Erosion and Sediment Control Design Guidance

Final Report

Project Number: SPRY-0010(71)RS Task Order Number: 2400-18-07 Contract J/P Number: 01946(70) Item Number:2400

Submitted to: Oklahoma Department of Transportation Office of Research and Implementation

Submitted By:
David Lampert, Maryam Ahmadvand
Oklahoma State University
School of Civil and Environmental Engineering

September 2019

Executive Summary

Construction projects typically require mass clearing and grading, causing many site areas to be unstable. As a result, they lack ground cover to protect against rainfall and runoff, which results in soil degradation and erosion. Erosion introduces nonpoint source suspended solids pollution (NPS) into water bodies that diminish water quality and reduce the lifetime of water resources. In the past few years, there has been a significant improvement in water quality by using erosion and sedimentation best management practices (BMPs). Due to the complexity of the sources of pollution caused by NPS, many challenges remain. Desirable environmental protection and appropriate drainage and erosion control are only achieved when drainage, erosion, and sediment control (ESC) work together. However, proper implementation of construction site erosion and sedimentation BMPs and post-construction maintenance minimize alterations in water quality throughout construction. Most construction stormwater violations are the result of lack of properly implemented BMPs.

The Oklahoma Department of Transportation (ODOT) is responsible for implementing approaches to reduce environmental impacts of construction on thousands of bridges and culverts across the state. One of the objectives of this research was identifying existing opportunities to reduce the environmental impact of transportation infrastructure construction. Another key objective of this research was to develop a practical and applicable ESC decision design guide document for use by ODOT field engineers and other personnel.

Development of the ODOT ESC guidance document required the compilation of a useful and convenient category for BMPs from available online sources. Hence, this research was achieved by communications with ODOT engineers from different departments and perspectives. Additionally, a literature review of available resources including other state Department of Transportation ESC guideline reports, ESC handbooks, and journal articles was conducted. The results were compiled into this report and summarized in the ESC document. Two approaches to BMP categorization were adapted for these purposes based on: 1) site construction activities and 2) intended application of each BMP. For each BMP, the functional life longevity and its categorization as temporary and permanent is provided.

Table of content Executive Summary	I
List of Acronyms	
Introduction	
Definitions	5
Required Regulation	6
Overview	6
The Effect of Clean Water Act Policy	8
The Erosion Process and Sedimentation	9
Types of Erosion	10
Factors Affecting Erosion	11
Effective Erosion and Sediment Control Plan	13
Erosion and Sediment Control Best Management Practices (BMPs)	15
Berm Interceptors.	17
Cellular Confinement Systems.	18
Compost Blankets	19
Energy Dissipators	20
Fiber Rolls and Wattles.	21
Gabions.	22
Hydromulching.	23
Hydroseeding.	24
Inlet Protection.	24
Mulching	25
Reinforced Silt Fences.	26
Riparian Zone Preservation.	27
Rock Check Dams.	29
Rolled Erosion Control Products (RECP).	30
Seeding.	32
Silt Dikes.	33
Slope Drains	34
Slope Texturing.	35
Sodding	35
Stabilized Worksite Entrances	36
Straw Mulching and Crimping	37
Topsoiling	37

Erosion and Sediment	Control	Design	Guidance
----------------------	---------	--------	----------

Suggested ESC categories summary	38
References	43
Appendix 1	46

List of Acronyms

NPS Nonpoint Source Suspended Solids Pollution

BMPs Best Management Practices ESC Erosion and Sediment Control

ODOT Oklahoma Department of Transportation SWPPP Storm Water Pollution Prevention Plan

CWA Clean Water Act

OPDES Oklahoma Pollutant Discharge Elimination System Act

ODEQ Oklahoma Department of Environmental Quality

NEPA National Environmental Policy Act EPA Environmental Protection Agency

NPDES National Pollutant Discharge Elimination System

ASCE American Society of Civil Engineers

WEF Water Environment Federal

ESCP Effective Erosion and Sediment Control Plan

TRM Turf Reinforcement Mat

RECP Rolled Erosion Control Products

ECB Erosion Control Blankets

C-TRM Composite Turf Reinforcement Mats

Introduction

The construction of roadways typically consists of mass clearing and grading, leaving many site areas unstable, lacking ground cover to preserve toward rainfall, induced erosion. Due to the magnitude of land-disturbing activities and their effects on the environment; ODOT has authority over ESC programs and is committed to reducing the stormwater impacts of construction. The purpose of this erosion and sediment control (ESC) decision guide design is to assist ODOT staff, land developers, consultants, and contractors across Oklahoma implement appropriate ESC on construction sites.

The primary objective of this document is to provide guidelines and summarize procedures of BMPs for selecting ESC on construction sites. It has been proven that the proper plan, installation, and inspection of BMPs; reduced the erosion and sedimentation on the exposed construction site. Protection of exposed area should be the primary goal in the ESC plan design. For this purpose, proper selection of the source control BMPs, by considering the application location should be considered. Also, it is not always possible or practical to provide surface cover for all disturbed areas during the construction. In the result methods which help to control the runoff in site area would be employed. Sediment control BMPs are two types. Filtering and Entrapment BMPs; technically filter the runoff suspended soil particles and Impoundment BMPs which promotes sedimentation by reducing flow velocity of runoff. Also, these guidelines describe appropriate temporary and permanent ESC for sites and conditions whenever construction activities disturb the soil or remove the natural ground cover. Proper construction planning includes temporary ESC BMPs early in the construction life cycle. Permanent ESC measures can be installed during or at the end of the construction phase.

Since the effective usage of ESC methods is a site-specific operation, another category provided by this document is BMPs based on construction activities. Any construction site required the unique ESC plan; it is necessary to meet the specific requirements of any given construction site at the design. A large number of erosion and sediment control BMPs are accessible for erosion and sediment control plan; the BMPs lists provided are common BMPs used by ODOT.

Definitions

The following are important definitions applicable to implementation and regulation of ESC on construction sites.

