 (9.98)	5.5 (8.18)
	2	Natural netting	1.0 (0.30)	0.80 (0.24)	21.4 (9.71)	5.4 (8.04)
	3	Natural netting	1.0 (0.30)	0.85 (0.26)	25.0 (11.34)	6.3 (9.38)
Premium coconut coir	1	Natural netting	1.0 (0.30)	0.85 (0.26)	24.2 (10.98)	6.1 (9.08)
	2	Natural netting	1.0 (0.30)	0.80 (0.24)	26.6 (12.07)	6.7 (9.97)
	3	Natural netting	1.0 (0.30)	0.90 (0.27)	25.4 (11.52)	6.4 (9.52)
Wood chips	1	Polyester sock	1.1 (0.34)	0.80 (0.24)	77.8 (35.29)	19.5 (29.02)
	2	Polyester sock	1.0 (0.30)	0.70 (0.21)	60.4 (27.40)	15.1 (22.47)
	3	Polyester sock	1.1 (0.34)	0.80 (0.24)	73.4 (33.29)	18.4 (27.38)
Synthetic fiber	1	HDPE netting	1.0 (0.30)	0.74 (0.23)	8.2 (3.72)	2.1 (3.13)
	2	HDPE netting	1.0 (0.30)	0.77 (0.23)	8.4 (3.81)	2.1 (3.13)
	3	HDPE netting	1.0 (0.30)	0.85 (0.26)	8.2 (3.72)	2.1 (3.13)
Miscanthus fiber	1	Polyester sock	1.1 (0.34)	0.78 (0.24)	53.8 (24.40)	13.5 (20.09)
	2	Polyester sock	1.1 (0.34)	0.82 (0.25)	50.6 (22.96)	12.7 (18.90)
	3	Polyester sock	1.0 (0.30)	0.74 (0.23)	47.4 (21.50)	11.9 (17.71)

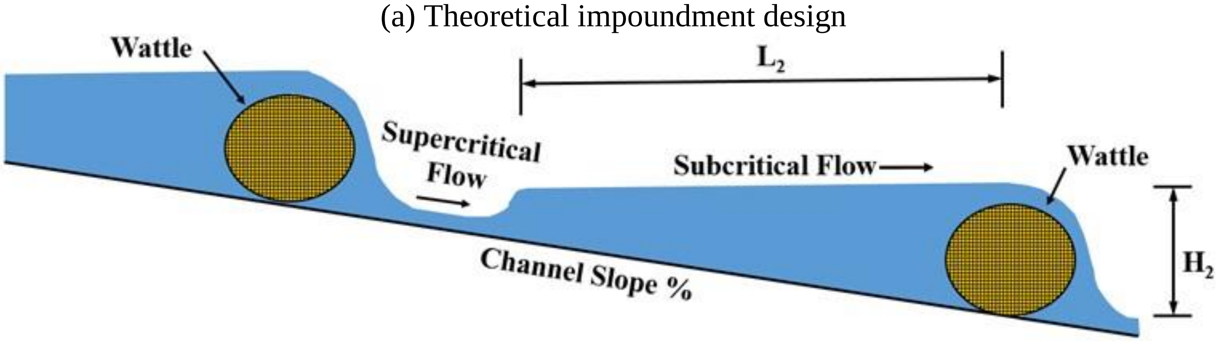
Note: HDPE = high density polyethylene

7.2.6 Evaluation Criteria

Each wattle tested was evaluated against the control test that maximized upstream subcritical flow length and minimized channelized flow velocity. The criteria used for evaluation were (1) impoundment depth ratio, (2) subcritical length ratio, (3) independent wattle performance as a function of flow rate and slope using ANOVA, (4) statistical relevance between each matrix media material tested and the control test, and (5) effects on media density due to water absorption. Impoundment depth and subcritical length ratios were determined by comparing measured maximum impoundment depth (H_2) and subcritical length (L_2) values to theoretical depth (H_1) and length (L_1) values calculated based on wattle installation height and channel slope. Theoretical depth and length values are typically calculated during the design of an SWPPP to identify spacing distances for wattles installed in channelized flows. Measured values were obtained during flume testing by measuring (1) water depths directly upstream of the installed wattle and (2) subcritical impoundment lengths that formed between the upstream face of the wattle and hydrologic jump. The developed ratios help normalize the relationship of measured value to theoretical value and allow comparisons to be made between wattles. Figure 7.2 illustrates the difference between theoretical impoundment depth (H_1) and measured impoundment depth (H_2), as well as theoretical impoundment length (L_1) and measured impoundment length (L_2).



(a) Theoretical impoundment design



(b) Observed dynamic impoundment

Figure 7.2. Wattle flow characteristics

Equations 1 and 2 define how depth and length ratios were calculated for each test. Results from ratio calculations indicate percent of theoretical design obtained during testing.

$$Depth\ Ratio = \frac{H_2}{H_1} \times 100\% \qquad (1)$$

$$Length\ Ratio = \frac{L_2}{L_1} \times 100\% \qquad (2)$$

where,
H_1 = theoretical impoundment depth (ft or m)
H_2 = measured impoundment depth (ft or m)
L_1 = theoretical impoundment length (ft or m)
L_2 = measured impoundment length (ft or m)

ANOVAs were conducted on ratio results determined for each manufactured wattle to identify if a significant performance variation occurred over the range of flow rates and slopes implemented during testing or if performance remained statistically unchanged. This analysis identified how effective a particular wattle performed over a wide range of treatment scenarios. Statistical relevance between wattle matrix media was achieved by developing a traditional multiple linear regression model. Wattle media materials (e.g., excelsior, wheat straw, synthetic fiber, wood chips, coconut coir, and miscanthus grass) were coded into independent binary variables that took values of 1 or 0, depending on whether a particular test includes a specific media material. Dependent variables were coded as average water depth (y) to specific energy (E) ratios, which ranged between 0.49 and 0.99. Donald et al. (2016) identified the y/E ratio to be a non-subjective performance metric to determine kinetic energy reductions of ditch check practices. Specific energy (E) is the cumulative sum of potential and kinetic energy per unit weight of water upstream of a wattle practice. Equation 3 defines the specific energy calculation.

$$E = y + \frac{v^2}{2g} \tag{3}$$

where,
E = specific energy (ft or m)
y = water depth (ft or m)
v = flow velocity (ft^2/s or m^2/s)
g = 32.2 (ft/s^2) or 9.81 (m/s^2)

The multiple linear regression model independently evaluates the relative impacts of each media material variable on reducing kinetic energy. The model provides regression coefficients that indicate the extent each independent variable (i.e., matrix media material) affects the dependent variable (i.e., y/E), as well as the significance of the affect. Model results provided insight into the most effective matrix media material for reducing kinetic energy. The regression model equation is defined in equation 4.

$$f(x) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_x \tag{4}$$

where,
$f(x)$ = dependent variable (i.e., y/E)
β_0 = coefficient intercept
β_i = ordinary least squares coefficients
x_i = independent variables (i.e., matrix media material)

Water absorption analyses were conducted on 1.76 oz (50 g) samples of each media material to determine the change in weight due to water absorption. Bouasker et al. (2014) conducted similar experiments that determined water absorption capacity for natural straw fibers. The methodology outlined within this study was used to determine the absorption capacity of each media material. The experimental process calls for each of the samples to be oven-dried, cooled, and weighted. Dry samples are then saturated by submerging in water for 12 hours at room temperature. Each sample is then drained to remove excess water and weighed to determine saturated weight. Using dry and saturated weights (Cruz et al. 2017), percent weight increase was calculated using equation 5.

$$Weight\ Increase = \frac{W_{Sat} - W_{Dry}}{W_{Dry}} \times 100\% \quad (5)$$

where,
W_{Sat} = saturated weight (oz or g)
W_{Dry} = oven dry weight (oz or g)

7.3 RESULTS AND DISCUSSION

The following is a summary of results and comparisons made from hydraulic experiments conducted on commercially available wattles. For each manufactured wattle, three individual installations were subjected to the tiered flow and slope testing regime. Hydraulic performance results obtained from the impervious weir control tests were used to identify a performance target window threshold for each manufactured wattle. Throughout the investigation, precedence was placed on identifying how wattle fill material performs at various flow rates and slopes, as well as how various fill materials affect overall hydraulic performance when compared to optimal control measures that minimize hydraulic kinetic energy.

7.3.1 Wattle Ratio Analysis

Depth and length ratios were calculated for each individual test conducted on the selected manufactured wattles and impervious weir. In total, 36 data points per wattle were calculated and plotted to identify overall performance characteristics. Data points were calculated for the impervious weir and used to establish a performance target window (PTW) for comparing the performance of each manufactured wattle. The PTW signifies the optimum performance range achievable and was determined by identifying the outer limits that encompassed all impervious weir ratio data points plotted. Simply put, the more data points that fall within the PTW the more effective the wattle is at reducing upstream supercritical flows. It should be noted that the results presented herein are based on a wattle installation strategy that promotes intimate contact between the wattle and underlying surface, thus minimizing flow bypass. Additionally, tested wattle installations were not subject to undermining or downstream scour caused by hydrodynamic forces that are commonly observed in field installations (Perez et al. 2015). To achieve the presented results in field installations, improved installations strategies above manufacturer installation recommendations would likely need to be employed.

Overall average depth and length ratios calculated for each practice are presented in Table 7.2, as well as the percent difference between the control test and wattle evaluated.

Table 7.2. Experimental results

Class	Wattle type	Avg. depth ratio[a]	Depth difference[b]	Avg. length ratio[a]	Length difference[b]
na	Control (impervious weir)	122%	na	96%	na
1	Excelsior fiber	94%	26%	61%	45%
2	Wheat straw w/ netting	102%	18%	72%	29%
	Wheat straw w/ sock	106%	14%	75%	25%
3	Std. coconut coir	104%	16%	80%	18%
	Prem. coconut coir	104%	16%	81%	17%
	Wood chips	110%	10%	83%	15%
	Synthetic fiber	109%	11%	82%	16%
4	Miscanthus	121%	1%	96%	0%

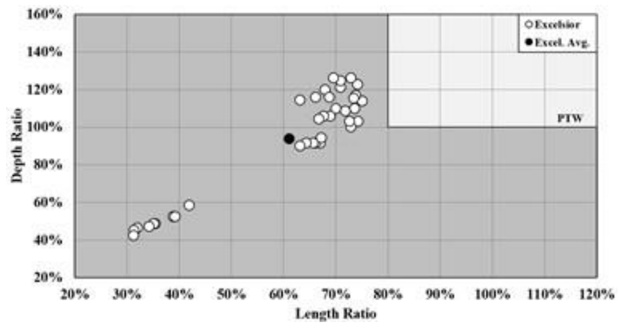
Note: na = not applicable; [a] = percent of theoretical design obtained during testing; [b] = percent difference between control and wattle.

Results suggest that four wattle classifications (e.g., Class 1, 2, 3, and 4) can be identified from the ratios, with Class 1 being the least effective and Class 4 being the most effective at reducing supercritical flows. Each class is defined by a percent difference range for depth and length ratios and can be defined as follows:

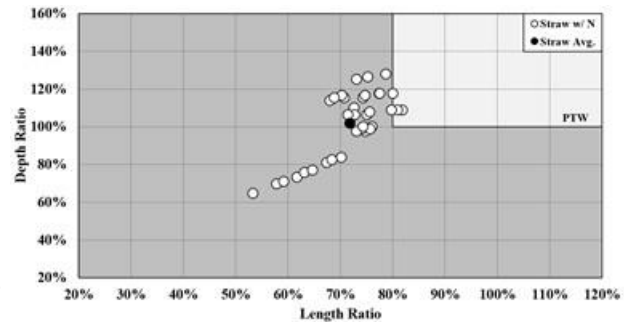
- Class 1 = depth difference >20% and length difference >30%
- Class 2 = depth difference 10%–20% and length difference 20%–30%
- Class 3 = depth difference 10%–20% and length difference 10%–20%
- Class 4 = depth difference <10% and length difference <10%

Based on this classification system, excelsior fiber wattles fall into Class 1 and were the least effective with percent differences of 26% and 45% for depth and length, respectively. Data suggest wheat straw wattles fall into Class 2 and that coconut coir, wood chips, and synthetic fiber wattles fall into Class 3. As indicated above, the key difference between Class 2 and Class 3 wattles is the wattle's ability to increase impoundment length while minimizing changes to impoundment depth. Class 4 wattles top out the classification system and indicate subcritical flows created by wattles are approaching optimum depth and length ratios. Miscanthus wattles were the only practices tested that fell into this classification with an average depth and length percent difference from the control of 1% and 0%, respectively.

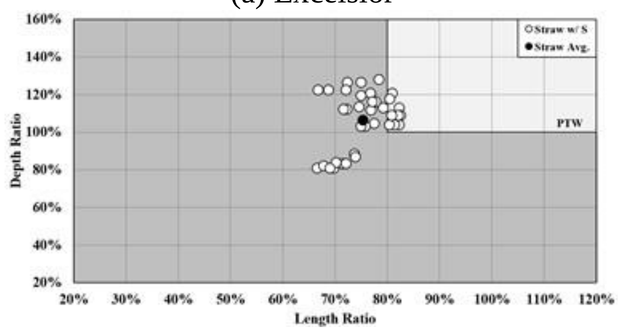
Figure 7.3 illustrates ratio data point distribution (i.e., white data points), average ratio data points from Table 7.2 (i.e., black data point), and data point relationships to the PTW (i.e., light gray window in the top right corner of each plot) for each wattle evaluated.



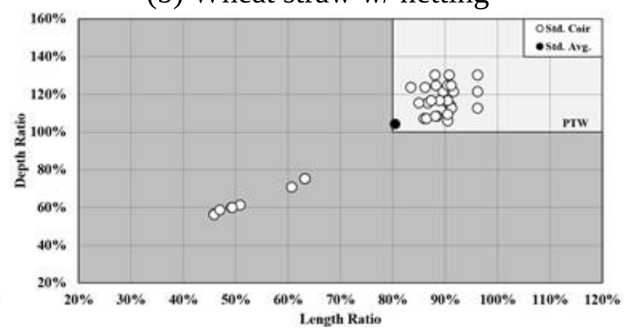
(a) Excelsior



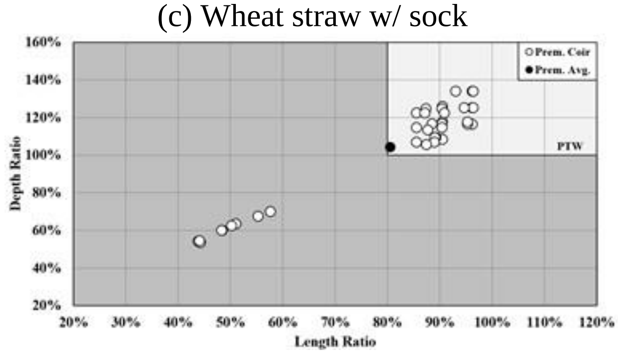
(b) Wheat straw w/ netting



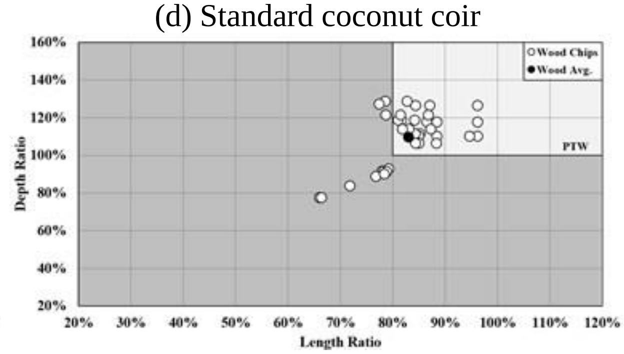
(c) Wheat straw w/ sock



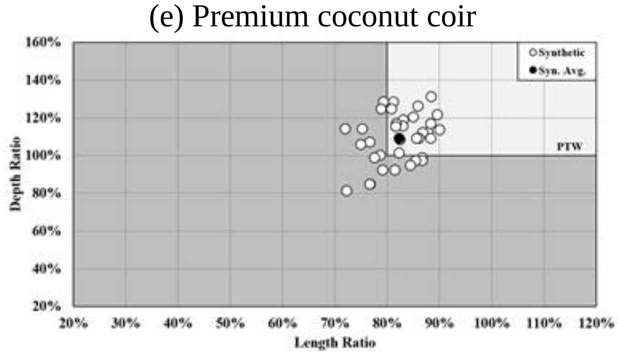
(d) Standard coconut coir



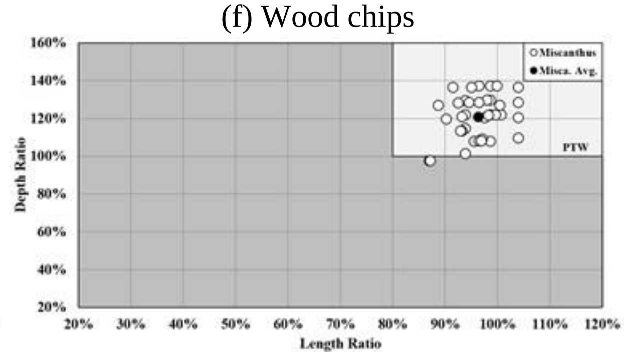
(e) Premium coconut coir



(f) Wood chips



(g) Synthetic fiber

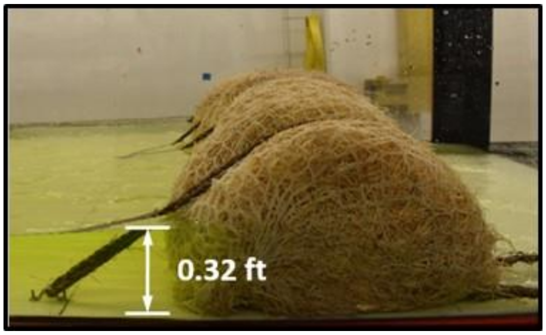


(h) Miscanthus

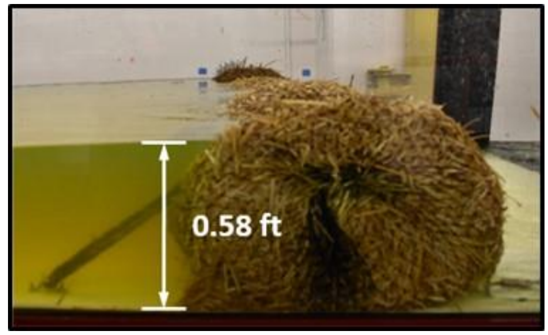
Figure 7.3. Comparison of depth ratio to length ratio

From the plots, it is evident that the majority of data points for excelsior fiber and wheat straw wattles are located outside the limits of the PTW. Plots for coconut coir, wood chip, and synthetic fiber wattles suggest that hydraulic performance is improved from those of excelsior fiber and wheat straw wattles with substantially more data points within the PTW. Finally, the miscanthus plot indicates that only two of the 36 ratio data points fell outside the limits of the

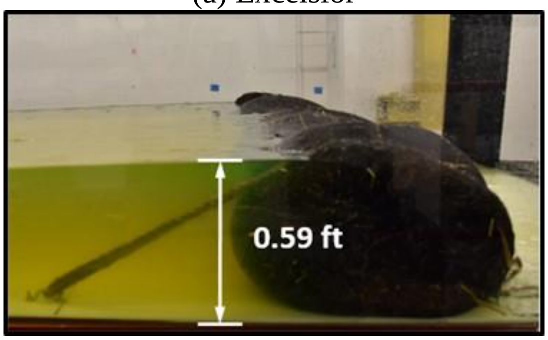
PTW, further suggesting superior performance capabilities. Figure 7.4 provides a comparison of impoundment depths created by each wattle when subjected to a flow rate of 0.25 ft^3/s (0.007 m^3/s) at a longitudinal slope of 5.00%.



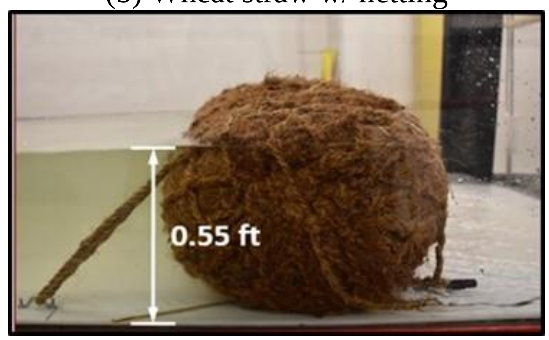
(a) Excelsior



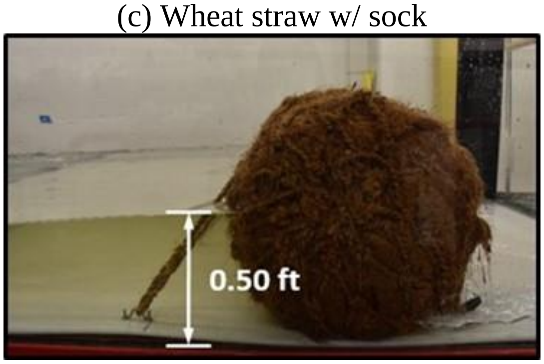
(b) Wheat straw w/ netting



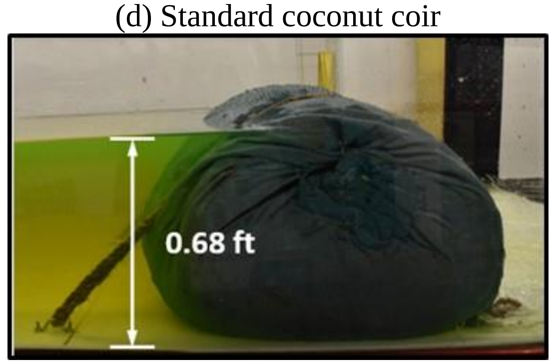
(c) Wheat straw w/ sock



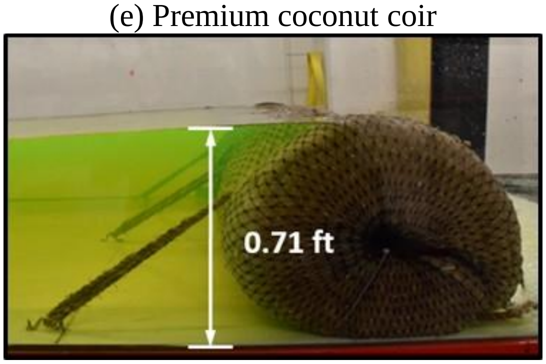
(d) Standard coconut coir



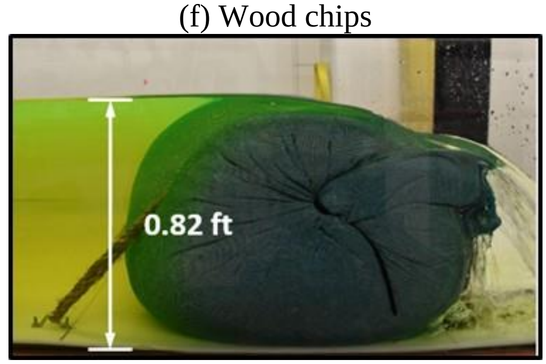
(e) Premium coconut coir



(f) Wood chips



(g) Synthetic fiber



(h) Miscanthus

Figure 7.4. Impoundments obtained at a constant flow rate of 0.25 ft^3/s (0.007 m^3/s), 5.00% slope grade

7.3.2 Independent Wattle Analysis

Two-way ANOVA tests were performed on the normalized depth and length ratios from each independent test associated with each wattle type to evaluate the effects on performance as flow rate and longitudinal slope change. This analysis was conducted to determine if a wattle is capable of performing statistically equivalent over a range of testing scenarios. For example, a wattle with performance results statistically equivalent to one another would be effective at treating a variety of storm events (or flow rates) typically seen on a construction site as opposed to a single design storm. The null hypothesis for the analysis was that flow rate and longitudinal slope do not affect hydraulic performance (i.e., impoundment depth and length ratios) of the wattle. A significance level of 0.05 was used to determine significance. P-values less than 0.05 indicate the null hypothesis is rejected and wattle performance is significantly affected by changing flow rates and longitudinal slopes. In total, eight ANOVA tests were performed to evaluate each wattle independently.

Results for ANOVA tests are shown in Table 7.3.

Table 7.3. Wattle ANOVA analyses

Wattle	F	F critical	P-value
Excelsior	8.977	1.757	<0.001
Straw w/ netting	2.988	1.757	0.001
Straw w/ sock	2.648	1.757	0.002
Standard coconut coir	17.134	1.757	<0.001
Premium coconut coir	22.573	1.757	<0.001
Wood chips	4.044	1.757	<0.001
Synthetic	1.046	1.757	0.447
Miscanthus	1.378	1.757	0.174

Results indicated that there were significant differences between performance values for excelsior, wheat straw, coconut coir, and wood chip wattles over the course of the tiered testing regime. However, no significant differences were indicated for synthetic and miscanthus wattles. These statistical findings correlate to the respective plots presented in Figure 7.3 and provide additional support to the performance evaluations. These finding suggest that synthetic fiber and miscanthus wattles would be the most effective practices to install in field applications with inconsistent slope topography while also being subjected to variable flow rates throughout the life cycle of the construction project.

7.3.3 Wattle Matrix Media Analysis

To statistically test the effects of different wattle media, a multiple linear regression model was developed. In total, seven independent variables (i.e., media) were considered in the analysis: (1) impervious, (2) excelsior fiber, (3) wheat straw, (4) synthetic fiber, (5) wood chips, (6) coconut coir, and (7) miscanthus fiber. For the regression model, the impervious weir was considered the base media, against which each wattle media was compared. Average y/E ratios, as used by

Donald et al (2016), were selected as the dependent variable within the model. Average y/E ratios can range between 0 and 1, with 1 being the optimum ratio. Results of the analysis, along with statistical significances, are shown in Table 7.4. The R^2 value for the model was 0.43.

Table 7.4. Wattle media regression analysis

	Statistical significance	
Matrix media material	**Coefficients**	**P-value[a]**
Base (impervious weir)	0.88	na
Excelsior fiber	-0.27	<0.001
Wheat straw	-0.15	<0.001
Synthetic fiber	-0.07	0.064
Wood chips	-0.06	0.141
Coconut coir	-0.04	0.192
Miscanthus fiber	-0.02	0.596

Note: na = not applicable; [a] = comparison to effects of impervious weir at 95% confidence interval and p-value <0.05.

Based on the statistical significance calculated by the model, the following conclusions were drawn: (1) each media material reduced the y/E ratio relative to the impervious weir, evident by the negative coefficients (i.e., negative coefficients indicate performance reductions), which was expected in the analysis; (2) coefficients for excelsior fiber and wheat straw are statistically significant at a 95% confidence level, as indicated by p-values less than 0.05, thus indicating significant reductions in performance compared to the impervious weir; (3) coefficients for synthetic fiber, woods chips, coconut coir, and miscanthus fiber are not statistically significant, as indicated by p-values greater than 0.05, thus indicating negligible reductions in performance and comparable performance to the impervious weir; (4) excelsior fiber had the most impact on performance reduction; and (5) miscanthus fiber had the least impact on performance reduction. These statistical conclusions correlate with the wattle ratio analysis in that excelsior wattles fell into the lowest performance classification and miscanthus wattles were in the highest classification. When comparing each of the measured performances to the impervious weir, it is evident that each matrix media material facilitates hydraulic performance reductions.

7.3.4 Wattle Matrix Media Absorption Analysis

Donald et al. (2013) proposed that hydraulic performance of wattle ditch checks can be correlated to matrix media density and further suggested that performance improves as density increases. Based on these suggestions, analyses were conducted to determine percent increase in weight due to water absorption and how these changes may correlate to the statistical analyses present above. Results from the experiments are shown in Table 7.5, as well as the average installed wattle weights (i.e., average wattle density as presented in Table 7.1) and calculated install saturated density (i.e., average install density multiplied by the average weight increase).

Table 7.5. Wattle media absorption analysis

Matrix media material	Avg. weight increase[a], %	Weight increase std. dev.[b], %	Avg. install density[c], lb/ft	Calculated install saturated density[d], lb/ft
Excelsior fiber	253	11	2.2	5.7
Wheat straw	484	24	2.1	10.1
Synthetic fiber	589	143	2.1	12.2
Wood chips	134	5	17.6	23.6
Coconut coir	271	24	6.0	16.3
Miscanthus fiber	281	7	12.7	35.5

Note: [a] = average weight change of 50 g of media material due to water absorption; [b] standard deviation of three observations; [c] = average dry density of wattles as presented in Table 7.1 ; [d] = average calculated saturated density based on installed density values.

While results suggest that wattle densities do correlate to hydraulic performance as suggested by Donald et al. (2013), results also suggest that a more effective means for predicting hydraulic performance can be correlated to saturated density.

7.4 CONCLUSIONS

Currently, there is a lack of scientifically backed data that analyzes the hydraulic performance of E&SC wattles using normalized methodologies. Performance capabilities readily accessible within industry are typically published by product manufacturers and can often be misleading and difficult to compare directly. Thus, this research sought to evaluate the hydraulic performance of eight manufactured wattles and identify the capabilities of each. To determine the effect of wattle matrix media material on performance, each wattle was tested using a tiered testing regime in a state-of-the-art flume. Using an innovative data analysis methodology, normalized data ratios were calculated, which facilitated direct comparisons between performance data.

The information obtained throughout this study suggest that wattles fall into four distinct classes. Class 1 wattles are those that are least effective at sustaining subcritical flows and have depth and length ratio percent differences less than 20% and 30%, respectively. Results suggest that excelsior wattles fall into this class. The performance of these wattles can be directly related to the extensive flow-through rate permitted to pass through the matrix media material during hydraulic loading. Class 2 and 3 wattles provide improved subcritical flows above those of Class 1 with depth percent differences ranging from 10%–20% and length percent differences ranging from 20%–30% for Class 2 and 10%–20% for Class 3. Test results indicate that wheat straw wattles fall into Class 2 and that coconut coir, wood chips, and synthetic wattles fall into Class 3. Class 4 wattles have proven to be the most affective at maximizing subcritical flows. The only practice that achieved this classification was the miscanthus wattle with a depth and length percent difference less than 10%.

To determine if performance variations occurred over the course of the tiered testing regime, ANOVA analyses were conducted on performance ratios for each manufactured wattle. The statistical results indicated that significant variations occurred in performance during excelsior, wheat straw, coconut coir, and wood chip wattle testing but not during synthetic and miscanthus wattle testing. These findings suggest that synthetic and miscanthus wattles would reliably create and sustain subcritical flows in a wide array of installation scenarios. The multiple linear regression model indicated that each wattle matrix media tested reduced the average y/E ratio; however, the only statistically significant reductions were associated with excelsior fiber and wheat straw matrix media materials.

Results presented in this chapter provide normalized comparisons that illustrate performance variations of eight manufactured wattles. The analyses presented can assist government agencies and designers in selecting wattle practices that best mediate runoff based on site-specific constraints. While testing was conducted in a controlled laboratory setting, the experimental protocol was designed in a manner that would closely mimic field installation conditions and performance expectations. However, further investigations are needed to assess performance during sediment-laden flow conditions. Future research efforts should emanate from this study that continue developing the overall body of knowledge by evaluating innovative wattle performance-enhancing strategies.

8 CONCLUSIONS

8.1 INTRODUCTION

Under the NPDES program, the Iowa DOT is required to develop a stormwater pollution prevention plan (SWPPP) for all construction activities under the permit. Current SWPPPs, which encompass the design, installation, and maintenance of E&SC practices, had potential for improvements. Many of the current E&SC practices had not been formally evaluated for field performance prior to this project.

The objective of this research project was to enhance the E&SC design guidance available to the Iowa DOT. The research team outlined three objectives to meet this goal including (1) compile and catalog E&SC practices that can be used on Iowa DOT construction projects, (2) install and evaluate selected practices on active Iowa DOT construction sites to determine their effectiveness in reducing erosion and capturing sediment, and (3) develop implementable improvements for Iowa DOT E&SC design guidance.

This study included a comprehensive literature and nationwide SWPPP review. Findings from these reviews provided a basis for enhanced practice modifications. Practice selection was based on frequency of use, agency interest, and potential for improved performance. Standard and modified practices were then field monitored for water quality improvements, erosion reduction, sedimentation potential, and structural integrity. Practices included in the review and monitoring included various ditch checks, perimeter controls, and detention practices. In addition to field monitoring, complementary laboratory testing was conducted to evaluate the hydraulic performance of wattles.

8.2 DITCH CHECK CONCLUSIONS

The three ditch check types included in this project were (1) silt fence ditch checks, (2) wattle ditch protection, and (3) rock check dams; however, only standard and modified silt fence ditch checks and wattle ditch protections were field tested.

8.2.1 Silt Fence Ditch Checks

Ditch checks were inspected weekly between July 26, 2019 and December 10, 2019. The standard silt fence installation was specified to be sliced or trenched at least 12 in. (30.5 cm) into the ground, extend 19 in. (48.3 cm) above ground, and attach to a T-post with zip ties. T-posts were to be spaced 4 ft (1.2 m) on-center. Modifications to the silt fence ditch check installation included a wire reinforcement backing, V-shaped installation, and dewatering weir. Modified 1 and 2 only differed by trenching and slicing, respectively. In total, there were 4 installation methods installed 3 times each for repeatability, totaling 12 monitored silt fence ditch checks.

The modified silt fence installation with the highest sediment retention had 4.0 times the sediment accumulation of the standard method and included a V-shaped installation, wire reinforcement, dewatering weir, and geotextile trenched into ground. A second modification had

2.5 times the sediment accumulation of the standard method and included the V-shaped installation, wire reinforcement, and dewatering weir, but had the geotextile sliced into ground.

By the final inspection, all three of the standard installations had experienced post deflection and two of three exhibited scour. Similarly, all three standard with proprietary material installation (SF-DC-SM) showed post deflection and two of three exhibited undercutting. Modified 1 and Modified 2 performed similarly with no post deflection, increased sedimentation, minimized channel erosion, and eliminated undercutting. The average sediment accumulation for Modified 1 was 4.0 times that of the standard installation and Modified 2 was 2.5 times that of the standard installation based on the stake survey and measurements. Some scour was recorded for both Modified 1 and 2 at the vertex of the dewatering weir.

It is recommended to adopt the wire reinforcement and dewatering weir to minimize T-post deflection and subsequent undercutting. Based on field observations, further recommendations include the addition of an energy dissipater, such as a geotextile splash pad downstream of the weir to minimize scour and trenching the silt fence geotextile into the ground due to maneuvering capabilities of the traditional slicing machine. Researchers understand the installation preference to slice silt fence practices into the ground and suggest testing a straight or curved, sliced installation with dewatering weir and reinforcement in future testing. By eliminating the V-shaped installation, silt fence geotextiles could be installed using a slicing machine. The weir would alleviate hydrostatic pressure applied to T-posts; however, impoundment patterns and sedimentation potential are unknown.

8.2.2 Wattle Ditch Protection

The standard wattle detail specified staking through the wattle with 1 in. by 1 in. (2.5 cm by 2.5 cm) wooden stakes every 2 ft (0.6 m). Modifications included non-destructive teepee staking and the addition of a special ditch protection underlay. Wood chip, excelsior, straw, and switch grass wattles were monitored in the field. There was a total of 30 wattles installed and monitored on-site.

Due to the time of practice installation and seeding coinciding, the wattle channels had rapid vegetation growth. The wood chip wattles were installed directly downstream of the silt fence ditch checks and had the least growth of all the monitored channels. Researchers considered the wood chip channel closest to representing a channel during grading and primarily used this channel for comparing installation techniques. The modified installation, which included a special ditch protection mat underlay sod stapled to the channel bottom and nondestructive teepee staking, captured 13.2 times more the sediment of the standard installation. By the final inspection, all five standard installations had undercut. The modified wattles decreased upstream channel erosion and increased the sedimentation potential. After 12 in. (30.5 cm) of rainfall, the monitored modified wattles appeared stable. Flow bypass was starting to occur due to deposition patterns, but that could be eliminated by extending the wattle up the side slopes.

Based on these field observations, it is recommended to adopt teepee staking and special ditch protection underlay; however, the downstream length of the special ditch protection mat should be increased to avoid downstream scour. The special ditch protection, a natural fiber excelsior matting, was used as an underlay by agency request; however, other underlay possibilities such as a geotextile or turf reinforcement mat should be considered in future testing to eliminate tenting and increase intimate ground contact.

In addition to installation technique, several wattle fills were assessed for performance efficiency. Field monitoring could not be used to compare different wattle fill media due to the varying channel conditions in which they were installed, so flume testing was conducted to evaluate the hydraulic performance of several wattle types. Average depth and length ratios were calculated for each tested wattle in addition to the percent difference between the wattle and an impervious weir. Four wattle classifications (e.g., Class 1, 2, 3, and 4) were identified from the ratios, with Class 1 being the least effective and Class 4 being the most effective at reducing supercritical flows. From flume testing, straw wattles met Class 2; coconut coir, wood chips, and synthetic fiber wattles fall into Class 3; and miscanthus fiber would qualify as Class 4.

8.2.3 Rock Check Dams

The standard rock check dam specifies a 6 in. (15.3 cm) channel excavation, lined with a geotextile, and stacked Class D revetment with 1.5:1 (H:V) side slopes. Proposed modifications included a geotextile underlay and overlay pinned and eliminating the channel excavation. Rock check dam performance was intended to be evaluated on structural integrity, sedimentation, and impoundment, similar to the other ditch protection types. However, due to grading and subcontractor activities, the rock check dams were not installed for evaluation in this study. Prior installations of rock check dams on Tama US 30 were inspected. Channel erosion and piping was observed. Researchers recommend the addition of a geotextile overlay to slow flow velocity and decrease channel erosion and to ensure the detailed underlay is properly installed.

Future rock check dam testing should assess the performance impacts of a geotextile overlay, geotextile underlay, increased channel excavation to key the rock check dam into ground, and the cross-sectional geometry in which the check dam is installed.

8.3 SEDIMENT BARRIERS

In total, 21 silt fence perimeter control installations were monitored. Three installation methods were tested at both 8 ft (2.4 m) T-post spacing and 5 ft (1.5 m) T-post spacing, in addition to a standard installation with manufactured material. There were seven total installation methods, installed three times each for repeatability.

Sediment barrier performance was assessed with weekly site inspections. By the final inspection, two of the three standard silt fence perimeter control installations (SF-PC-S) had failed due to T-post deflection leading to overtopping. Similarly, the standard installation with belted material (SF-PC-SM) had two of the three installations fail, one due to undercutting and another due to T-post deflection leading to overtopping. The primary observed deficiency in the standard installation was T-post deflection leading to overtopping failure.