- Erosion. The process in which soil particles and surficial soils are lost due to the actions of water, ice, gravity, or wind. Rainfall-based erosion is the predominant factor on construction sites while they are under development [1].
- **Sedimentation.** The consequence of erosion when the eroded soil particles are deposited in a new location. Erosion and sedimentation are tremendous factors in creating the earth surface as it is today [1].
- **Stormwater**. The water runoff from precipitation events, including snow and ice melt that flow over land or impervious surfaces and does not soak into the ground [2].
- Storm Water Pollution Prevention Plan (SWPPP). Erosion and sediment control plan required by a federal regulation of the United States of America governing stormwater runoff from active construction sites that are more than one acre in area; created by constructors and it would be comply and fulfillment during the different construction phase [3].
- Clean Water Act (CWA). A framework for the regulation of pollutants into navigable waters. Phase □ provides regulations for construction activities encompassing more than one acre, and requires them to obtain a permit along with an approved Storm Water Pollution Prevention Plan (SWPPP) [4] [5].
- Section 404 of CWA. CWA Section 404 established a program to regulate the discharge of
 dredged or fill material into waters of the United States, including wetlands. Activities
 regulated under this program include fill for development, water resource projects (such as
 dams and levees), infrastructure development (such as highways and airports) and mining
 projects. Section 404 requires a permit before dredged or fill material may be discharged into
 waters, unless the activity is exempt [4].
- Section 401 of CWA. CWA Section 401 requires a federal license or permit to conduct any activity that may result in a discharge of a pollutant into the waters of the United States. A certification from the State in which the discharge originates must be obtained stating that the discharge complies with the applicable water quality standards [4].
- Point Source. Any distinct, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, landfill leachate collection system, vessel, or other floating craft from which pollutants are or may be discharged. This term does not include diffused pollution source [6].
- Nonpoint Source. Pollution resulting from many diffuse sources, such as land runoff, precipitation, atmospheric deposition, drainage, seepage. In direct contrast to point source pollution.
- Maintenance. The selective removal of woody material and accumulated debris from, or repairs to, a stormwater facility so that such facility will perform its natural functions or the functions for which it was designed and constructed.
- Best Management Practices (BMPs). Design, construction, and maintenance practices and criteria for site development that promote infiltration, minimize impacts from stormwater runoff rates and volume, prevent erosion, and capture pollutants.
- Erosion and Sediment Control (ESC). Measures proposed and provided to prevent or reduce
 the displacement of soil by the running water on road embankment fills, banks, and at various

drainage structures (i.e., culvert inlets and outlets, channels, detention pond overflow areas, junctions, etc.).

- OKR10 Permit. The Oklahoma Pollutant Discharge Elimination System Act (OPDES) authorizes the Oklahoma Department of Environmental Quality (ODEQ) to issue OKR10 general permits, which regulate the discharge of storm water associated with construction activity [7].
- **Permanent BMPs.** Measures incorporated into the overall design to address long-term, post construction erosion and sediment control [8].
- Sliver Cuts and Fills. Sliver fills created on steep side slopes where ground slope and fill slope angles differ by less than 7° and fill slope height greater than 6.0 meters are inherently unstable. Side cast or wasted material cannot remain stable on side slopes exceeding 60 to 70 percent. Under such conditions excavated material has to be end hauled to a safe disposal area. This requires dump trucks and excavators or shovels for loading and hauling [9].
- Temporary BMPs. Measures during the construction phase that will be completely removed once permanent measures are installed and/or vegetative cover is established [8].
- Vegetation. Plants in general or all plant life in the area.
- Soil Stabilization. Preventing the soil particles from being dislodged and transport, in the other word, preventing erosion from initiating or continuing [6].
- Pollutant: Dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials (except those regulated under the Atomic Energy Act of 1954, as amended (42 U.S.C. 2011 et seq.)), heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water [6].

Required Regulation

Overview

Any designer who is willing to work on ESCs should be aware of Federal and State laws and regulatory. The National Environmental Policy Act (NEPA) was enacted in 1970 to promotes the enhancement of the environment. Correspondingly in 1972, the Clean Water Act (CWA) implemented by the Environmental Protection Agency (EPA) in order to prevent and eliminate discharged of pollution from a point source into the navigable water and regulate stormwater [2]; unless the required National Pollutant Discharge Elimination System (NPDES) permit obtained. Point sources pollution can be such as sewage treatment plants, or storm sewers, pipes or manmade ditches or industrial, municipal, and other facilities if their discharges go directly to surface waters. EPA in 1987, modified the CWA by focusing to regulate storm water discharges form industrial activities which disturbed the land five acres or more than five acres. This also known as a Phase of the NPDES. There was different option for industrial facilities to conform with the permit requirements, however EPA in 1992, by providing the general permit procedure provide a more manageable way by a general permit that covers discharges form more than one facility. Expectation such as being less costly, burdensome permitting process, and minimal monitoring and reporting were expected from the general permit [10]. Also, general permit required pollution prevention plan and compliance of the plan within six months. However, in 1999 Phase

of regulates storm water discharges from smaller construction activities that disturbing the land equal or greater than one acre has been modified [11]. Stormwater requirements are one element of the comprehensive permit program, the NPDES, authorized in Section 401 of the act [10] along with an approved Storm Water Pollution Prevention Plan (SWPPP). As the result it is required for builder to apply for construction general permit and submit and comply a SWPPP to prevent stormwater pollution. [3]

Since 1996, under EPA's approval of the Oklahoma Pollutant Discharge Elimination System (OPDES) program Department of Environmental Quality (DEQ) has had stormwater permitting and enforcement responsibility for large and small construction activities. This obligation does not include construction activities associated with oil and gas extraction, agricultural activities and construction activities which are located on Indian County Land in Oklahoma. The permit is reissuance by Oklahoma DEQ on 2017 and authorization issued under the permit shall expire on 2022 [7].

Figure 1 shows the history of the federal water pollution control regulations along with the state of Oklahoma specific water pollution control regulation.

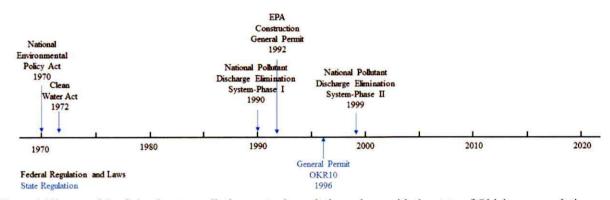


Figure 1 History of the federal water pollution control regulations along with the state of Oklahoma regulation.