It is recommended to adopt either the wire reinforcement at 8 ft (2.4 m) spacing or decreasing spacing to 5 ft (1.5 m) to aid in the structural integrity and offset the silt fence material 6 in. (15.3 cm) from the post. In addition to these modifications, it is recommended to decrease the length of the silt fence segments and implement J-hooks or C-configurations to reduce the load on low points of the silt fence. Researchers suggest testing the performance of a wooden stake system to replace the steel T-posts to decrease cost.

8.4 DETENTION PRACTICES

Temporary sediment control basins were evaluated for water quality improvements. In the fall of 2018, a single basin was monitored, and monitoring continued on basins in a series system throughout the summer of 2019. A treatment ratio was calculated to compare turbidity at discharge to turbidity at inflow; values under 1.0 indicated water quality improvements and above 1.0 indicated decline. All monitored basins commonly had performance efficiencies above the threshold of 1.0, indicating a decline in water quality after residence in the basins. In the single basin, turbidity increased by an average of 92 NTUs after residence in the basin, whereas the basins in series provided a turbidity reduction of 215 NTUs in the first basin and 870 NTUs in the second basin. However, the system of basins provided and average reduction of just 9 NTUs. Comparisons of the individual basins had different monitored dewatering mechanisms. After monitoring the DOT's standard temporary sediment control basin, suggested modifications include treatment features such as an upstream forebay, geotextile lining, baffles, and a floating surface skimmer for enhanced performance.

The basins did not have defined inflow channels and received sediment-laden flows from several directions due to lacking sediment barriers along the site perimeter. The channels that existed eroded with each storm, contributing to the incoming sediment load. As the basins dewatered, there was progressive widening due to sloughing of the basin walls and the length-to-width ratio of the basin minimized. Additionally, materials from the sloughed walls would suspend with captured runoff. Due to the lack of maintenance, there was accumulation sediment in the basin, which presumably exceeded the dead storage available, consequently decreasing the available live storage volume during subsequent storm events. In the single basin system, the riser pipe's buoyancy eventually caused the anchoring T-post to dislodge from the basin floor.

Based on water quality results and comparisons, it is recommended to implement a skimmer dewatering system and sizing basins based on the 2 year, 24 hour storm to increase storage volume. In addition, researchers suggest testing treatment features including an upstream forebay, geotextile lining, baffles, and a floating surface skimmer for enhanced performance.

8.5 LIMITATIONS

This study provided researchers and the TAC a strong basis for enhancing E&SC specifications, standard drawings, and design guidance; however, field monitoring during active construction presented several unknown and immeasurable variables including changing grade, thus altering flow patterns and drainage areas, vegetative growth, maintenance, and variability in storm events.

8.5.1 Ditch Checks

Due to site layout and interest in evaluating varying types of ditch checks, practices were installed in several different flow channels, mainly in constructed highway medians. Although similar practices were installed in the same channel for comparison, each practice was subjected to slightly different drainage areas, and thus encountered varying flow patterns and sediment loads. In addition to drainage conditions, channels had different slopes and geometries, which did not allow for cross-comparison of ditch check practices.

Installation and monitoring areas were selected based on the intended summer 2019 grading schedule. Installation was planned for May 2019, but due to contractor schedule, practices were not installed until July 2019. Subcontractors had started to work away from the installation area and temporary stabilization seeding was applied, as required under the NPDES permit. While the vegetative growth stabilized channels, it made data collection and comparisons difficult. The vegetation in the channels impeded the function of the LiDAR scanner by capturing the highest elevation. Data analysis was reliant on field observations, initial survey, and hand measurements of sedimentation at the practices.

8.5.2 Sediment Barriers

Similar to the ditch check practices, site layout required the silt fence perimeter control practices to be installed in various locations. Spanning several hundred feet, each span of silt fence was subject to varying drainage patterns, slopes, sediment loads, and vegetative conditions. Late season installation allowed for thick vegetation to grow. While the vegetative growth stabilized slopes, it impeded the function of the LiDAR scanner. Due to undefined flow patterns, performance evaluations were reliant on aerial and field inspections and lacked numerical backing. Sediment accumulation was approximated from aerial images and GIS surface models. Modes of failure and T-post deflection were captured. Data analysis was reliant on field observations, initial survey, and hand measurements of sedimentation at the practices.

8.5.3 Detention Practices

Due to the site boundary, the modified sediment basin could not be installed near the monitored basins. If installed elsewhere on-site, the drainage area, soil type, and storm events would vary, making comparison between the standard and modified basin designs difficult. Monitoring was conducted on existing basins, and conditions including live and dead storage capacities were unknown. Installation of the basins were not monitored and could have varied from DOT specification, so results cannot be extrapolated to other basins. The monitored sediment basins were subject to unpredictable site conditions including rainfall, soil types, drainage areas, and topography. While results may be indicative of the basins on the Tama US 30 site, it is unlikely they would be reproduced on other Iowa DOT sites.

Samplers were programmed on time-based intervals and collected every 12 days. In several samples, there was algae growth or other organic matter that contaminated samples. This only allowed for measurements of turbidity, rather than total solids. Total solids tests would have provided a quantity of rapidly settable solids that may not be present during turbidity readings. Pollutant reduction for nitrates, phosphates, and heavy metals was not determined.

8.6 FUTURE RESEARCH RECOMMENDATIONS

Further laboratory testing of practices should be conducted to verify field results. Practices that exhibit improved performance should be tested in a full-scale laboratory setting to evaluate and adjust new components for maximum performance and repeatability. Full-scale testing would allow practices to be subjected to known rainfalls, flows, drainage areas, slopes, sediment loads, and vegetative conditions. This would allow major components or groups of components contributing to practice success to be isolated and adopted. Laboratory-based research would eliminate several assumptions made during in-field testing. Full-scale testing also provides opportunities for longevity evaluation and determination of necessary maintenance procedures.

8.7 IMPLEMENTABLE OUTCOMES

Implementable improvements for the Iowa DOT stormwater program have been developed as a result of this research. Improvements are suggested for both the Stormwater Pollution Prevention Plan documentation and practice implementation.

Improvements for the Stormwater Pollution Prevention Plan include outlining areas of environmental sensitivity, key land feature changes, temporary encroachments on water resources, an E&SC implementation timeline, project personnel and training, and E&SC project contacts in addition to the existing site description, E&SCs, maintenance and inspection requirements, non-stormwater discharges, potential site pollutants, and definitions. It is recommended to document, consider, and include soil properties and hydrology in SWPPP design. The SWPPP should be reviewed and approved by a design and water resources engineer. It is highly recommended to provide a project map with E&SC locations in all project phases to encompass existing contours, slope lines delineating cut and fills, drainage divides, grading areas, and symbolic E&SC features.

In addition to improvements for SWPPP documentation, several improvements for practice implementation are suggested based on the findings of this study. Improvements for silt fence ditch checks include the addition of wire reinforcement backing and dewatering weir to prevent T-post deflection, and a splash pad at weir to prevent downstream scour. Wattle ditch protection details are suggested to include a pinned underlay and non-destructive teepee staking to prevent undercutting and promote intimate ground contact between the channel and wattle. Inspectors should ensure geotextile underlay is present on all rock check dam installations. In addition, it is suggested to add a geotextile on the rock check dam detail to aid in impoundment, particularly in low flow conditions. Recommendations for silt fence perimeter control include decreasing the segment lengths and requiring either C- or J-hook installations to decrease the pressure on low points along the fence. Based on the findings of this study, it is recommended to either decrease the T-post spacing or include wire reinforcement backing to decrease the frequency of T-post deflection. In addition, the silt fence material should be offset from the T-posts. Several components were suggested to improve the performance efficiency of temporary sediment control basin design; however, they were not tested. Based on the water quality results and areas of sampling, it is recommended to replace the dewatering riser pipe with a skimmer to ensure dewatering occurs at the top of the water column. In addition, it is suggested to better define the inflow channel and basin geometries to prevent side sloughing or widening of the channel.

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APPENDIX A. IOWA DOT STANDARD E&SC DETAILS