The following summarized the required federal and states mandated for controlling stormwater discharges:

- Federal permits for construction sites over 1 acre are issued by the U.S. Army Corps of Engineers.
- 1.1.Section 404 permits (CWA) are required for anyone who is willing to conduct the activities which involve the discharging into or filling streams, wetlands or open waters of the United States obtain the permit to ensure that the physical, biological and chemical quality of U.S. waters is protected from irresponsible and unregulated discharges of dredged or fill material that could permanently alter or destroy these valuable resources. Section 404 permits for the State are the responsibility of the U.S. Army Corps of Engineers Tulsa District Regulatory Office. [4] [12]. More information about Laws, Regulations, and Executive Orders related to Section 404 can be found at the website:
 - https://www.epa.gov/cwa-404/clean-water-laws-regulations-and-executive-orders-related-section-404
- 1.2. Isolated and Other Non-404 and 401 Jurisdictional Wetlands and Waters Permits are required for impacts to isolated and other non-404 wetlands, isolated streams or other isolated waters. The required wetland regulatory in Oklahoma state are as follow:

- Permits issued by the U.S. Environmental Protection Agency (EPA), under NPDES program;
- Applications to the Federal Energy Regulatory Commission for a federal license to construct and operate a hydroelectric facility;
- Applications to the Nuclear Regulatory Commission for a license to operate a facility;
- Permit issued by the U.S. Coast Guard that results in the discharge of wastewater or pollutants into navigable waters [13].

More information about Isolated and Other Non-404 and 401 Jurisdictional Wetlands, could be found at the website:

https://www.aswm.org/aswm/58-wetland-programs/state-summaries/785-oklahoma

- 2. State certifications and permits are issued by Oklahoma.
- 2.1 Section 401 Water Quality Certifications (CWA) correspond with the permits issued by the Oklahoma DEQ. They are required for any federally permitted or licensed activity that may result in a discharge to or filling of streams, wetlands or open waters of the State of Oklahoma. A Section 401 Certification is required in conjunction with any Section 404 permit, individual or nationwide. ODOT Environmental Programs Division is responsible for securing Section 404 permits and 401 Certifications. More information about Clean water Clean Water Laws, Regulations, and Executive Orders related to Section 401 could be found at: https://www.deq.ok.gov/divisions/wqd/
- 2.2 General Permit OKR10 is the regulation for storm water discharges from construction activities except for construction activities associated with oil and gas extraction and agricultural activities that The ODOT's Roadway Design Division, Roadside Development Support Unit use to assist hydraulics designers in the Roadway Design Division to satisfy state and Federal regulations in regard to ESC problems related to their project. More information about erosion and sediment control procedures could be found at the website: http://www.okladot.state.ok.us/roadway/Rdy-rdydev.htm https://www.deq.ok.gov/wp-content/uploads/water-division/OKR10Permit_2012_final-Review_August_Updated.pdf
- 2.3 Threatened and Endangered (T&E) Species Regulations, requires that federally listed species and habitat not be adversely affected during any activity with federal involvement or subject to federal oversight (i.e., projects that require a NPDES stormwater permit for construction). who wish to conduct activities on their land that might incidentally harm (or "take") a species listed as endangered or threatened must first obtain an incidental take permit from the U.S. Fish and Wildlife Service when compiling the ESC plan base map. Permittees and contractors have an independent obligation to ensure that their activities do not result in any prohibited "take" of identified species. More information about Threatened and Endangered (T&E) Species Regulations could be found at:

https://www.deq.ok.gov/wp-content/uploads/water-division/OKR10Permit_2012_final-Review August Updated.pdf

The Effect of Clean Water Act Policy

Sediments are the main pollutant of construction site, according to American Society of Civil Engineers(ASCE) and Water Environment Federal (WEF), Stormwater runoff from unprotected exposed area on construction site can cause stormwater runoff which carry 35-45 tons of loss

sediment per acre per year [3]. In the other hand expanded the urban area increases the amount of impervious surface and the runoff. Excess stormwater runoff considers as a diffused source and difficult to control and also does not recognize as a pollutant in the result could potentially end up in water bodies and cause impairment [14].

According to [15] unlike the main believe that the major failure of water pollution on construction site are not only caused by deficient onset factors by contractors (construction teams' site-based failures). But also, outset factors (such as change order, design error and schedule changes, which involve off-site personnel) have the critically role which should be consider. Any violation of clean water act addition to irreparable environmental consequences, has legal aspect for contractor who were responsible for improper storm water management. EPA may seek criminal or civil penalties resulting in fines up to \$16,000 per day of violation, with a maximum cap of \$187,500 and imprisonment in any single enforcement action [2].

The study on 163 closed stormwater violation cases in Minnesota from 2001 to 2007 and analyzing different violation such as lack of stormwater construction permit, minor permit related violations, major environmental damage associated with construction projects, BMPs related violations; indicate that in 2007 in compare to the past the number of construction stormwater violations has been increased. This study also indicate that the major violations were related to BMPs violation [14] By increasing the awareness of the responsible parties and choosing the proper BMPs regular inspecting the sites, erosion from the construction sites could be prevent.

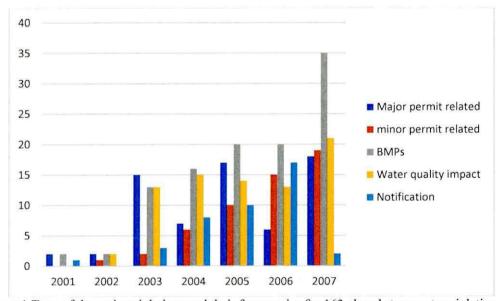


Chart 1 Type of the major violations and their frequencies for 163 closed stormwater violation cases in Minnesota from 2001 to 2007, adopted table from [14]

The Erosion Process and Sedimentation

The erosion process is a tremendous factor in creating the earth surface as it is today. This process can occur naturally, but it considerably accelerates by human activities. In order to minimize and control erosion and sedimentation, it is important to understand the process and cause of each.

Erosion is a natural process where a detachment of soil particles and loss of surficial soil by the actions of water, ice, gravity, or wind occurs. Water-generated erosion causes the most severe type of erosion, specifically on the site under development. Accordingly, methods for controlling water erosion mainly will be discussed in this report. It should also be considered that many of water erosion control methods also are effective on the erosion caused by the wind. Suspended solid particles (minerals and organic materials) which carried from origin site by water or wind, gravity or ice; are called sediments. So, sedimentation is the consequence of erosion when the suspended eroded soil particles in water are deposed in a new location. Deposition of particles usually happened with the reduction in water flow velocity and the effect of gravity. Initially, larger particles would be settled down, and as flow velocity reduces further, smaller particles settled out. Usually settling by gravity alone is often ineffective for clay size particles. Clay particles will only settle out after long periods time due to their fine particle size. As a purpose of this document sediment control would be equivalent to the control of the sedimentation process [8] [6] [16].

Types of Erosion

There are four main erosion types as indicated in the Figure 2 and described as below:

1.Erosion from Raindrop Impact and Sheet Erosion. The dislodgement of soil particles by falling raindrops is a primary agent of erosion, particularly on soils with sparse vegetative cover. Raindrops typically fall with a velocity of 20 to 30 feet per second and individual soil particles can be splashed over 1.5 feet in height and 5 feet to the side. In addition, the impact of rainfall on bare soil can compact the upper layer of soil, creating a hard crust that inhibits plant establishment and infiltration [6]. Sheet erosion occurs as runoff travels over the ground, picking up and transporting the particles dislodged by raindrop impacts in a semi-suspended layer uniformly over the land surface. The distance of sheet flow depends on slope, soil roughness, type of vegetative cover, and rainfall intensity. Often this kind of erosion is difficult to detect until it develops into rill erosion.

The method used to prevent erosion from raindrop splash and sheet erosion is stabilization. Stabilizing techniques such as temporary and permanent vegetation, sodding, mulching, compost blankets, and rolled erosion control products absorb the impact of raindrops and protect the ground surface. By protecting the surface, soil particles are not dislodged and transported by sheet flow. Typically, sheet flow does not have enough volume or velocity to dislodge soil particles from a bare surface by itself. It is dependent on raindrop impacts to disturb the surface. Therefore, stabilizing a surface protects the ground from both raindrop and sheet erosion [6].

- 2. Rill and Gully Erosion. As runoff concentrates, tiny channels will be formed called rills. Rill erosion is the form that produces the greatest amount of soil loss worldwide. As rill erosion begins, erosion rates increase dramatically due to the resulting higher velocity concentrated flows. Rills are channels small enough to be smoothed by normal tillage. As the runoff accumulates in the rills, they erode further, causing gullies to form. Gullies are so large that they cannot be smoothed by normal tillage. Gullies must typically be repaired with earthmoving equipment. Gully erosion can be prevented by quickly repairing rill erosion and addressing the cause of the rill erosion. The rate of rill erosion can easily be 100 times greater than that of sheet flow, and the rate of gully erosion can easily be 100 times greater than rill erosion. Due to the significant amount of sediment generated by rill and gully erosion, these types of erosion shall be given top priority for elimination, reduction, and control.
- 3. Ditch and channel erosion. is produced by a concentrated flow moving within a ditch or channel without energy dissipation such as the access to a floodplain. This type of erosion consists of both streambed and streambank erosion. Streambed erosion occurs as flows cut into the bottom of the channel, making it deeper. This erosion process will continue until the channel reaches a stable slope. The resulting slope is dependent on the channel materials and flow properties. As the streambed erodes and the channel deepens, the sides of the channel become unstable and slough

off, resulting in streambank erosion. Streambank erosion can also occur as soft materials are eroded from the streambank or at bends in the channel. This type of streambank erosion results in meandering waterways. One significant cause of both streambed and streambank erosion is the increased frequency, volume, and duration of runoff events that are a result of urban development. Depending on the channel capacity, this form of erosion can do severe damage to a drainage system [6] [17].

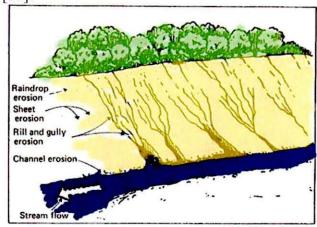


Figure 2 Different type of erosion caused by water, adopted picture from [18]

Factors Affecting Erosion

The degree of erosion that occurs is dependent on several factors like soil erodibility, which itself depend on soil type and soil physical properties, climate, vegetative cover, topography, and seasons [6]. The ability of the soil to resist detachment and infiltration capacity of the soil plays an important role in potential erosion. Also, soil properties such as texture, organic matter content, soil structure, and permeability are affecting in erodibility. Soils with a high percentage of fine sand and silt are the most erodible, and existing of clay and organic content in a soil cause decrease in erodibility of the soil by increases water-holding capacity, and may increase the infiltration rate (Chart 1). However, clay minerals are also more impermeable, and in the resulting runoff and the erosion, the potential will be increased (Chart 3). Because of the fine size of eroded clay minerals, they are easily transported by water and hard to capture. In the other hand, the erosion and sediment rate are highly related to amount and type of precipitation. High intensity storms increase the particle detachment, also frequent and lengthy rain can reduce infiltration and increased the runoff. Ground cover can reduce the erosion potential by protecting the soil particles from raindrop impacts. Also, by decreasing the runoff velocity, it can increase infiltration.

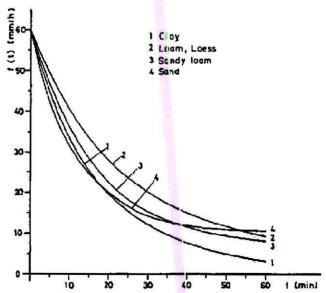


Chart 2 Infiltration capacity curves for different soil types verses time, adopted picture from [19].

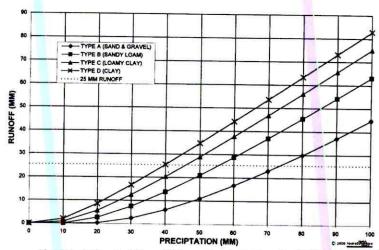


Chart 3 Estimated Runoff from Precipitation for Different Soil Types, adopted picture from [8].