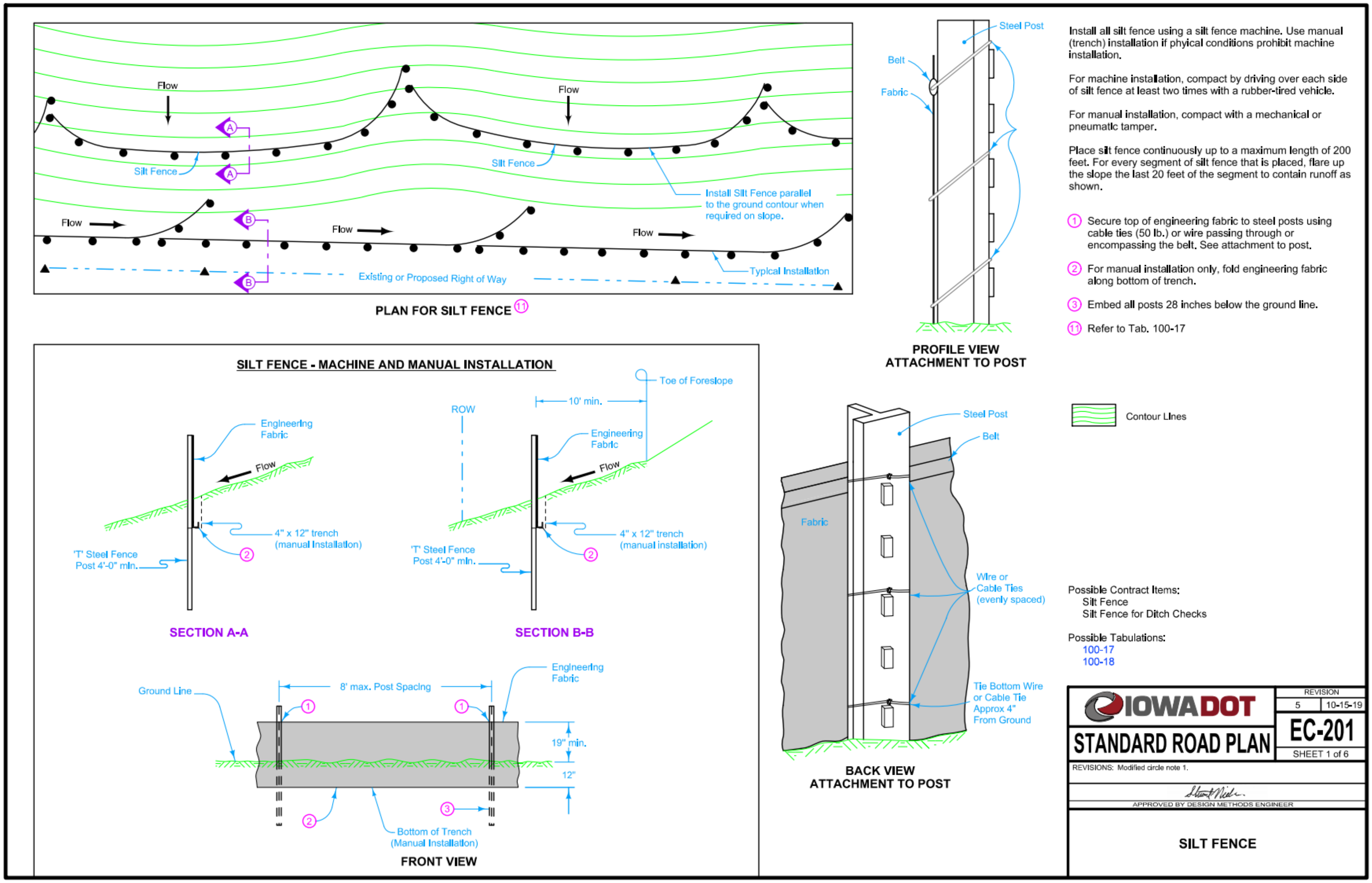


Figure A.1. E&SC silt fence perimeter control detail

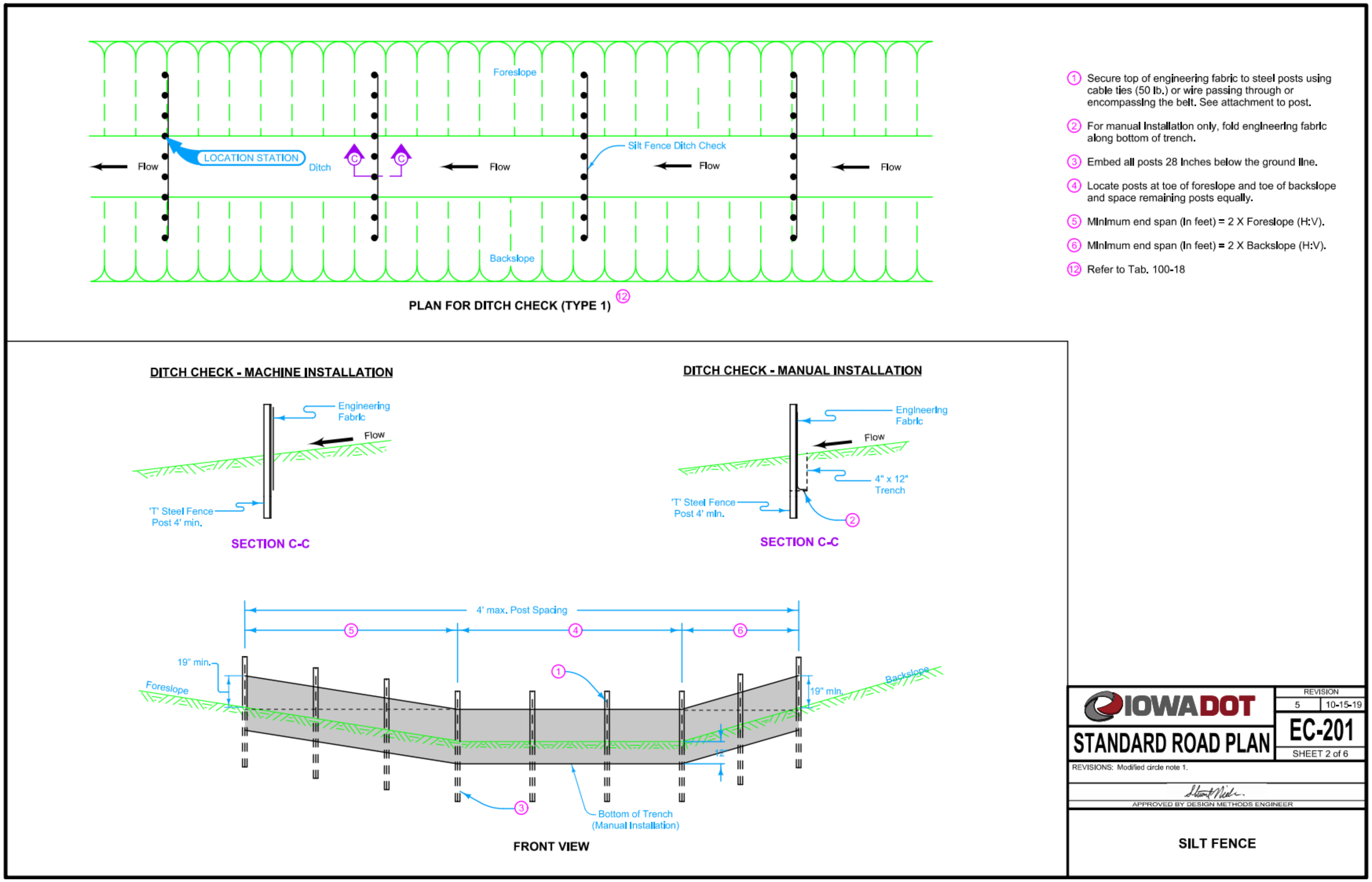


Figure A.2. E&SC silt fence ditch check detail

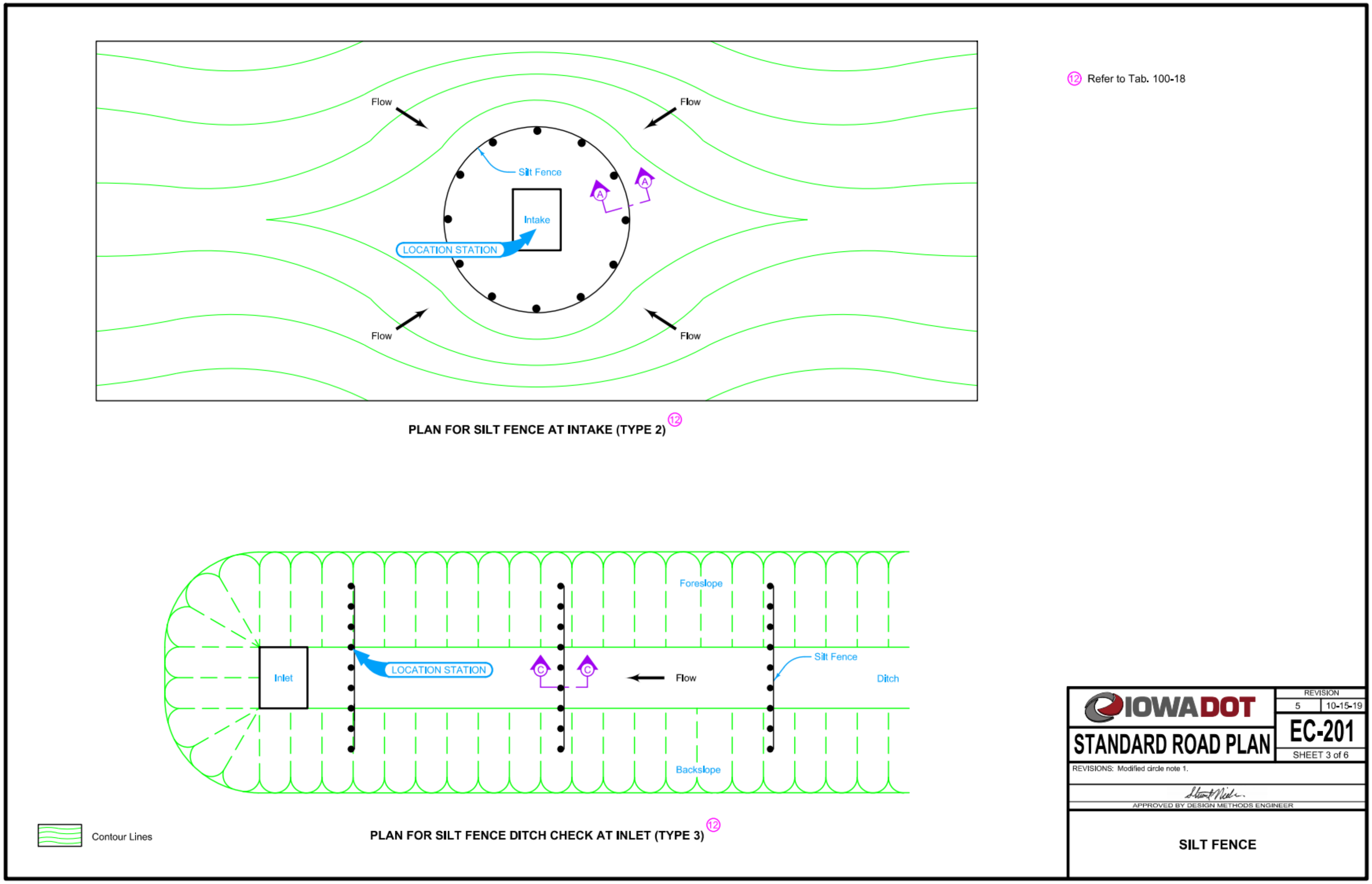


Figure A.3. E&SC silt fence inlet protection detail

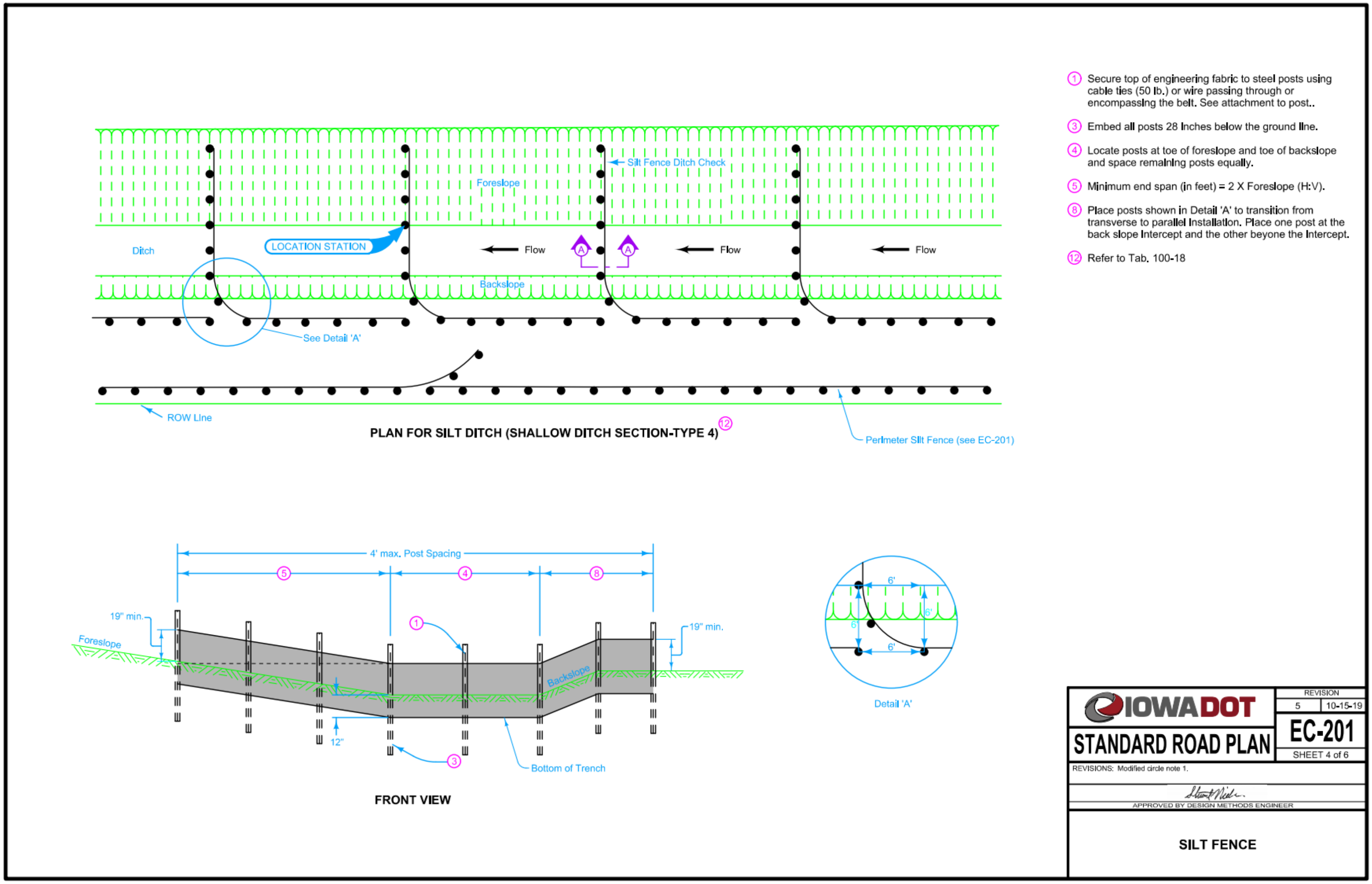


Figure A.4. E&SC silt fence ditch check detail

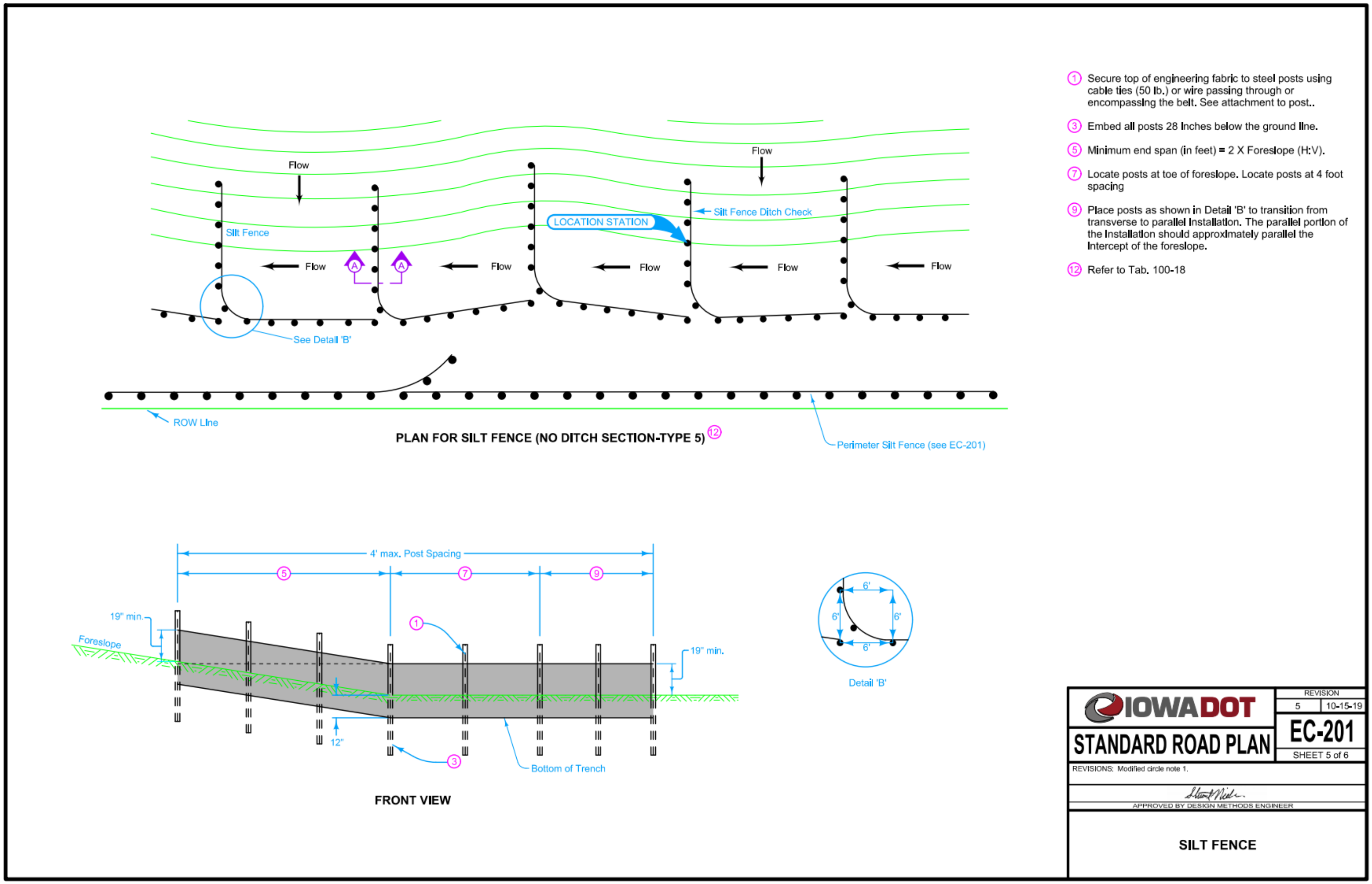


Figure A.5. E&SC silt fence perimeter control hook detail

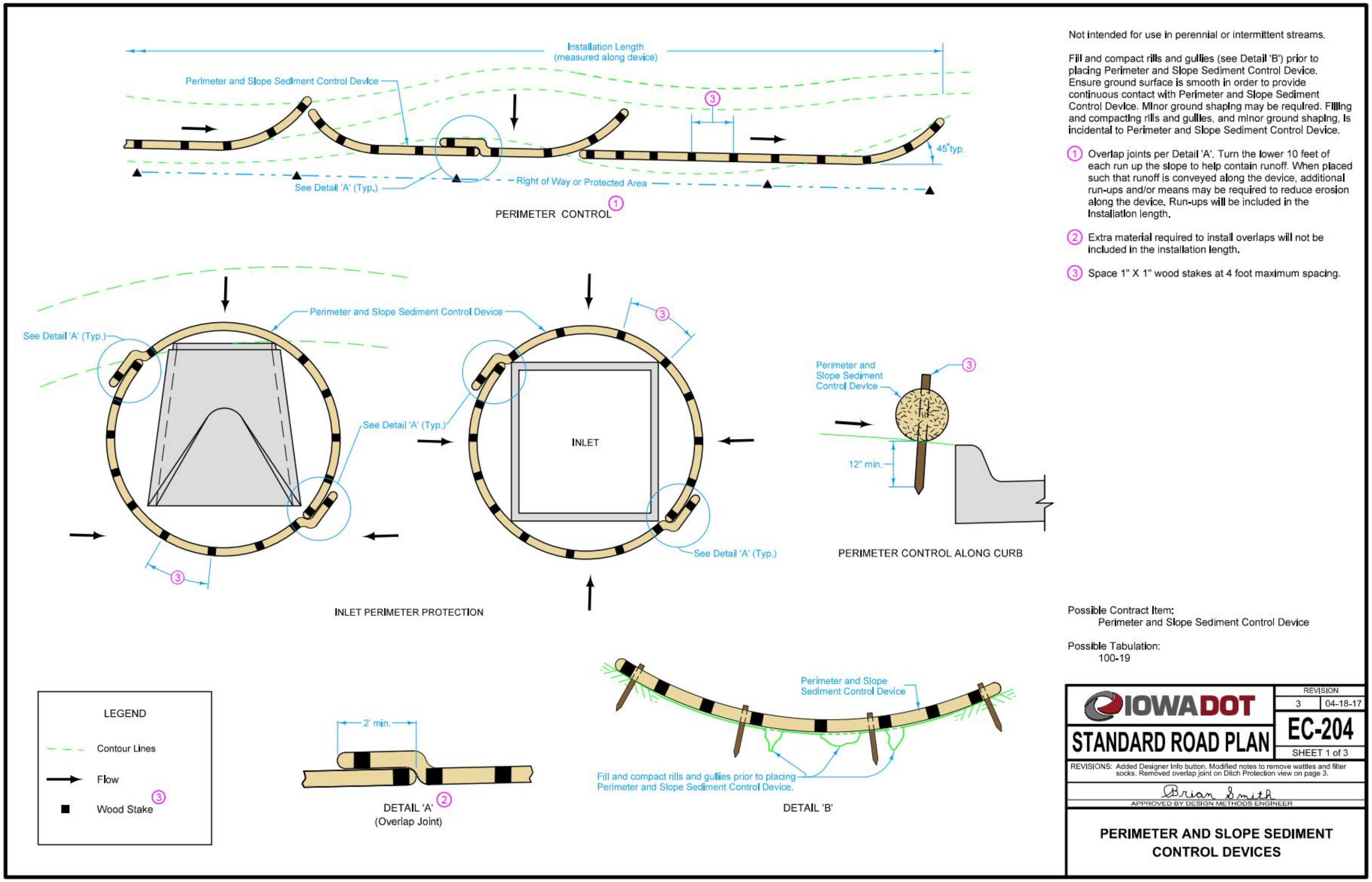


Figure A.6. E&SC wattle details

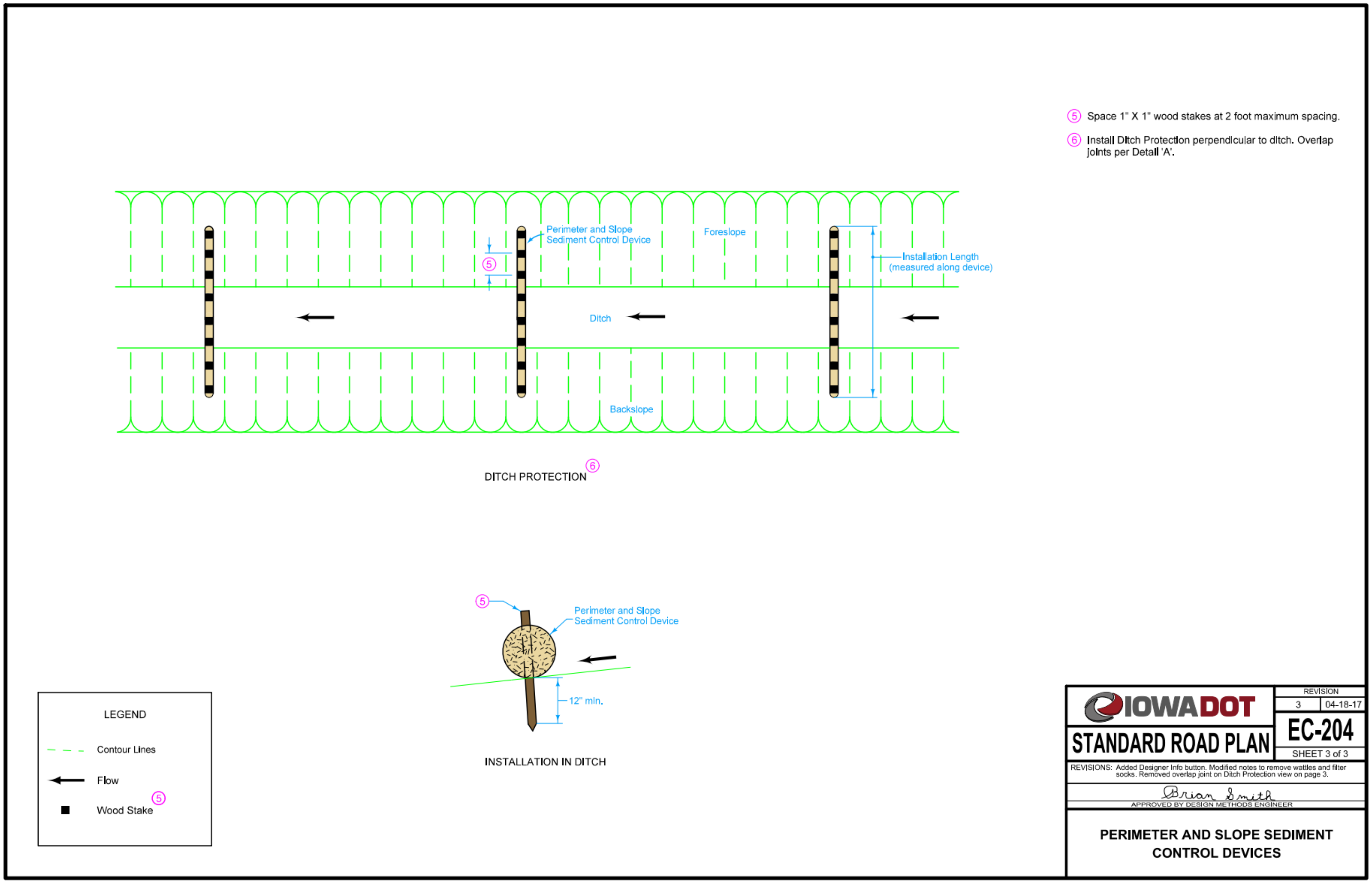


Figure A.7. E&SC wattle ditch protection detail

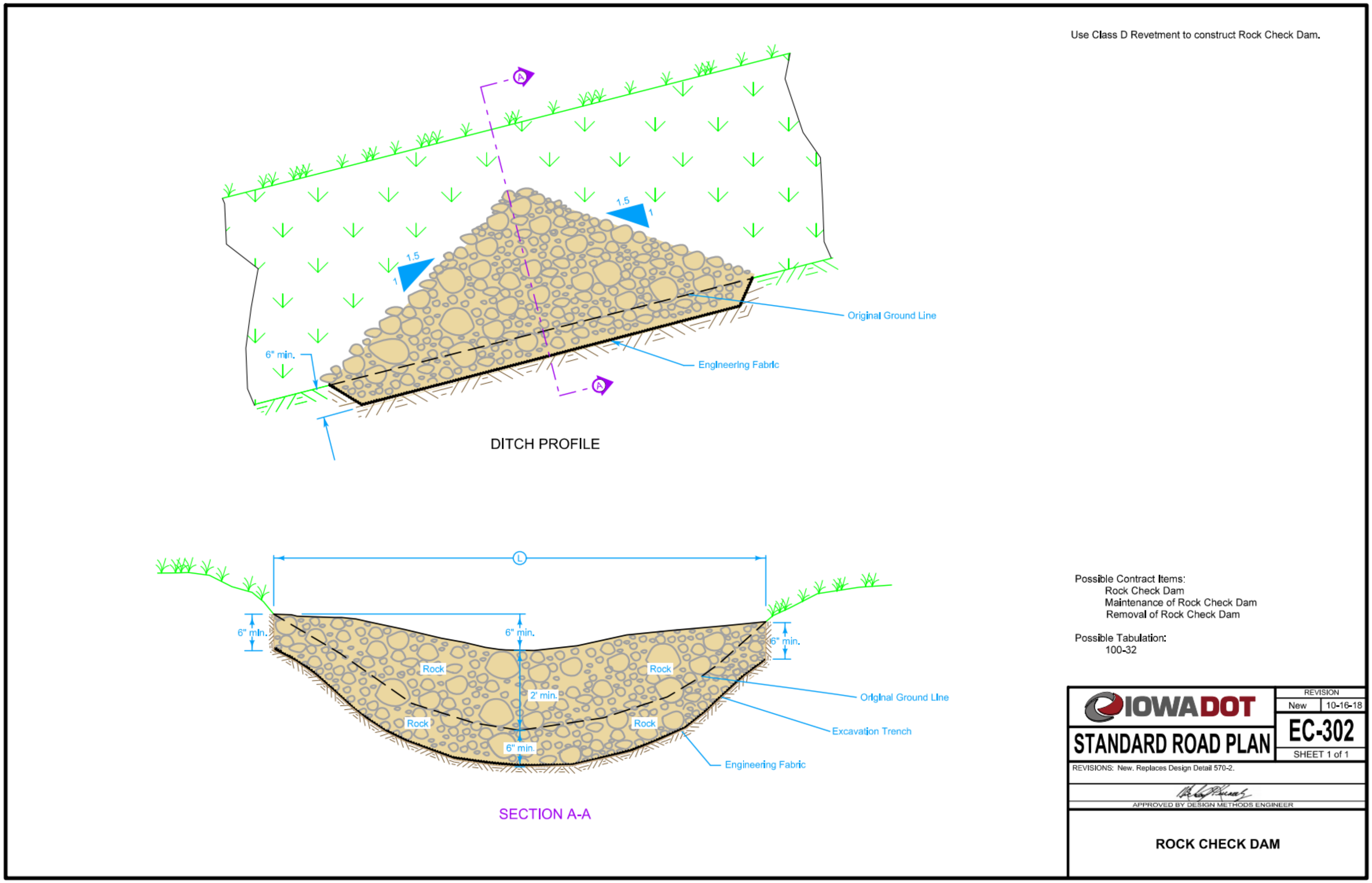


Figure A.8. E&SC rock check dam detail

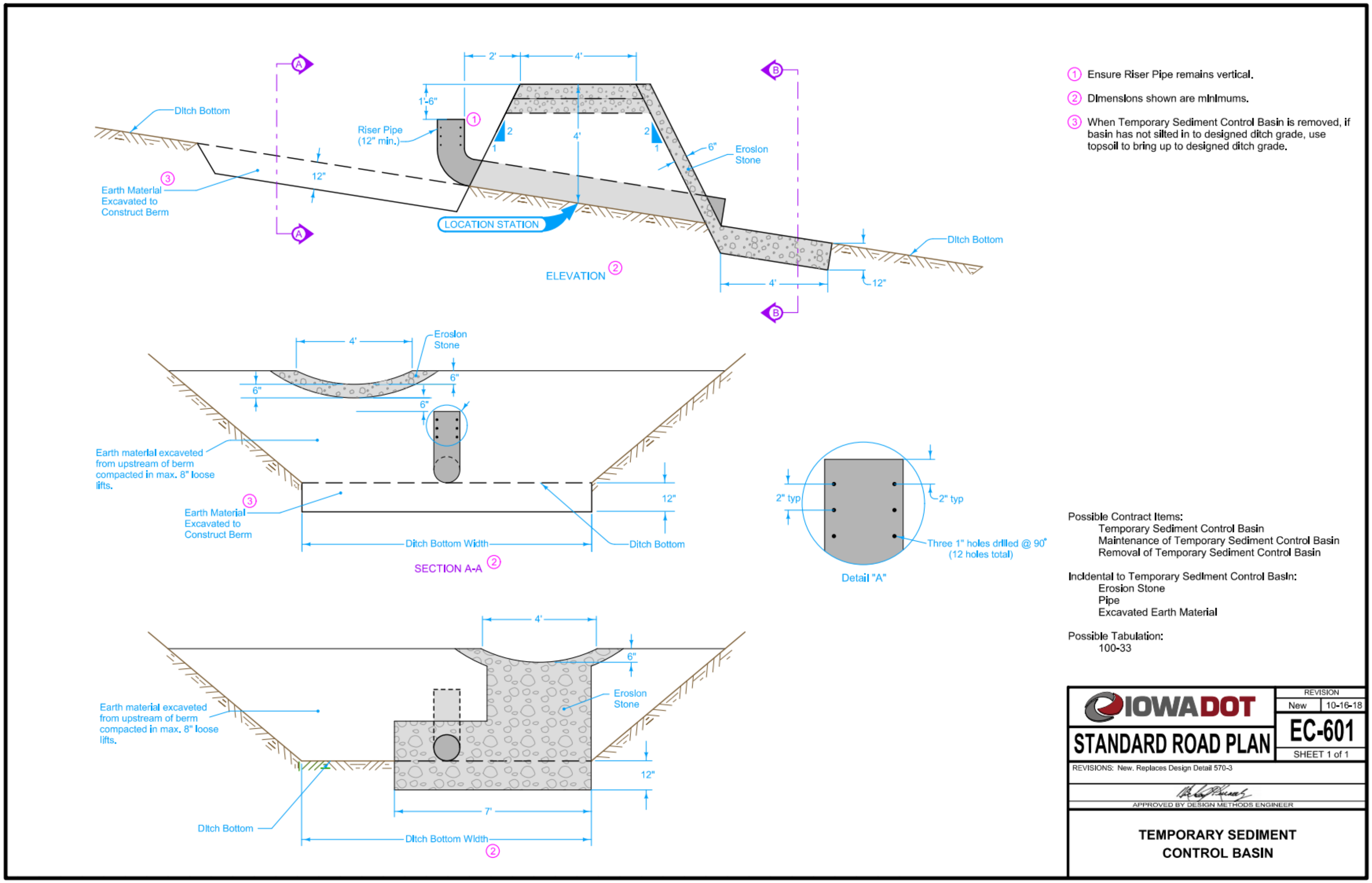


Figure A.9. E&SC temporary sediment control basin detail

APPENDIX B. MODIFIED E&SC DETAILS

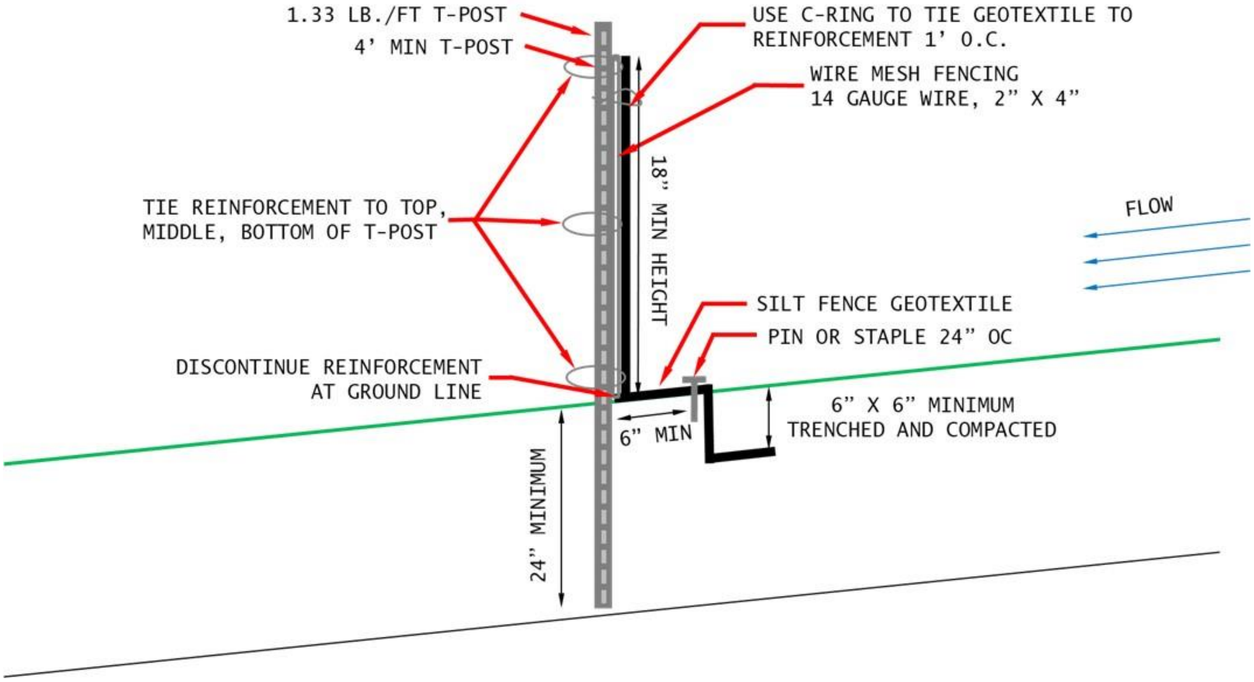


Figure B.1. Silt fence ditch check (EC-201) - Modified 1, SF-DC-M1

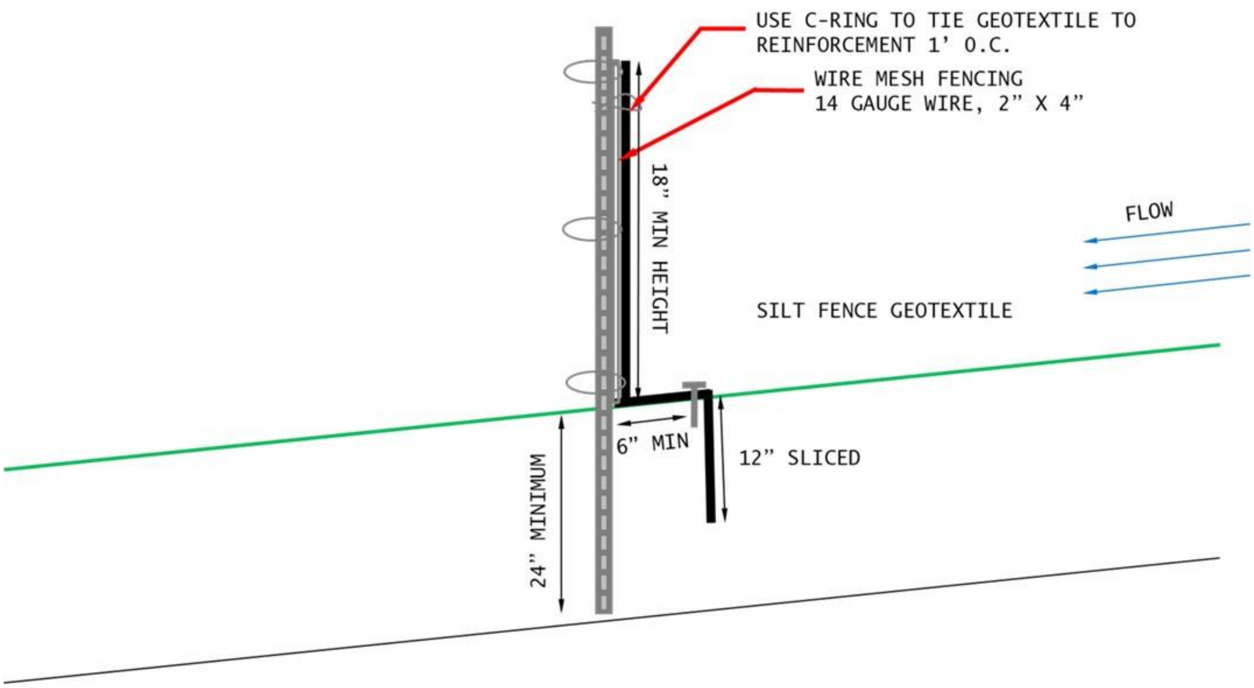


Figure B.2. Silt fence ditch check (EC-201) - Modified 2, SF-DC-M2

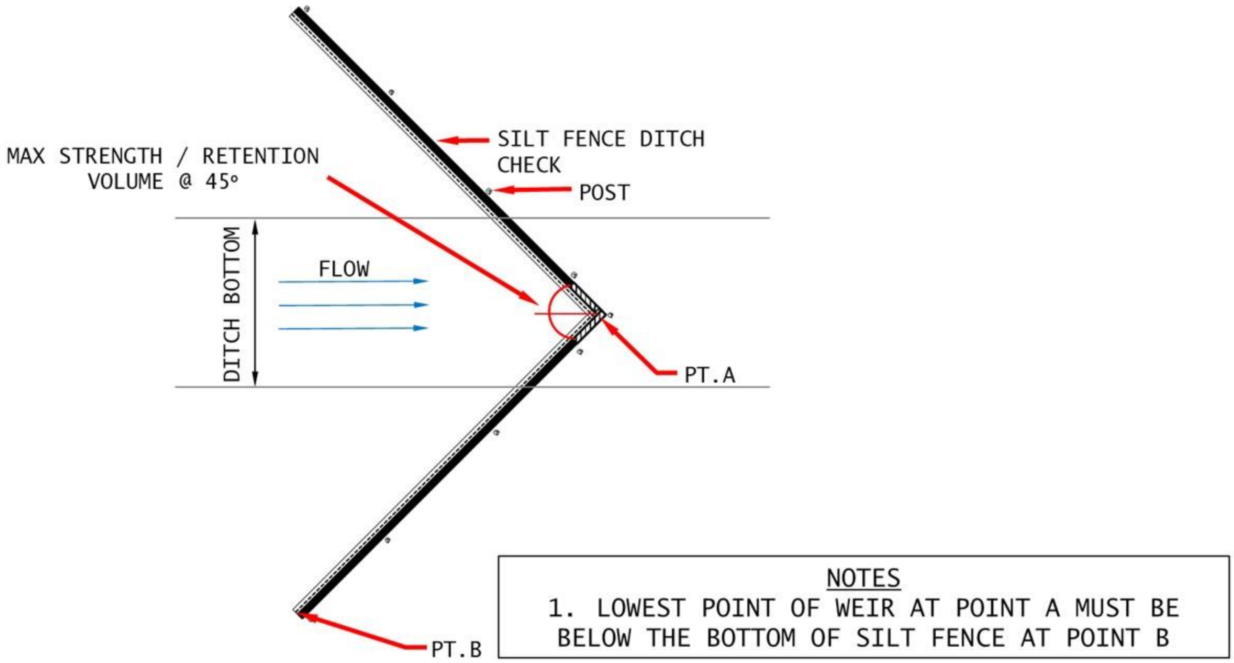


Figure B.3. Silt fence ditch check V-installation

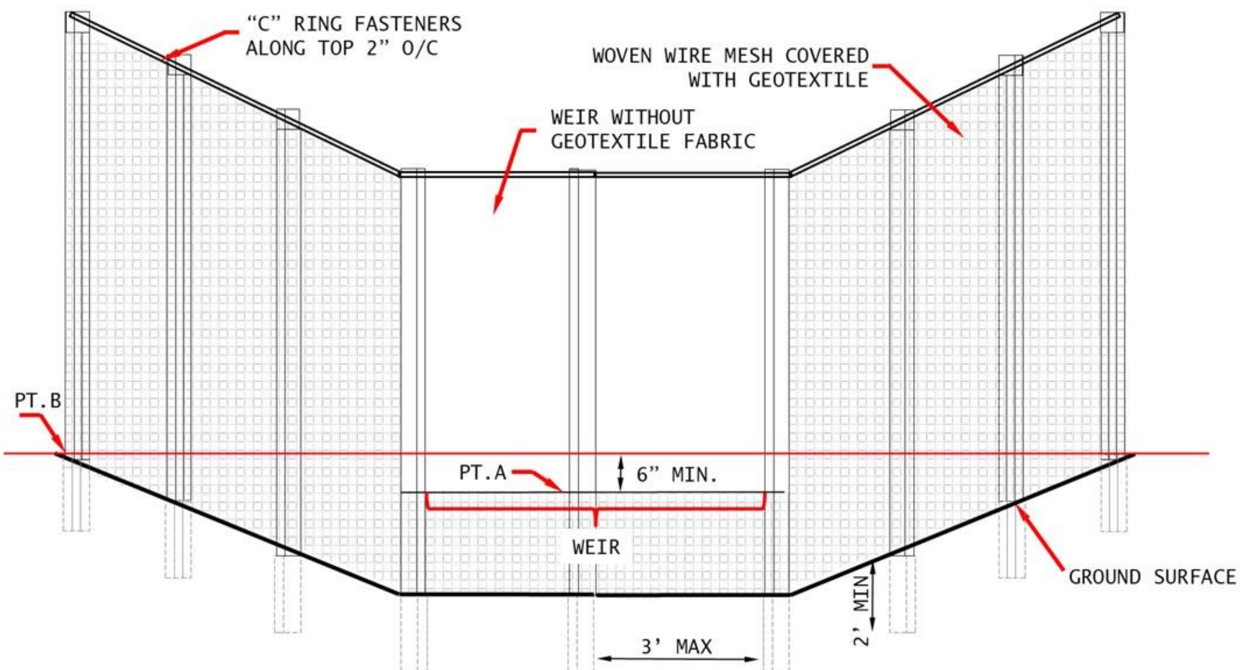


Figure B.4. Silt fence ditch check weir

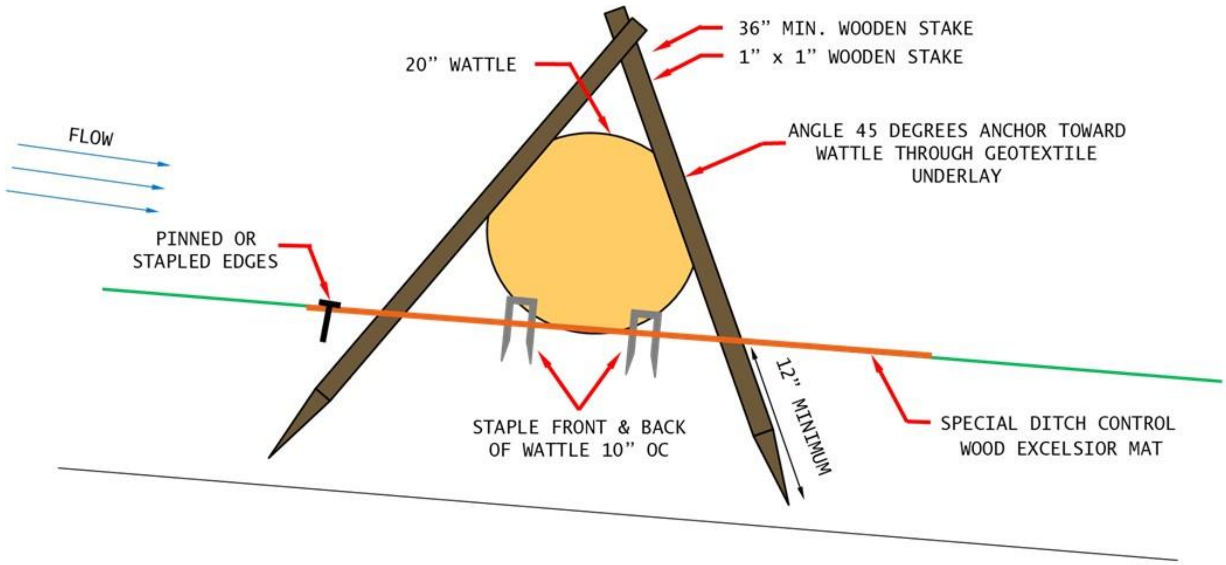
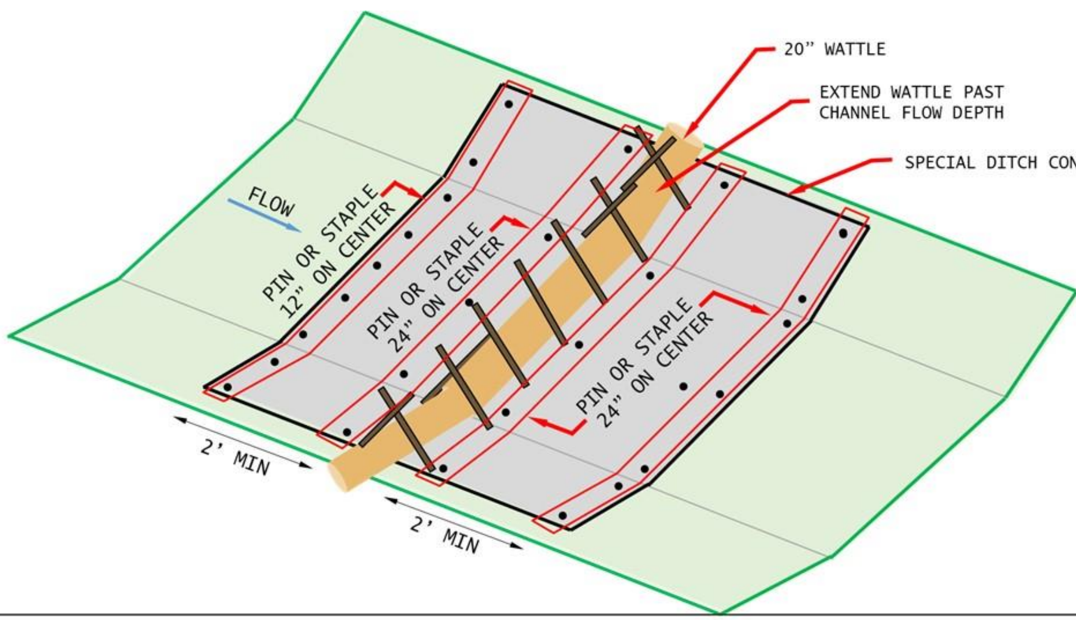


Figure B.5. Wattle ditch protection - modified detail 1



NOTE
STAKES SHOULD BE SPACED A MAXIMUM OF 24" APART ON UPSTREAM AND DOWNSTREAM SIDE OF THE WATTLE

Figure B.6. Wattle ditch protection - modified detail 2

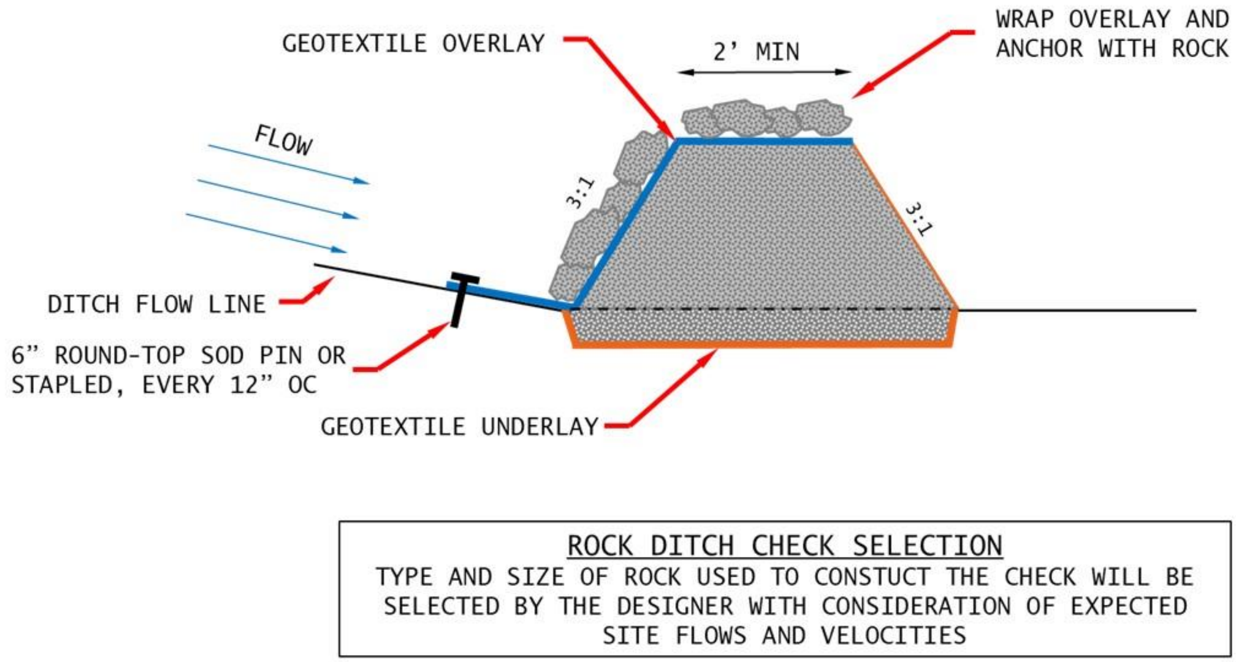


Figure B.7. Rock check dam - modified detail

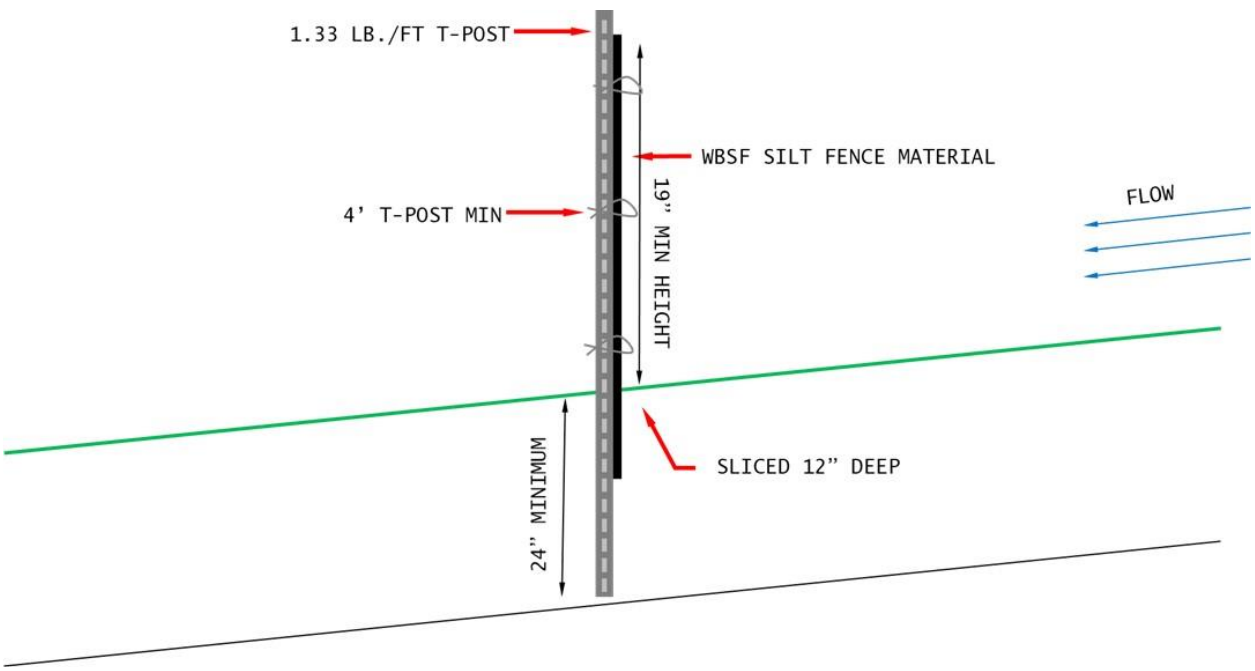


Figure B.8. Silt fence perimeter control – Standard-M

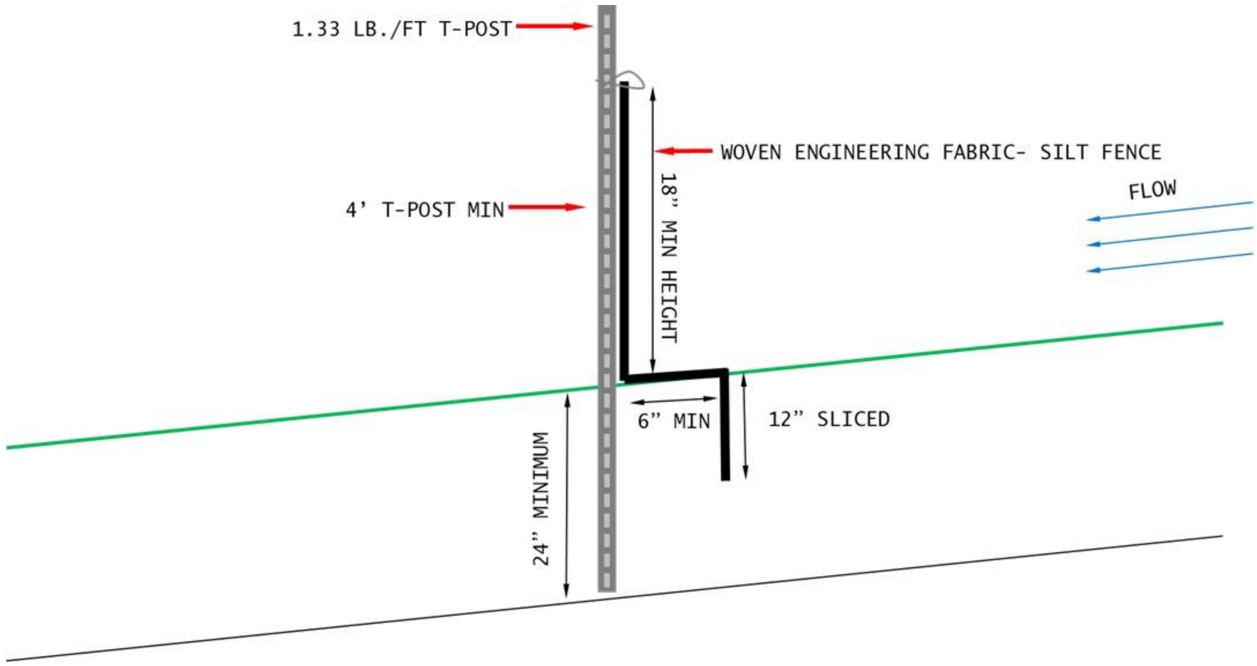


Figure B.9. Silt fence perimeter control Modified 1 & 4 - offset and sliced

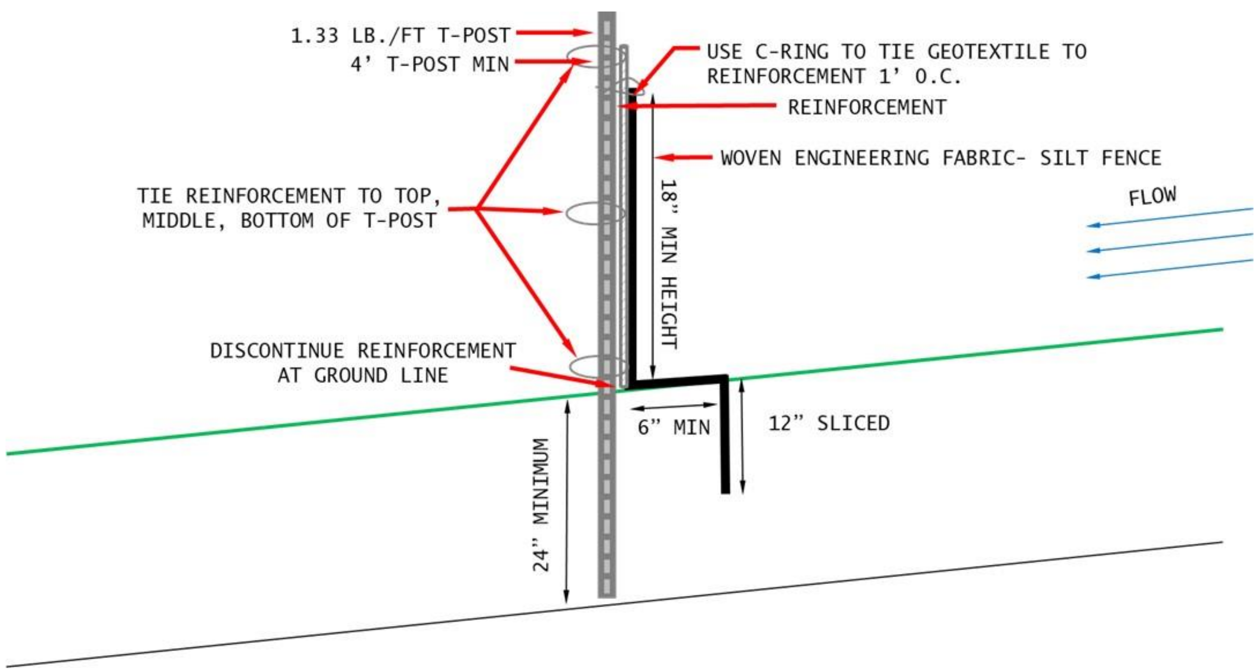


Figure B.10. Silt fence perimeter control Modified 2 & 5 - offset, sliced, with reinforcement

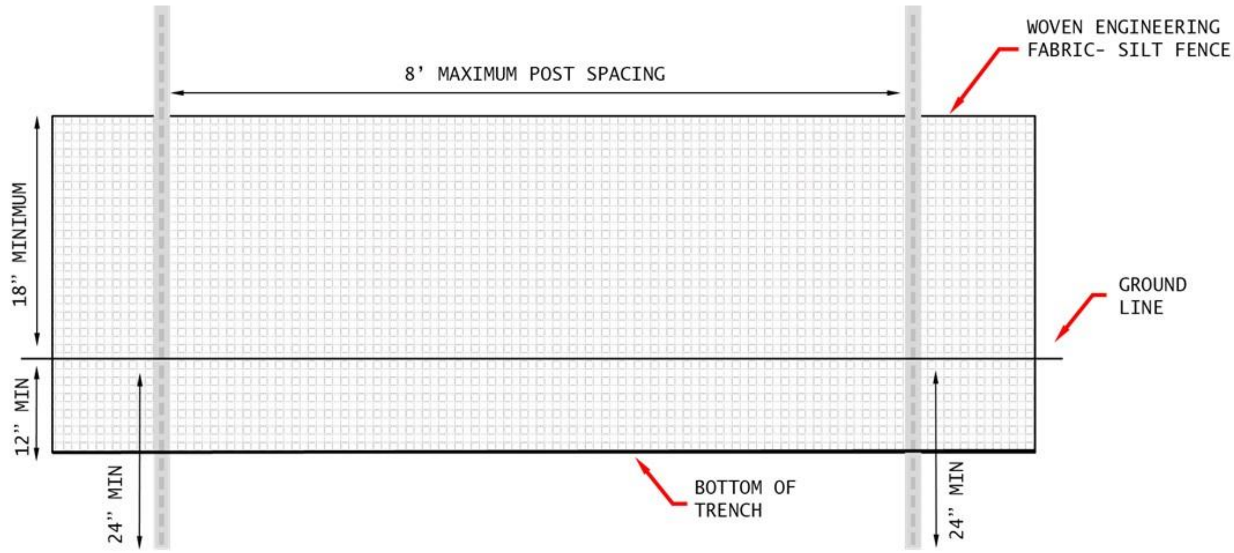


Figure. B.11. Silt fence perimeter control 8 ft spacing - Standard, Standard-M Modified 1, and Modified 2

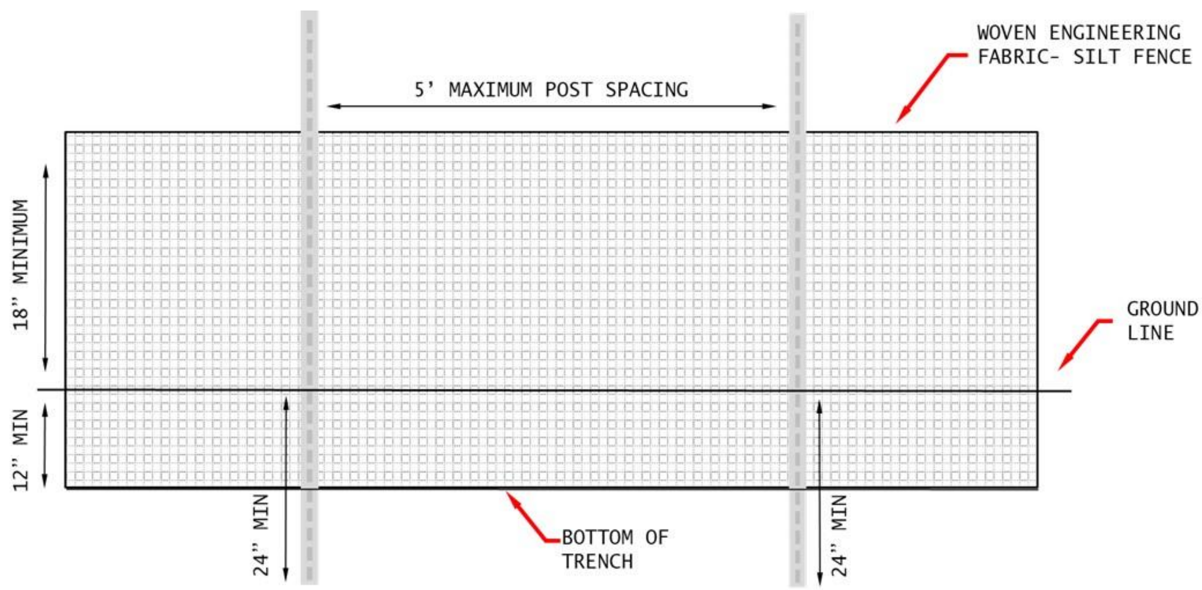


Figure B.12. Silt fence perimeter control 8 ft spacing - Modified 3, Modified 4, and Modified 5

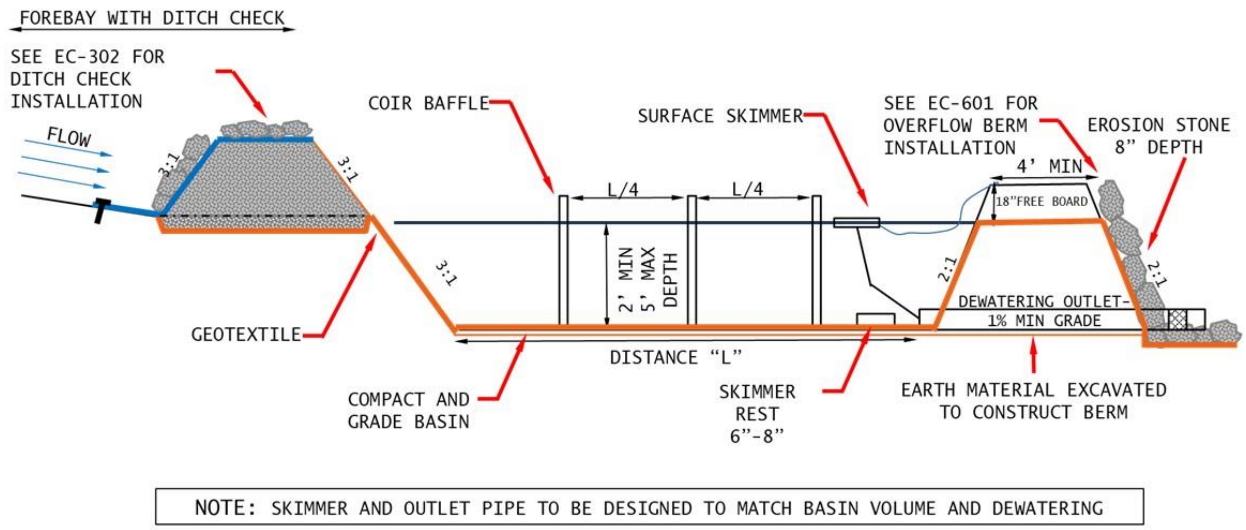


Figure B.13. Temporary sediment control basin - modified

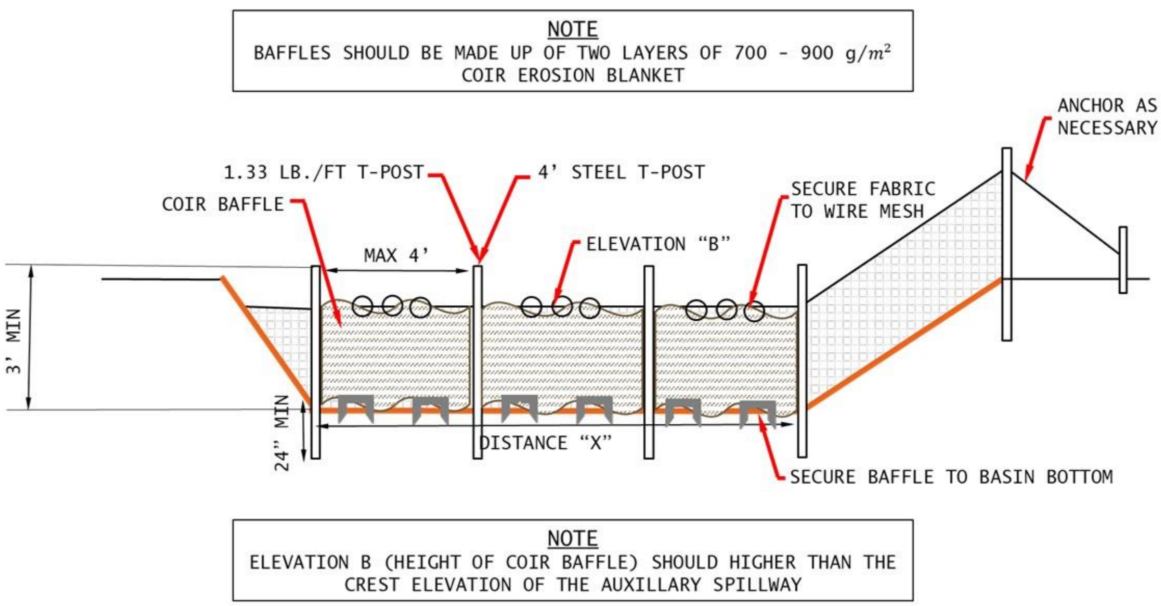


Figure B.14. Temporary sediment control basin cross section – modified

APPENDIX C. WATER QUALITY LABORATORY/TURBIDITY AND TOTAL SOLIDS PROCESSING PROCEDURES

TURBIDITY ANALYSIS

Step 1: Prepare laboratory space with stirring plate and turbidimeter. Prepare ample deionized (DI) water should the samples require dilution.