Natural erosion typically occurs at a very slow rate, but on a construction site the erosion rate often increases dramatically due to several reason such as disturbing the land surface, removing the natural vegetation, excavated or filled land slopes, ground surfaces are paved over, and modifying the stream channels. When erosion occurs on a construction site and runoff carries sediment off the site, there is often a negative impact on downstream drainage systems and water quality and as a result the runoff increase and the ability of the land to provide natural treatment to the runoff decrease [20].

The purposes of erosion and sediment controls are to minimize the amount of erosion that occurs as a result of construction activity and to prevent the sediment that is produced from leaving the property. Effective erosion and sediment control require that the soil surface be protected from the erosive forces of wind, rain, and runoff and that the eroded soil be captured and retained onsite. Once sediment reaches a natural waterway or stream, it is nearly impossible to remove [6]. Variability in topography, soils, and vegetation makes erosion control unique to each development.

In order to gain this goal, there is several different temporary and permanent erosion control measures which function best when proper operation and maintenance of these measures are based on implementing the data collection and evaluation of the project vicinity to identify areas that are susceptible to erosion; also planning and design for the most suitable and sustainable erosion and sediment control and landscape measures should be based on assessment of the project site and determination of landscape requirements. Choosing the proper method is not adequate enough without proper inspection, installation, and maintenance of the proposed erosion and sediment control and permanent landscape control measures coordinated with the construction schedule [17].

Effective Erosion and Sediment Control Plan

Effective Erosion and Sediment Control Plan (ESCP) should identify the potential for erosion and sedimentation and minimize the amount of erosion and sediment while the construction activities by providing the measures to control the current problem [12]. The appropriate ESCP would consist of design, coordination, maintenance and operation [21]. Good understanding of ESCs process principles for the designer is the primary requirement of successful design [8]. Stabilizing sites as soon as possible is a primary goal of every ESC plan. To minimize or prevent degradation of downstream water resources and stabilize construction assets, erosion control should be viewed as the primary goal whereas sediment control should be viewed as a contingency plan. In particular, areas of elevated erosion potential where fine particles will not readily settle out in a practical time frame should receive a greater emphasis on erosion control. Sediment control measures are then incorporated to capture and settle sediment and prevent or minimize the sedimentation into receiving waters. However, measures to address both erosion and sediment control are required for most sites [8]. The design of an ESC plan should be a flexible process that responds to new information as it is obtained throughout the construction life cycle [22]. For these reasons this design guide approaches ESC based on construction activities. All the BMPs will maintained during all construction phase until an acceptable stabilization. Periodic inspection and any necessary repairs will need to be done once every 7 calendar days and within 24 hours after any storm event greater than 0.5 in [12].

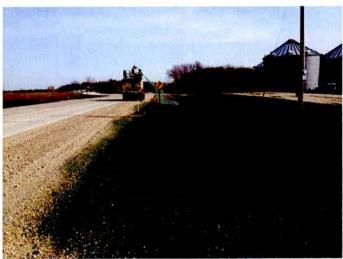


Figure 3 Hydroseeding (adopted picture from Coleman Moore Company's website)

ESC measures in project plans should be evaluated on a site-specific basis and be coupled with proactive management. Basic design considerations include [22] [23]:

- 1. Limit the area that is exposed to construction during planning and management
 - 1.1. Carefully delineate and control the disturbed area
 - 1.2. Only disturb areas where construction is taking place
 - 1.3. Maintain natural vegetation to maximum extent
 - 1.4. Protect and preserve topsoil
- 2. Maximize the use of existing and proposed vegetative cover to assist with the preservation of greenspaces and tree protection
- 3. Minimize sliver cuts and fills
- 4. Determine the appropriate shape for ditches (i.e., flat-bottomed versus v-ditches)
- 5. Use natural topographic features to prevent disturbances of the surface, minimize the potential for erosion and sedimentation, and reduce the need for other ESC design measures

Roadway systems may include several drainage areas and convey significant runoff and sediment from off-site, which results in intensive inspection requirements of drainage outlets and stormwater discharge outfalls subject to stormwater regulations. Designers need to select appropriate erosion and sediment control measures that are effective and applicable to the roadway design to collect and convey runoff from impervious areas to maintain the structural integrity of the roadway and protect public safety. The effectiveness of the erosion and sediment control measures on a site is highly dependent on proper implementation of a well-prepared ESC plan.



Figure 4 Sediment in Street Due to Inadequate Erosion and Sediment Control During Construction, adopted picture from [6]



Figure 5 Install hydro mulch and netting to prevent soil erosion along Kawainui Watershed (adopted picture from Hawaii Department of transportation website)

Erosion and Sediment Control Best Management Practices (BMPs)

Best Management Practices (BMPs) are measures to prevent the release of toxic and hazardous chemicals to receiving water, under the NPDES permit [24]. BMPs for erosion control are measures that have been developed and proven to work on construction sites. Best result obtains when they were properly planned and constructed. These measures reduce erosion and sediment potential by stabilizing exposed soil or reducing surface runoff flow velocity.

Technically erosion control BMPs can be divided in two categories, source control and runoff control BMPs. In ESC primary goal is to protect the expose soil surface from erosion factors such as rain drop impact and surface energy. To aim this goal cover is the single most effective erosion control BMP for preventing erosion. BMPs method such as topsoiling, seeding, mulching, hydroseeding, sodding, erosion control blankets, turf reinforcement mat (TRM), riprap, gabion mat, aggregate cover and paving are some examples for erosion control. However, it is not always possible and practical to provide surface cover during the construction. On this term commonly used methods are for runoff control. These methods widely focusing on diverting the flows around the affected area. In this category we can name methods such as the modification of slope surfaces, the reduction of slope gradients, controlling flow velocity, and providing upstream storage for runoff.

BMPs for sediment control mostly focusing to reduce off-site sedimentation. There are generally two types of BMPs for sediment control, filtering and entrapment BMPs and impoundment BMPs. In filtering and entrapment BMPs runoff will filtered through porous media consisting of natural and artificial materials. Stream banks and the perimeter of regions of higherosion potential are typical sites where filtering BMPs are usually used. Methods such as silt fences, check dams are commonly used sediment control BMPs. Sedimentation may take a long time, in impoundment BMPs by reducing flow velocity and lower the internal energy of runoff sedimentation shall be promoted. This technique is normally applied to concentrated flow. Common types of impoundment structures are sedimentation basin/trap and temporary barriers such as synthetic weave barrier, rock check.

Conventionally, the successful BMPs plan consist of combination of multiple appropriate erosion and sediment control methods (Figure 6) [8].

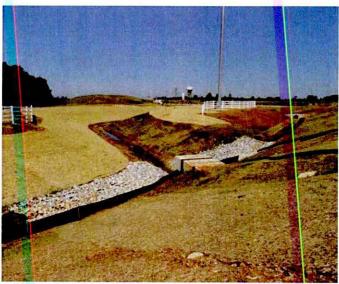


Figure 6 Multiple BMPs working together to protect slopes and waterway, adopted picture from [25]

Berm Interceptors.



Figure 7 Berm Interceptors, adopted picture from [6]

Description:

Earth dyke barrier constructed of compacted soil used in erodible slopes, sensitive areas or water bodies to divert or intercept the flow of runoff.

A Longevity:

Used as a temporary or permanent measure.

❖ Application:

- Used to divert water to sediment control structures
- Used instead, or in combination with, diversion ditches
- Perimeter control
- Placed along outlines and/or at toe of slope to divert run-off from sensitive areas

❖ Maintenance:

- Should remove accumulated sediment
- Should install new berm, when sediment reaches approximately one-half of the berm height.
- Should expanded, enlarged, or augmented with additional erosion and sediment control practices, if concentrated flows are bypassing or breaching the berm.
- Should add additional filter material as required to maintain the dimensions of the berm.
- Should repair any damages immediately to prevent further erosion [25].
- Deactivate and remove barrier once slope soils have stabilized and return barrier location to an acceptable condition [8].

Cellular Confinement Systems.

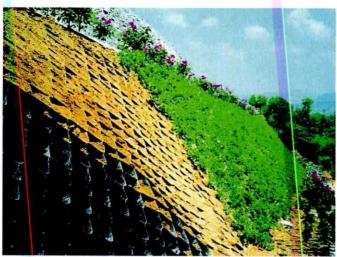


Figure 8 Cellular Confinement Systems, adopted picture from [26]

* Description:

Geosynthetics with a three-dimensional matting of open cells filled with topsoil or aggregate that are used to stabilize cut or fill slopes and protect root zone while permitting surface drainage. Also known as geocells [8].

. Longevity:

Used as a permanent measure.

* Application:

- Might be used with granular infill on cut or fill slopes up to 1H:1V.
- May be used with granular infill on slopes and in ditches with 3 m/s or less flow velocities.
- May be used as a flexible channel lining.
- May be used in temporary low-water stream crossing as granular pad for stream fording
- Matting is light, expandable, and easy to transport and place
- Use of native fill materials reduces costs; local granular fill is preferred

* Maintenance:

- Should be inspected regularly, especially after periods of heavy rainfall.
- Should repair any damages immediately to prevent further erosion.
- Should continue temporary inspection until vegetation is established and areas where vegetation fails to grow should be reseeded immediately
- Should replace or repair the matting after re-grading the slope if it is broken or damaged and washout of the underlying soil occurs.

Compost Blankets [6].



Figure 9 Compost Blankets, adopted picture from [6]

❖ Description:

Layers of loosely applied composted material placed on the disturbed soil surface areas to reduce stormwater runoff [4].

A Longevity:

Used as a temporary erosion and sediment control measure [4].

❖ Application:

- Depth between 2 to 3 inches (270 to 405 cubic yards per acre), greater depths for steeper slopes.

Table 1 Compost Blanket Thickness on Slopes, adopted table from [6]

Slope	Compost Thickness
	(inches)
2:1 *	4
3:1	3
4:1	2

^{*:} may be used to stabilize steep slopes (up to 2:1) if additional measures are provided

- Installation is possible when the ground is wet or frozen.

❖ Maintenance:

- Should check the disturbed ground under the blanket for the spots with failure potential.
- Should repair any damages immediately to prevent further erosion.

Energy Dissipators. [8]



Figure 10 Energy Dissipators, adopted picture from [27].

* Description:

Hard armor (riprap, gravel, concrete) placed at pipe outlets, in channels, and at downstream side of check structures to reduce velocity and dissipate energy of concentrated flows.

A Longevity:

Used as a permanent sediment control product.

* Application:

- May be used at outlets of pipes, drains, culverts, conduits, or channels with substantial flows
- May be used at slope drain outlets located at the bottom of mild to steep slopes
- May be used where lined channels discharge into unlined channels
- May be used as splash pad on downstream side of gabions, check structures, berms, barriers, and silt fences to prevent erosion caused by overtopping of structure

Maintenance:

- Should inspect frequently.
- Should repair any damages immediately to prevent further erosion.

Fiber Rolls and Wattles.

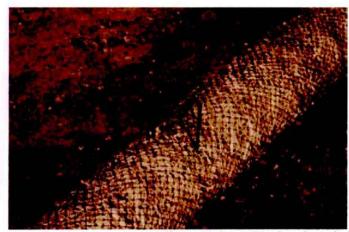


Figure 11 Straw Wattle, adopted picture from [6]

❖ Description:

Bundled live fascine staked into the soil along slope contours that capture sediment, organic matter, and seeds carried by runoff.

Longevity:

Used as a temporary method.

❖ Application [25]:

- Fiber rolls by reducing runoff velocity, reduce erosion potential. It should be Installed across slope contours as a grade break.
- Wattles are available in a variety of diameters ranging from 9 inches to 20 inches. The most common sizes are 9 and 12-inch wattles.
- The allowable spacing for these diameters is given in Table 2.

Table 2 Recommended Wattle Spacing by Slope, adopted from [25]

Slope Spacing Intervals

Slope		Spacing Interva feet)	ıls
9" Diameter		12" Diameter	
< 4:1	20	40	
2:1 to 4:1	15	30	
2:1 or greater	10	20	

❖ Maintenance:

- Should inspect frequently.
- Should repair any damages immediately to prevent further erosion.
- Additional stormwater control measures should be considered for rill areas damaged by runoff

Gabions.