Step 2: Confirm turbidimeter readings using standard samples (10, 20, 100, and 800 NTUs). If outside of threshold, recalibrate turbidimeter.

Step 3: Vigorously shake ISCO sample bottle to resuspend any settled solids. Transfer contents to a 1,000 mL beaker, insert stir bar, and place on stir plate. Continue mixing until sample appears to be homogeneous.

Step 4: Set pipette to 7.5 mL and carefully extract 15 mL from the sample to fill turbidity cell to line. Cap the cell. Using a soft cloth, wipe the cell to ensure there is no residue on the outside.

Step 5: Place the cell into the turbidimeter, matching the arrow on the cell to the arrow on the turbidimeter. Secure the cell and read the NTU value. If the value is over range, proceed to Step 6.

Step 6: If the sample is outside of the range, dilute the sample 1:2 by mixing 25 mL of the sample with 25 mL of deionized water in a beaker using the stir plate.

Step 7: Repeat steps 4 through 6 as necessary.

Dilution Note: If the sample is still outside of ranger after dilution, transfer the sample from the cell and add another 25 mL of water and reread. Continue this process until you get a reading. The dilution factor will be DF = (NTU) × (x+1), where x is the amount of times 25 mL of water is added. For example, DF = (NTU) × (2+1) after two dilutions are performed.

TOTAL SOLIDS PROCESSING PROCEDURES

Step 1: Allow all collected samples to be refrigerated for a minimum of 24 hours to allow sediment to settle out. After at least 24 hours, continue with the experiment.

Step 2: Mark and weigh all evaporating dishes. Record the mass to the nearest 0.0001 g.

Step 3: Using a vacuum pump and flask, vacuum the supernatant from the samples using a hose with a J-hook attachment. Vacuum the maximum amount of water without disturbing the sediment. Retain supernatant in the flask and record the volume.

Step 4: Measure the remaining water in the original sample bottle by marking the water level line.

Step 5: Use DI water to wash the sediment and remaining water into an evaporating dish.

Step 6: With the empty sample bottle, refill the bottle to the marked level line. Transfer the water to a graduated cylinder and record the volume.

Step 7: Bake the samples in a laboratory oven at 210°F (99°C) for 3 hours. Ensuring that the water has evaporated, increase the temperature to 221°F (105°C) for another 2 hours.

Step 8: After the samples have completed baking, weigh the dishes with the samples to the nearest 0.0001 g. Discard the sediment.

The following steps are to determine the dissolved solids correction factor.

Step 9: Weigh empty evaporating dishes. Record the mass.

Step 10: Transfer a measured volume (100 mL), using a pipette, from the supernatant from Step 3 to an evaporating dish.

Step 10: Dry the samples as defined in Step 7.

Step 11: After baking, record the mass of the dish and sample to the nearest 0.0001 g and discard the sample.

Step 12: Calculate the dissolved solids correction factor using:

$DSc = (DS/Va) \times Vs$
where,
DSc = Dissolved-Solids Correction, (g)
DS = Weight of Dissolved Solids, (g)
Va =Sample Volume for Dissolved Solids, (mL)
Vs =Volume of Supernatant with Sediment, (mL)

Step 13: Subtract this correction factor from the net weight.

Step 14: Divide the net weight of the sediment by the net weight of the sample, multiply the quotient by 1,000,000. This will provide a sediment concentration result in parts per million.

Repeat this process for each sample taken.

APPENDIX D. MATERIAL COST

Practice	Name	Description	Cost: Des Moines, Iowa	Cost: Des Moines, Iowa	Cost: Birmingham, Alabama	Cost: Illinois	Cost: Avg.
Silt Fence Ditch Check/ Perimeter Control	SF Engineering Fabric, 36 in.	woven, 150 lbs grab strength (Iowa DOT 4196.01.B.1), minimum 36 in. wide	$ 0.08	*$ 0.28 ft.* [A]	$ 0.03 ft.	$ 0.13 ft.	$ 0.08
	Studded T-Post, 4 ft	Painted, 1.33 lbs/ ft. (Iowa DOT 4154.09)	$ 3.25 ea	$ 2.95 ea.	$ 4.00 ea.	*$ 19.00 ea*	$ 3.40
	MOD Studded T-Post, 4 ft	Unpainted, 1.25 lbs/ ft	$ 2.50 ea		$ 3.00 ea.		$ 2.75
	Cable Ties, 50 lb	50 lbs		$ 0.02 ea			$ 0.02
	Sod Staples, 6 in.	11 gauge metal, 6 in. (15 cm) long by 1 in. (2.5 cm) U-shaped staples	$ 0.03 ea	$ 0.04 ea	$ 0.03 ea.		$ 0.03
	Welded Wire Fence, 18 in.	14 gauge steel wire mesh with a minimum 6 in. by 6 in.			$ 0.89 ft.		$ 0.89
	C-Ring Ties, 1 in.	1 in. (1.7 cm), 16 gauge, galvanized steel.			$ 0.03 ea.		$ 0.03
	Silt Saver WBSF				$ 0.70 lf		$ 0.70
Wattle	Wooden Stakes, 36 in.	1 x 1 in. , 36 in. long	$ 0.80 ea	$ 0.52 ea	$ 0.55 ea.		$ 0.62
	Excelsior Wattle, 10 ft	20 in. Wattle	$ 2.45 ft.	$ 2.00 ft.	$ 2.85 ft.	*$ 9.00 ft*	$ 2.43
	Special Ditch Protection, 8 ft	Wood Excelsior Mat, single net	$ 46.50 rl	$ 55.00 rl	$ 44.40 rl.		$ 48.63
Basins	Erosion Stone	6 in. nominal size. Broken limestone, dolomite, quartzite, granite, or concrete (Iowa DOT 4130.03-.05					$ 56.03
	Riser Pipe	12 in. corrugated pipe			$ 7.45 ft.	$ 1,400.00 ea	$ 703.73
	Coir Baffles	700-900 g/m^2 coir erosion blanket, min 36 in. wide			$ 195.00 rl.		$ 195.00
	Surface Skimmer	4 in.			$ 1,328.00 ea		$ 1,328.00
	PVC Outlet	4 in.					
Various Wattles Fills	Excelsior	20 in., 10 ft.	$ 2.45 ft.	$ 2.00 ft.	$ 2.85 ft.		$ 2.43
	Wheat Straw w/ netting	20 in., 10 ft.	$ 2.35 ft.		$ 2.25 ft.		$ 2.30
	Wood chip w/ sock	20 in., 10 ft.			$ 6.00 ft.		$ 6.00
	Coconut coir	12 in., 10 ft.				$ 6.27 ft.	$ 6.27
	Premium coconut coir	12 in., 10 ft.				$ 7.04 ft.	$ 7.04
	Miscanthus **[B]**	12 in., 10 ft.					$ 1.75
	GeoHay **[B]**	20 in., 10 ft.					$ 4.13
RCD	Class D Erosion Stone **[C]**	Limestone/ dolomite/ quatzite/ granite				$ 44.93 cyd.	$ 56.03

Notes: [A] denotes values outside of inner quartile range, and thus were not included in calculating average cost
[B] cost received directly from manufacturer
[C] mobilization cost was added for up to 30 miles.