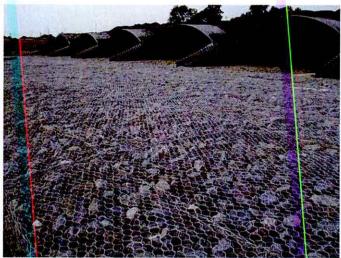


Figure 12 Gabions, adopted picture from [28]

❖ Description:

Rectangular trap sediment wire mesh baskets filled with rock that can be placed on slopes and channels for erosion protection or stacked to create retaining walls.

* Longevity:

Permanent measure

❖ Application:

- May be used on stream bank aprons and blankets where flow velocities do not exceed 6 m/s
- May be constructed to 0.5H:1V as a low height slope toe protection structure
- May be used on slopes up to 1.5H:1V as slope protection, a grade break and flow check
- Gabion matting is an alternative to riprap armoring of channels
- May be used to construct dikes or weirs
- Used as a check structure to reduce grade between structures and as flow check in channels
- Used as a splash pad to slow down flow velocity and dissipate flow energy

Maintenance:

- Inspected frequency and should be after major storm events,
- Repair as necessary; may include hand grading and/or infilling undermined area with rocky material
- Should removal the silt, determined based on depth of siltation, channel erosion and establishment of vegetation

Hydromulching.



Figure 13 Hydromulching, adopted from [29]

Description:

Measures similar to hydroseeding that adds a fiber-mulch to the mixture of seed, fertilizer and water. The mulch acts as a cover for the seed, helping it retain moisture for faster germination and growth, while protecting the soil from erosion and the seeds from washing away in the rain. The hydromulching mix is applied in the same way as hydroseeding and typically consists of a slurry of seed, fertilizer, water, tackifiers, biologically active soil conditioners, an optional color dye, and organic mulch fibers which degrade over several months.

Longevity:

Used as a temporary measure.

Application:

- Should use in an area with little topsoil is available [8].
- The specific content of the mulch and application rates should be base on the plan specification

Maintenance:

- Should inspect frequently.
- Should repair any damages immediately to prevent further erosion

Hydroseeding.



Figure 14 Hydroseeding, picture adopted from [30]

Description:

Seed, fertilizer, mulch, tackifiers, and water mixed together in a tank into a slurry and applied to a slope or channel surface to provide a layer of seed and growth bedding medium.

A Longevity:

Used as a temporary measure.

* Application:

- May be used to provide soil stabilization for seeding disturbed soil areas
- Using high pressure pumps to spray onto disturbed areas, slurry is held in suspension through consistent agitation.
- Can be spray after placement of topsoil, to provide stabilization, and seeding the large area.
- Can be used in areas where little topsoil is available.

❖ Maintenance:

- Small bare spots may need to be reseeded
- Should inspect frequently.
- Should repair any damages immediately to prevent further erosion

Inlet Protection.



Figure 15 Inlet protection, adopted from [30]

Description:

Interception and/or filtration of sediment before it is transported from a site into the storm drain system and discharged into a lake, river, stream, wetland, or other waterbody.

A Longevity:

Used as a temporary measure.

❖ Application:

- Used as inlet barrier in gently sloping ditches and gutters, municipal sewers or watercourses
- Used prior to establishing the vegetation.
- Used in drainage areas 0.4 ha (1ac) or less where nearly leveled (less than 5% degree)
- Used in areas where expected sheet flow and concentrated flow less than 0.014 m³/s (0.5 cfs)
- In concentrated flow more than 0.014 m³/s (0.5 cfs), block and gravel bag barriers are applicable
- Excavated drop inlet sediment traps used in areas where expected heavy flows and overflow capacity is required.

❖ Maintenance:

- Should inspect frequently.
- After each store event, build up sedimentation should be removed.
- Should replace gravel, if it blocked with sediments.
- Remove all inlet protection after stabilization when protection is no longer required

Mulching.



Figure 16 Mulching, adopted picture from [25]

❖ Description:

Applications of organic material or other normally biodegradable substances as a protection layer to the soil surface to minimize raindrop/runoff erosion and conserve a desirable soil moisture property for plant growth, and/or to promote seed germination and plant growth.

A Longevity:

Used as a temporary measure.

Application:

- Used as an organic cover or growth medium for seeds
- May be used without or with seeding to promote plant growth.

- May contain organic mulches such as straw, wood fibers, peat moss, wood chips, pine needles, compost or chemical mulches such as vinyl compounds, asphalt, rubber, or other substances mixed with water.
- Chemical mulches may be used in hydroseeding and hydromulching to bind other mulches.

* Maintenance:

- Inspect mulched areas for signs of thin or bare spots.
- Correct eroded areas, reseed and reapply mulch as needed.
- If erosion is severe, reoccurring or in channelized flow, consider using erosion control blanket and slope drains.

Reinforced Silt Fences.

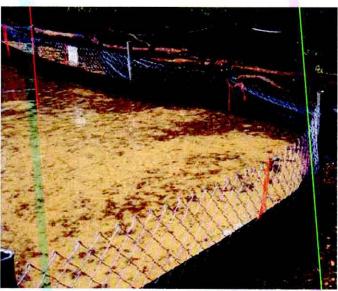


Figure 17 Reinforced Silt Fence, adopted from [4]

Description:

Permeable fabrics reinforced by a wire mesh or chain link fence, with barriers installed vertically on support posts along contours to collect sediment laden sheet flow runoff.

Longevity:

Used as a temporary method.

❖ Application:

- Collecting sediment from runoff at the bottom of cut or fill slopes.
- Used along streams (channels) banks, around stockpiles
- Used at mid-slope grade break; to increase ponding, filtering and sedimentation, "J-hook" or "smile" pattern recommended.