Figure D.1. Material cost catalog

APPENDIX E. SILT FENCE DITCH CHECK PROFILES

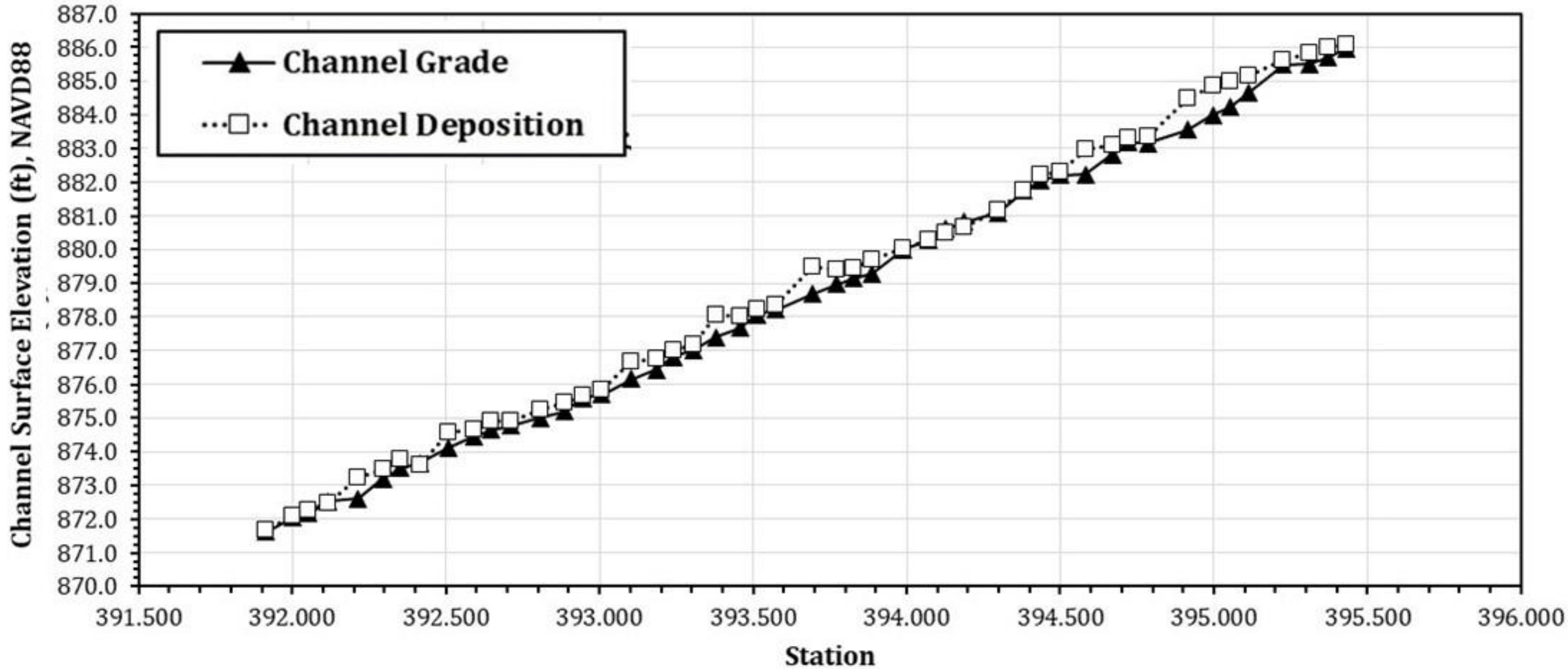


Figure E.1. Silt fence ditch check channel grade profile

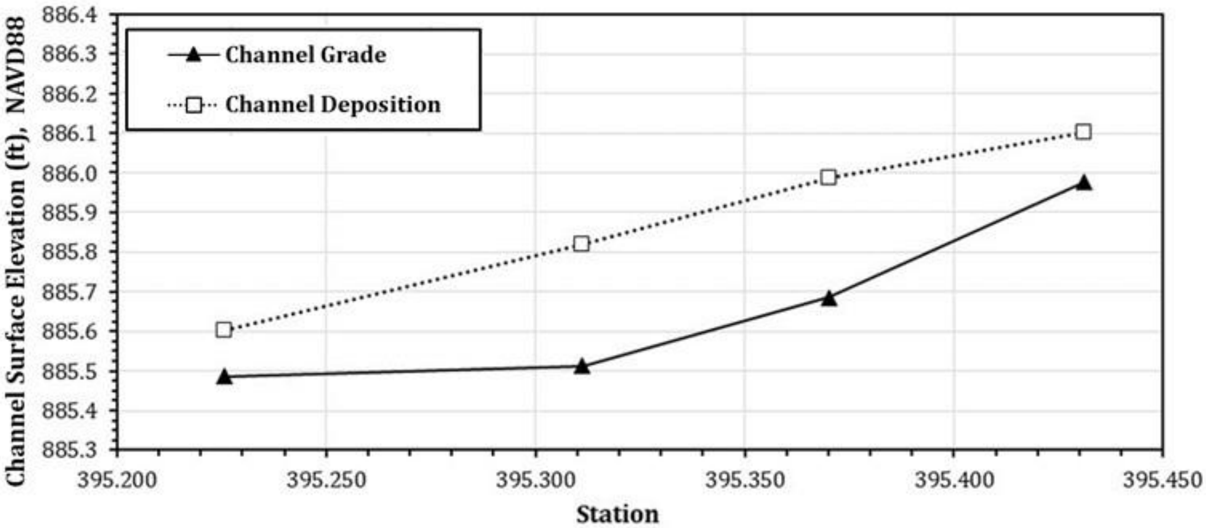


Figure E.2. SF-DC-S1-1

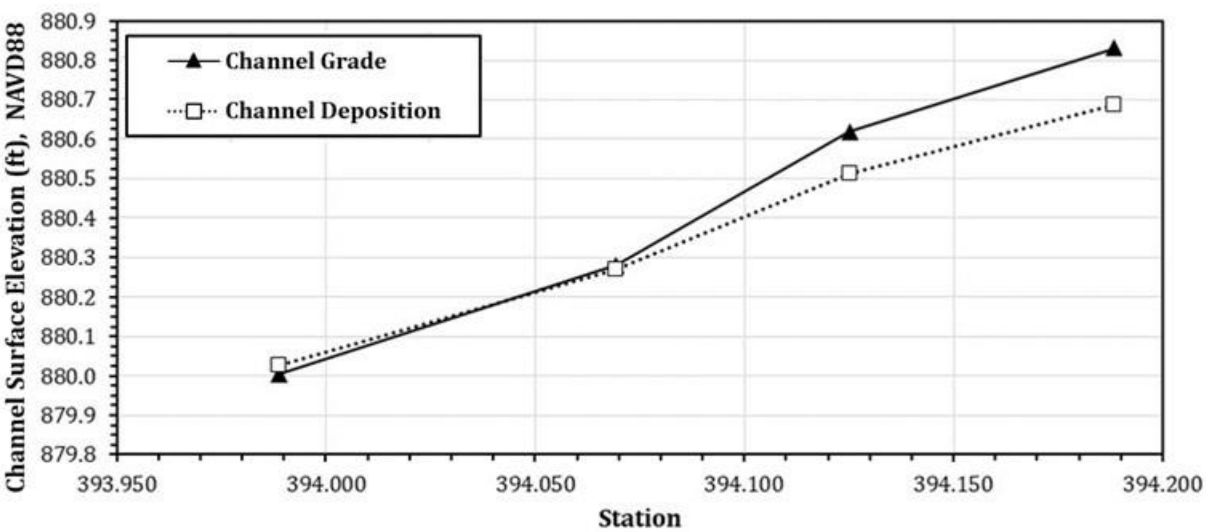


Figure E.3. SF-DC-S1-2

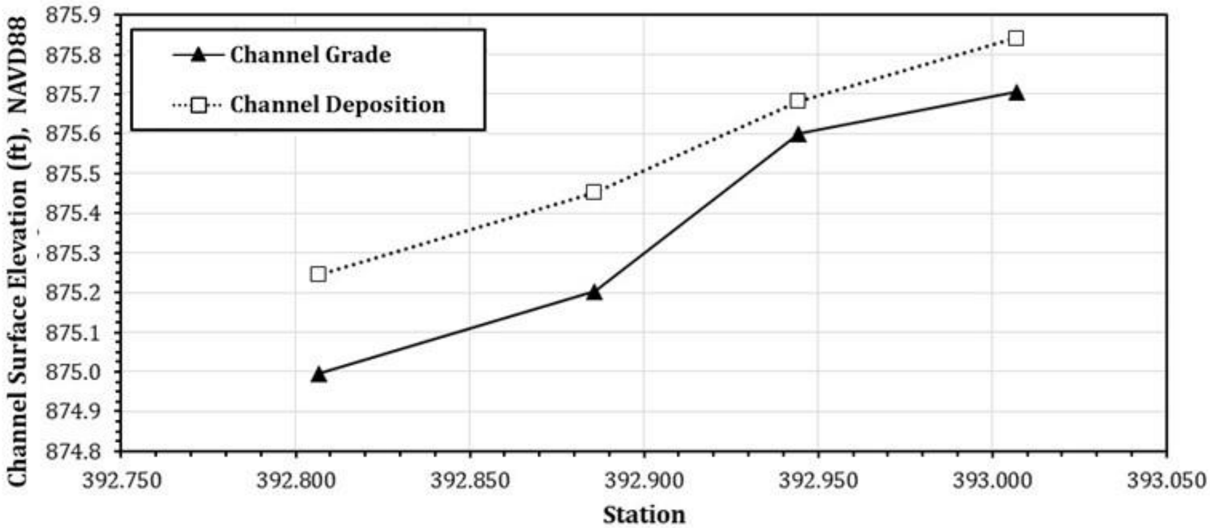


Figure E.4. SF-DC-S1-3

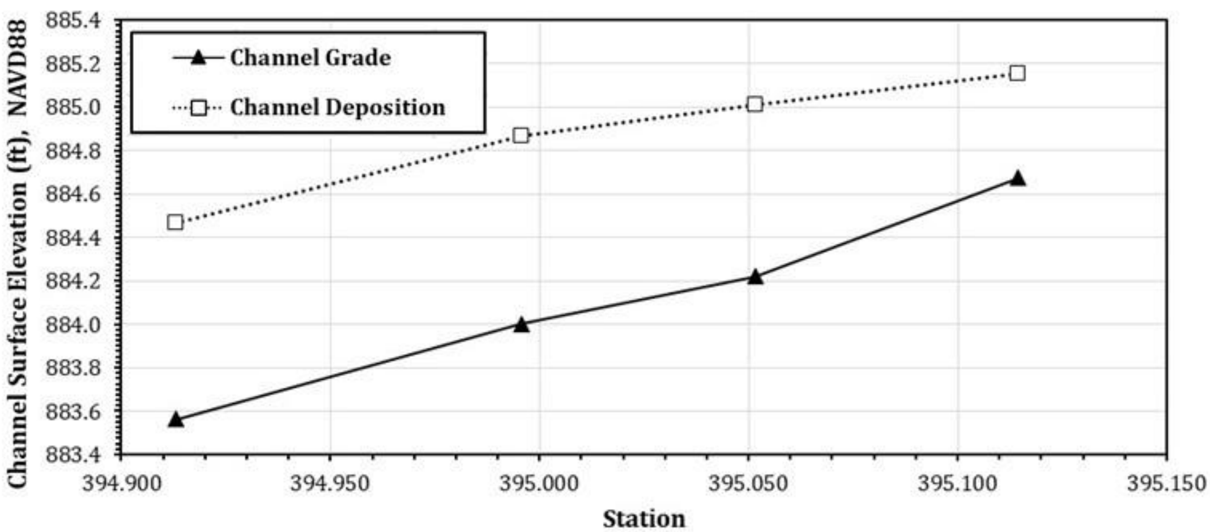


Figure E.5. SF-DC-M1-1

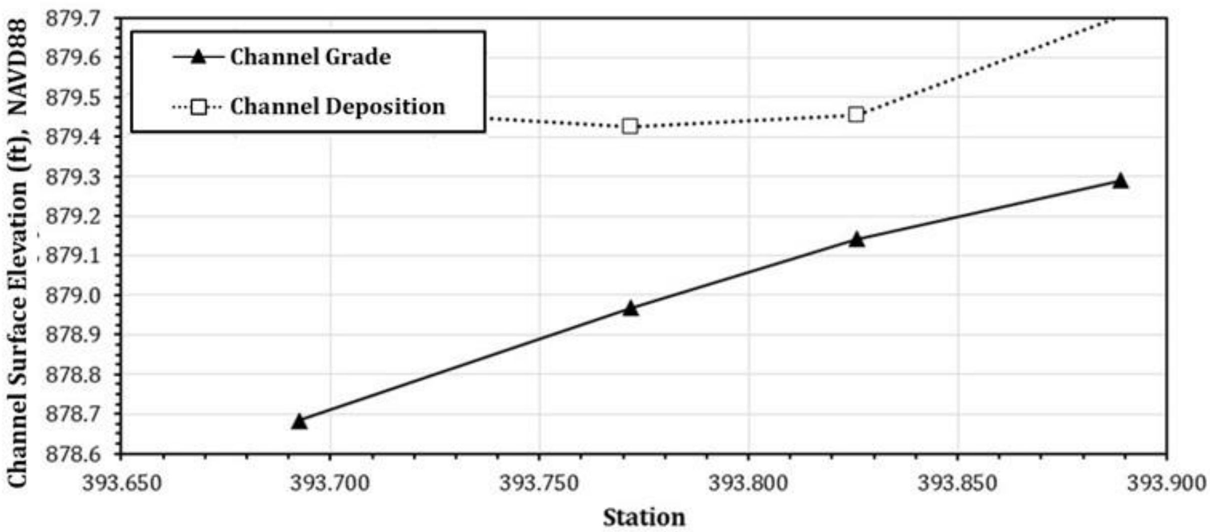


Figure E.6. SF-DC-M1-2

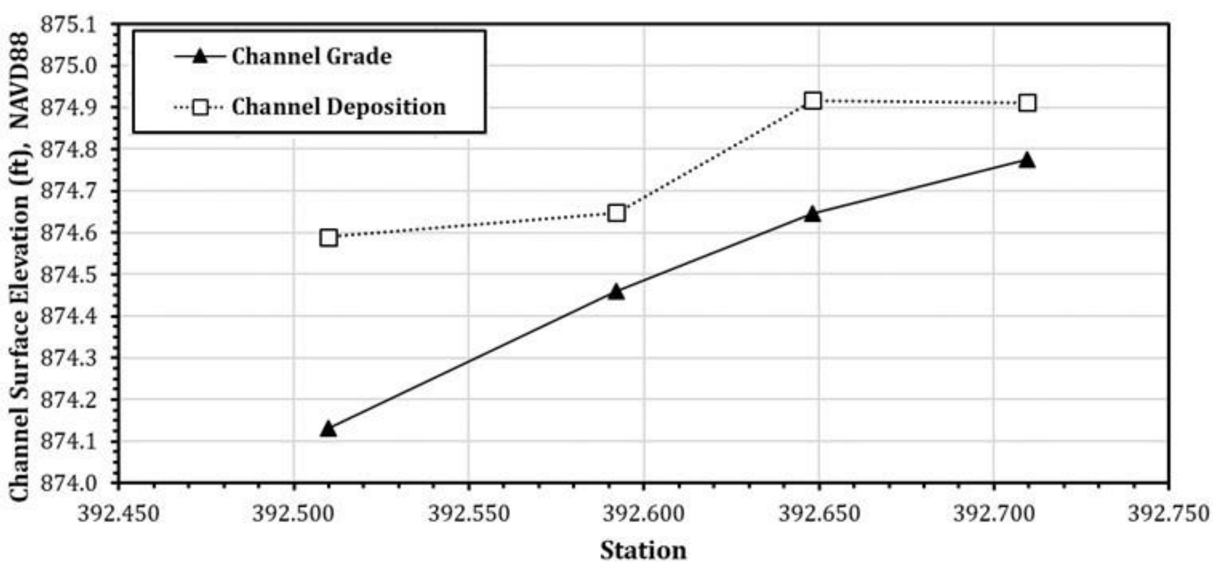


Figure E.7. SF-DC-M1-3

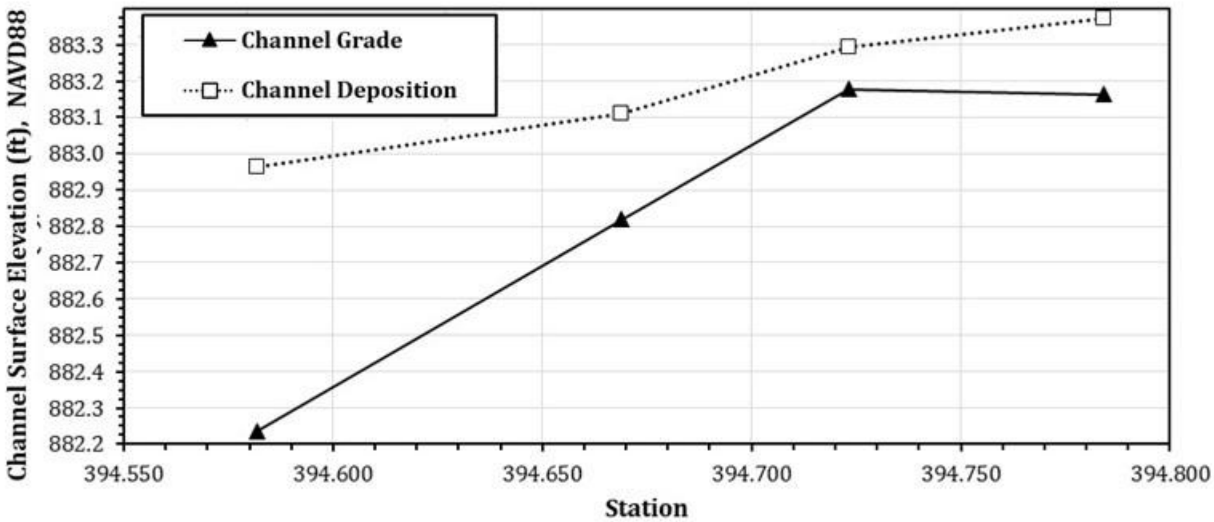


Figure E.8. SF-DC-M2-1

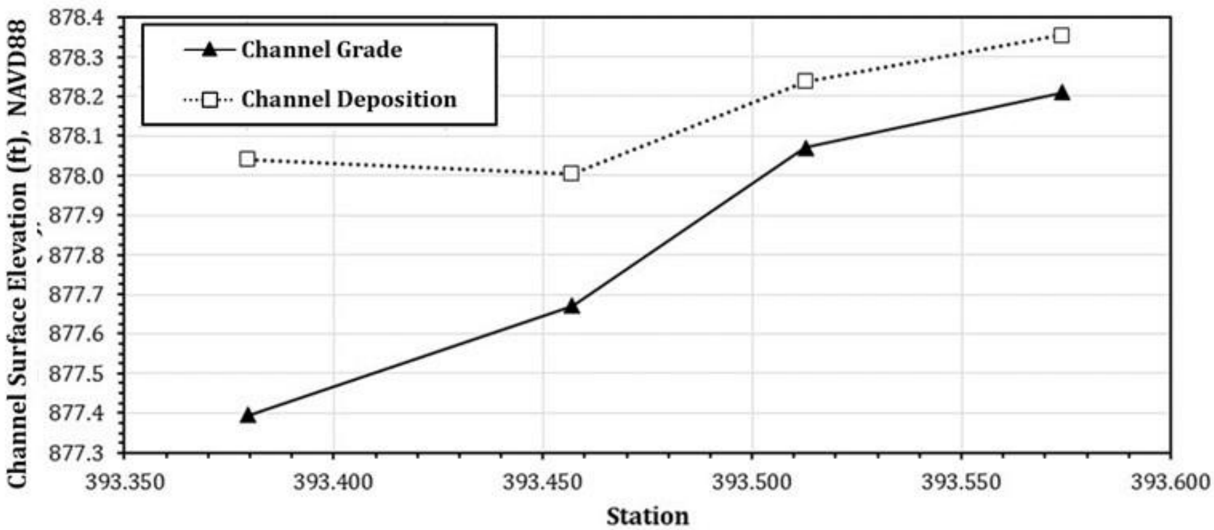


Figure E.9. SF-DC-M2-2

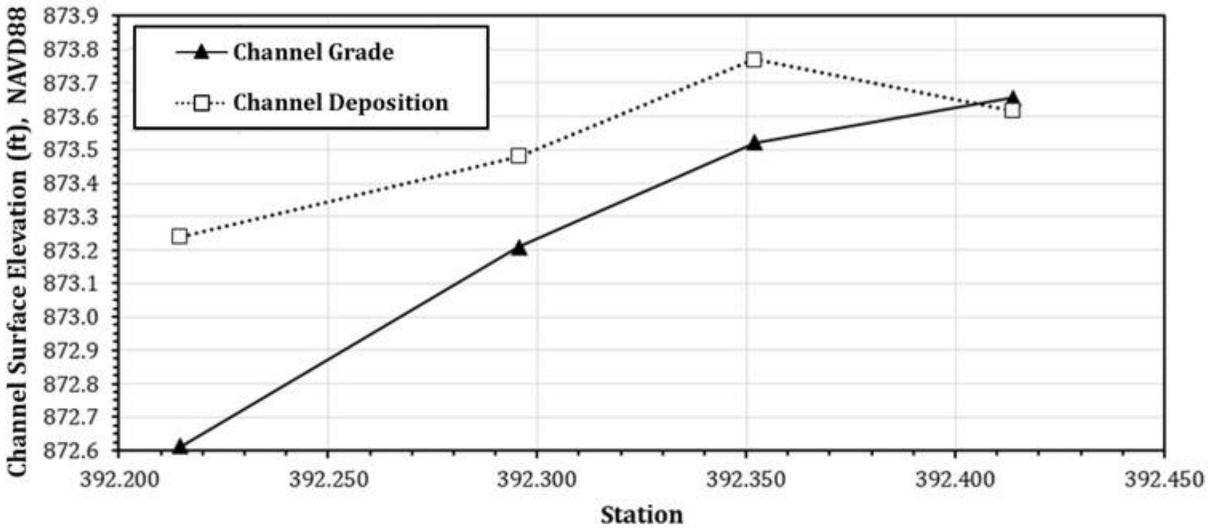


Figure E.10. SF-DC-M2-3

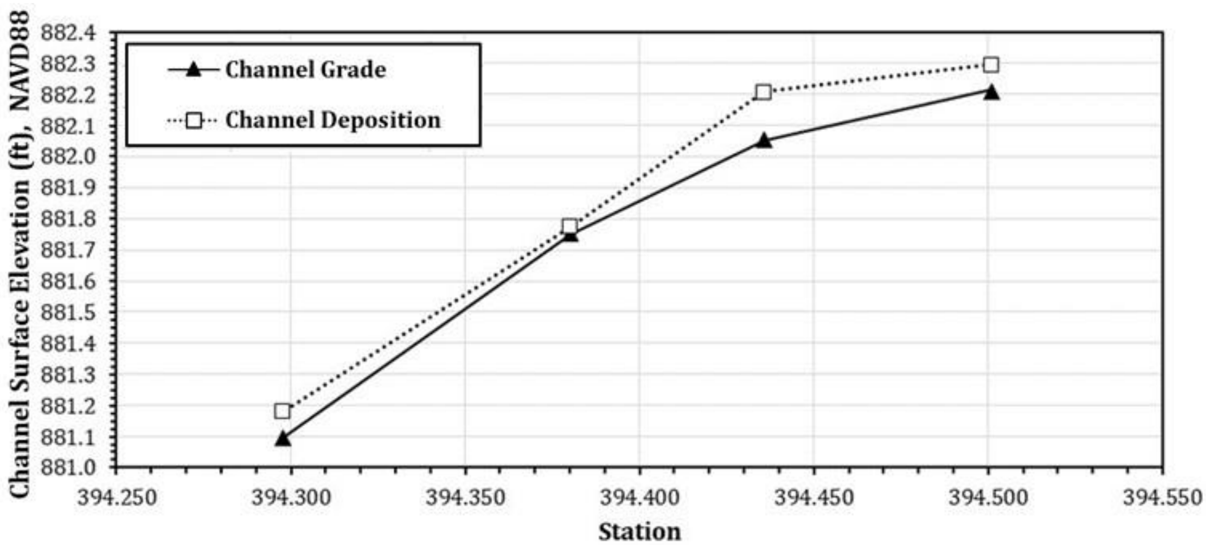


Figure E.11. SF-DC-SB-1

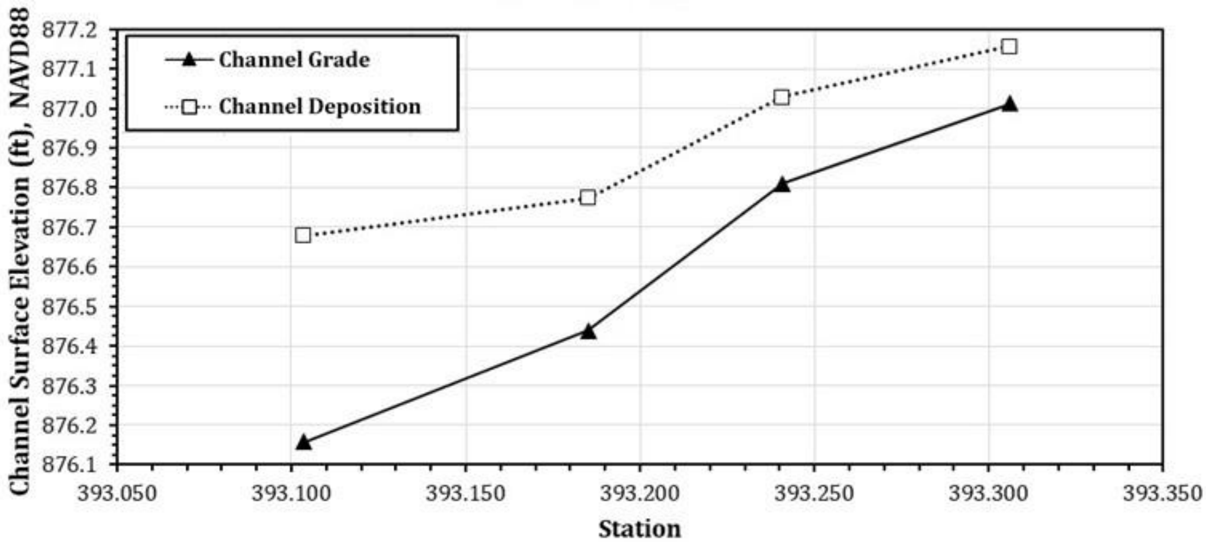


Figure E.12. SF-DC-SB-2

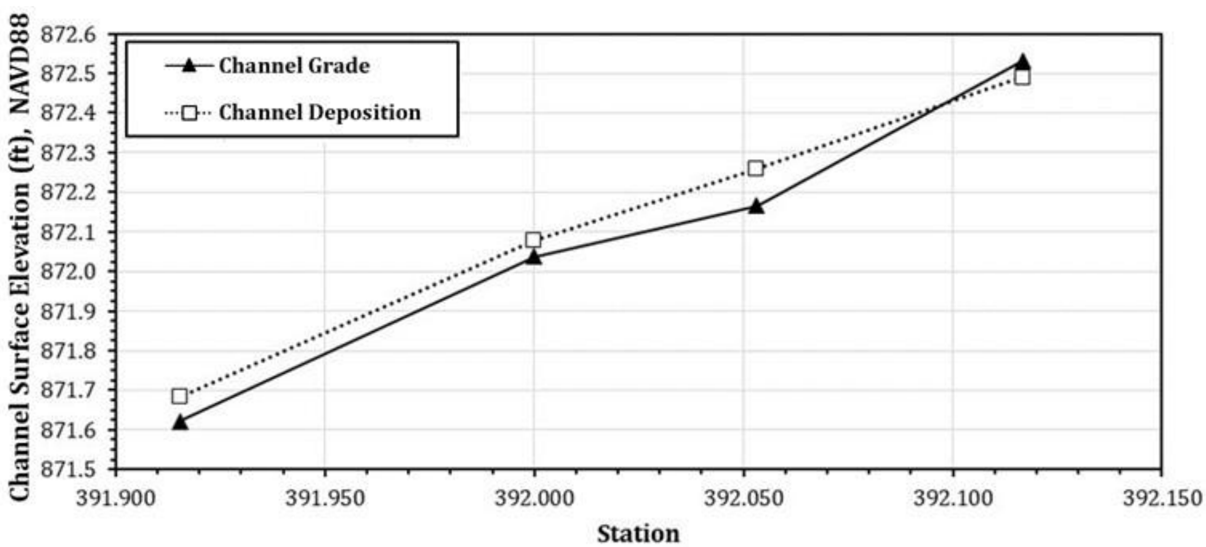


Figure E.13. SF-DC-SB-3

APPENDIX F. WATTLE DITCH CHECK PROTECTION PROFILES

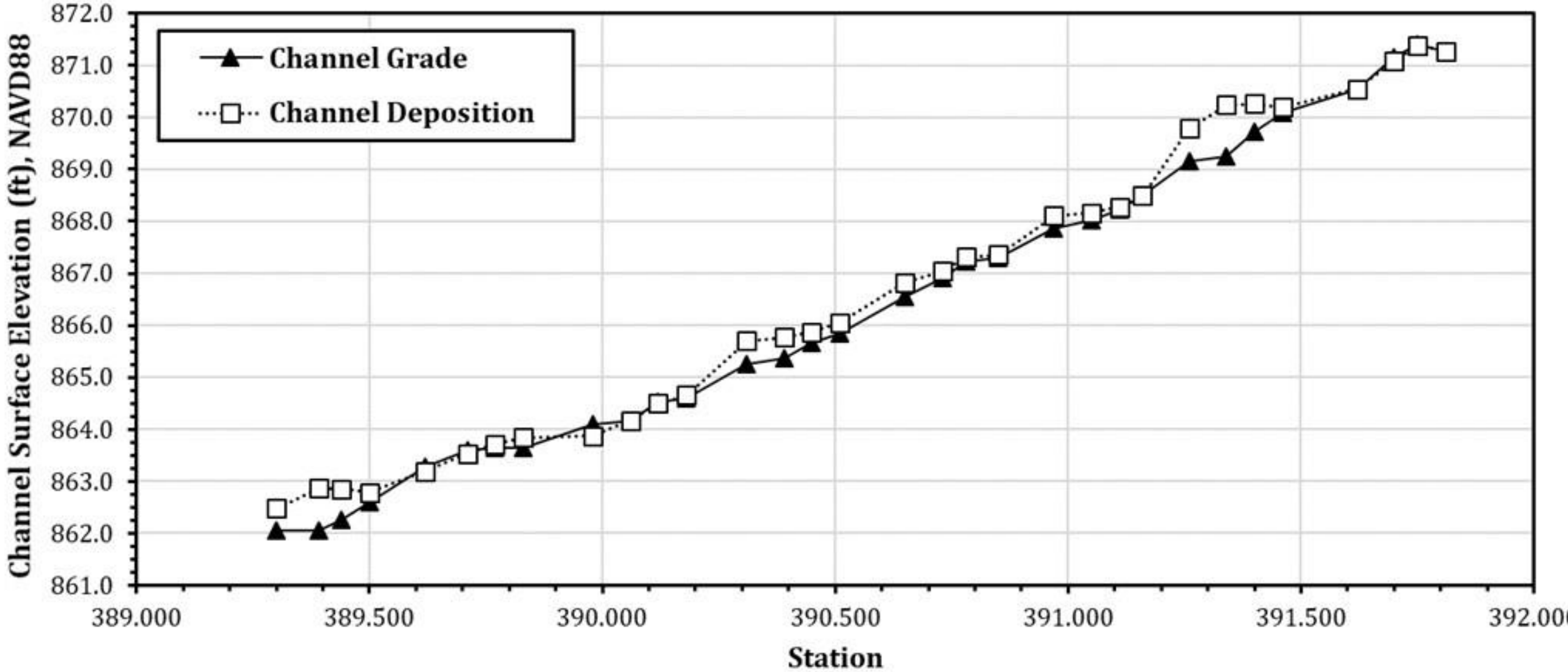


Figure F.1. Wood chip wattle ditch check channel profile

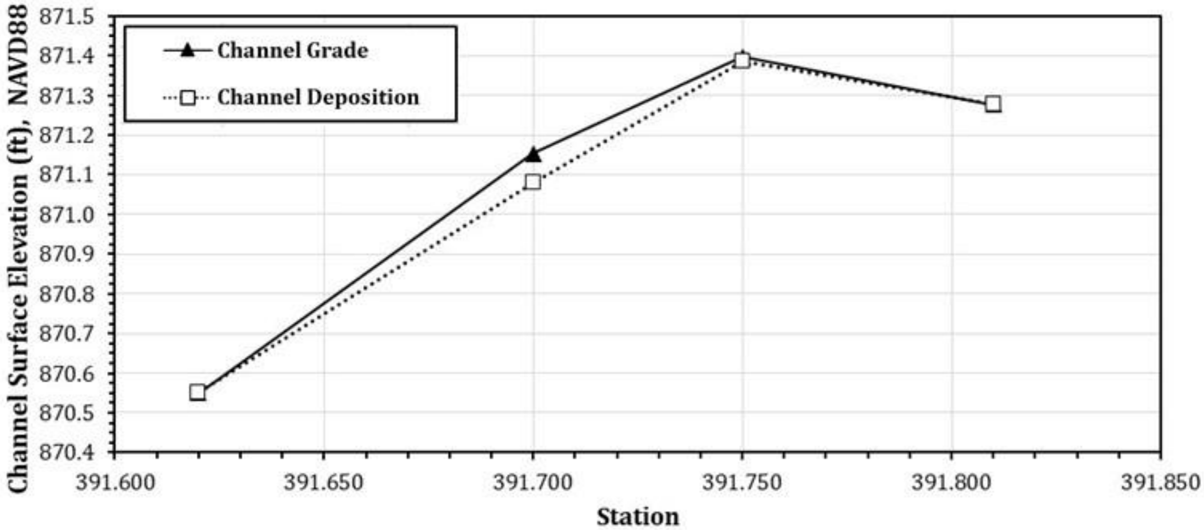


Figure F.2. W-WC-S1

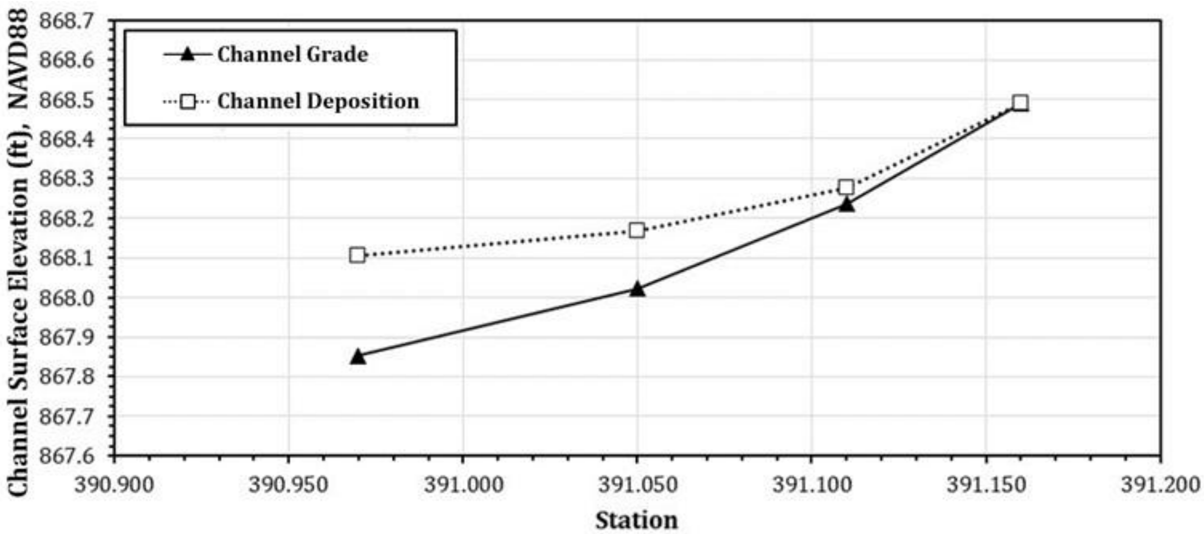


Figure F.3. W-WC-S3

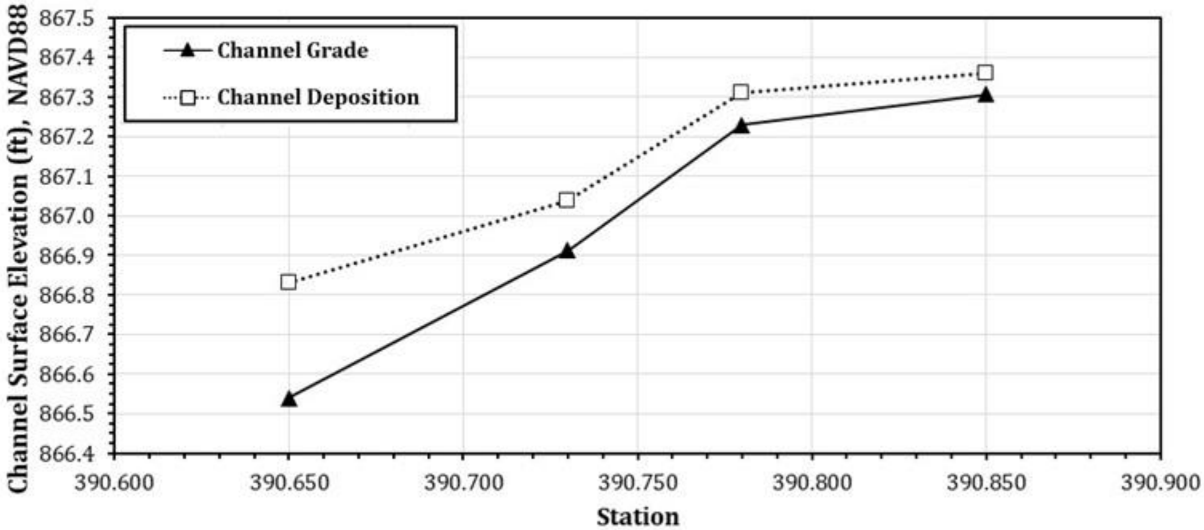


Figure F.4. W-WC-S4

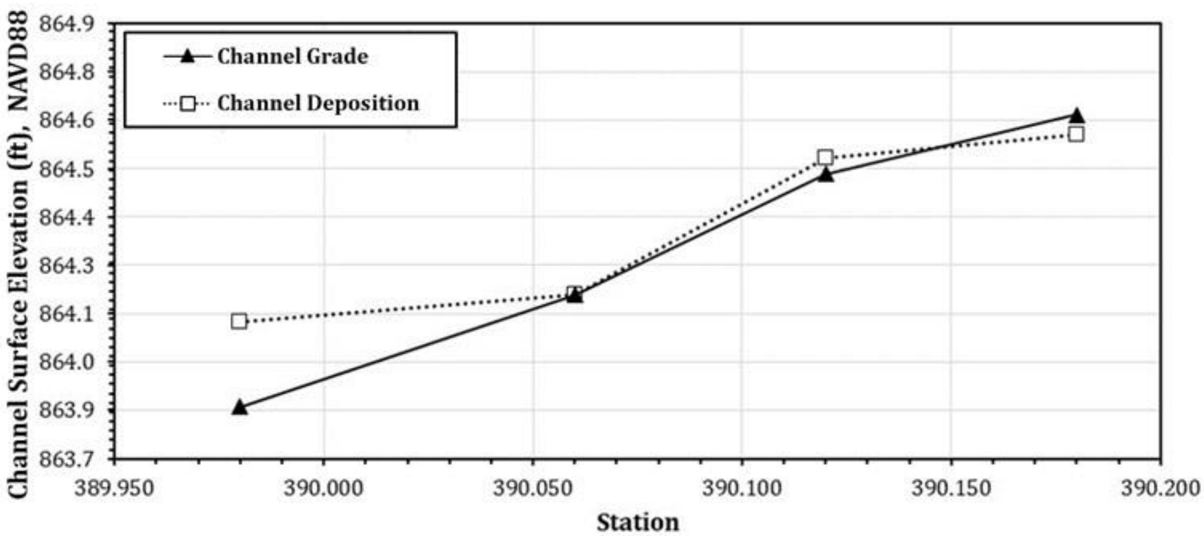


Figure F.5. W-WC-S5

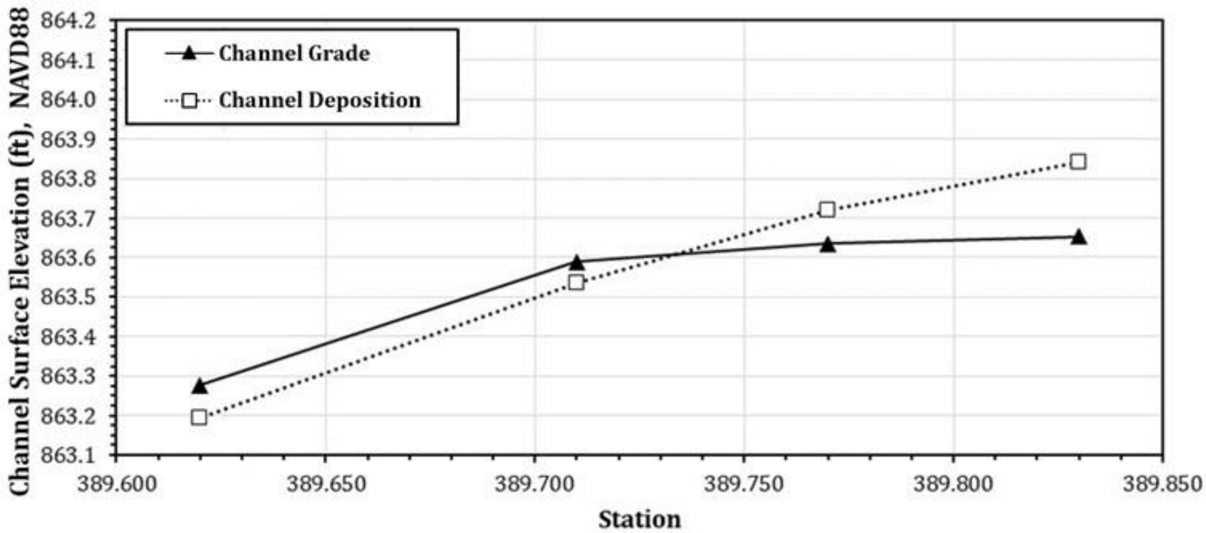


Figure F.6. W-WC-S6

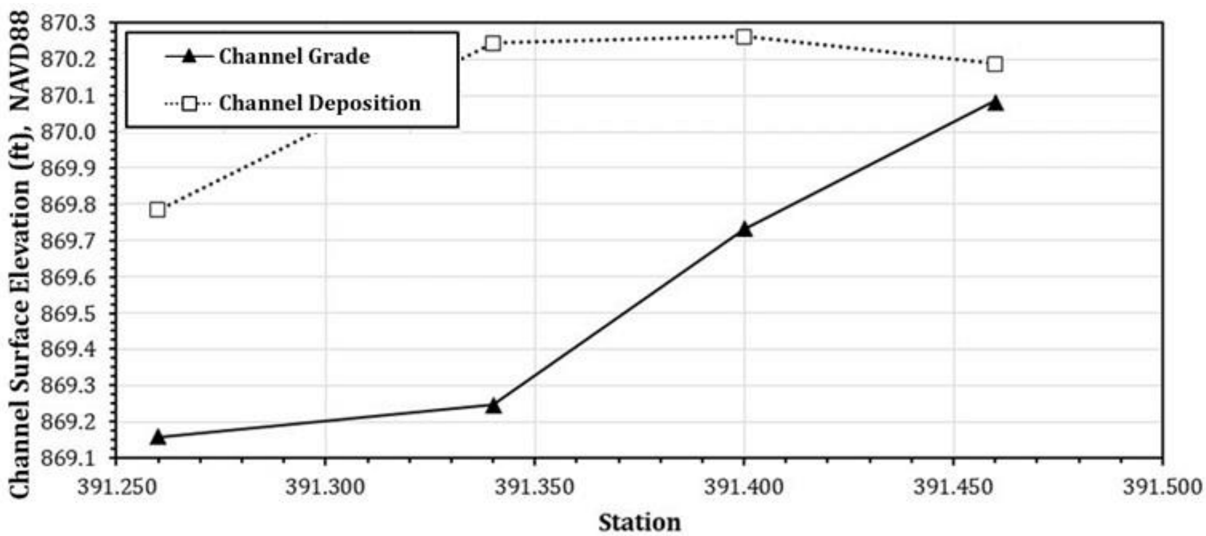


Figure F.7. W-WC-M1

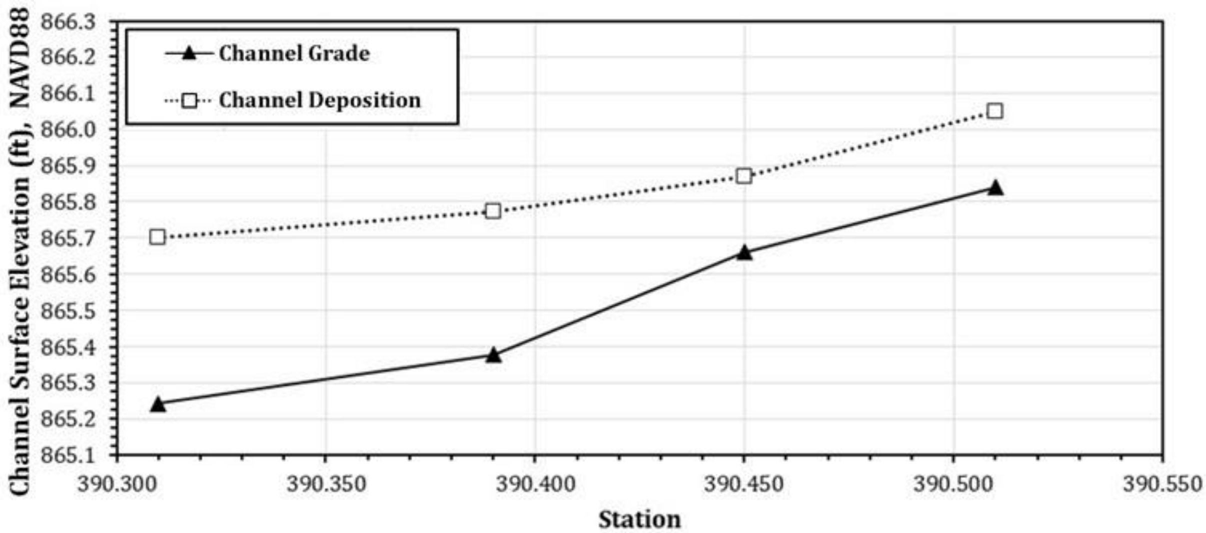


Figure F.8. W-WC-M2

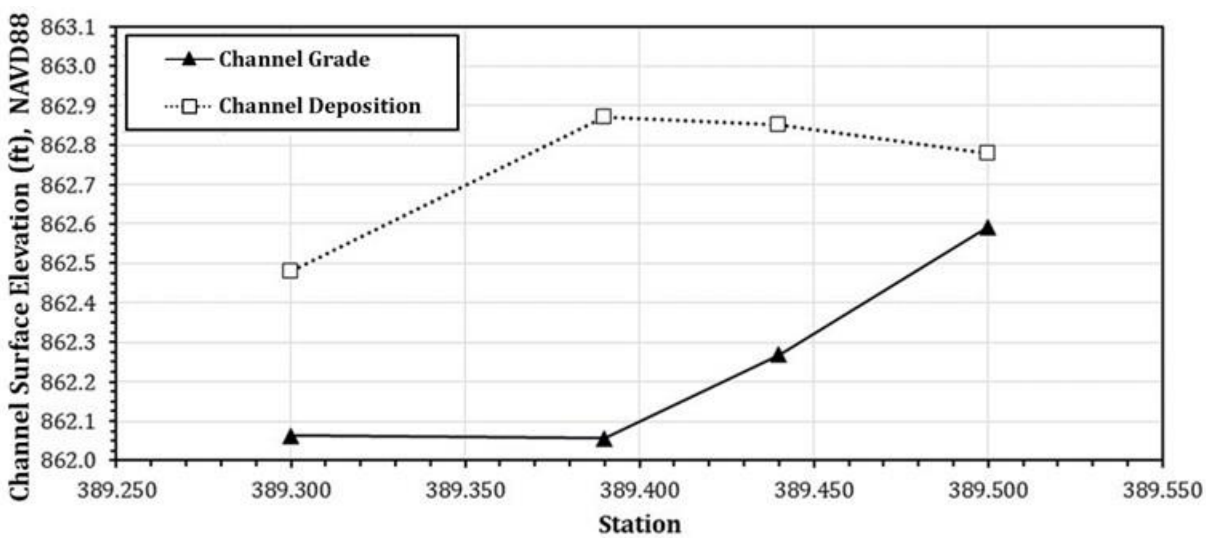


Figure F.9. W-WC-M3

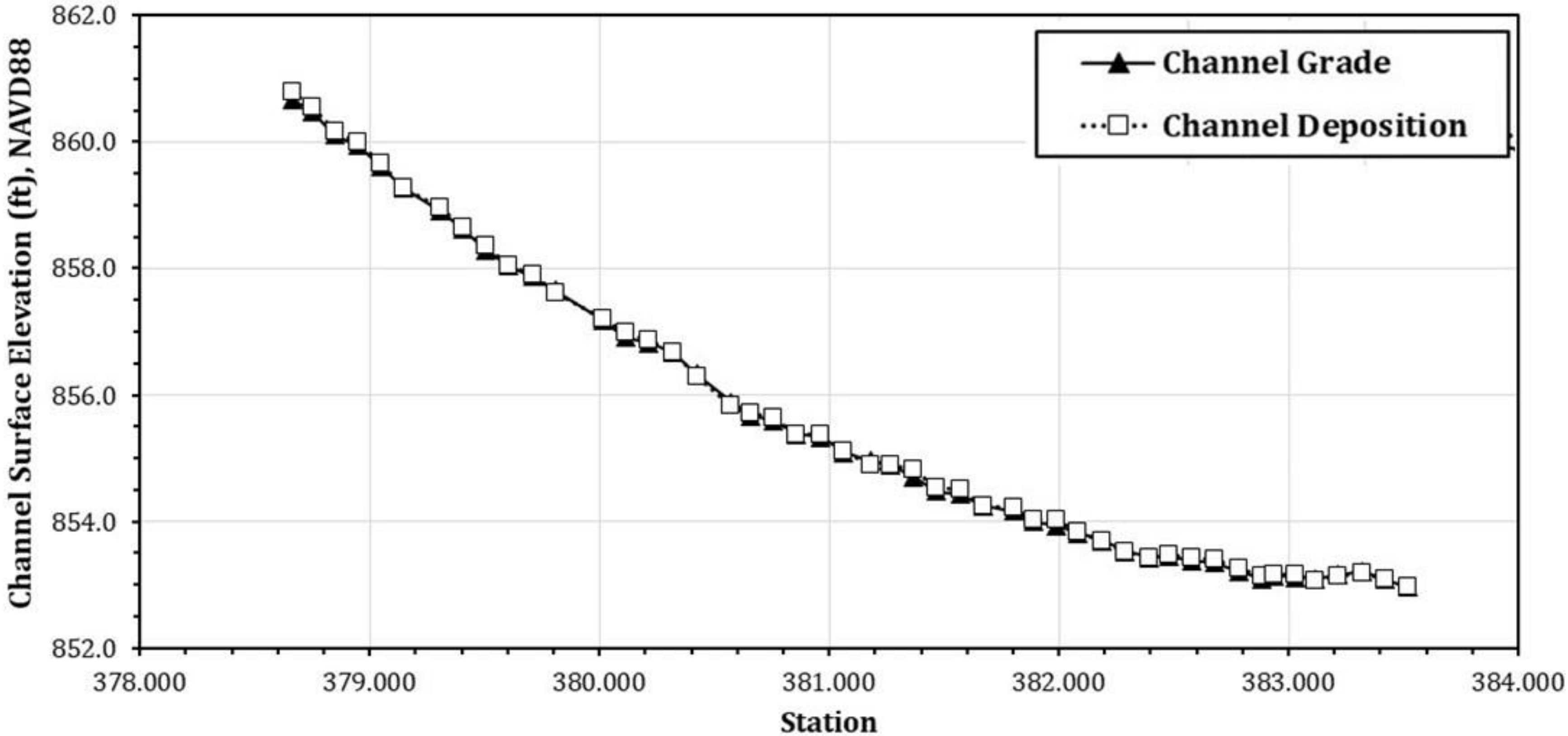


Figure F.10. Excelsior wattle ditch check channel profile

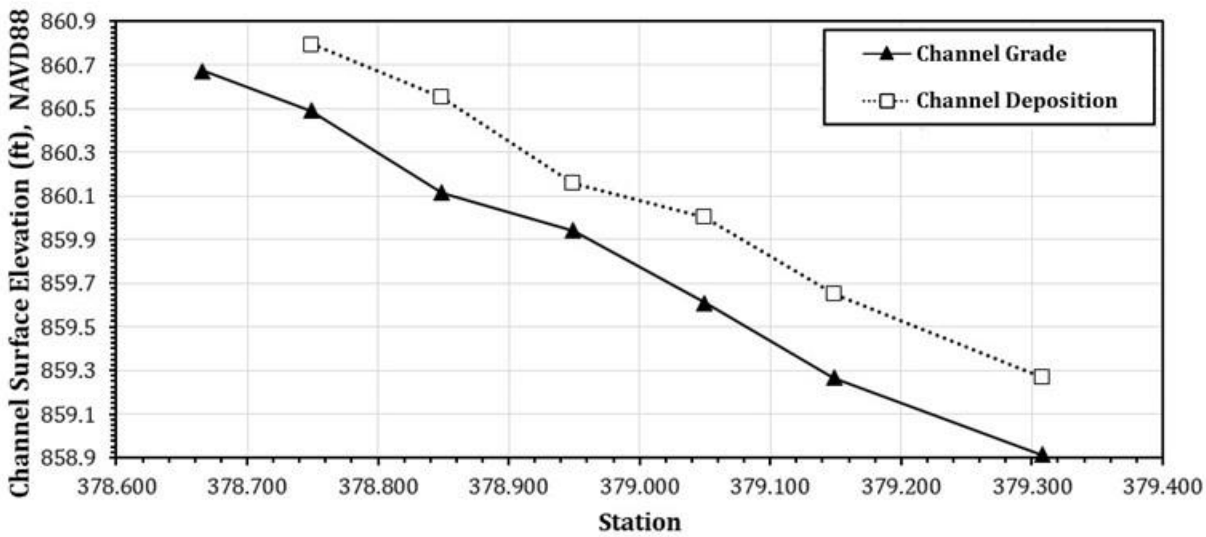


Figure F.11. W-EX-S2

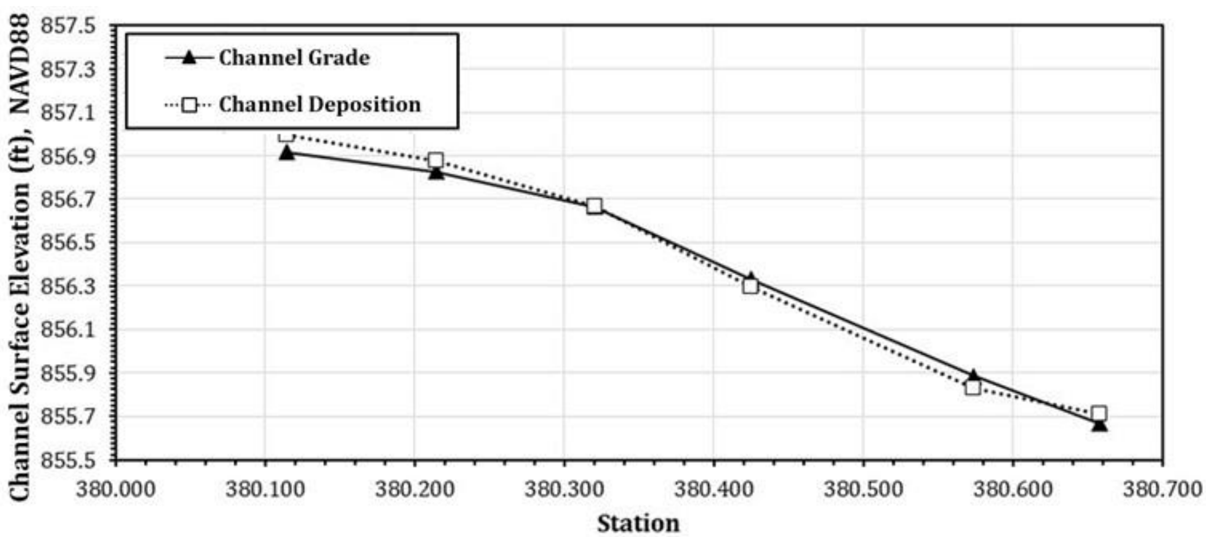


Figure F.12. W-EX-S3

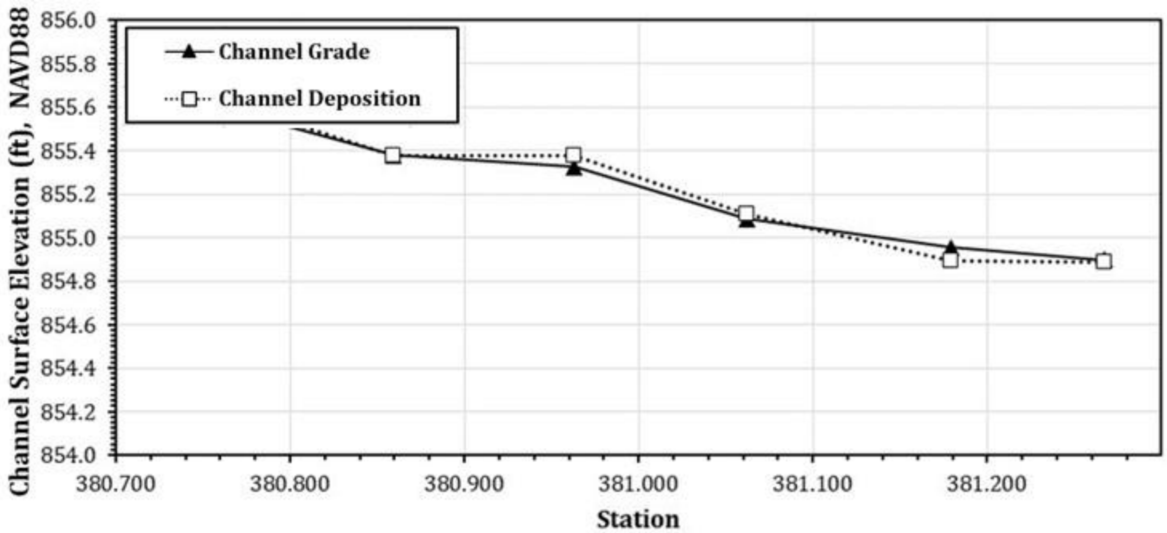


Figure F.13. W-EX-S4

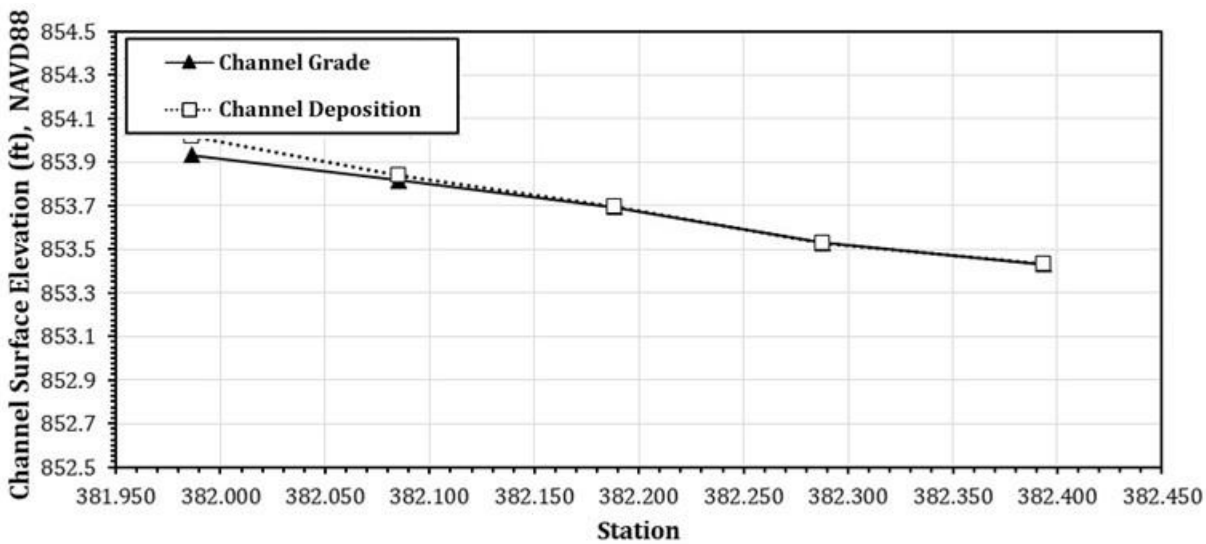


Figure F.14. W-EX-S5

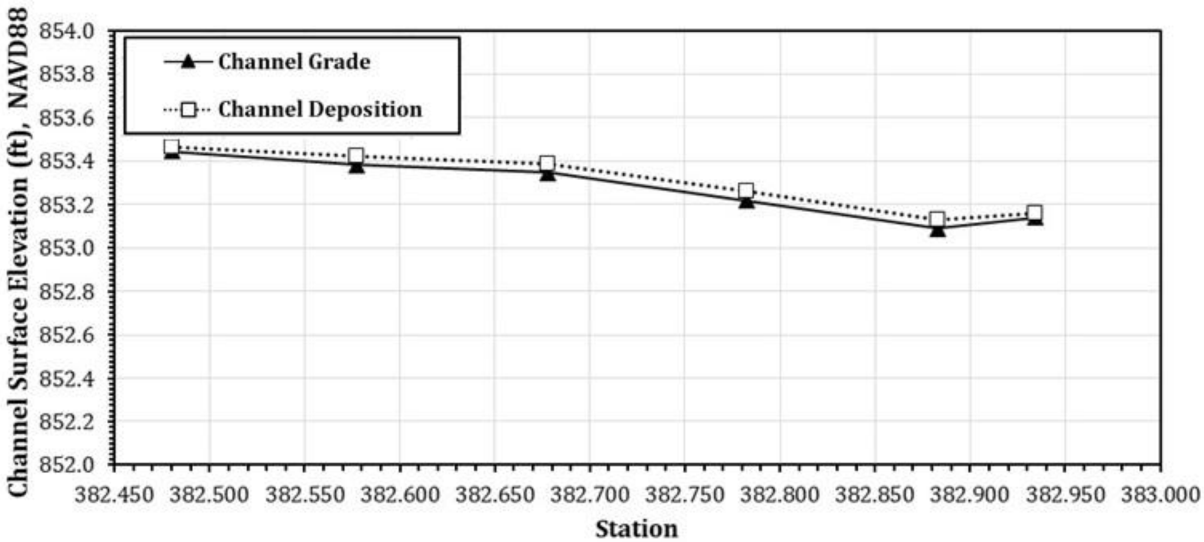


Figure F.15. W-EX-S6

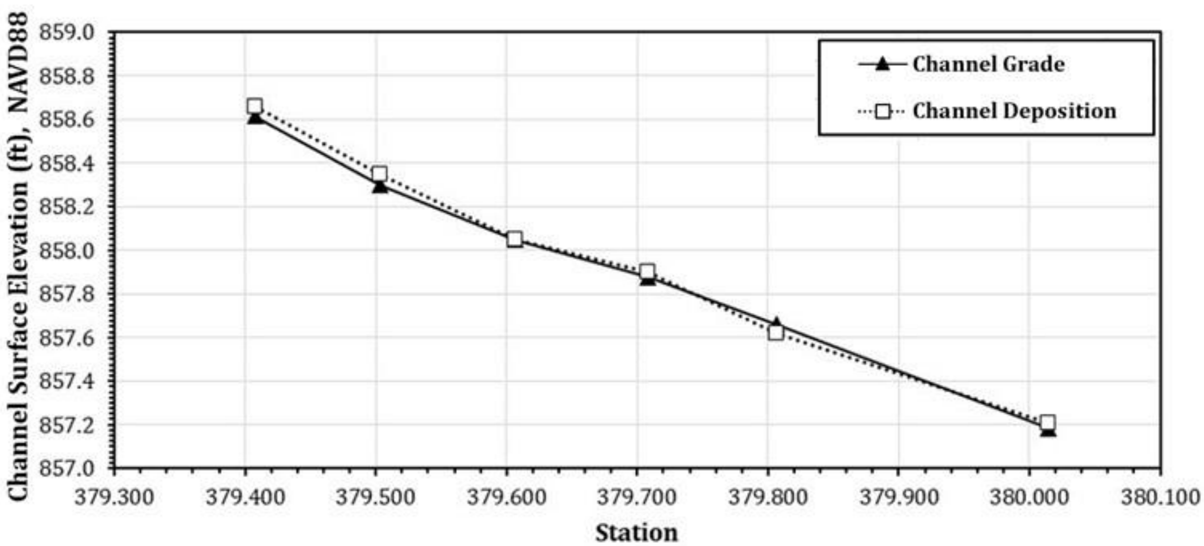


Figure F.16. W-EX-M1

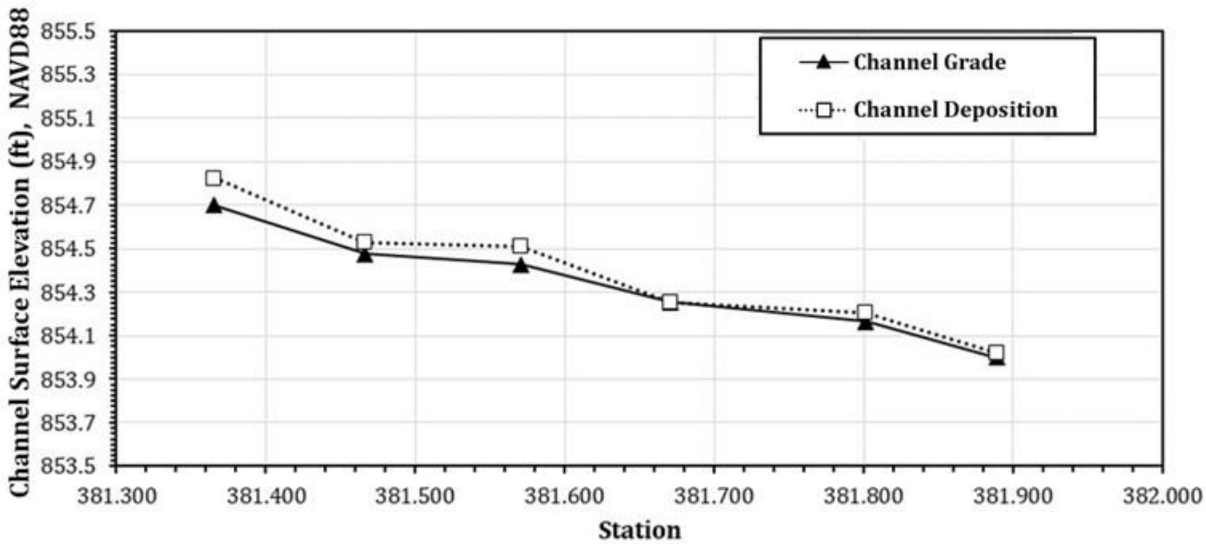


Figure F.17. W-EX-M2

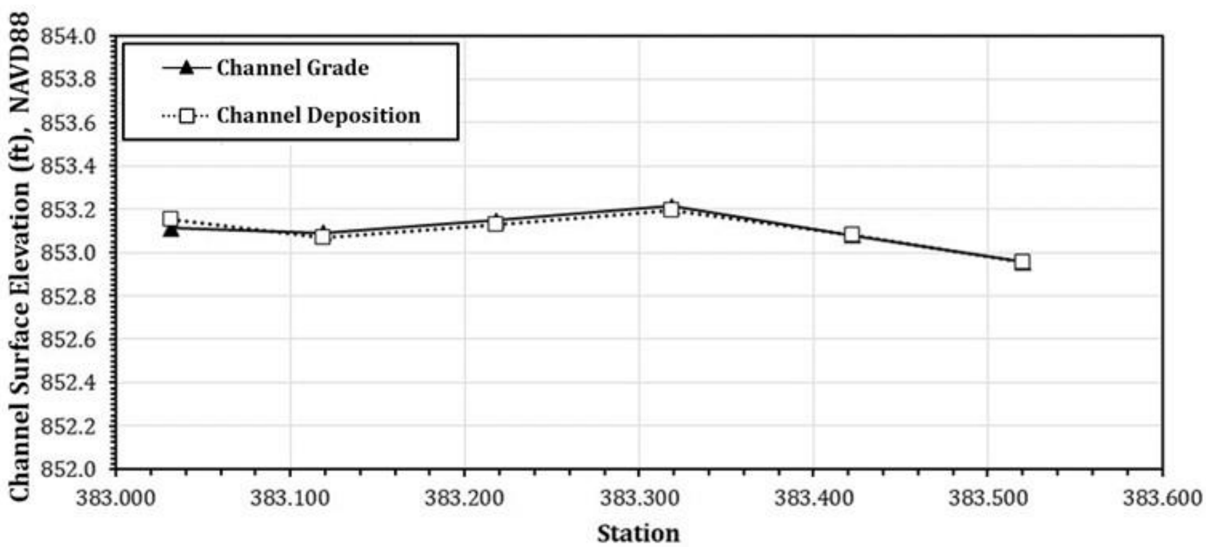


Figure F.18. W-EX-M3

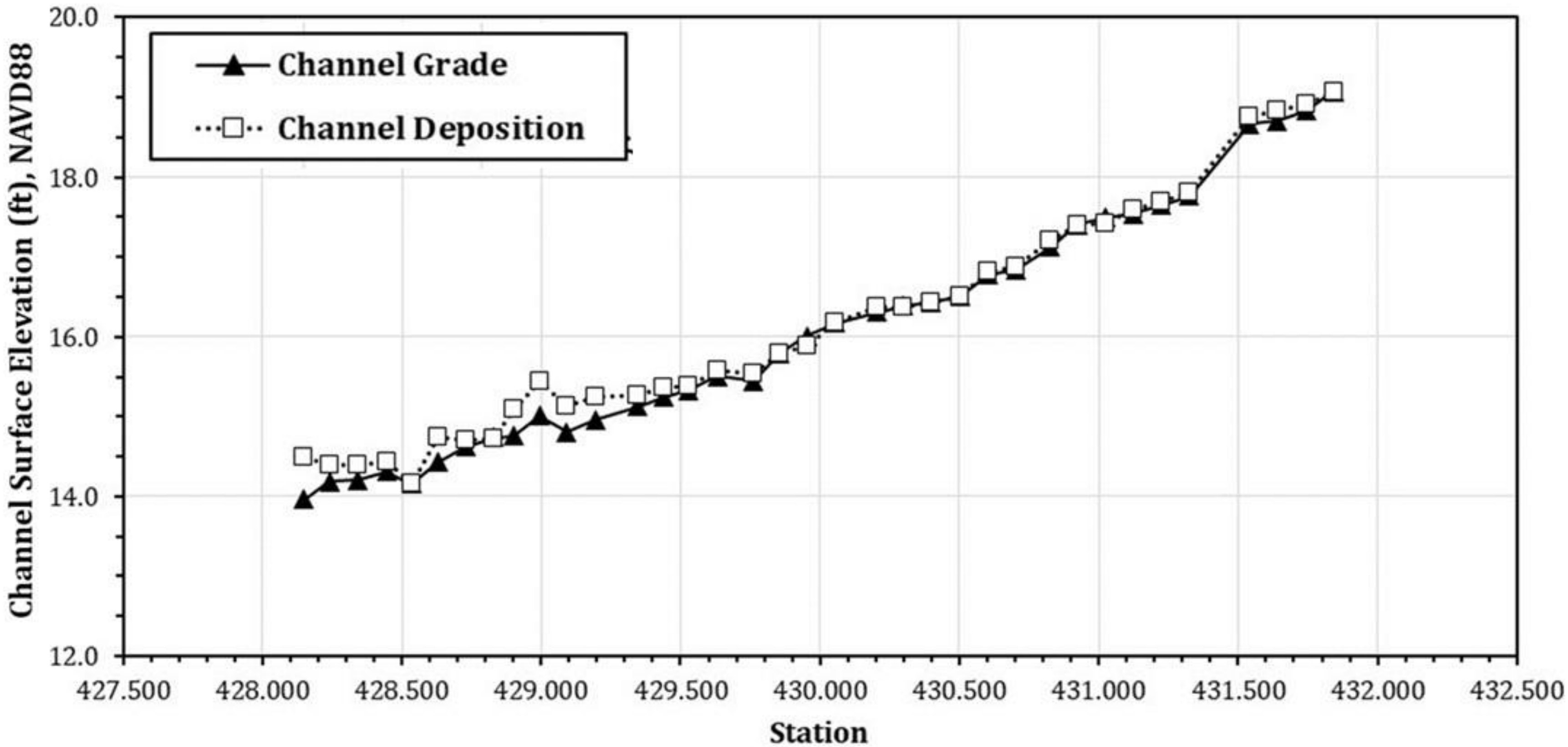


Figure F.19. Straw wattle ditch check channel profile

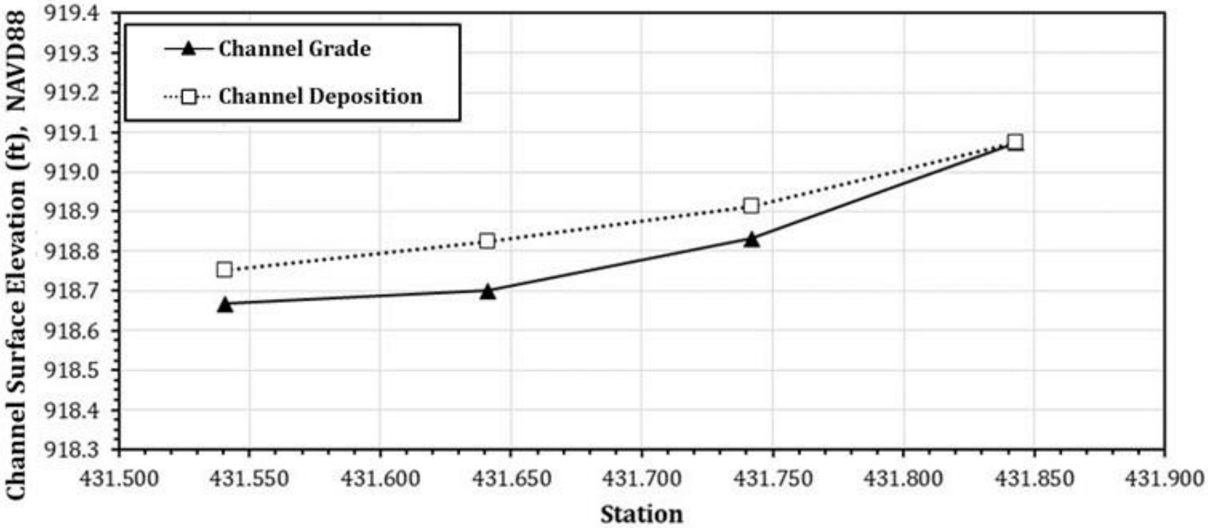


Figure F.20. W-ST-S2

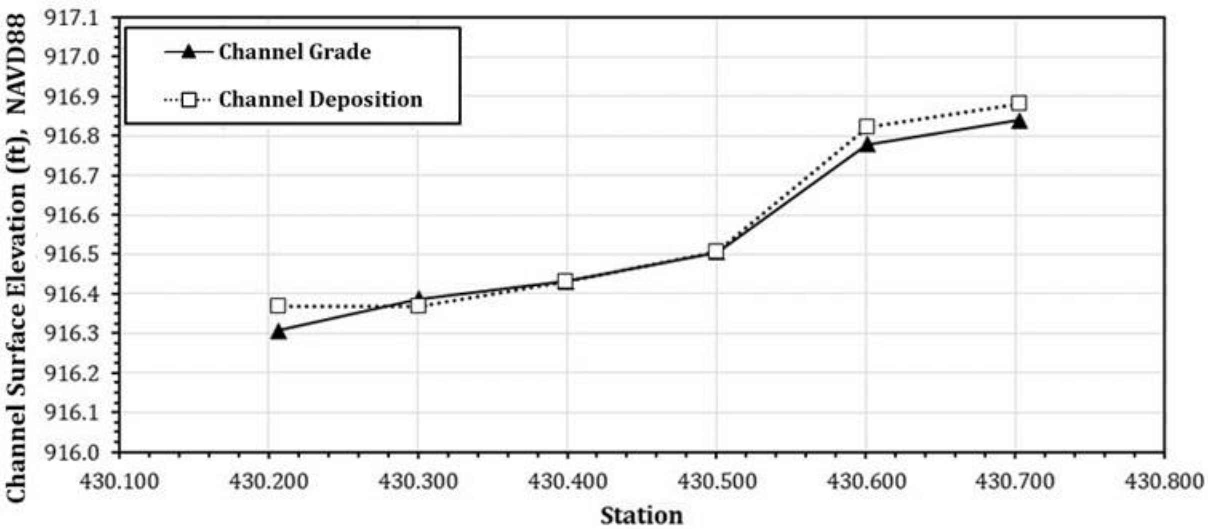


Figure F.21. W-ST-S3

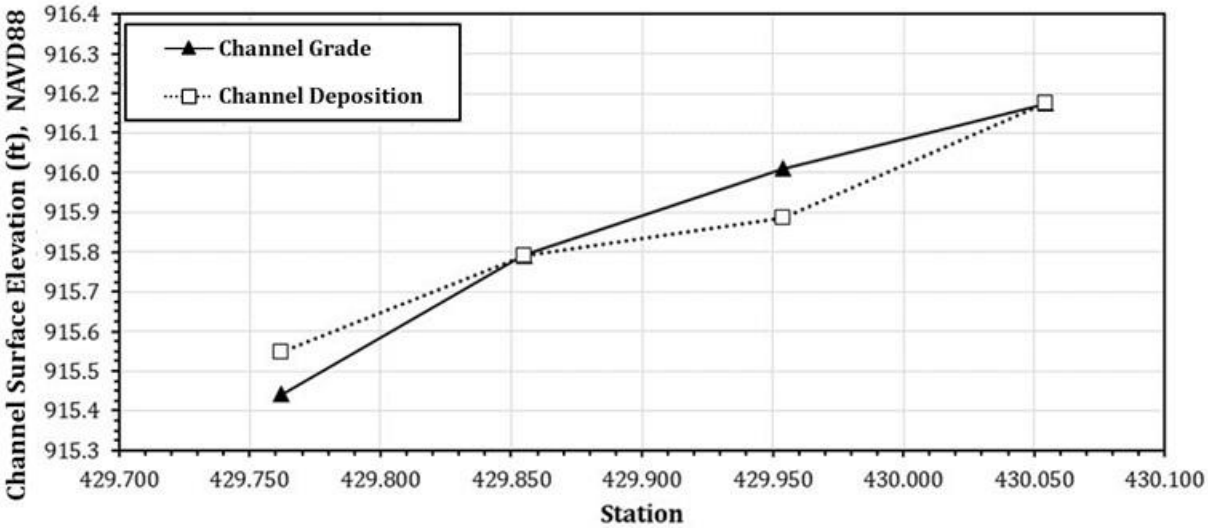


Figure F.22. W-ST-S4

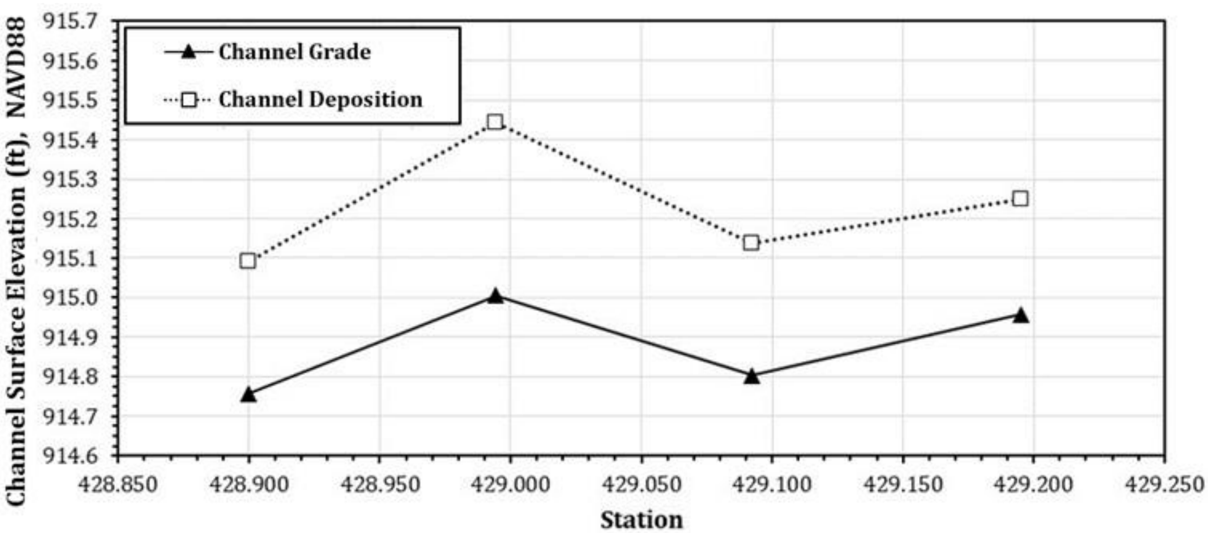


Figure F.23. W-ST-S5

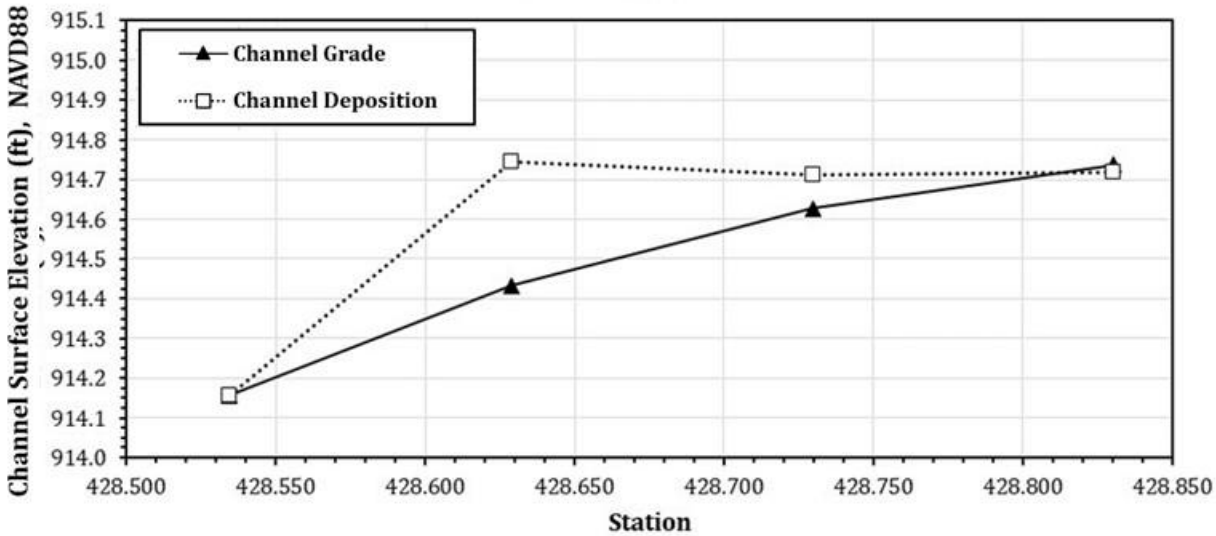


Figure F.24. W-ST-S6

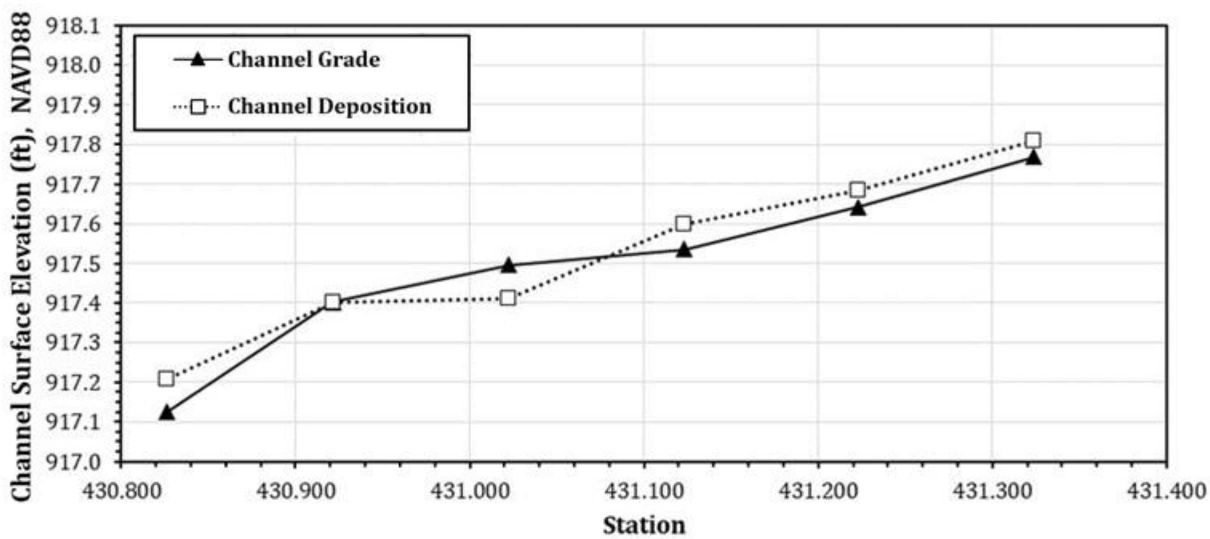


Figure F.25. W-ST-M1

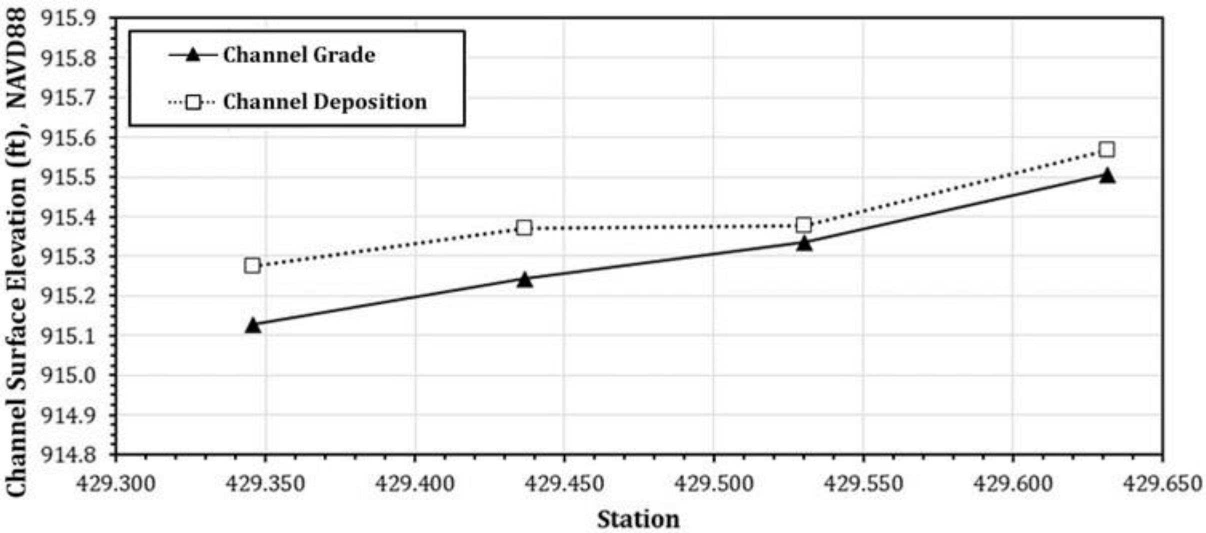


Figure F.26. W-ST-M2

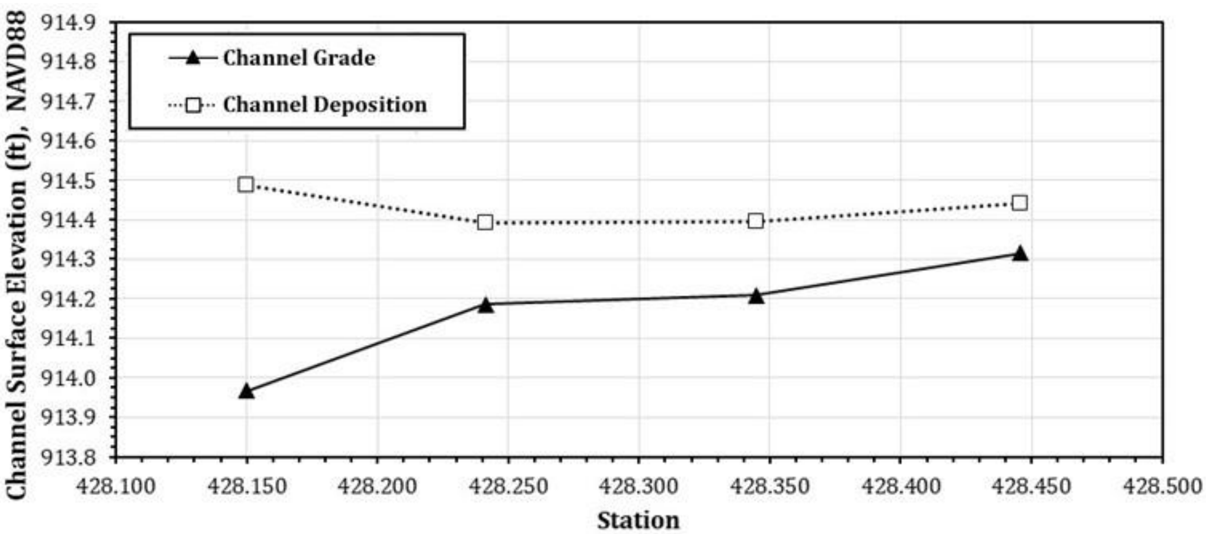


Figure F.27. W-ST-M3

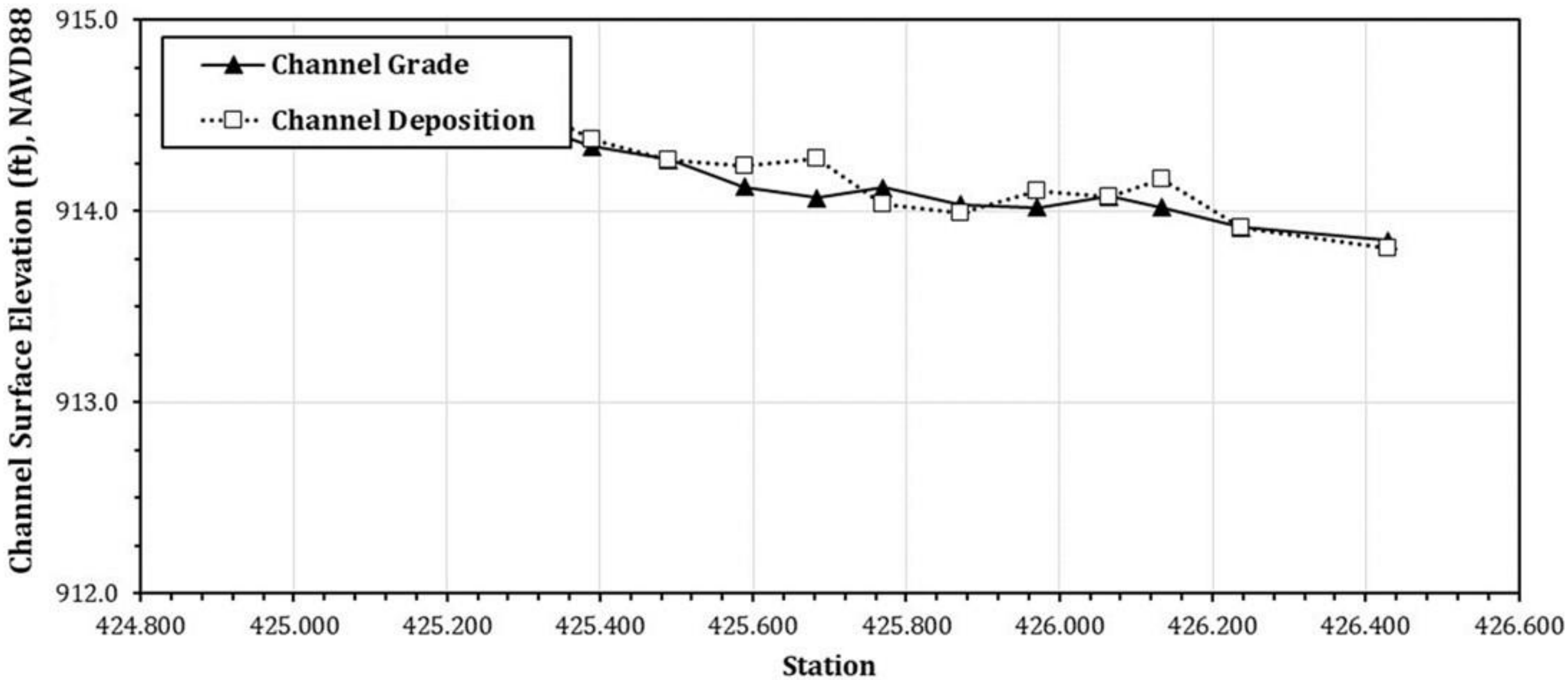


Figure F.28. Switch grass wattle ditch check channel profile

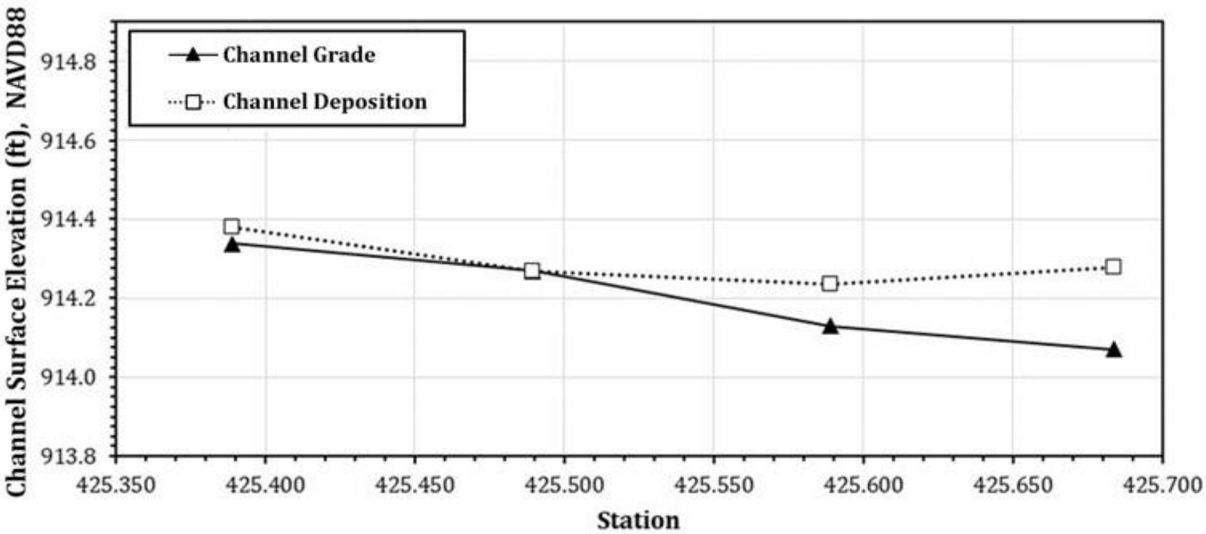


Figure F.29. W-SG-S1

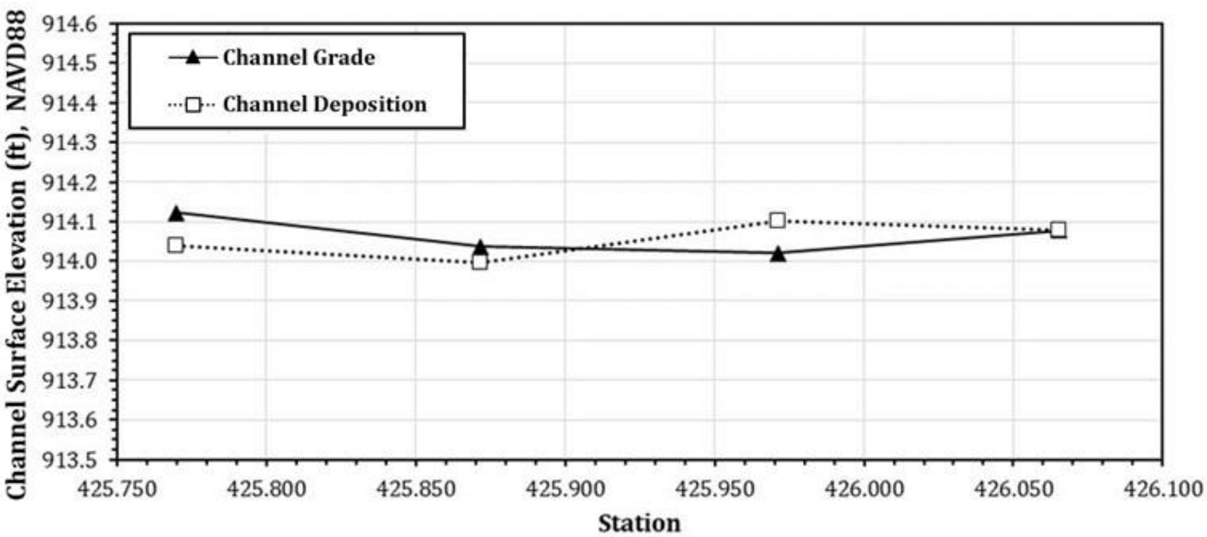


Figure F.30. W-SG-S2

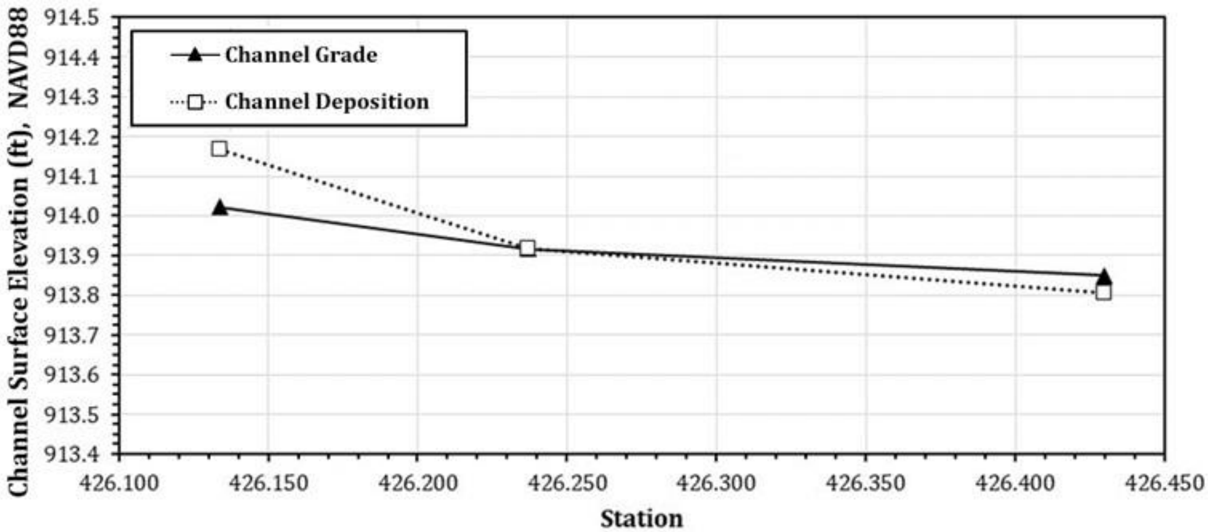


Figure F.31. W-SG-S3

APPENDIX G. SEDIMENT BASIN PERFORMANCE PER STORM EVENT

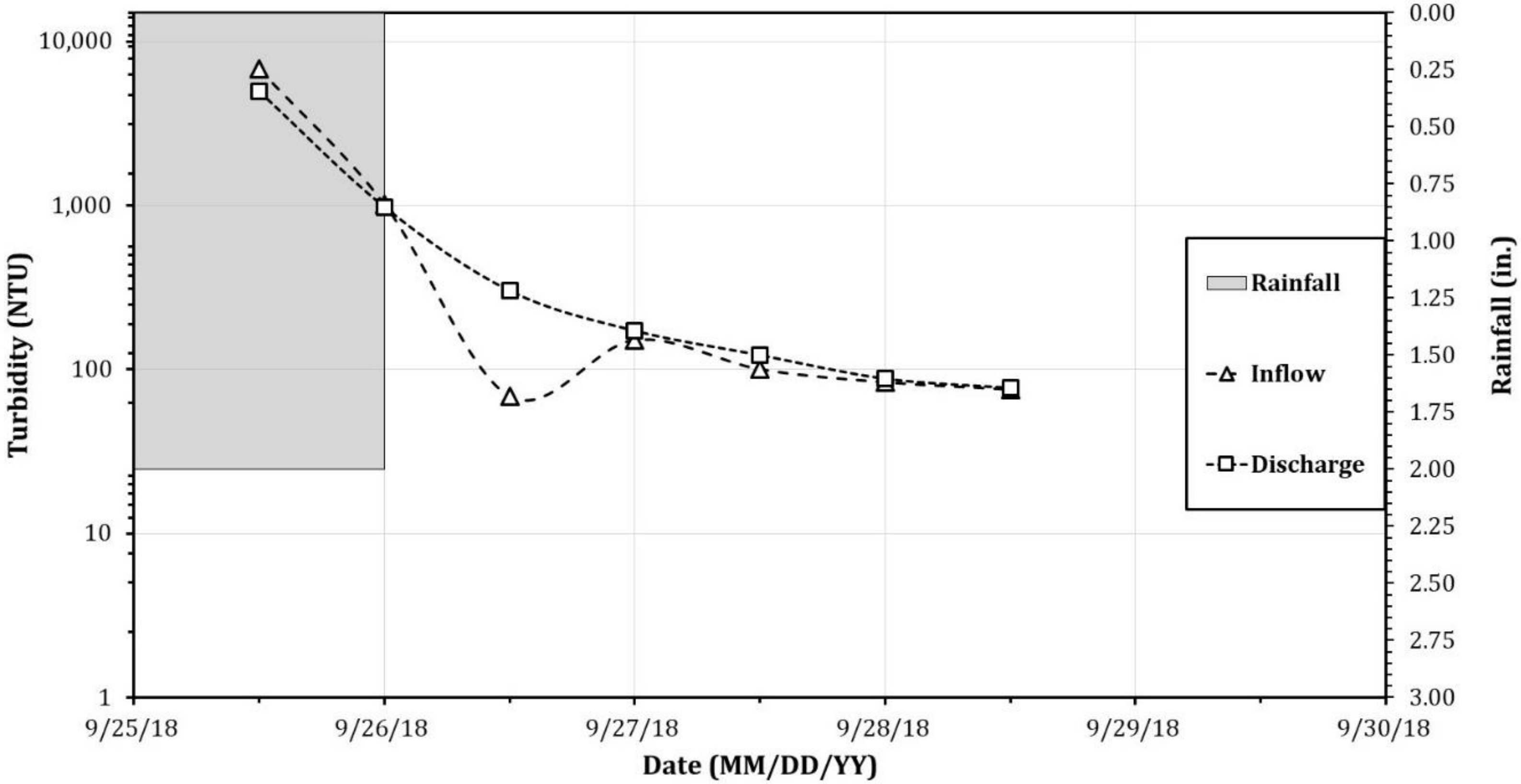


Figure G.1. Event 1

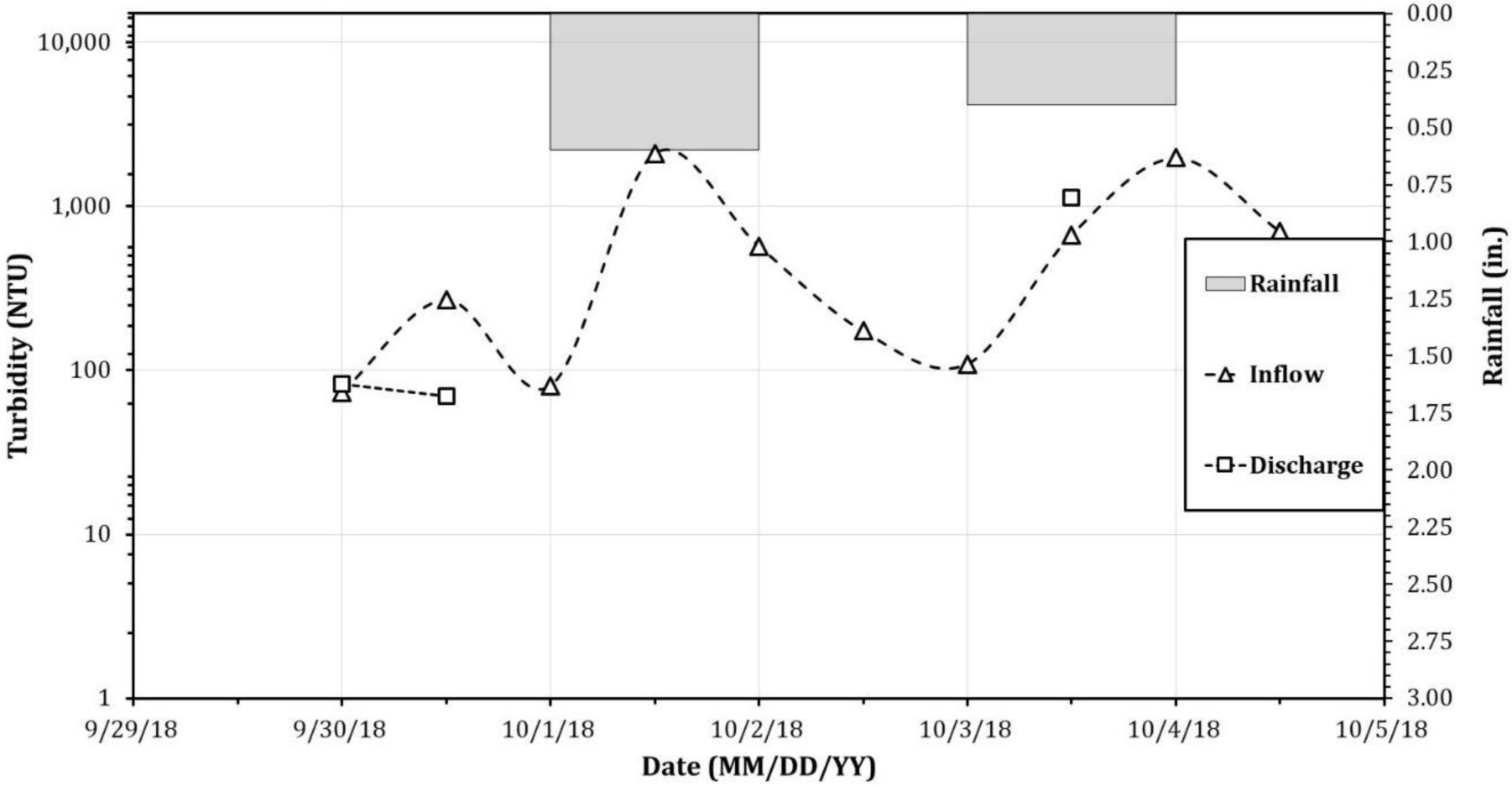


Figure G.2. Event 2

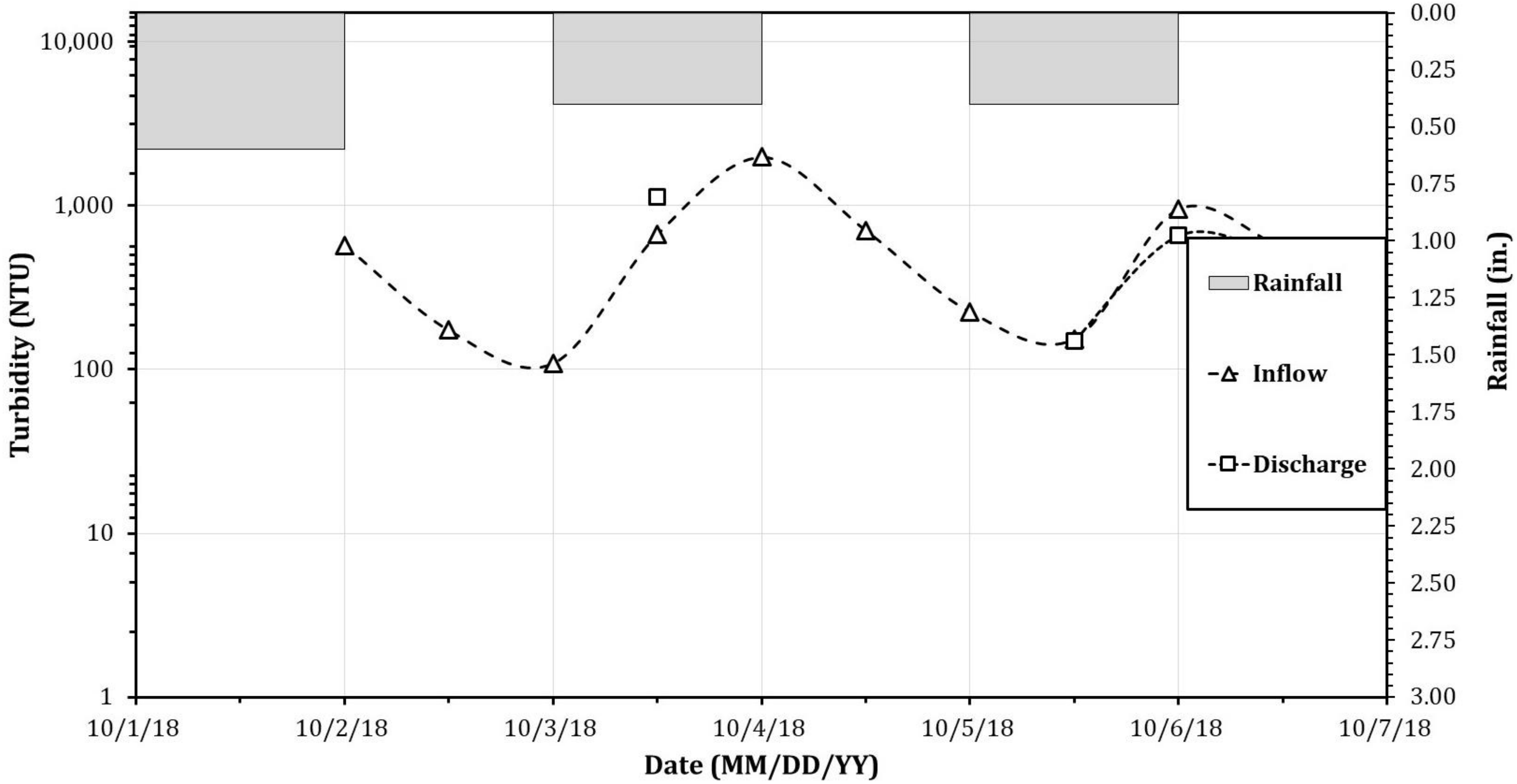


Figure G.3. Event 3

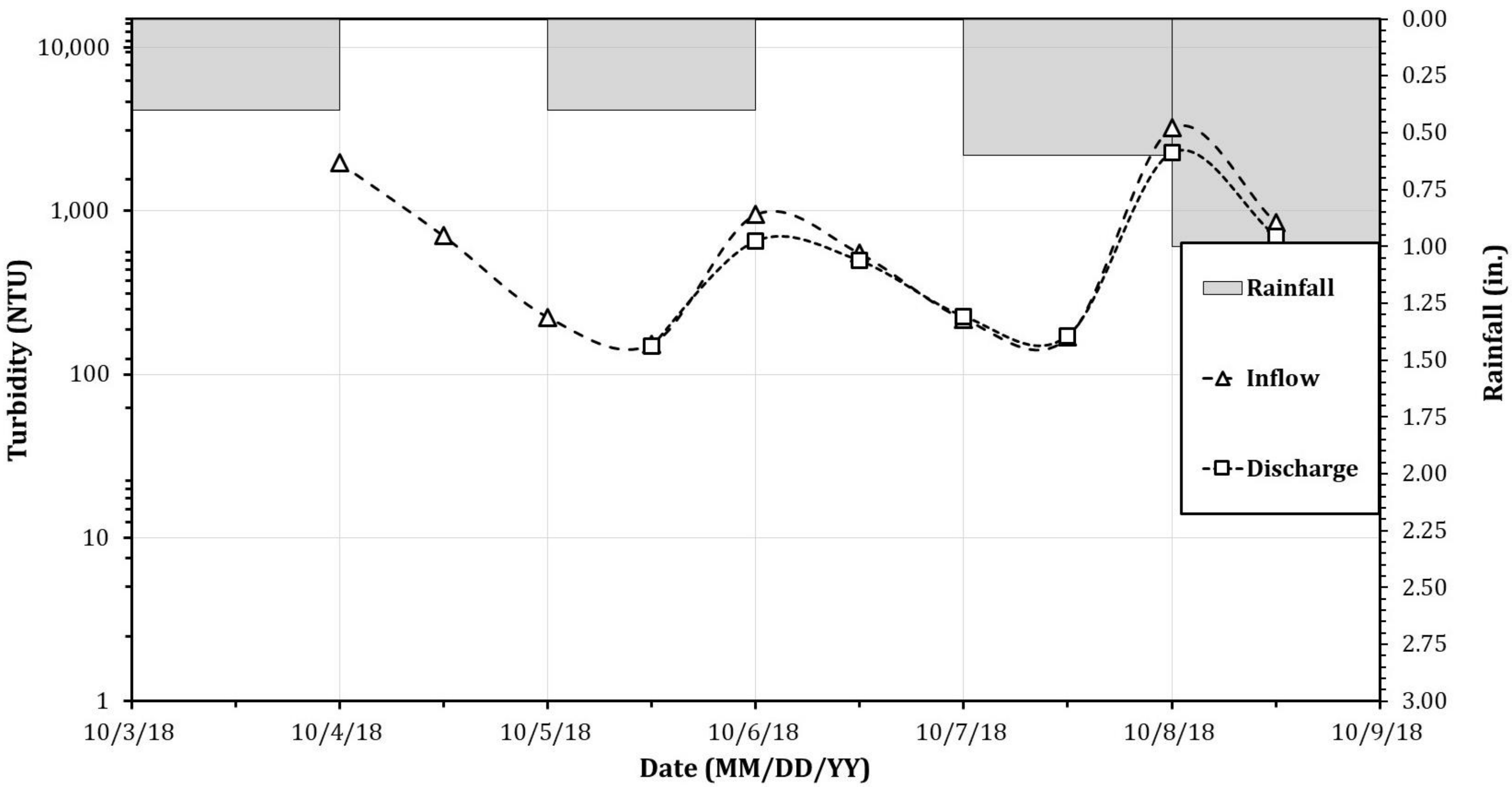


Figure G.4. Event 4

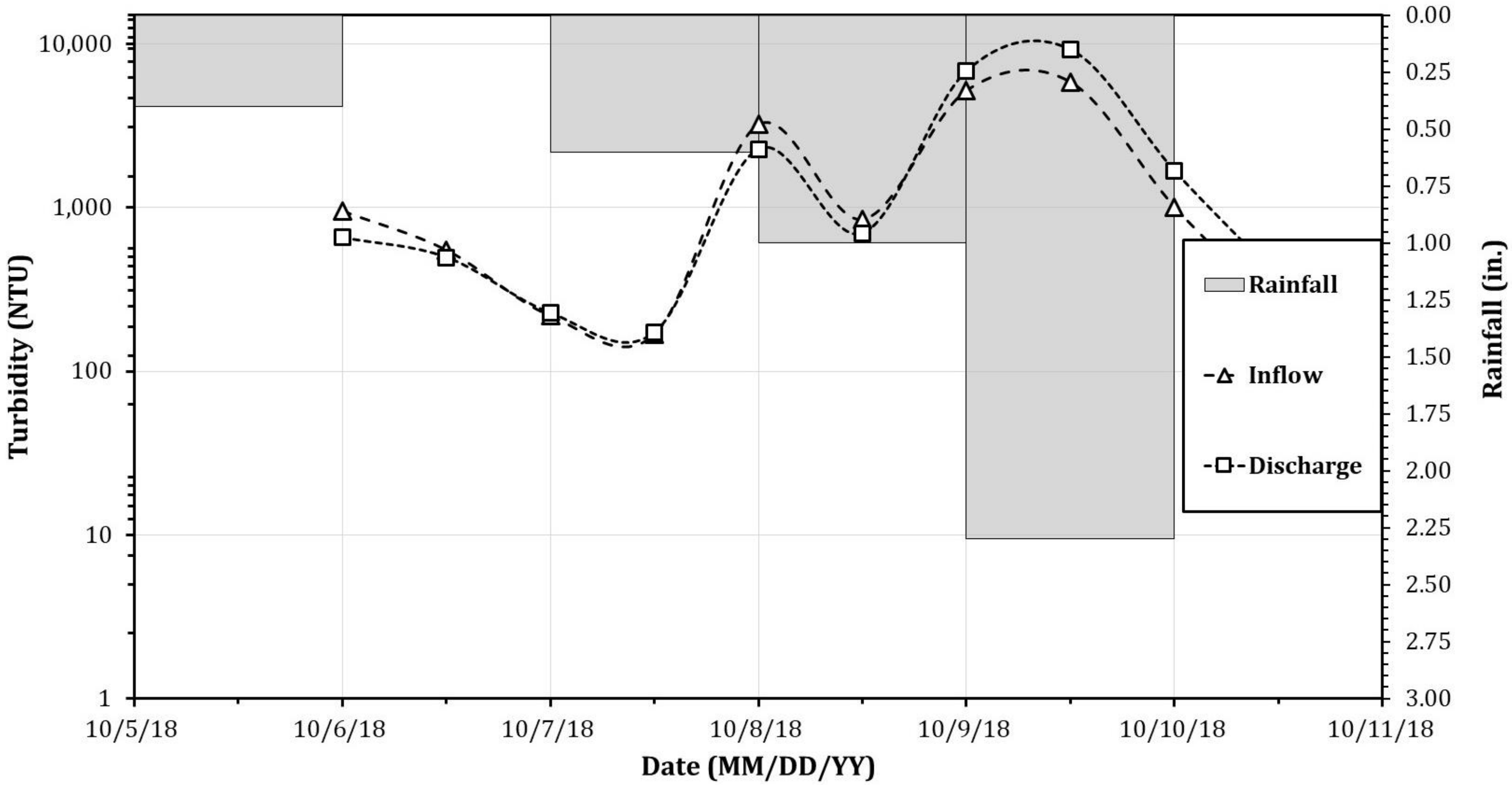


Figure G.5. Event 5

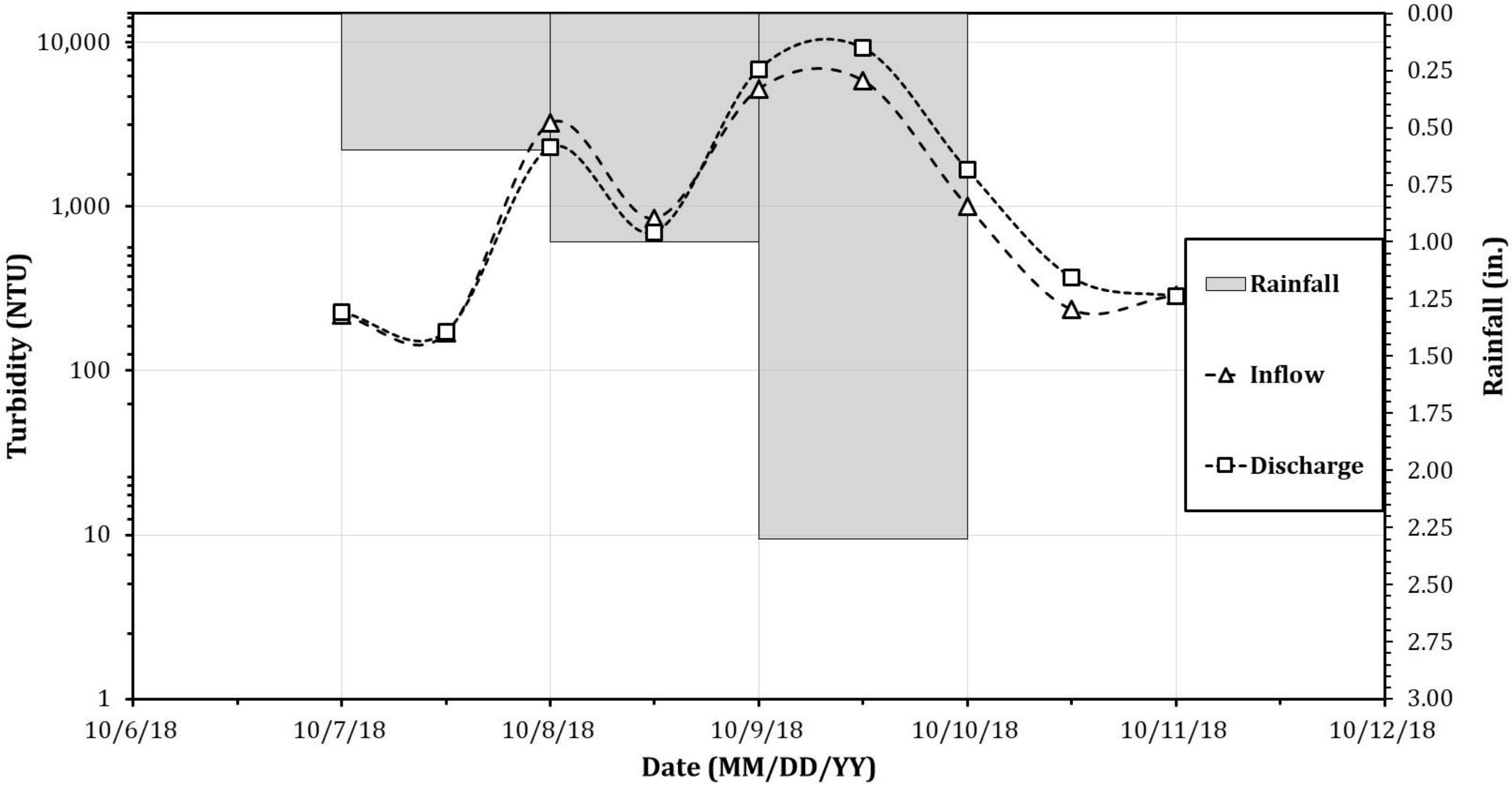


Figure G.6. Event 6

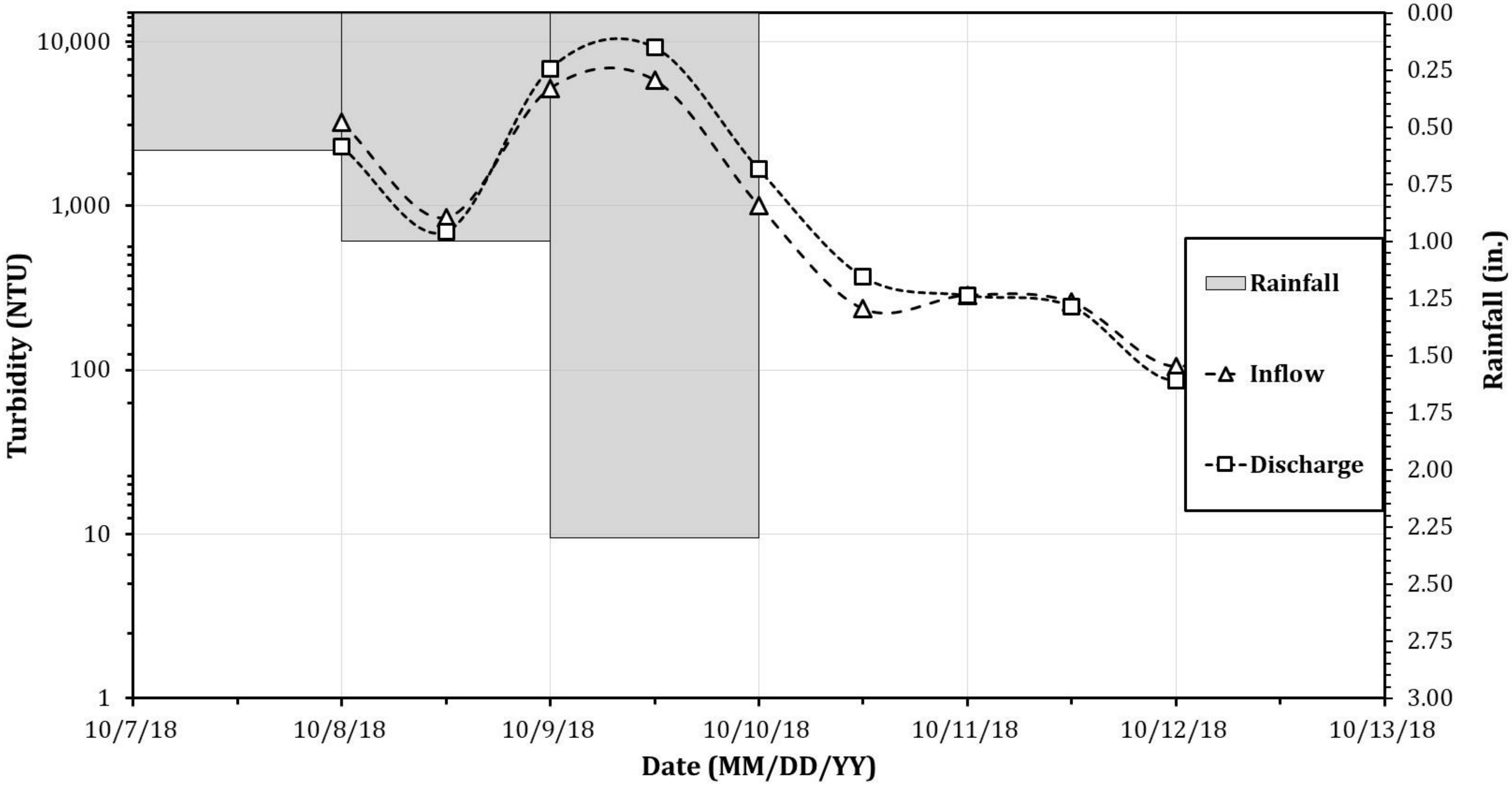


Figure G.7. Event 7

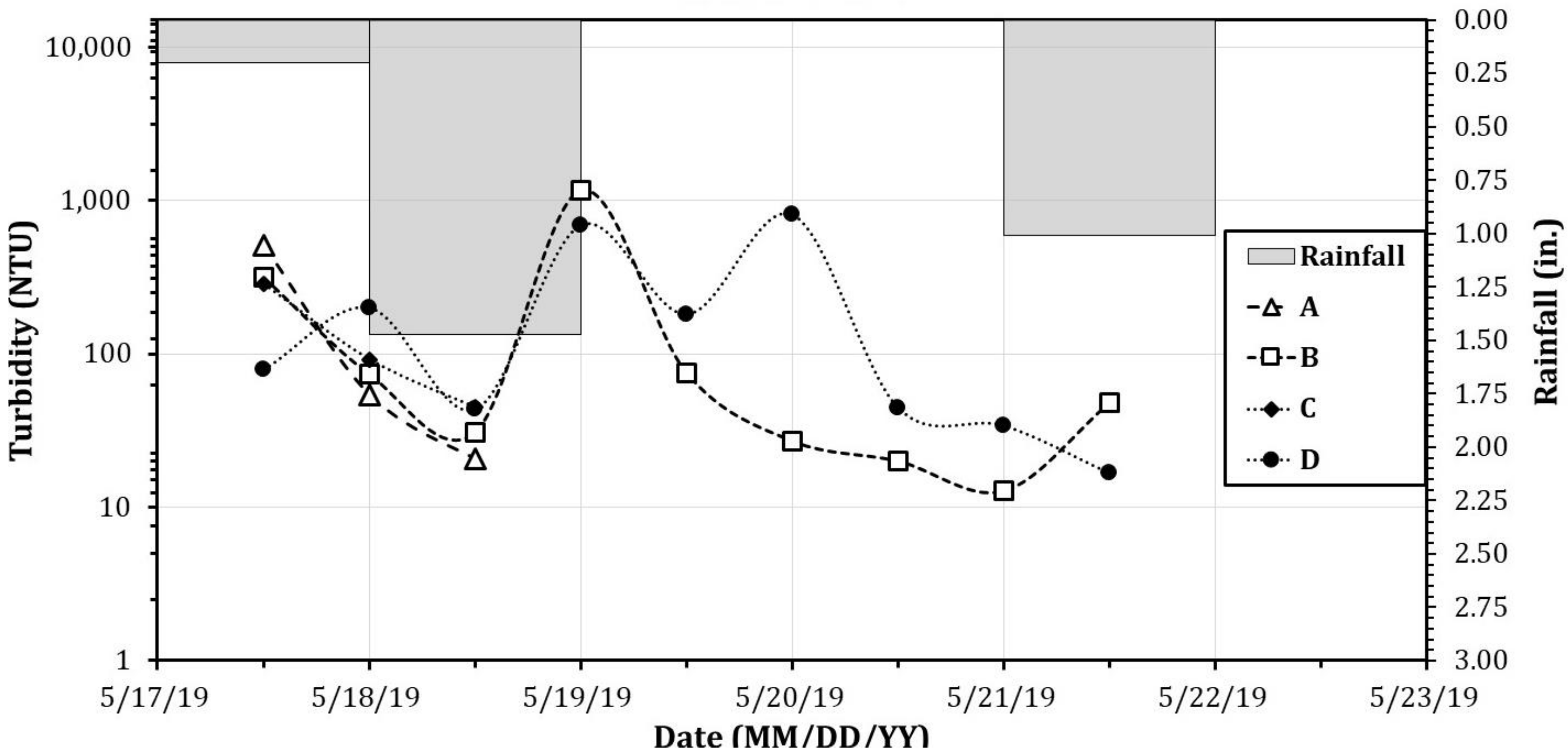


Figure G.8. Events 8 and 9

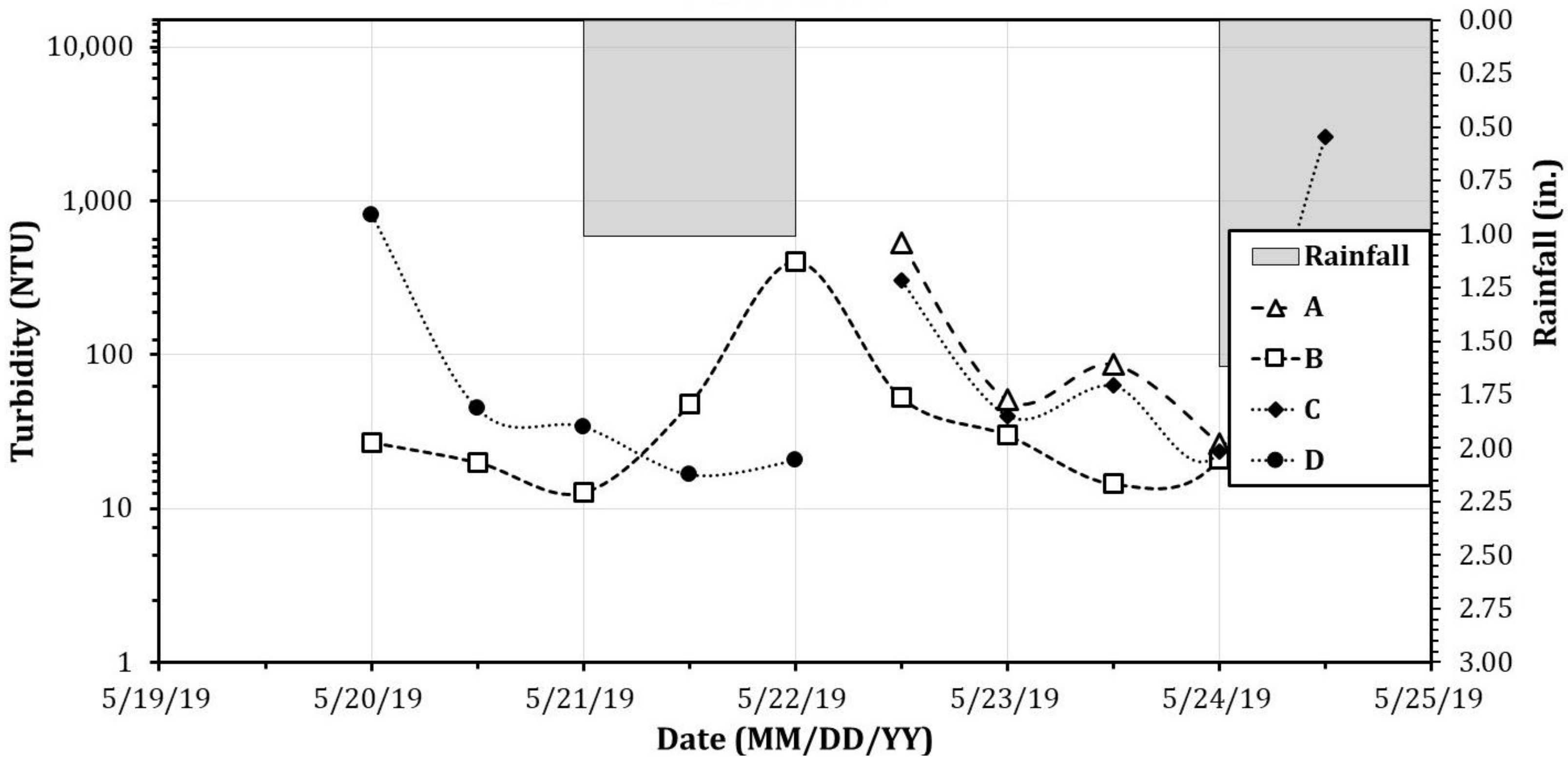


Figure G.9. Event 10

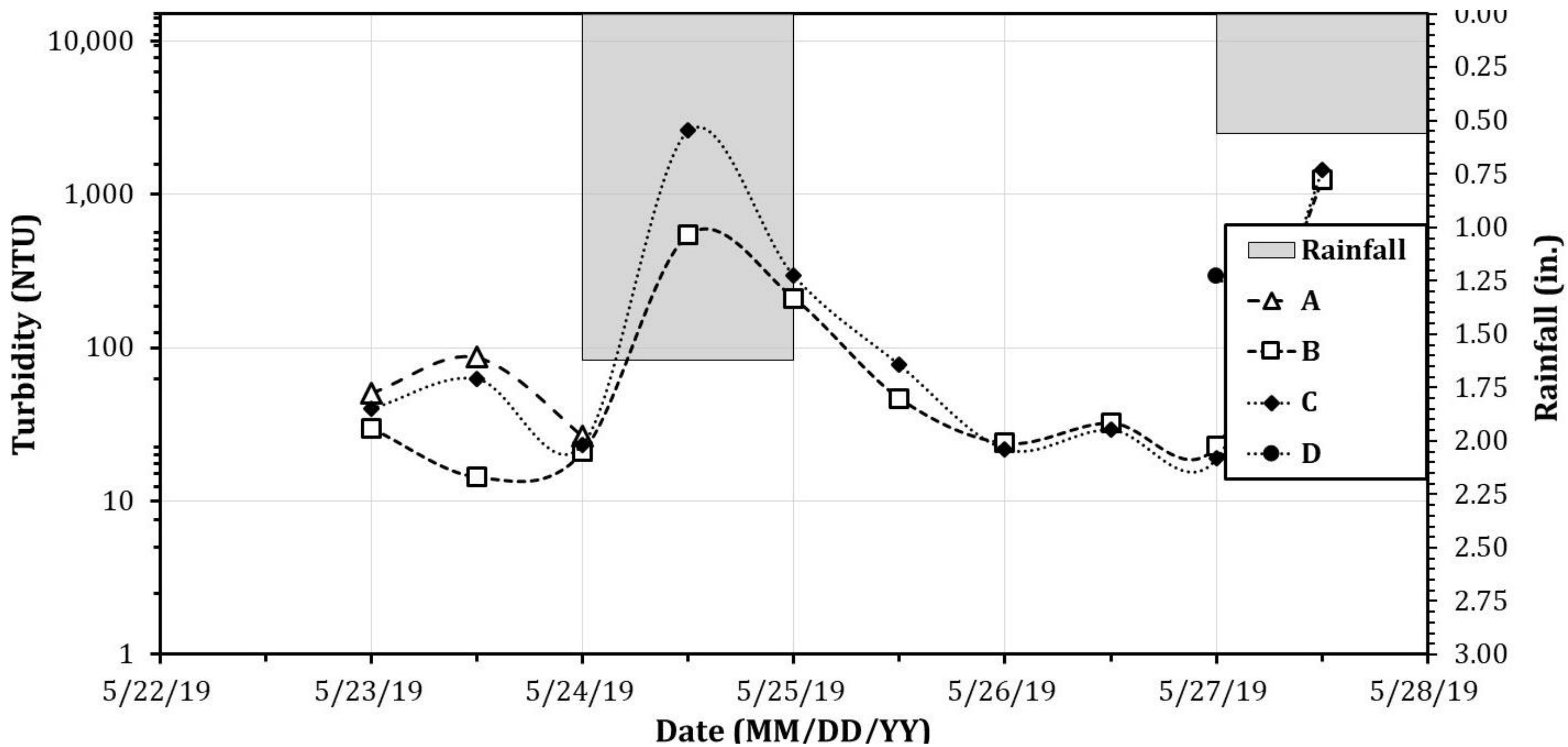


Figure G.10. Event 11

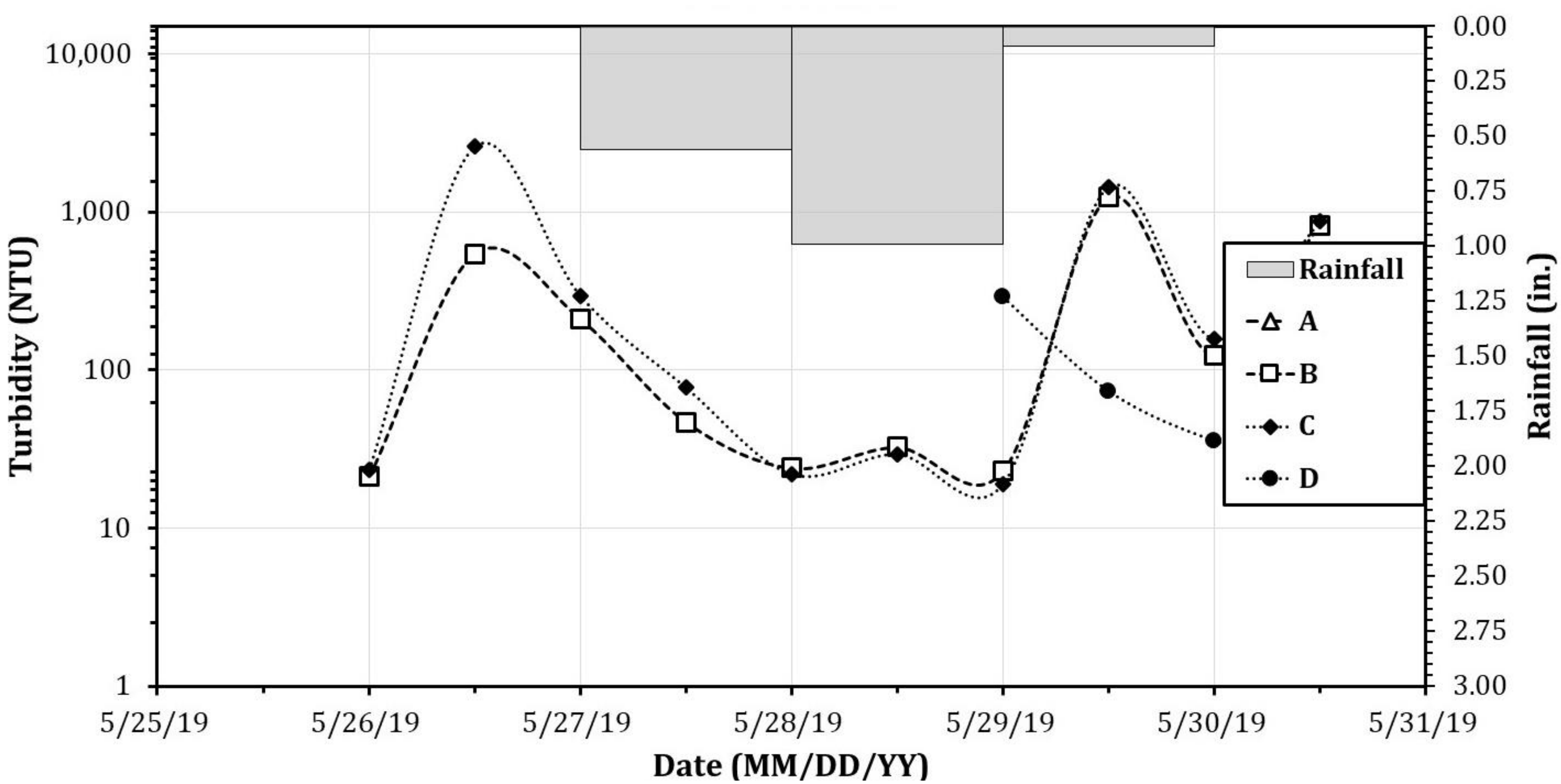


Figure G.11. Event 12

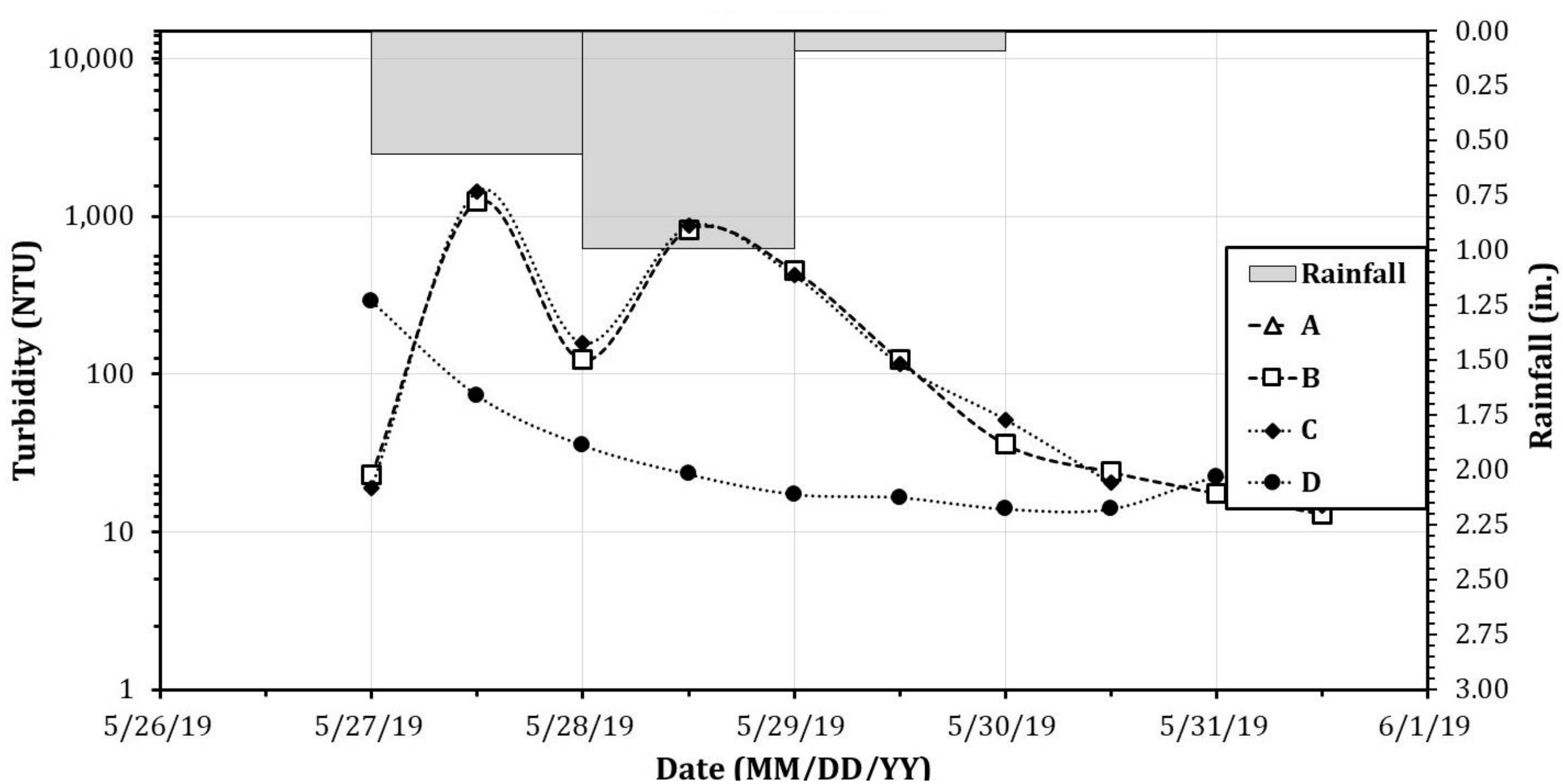


Figure G.12. Event 13

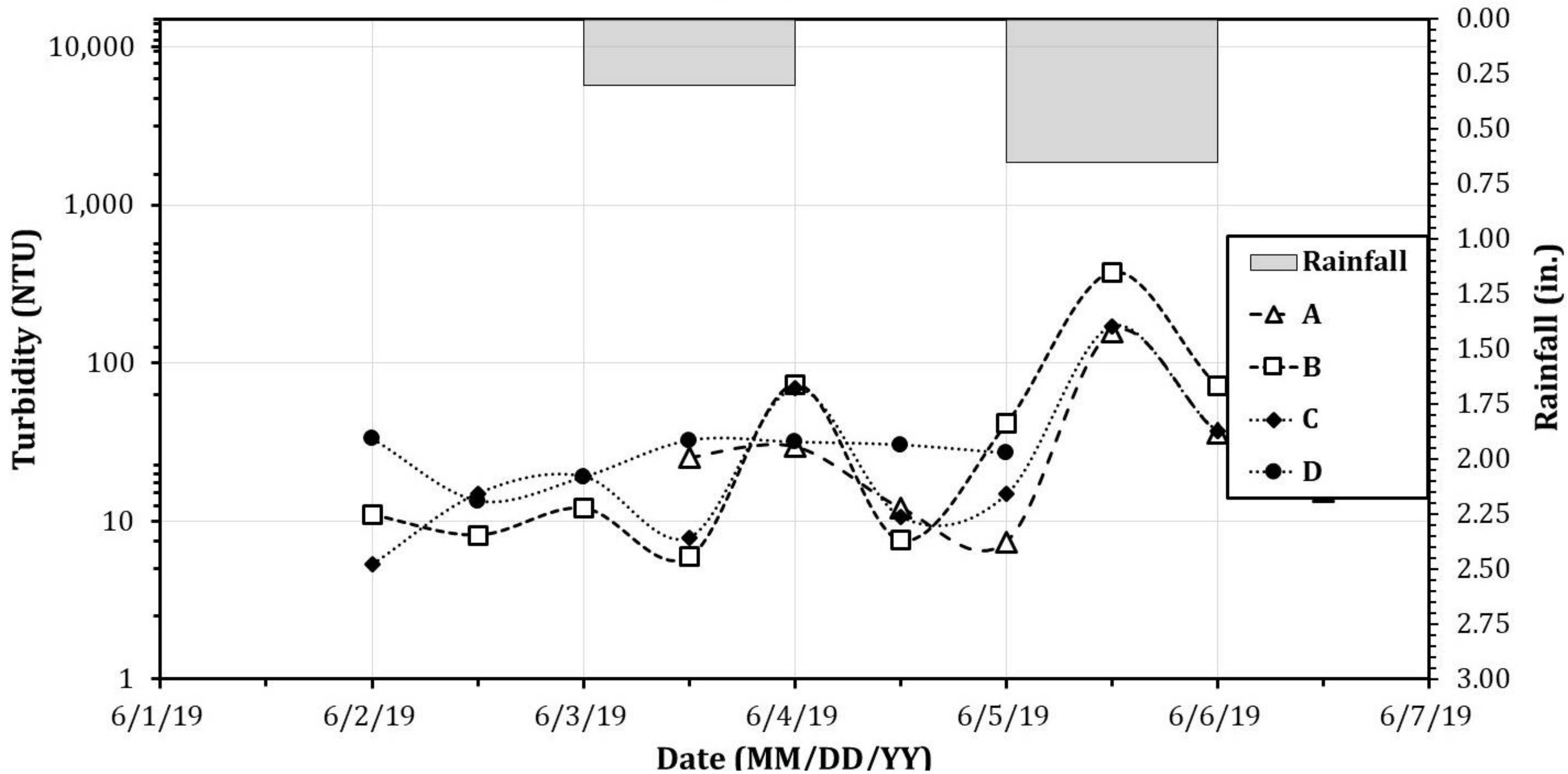


Figure G.13. Event 14

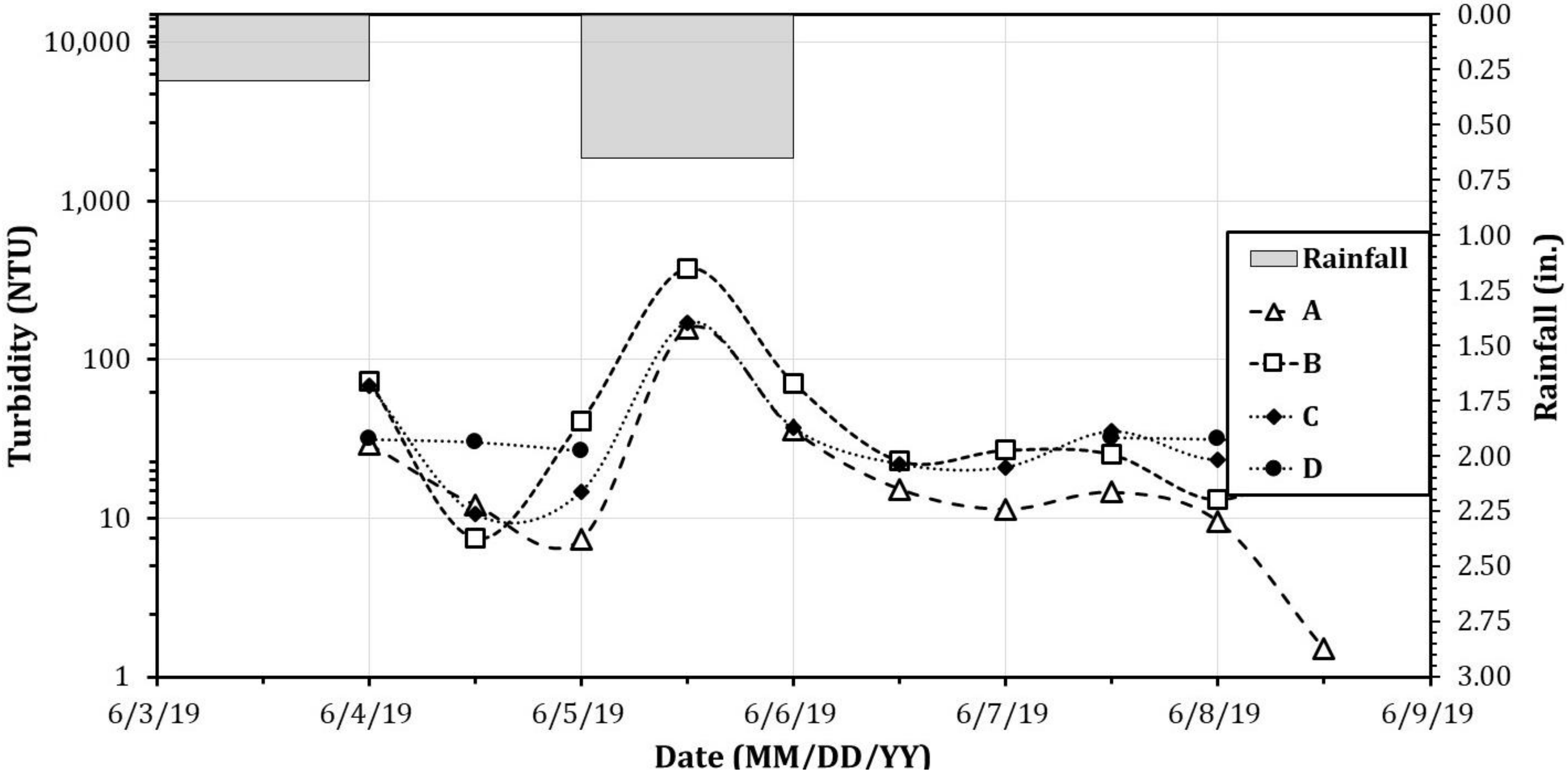


Figure G.14. Event 15

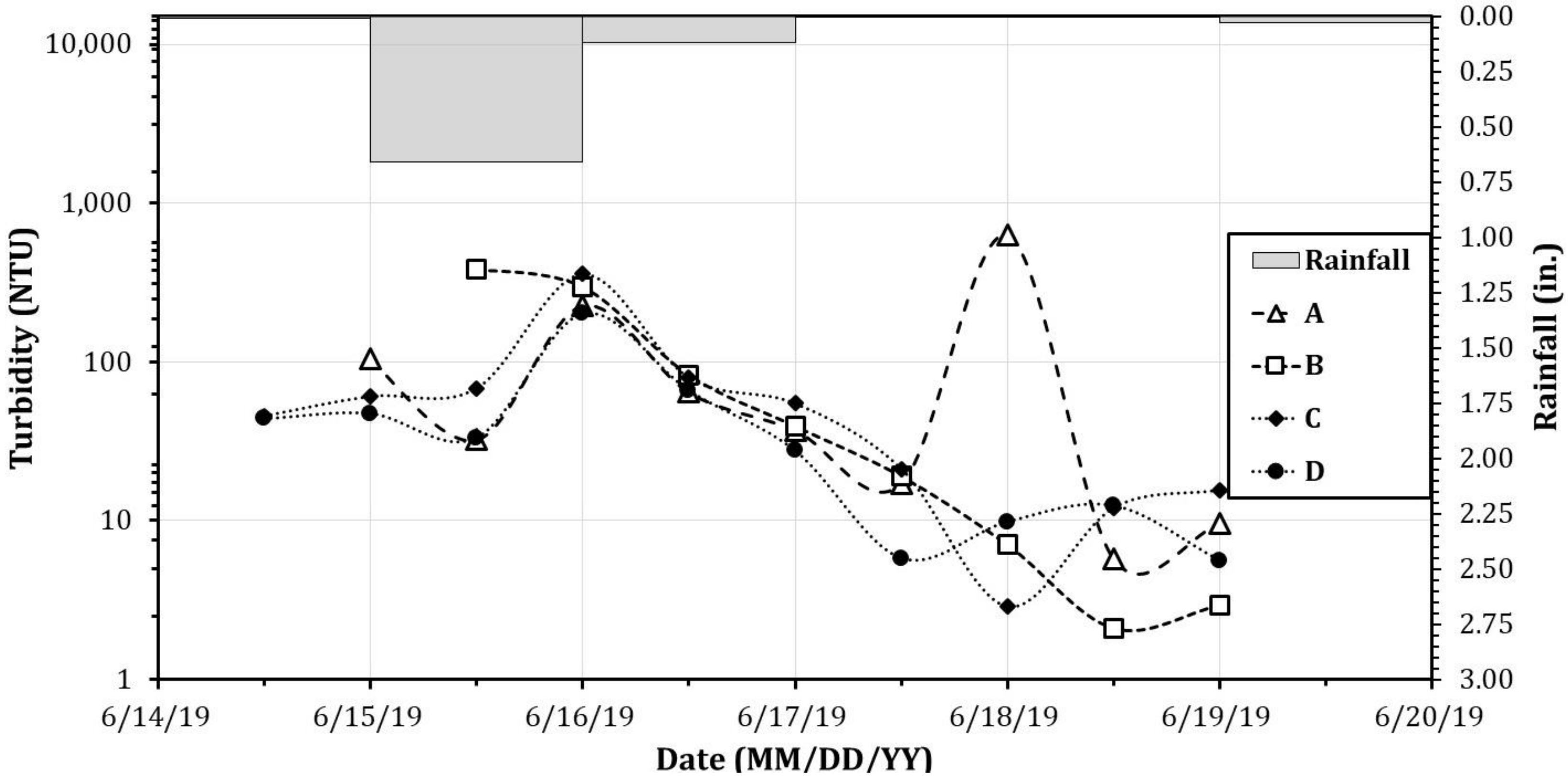


Figure G.15. Event 16

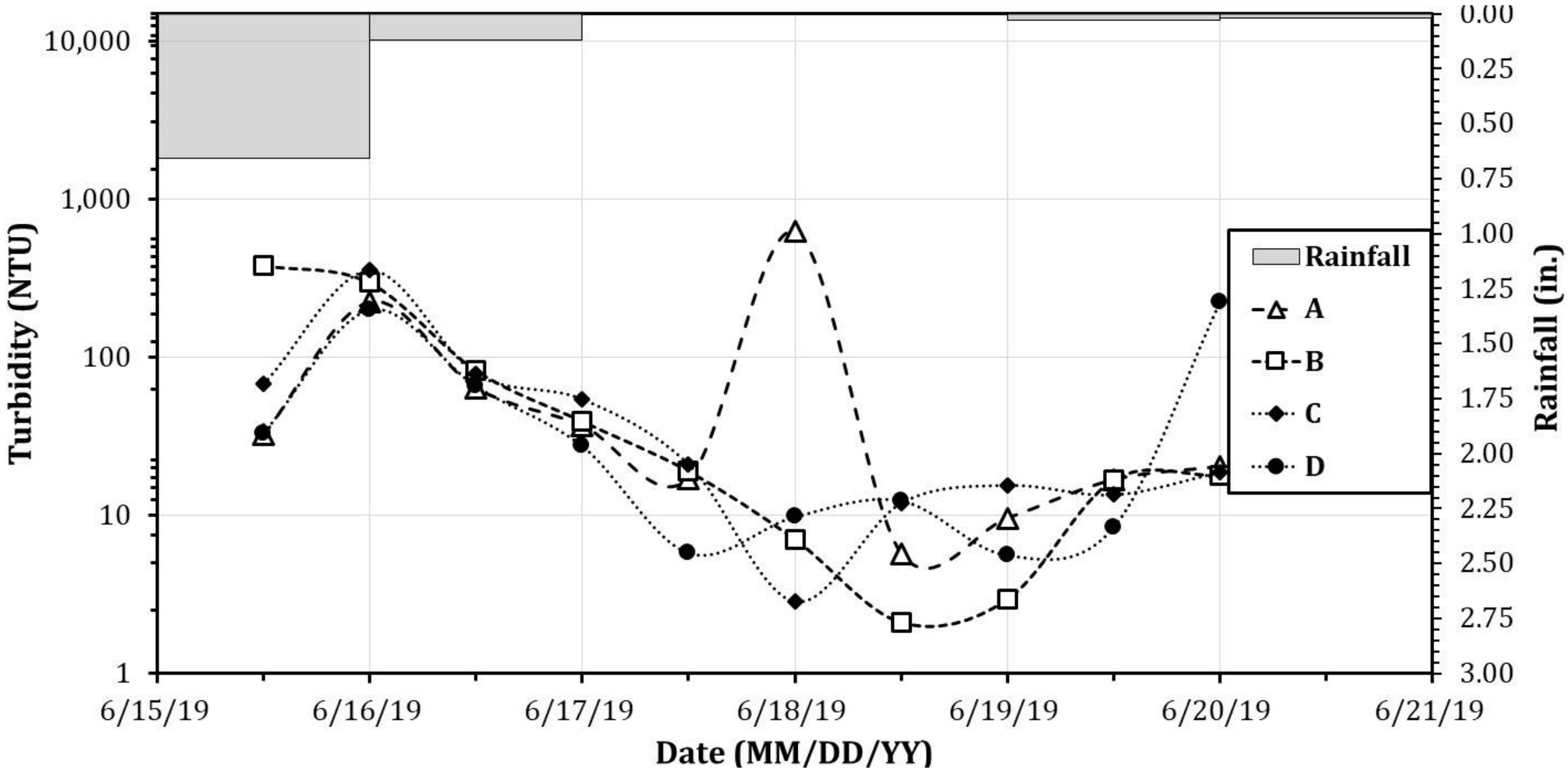


Figure G.16. Event 17

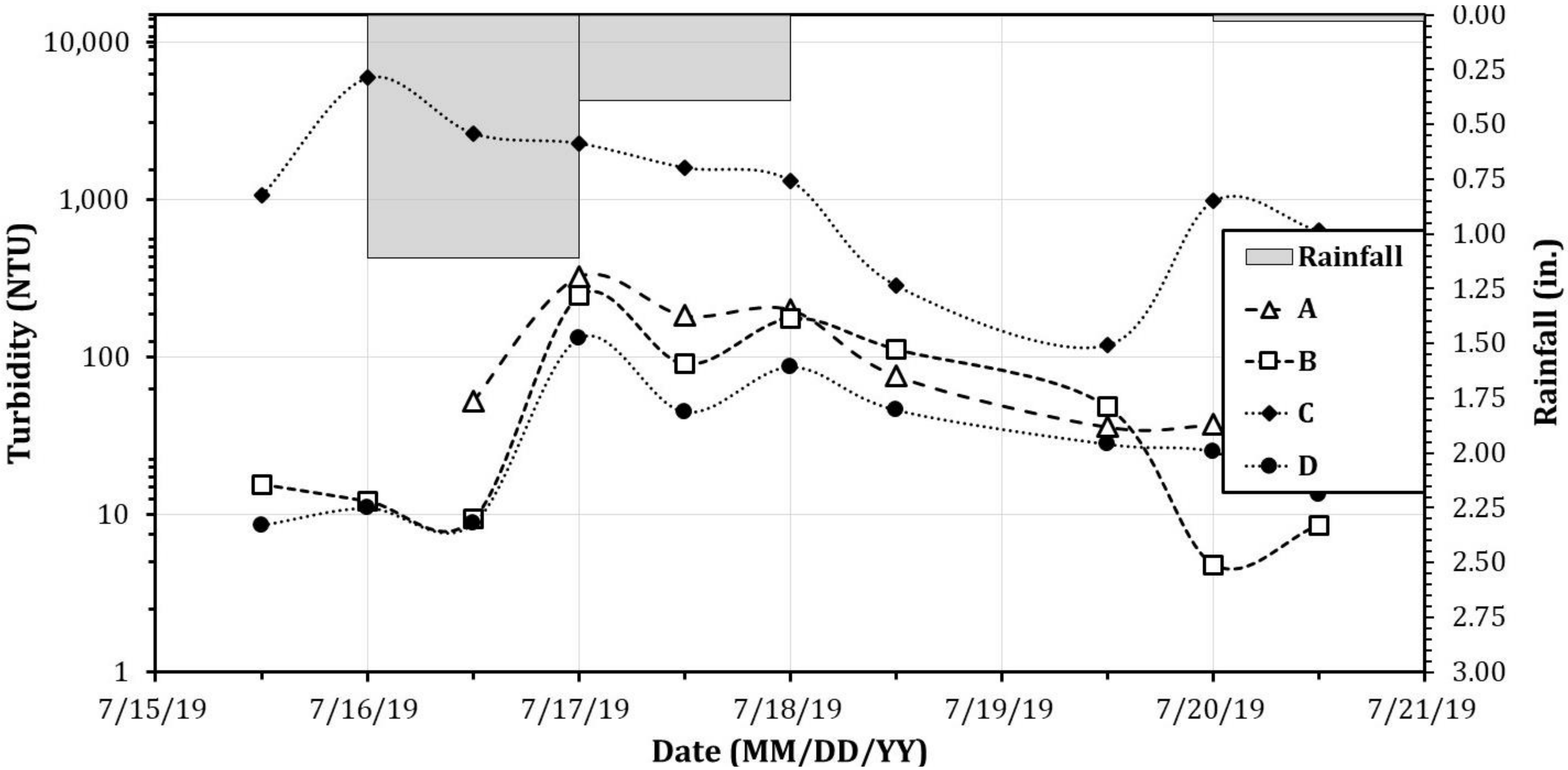


Figure G.17. Event 18

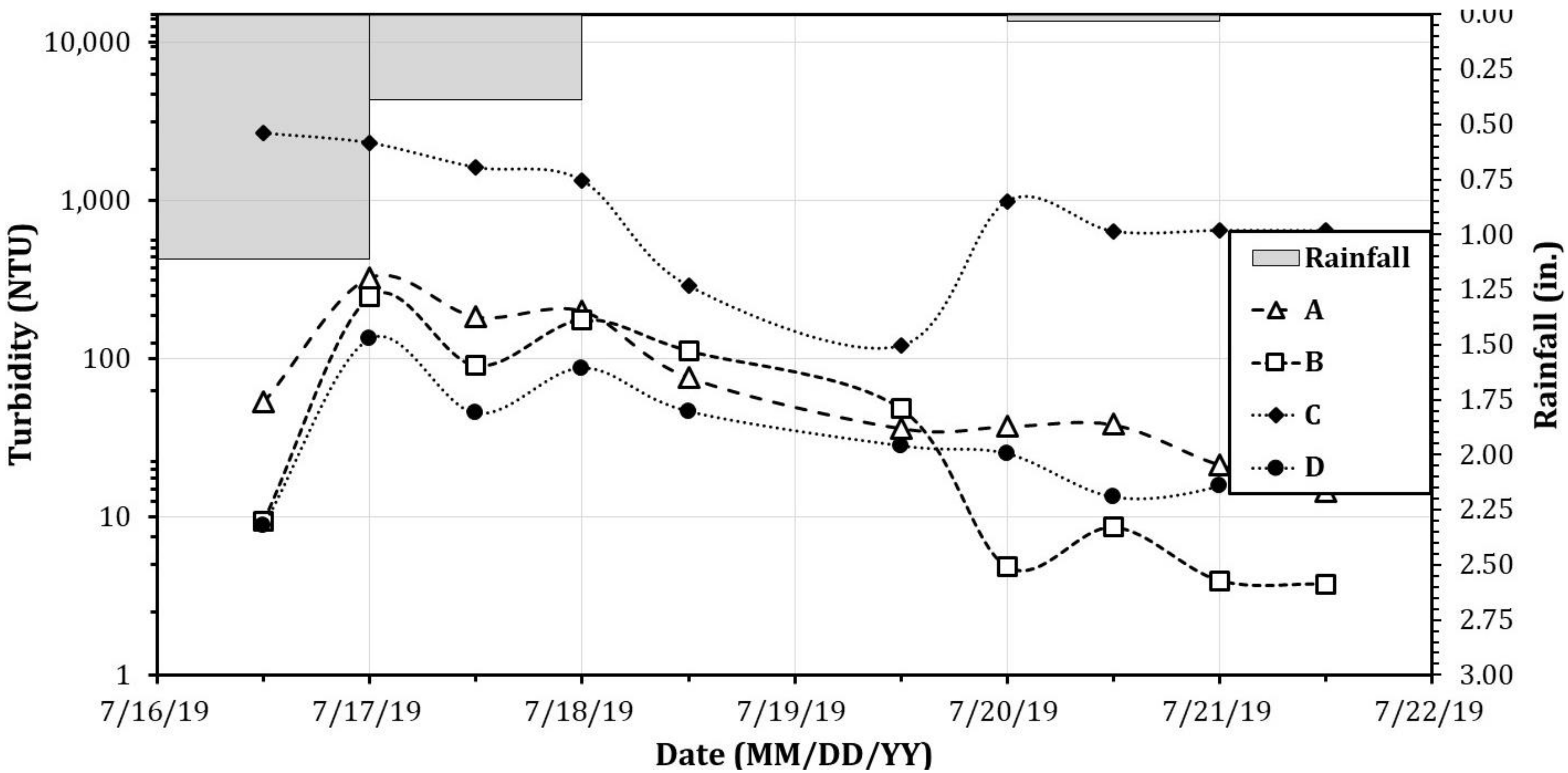


Figure G.18. Event 19

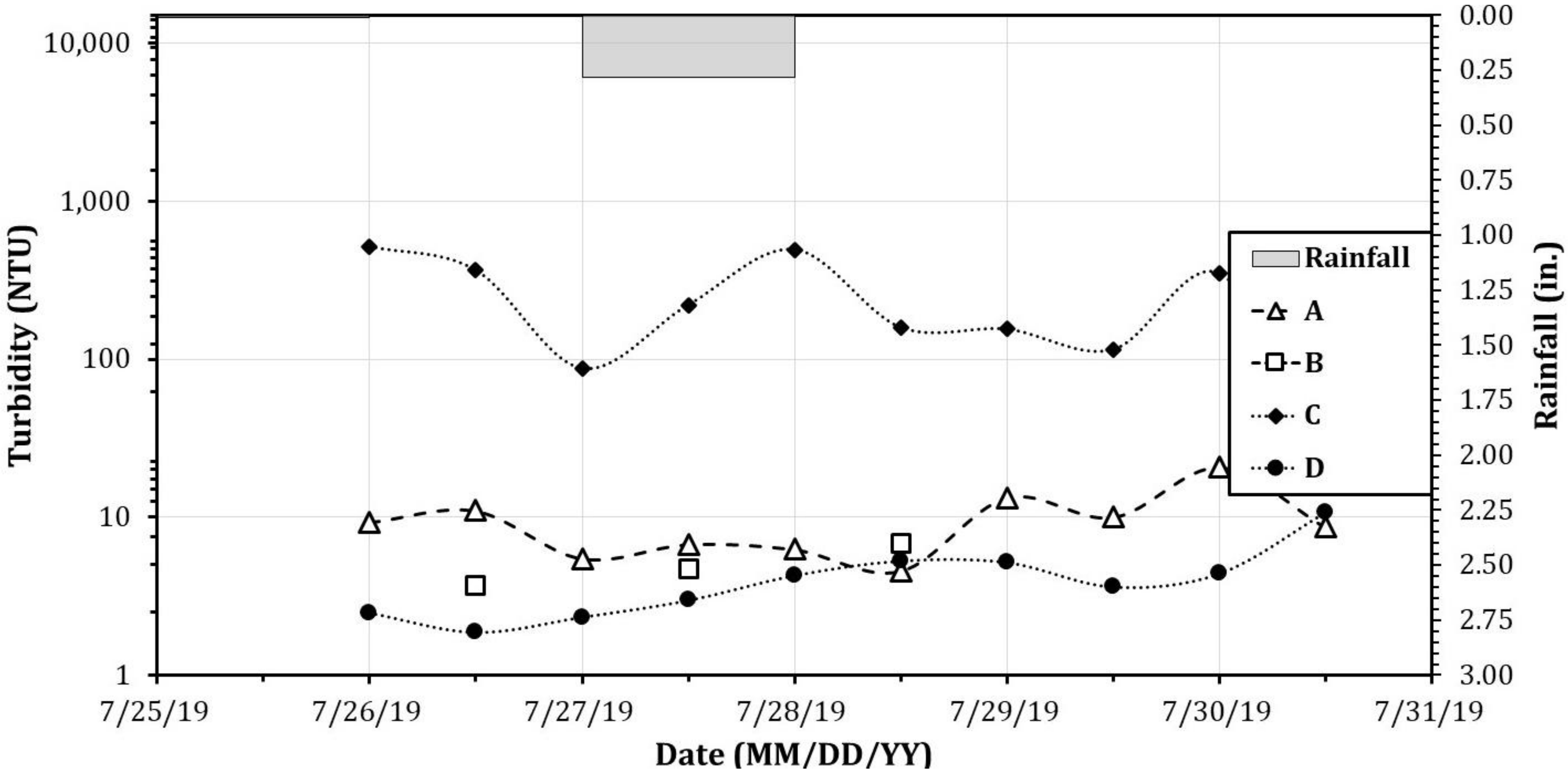


Figure G.19. Event 20

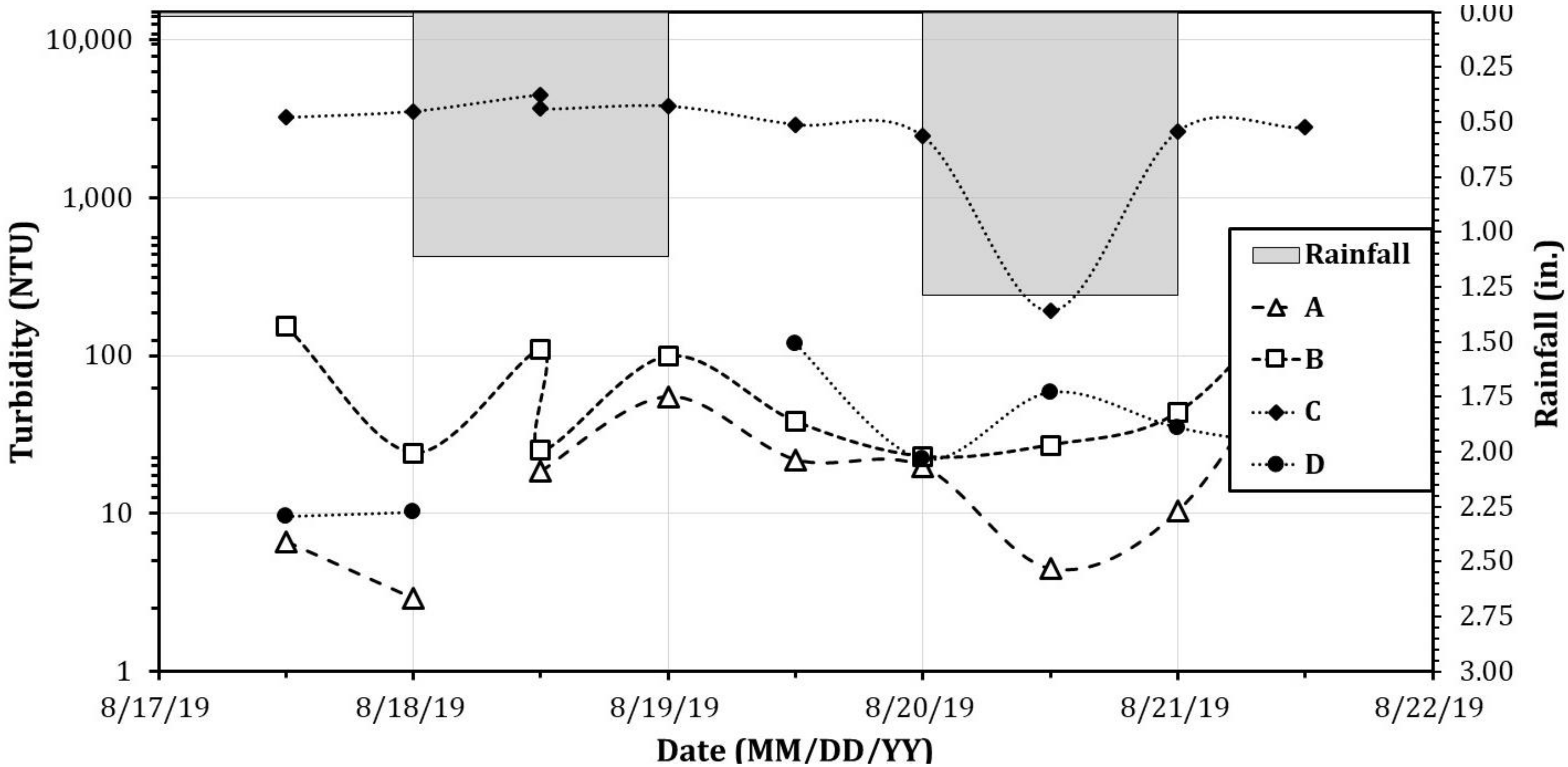


Figure G.20. Event 21

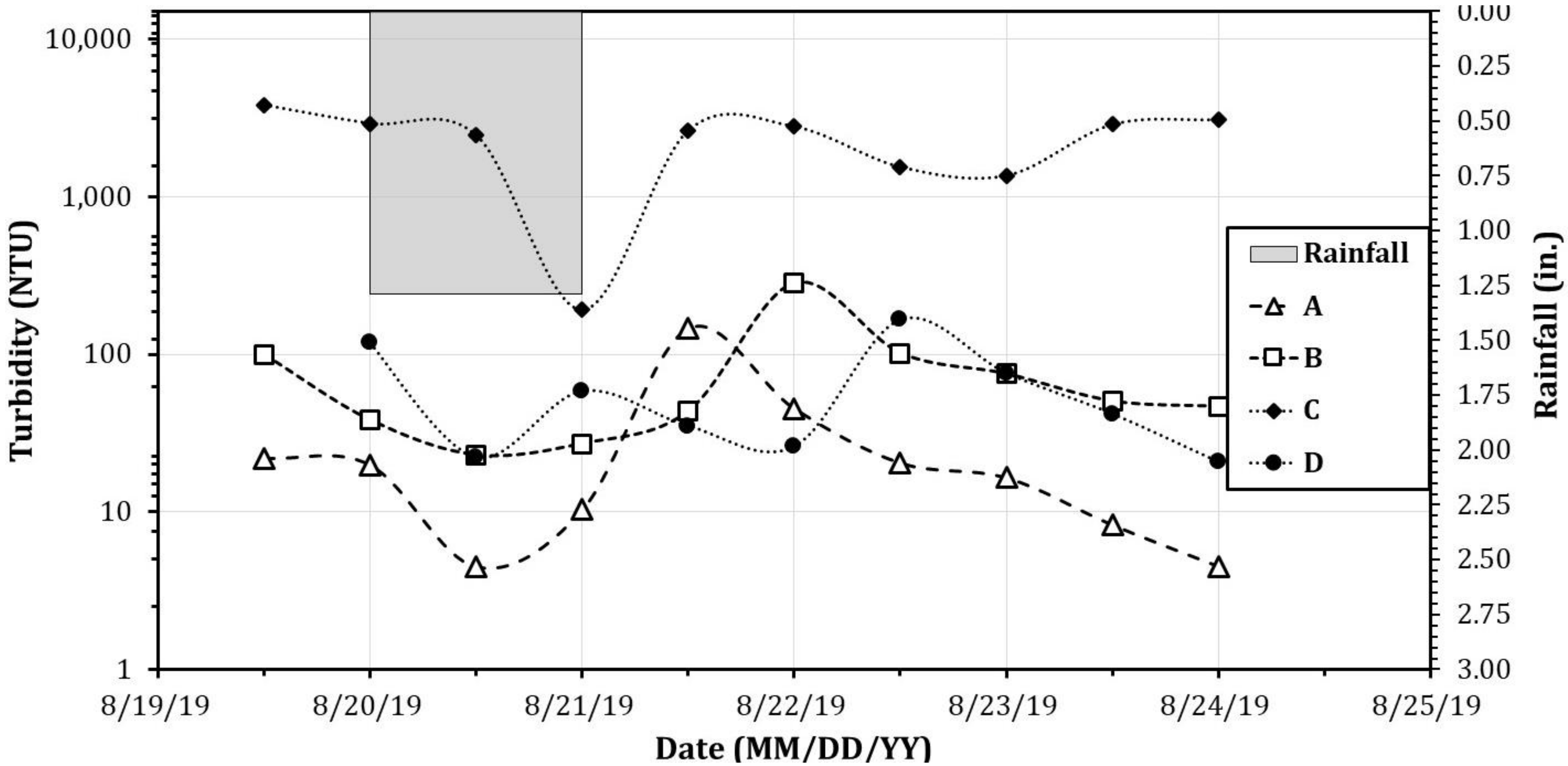


Figure G.21. Event 22

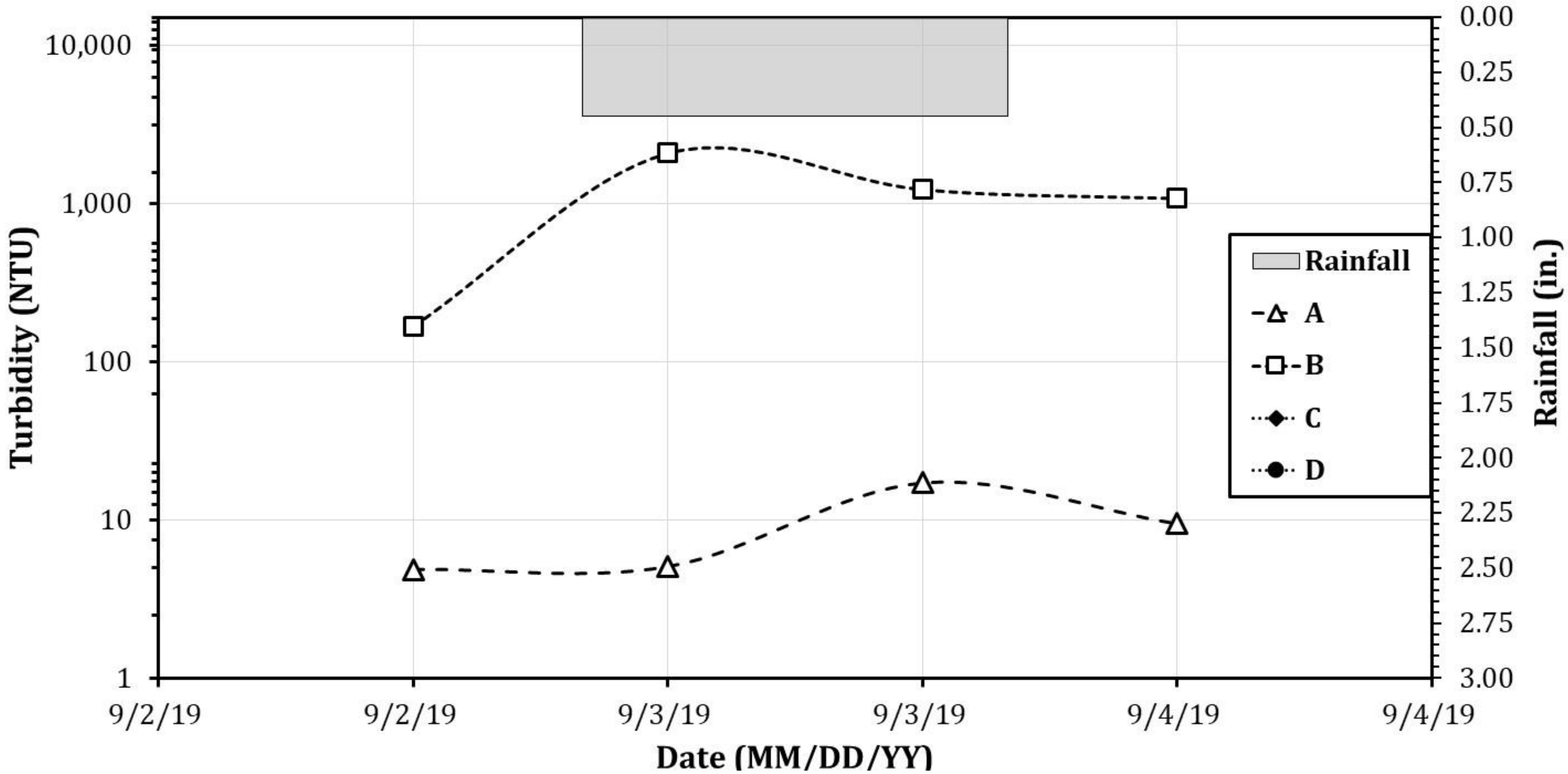


Figure G.22. Event 23