* Maintenance:

- Should inspect frequently.
- Should repair or replace any damages immediately to prevent further erosion
- Remove the buildup sediment when design capacity reduced by 50% [6].
- Remove the fences after vegetation establishment in the site, by minimize soil disturb [8]

Riparian Zone Preservation. [8]



Figure 18 Riparian zone preservation, adopted from [31]

Description:

Permanent measures of protection of existing plants and trees in narrow strips of land adjacent to natural water bodies (riparian zones) that act as effective vegetative buffer strip as a form of erosion and sediment control.

A Longevity:

Used as a permanent method.

Application:

- Existing vegetation on site acts as an effective sediment and erosion control buffer strip to slow down flows and capture sediment in site.
- Used along property boundaries despite non-presence of watercourse adjacent to minimize sedimentation off construction site.
- Even though the existing dense vegetation is effective, additional BMPs may be required on construction site to preserve riparian zones.

* Maintenance:

- Should inspect frequently.

• Riprap Armoring.



Figure 19 Riprap armoring, adopted from [32]

* Description:

Large, loosely placed cobbles or boulders placed along channel banks or slopes to protect underlying soil from erosion due to flowing water.

* Longevity:

Used as a permanent measure.

* Application:

- Easy to install and easy to repair
- Use in slope up to 2H: 1V, and on channel banks and slope which flow range is from 2 m/s to 5 m/s.
- It needs to place a lower portion of the channel section to the mean annual peak flow height.
- Other BMPs such as RECP blankets and seeding may be used to improve ESC at the upper portion of the channel.
- Non-woven geotextile should be used for the underlying to act as sediment filtration.
- A layer of granular filter material should underlie the riprap with cyclic drawdown long-term performance with/without an extra layer of non-woven geotextile as underlay, for fluctuating high flow channel.

Maintenance:

- Should inspect frequently.
- Inspecting the protected material from erosion and checking movement of riprap should happen periodically.

Rock Check Dams. [8]



Figure 20 Rock Check Dams, adopted picture from [6]

❖ Description:

Dams constructed across a water way, swale or drainage ditch to counteract erosion by reducing water flow velocity.

***** Longevity:

Used as a temporary control measure.

❖ Application:

- Check dams should not be spaced closer than 20 feet.
- If slopes and check dam height call for a spacing closer than 20 feet, a Rolled Erosion Control Product or Turf Reinforcement Mat should be considered as an alternative [6].

* Maintenance:

- Should inspect frequently.
- Buildup sedimentation should be removed before it reaches one half the check structure height.
- The failed point in the structure should be repaired immediately to prevent failure of the whole structure.
- Dislodged aggregate should replace with more substantial aggregate or gabion structures.

Rolled Erosion Control Products (RECP) [6].

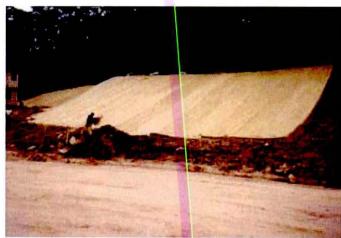


Figure 21 Rolled Erosion Control Products (RECP), adopted picture from [6].

Description:

Biodegradable or synthetic soil coverings used for protection of disturbed soils at slopes and channels to protect against raindrop impact and surface runoff erosion, increase water infiltration into soil, retain soil moisture, and decrease evaporation losses. Categories of rolled erosion control products (RECP) can be: (1) Erosion control blankets (ECB) (generally biodegradable and temporary) (2) Turf reinforcement mats (TRM) (3) Composite turf reinforcement mats (C-TRM) [4].

A Longevity:

Used as a temporary or permanent control measure [4].

❖ Application:

- bare ground that is highly susceptible to erosion, such as slope and channels, and in locations where establishing vegetation may otherwise be difficult.
- A manufacturer or supplier can provide further assistance in selecting an appropriate RECP.
- For channel applications, products that contain straw are not recommended

* Maintenance:

- Once installed, there is little maintenance that needs to be done to RECPs.
- If the RECPs are vegetated, the vegetation should be watered as needed
- Until the vegetation is fully established, the surface should be inspected for signs of rill or gully
 erosion below the matting.
- Any signs of erosion, tearing of the product, or areas where the product is no longer anchored firmly to the ground should be repaired

Sediment Traps and Basins.



Figure 22 Sediment Traps and Basins, adopted from [32]

Description:

Low height dam enclosures that promote settlement of sediment by impoundment of sediment-laden storm water, sedimentation of silt size particles, and release of treated storm water.

❖ Longevity:

Used as a temporary sedimentation area with permanent pool [30].

❖ Application:

❖ Maintenance [30]:

- Should inspect frequently, until all the area draining to the trap have been stabilized.
- Should inspect regularly for possible damaged by erosion or construction equipment.
- Damaged point should repair immediately.
- Filter stone should be checked to ensure that filtration performance is maintained.
- Buildup sedimentation should be removed before it reaches one half the design volume of the wet storage.
- Sediment removed from the trap should be deposited in an area up gradient from the sediment trap and other measures and stabilized or removed from the site.
- It may be removed or deactivated after vegetation of upstream stabilized [8].

Seeding.



Figure 23 Seeding, adopted picture from [33]

* Description:

Applications of seed, which provides erosion protection through the planting or placing of seed into soils of cut slope or fill embankment slopes after a layer of organic topsoil is spread over the slope.

* Longevity:

Used as permanent or temporary measures.

* Application:

- Temporary seeding with rapidly growing plants may be applied to interim stockpile/excavation areas which will be exposed for more than 30 days
- Permanent seeding may be applied to exposed bare soil areas which have been graded to final contours
- Permanent seeding may be applied to landscape corridors, slopes and channels by broadcasting, furrowing or spraying on with mulch tackifier
- Provides habitat for wildlife after vegetation establishment
- Can be enhanced with a protective layer of mulches or rolled erosion control products (RECPs) to improve growth environment

❖ Maintenance [8]:

- Once the area is seeded, it should not be disturbed and should be protected from traffic.
- Should inspect frequently.
- Freshly seeded areas should be inspected frequently to ensure growth is progressing
- Additional stormwater control measures should be considered for areas damaged by runoff
- Small bare spots may need to be reseeded several times at subsequent years after initial application
- Larger areas may need to be completely retreated
- Cutting or mowing grasses will encourage the establishment and spread of the grass

Silt Dikes.

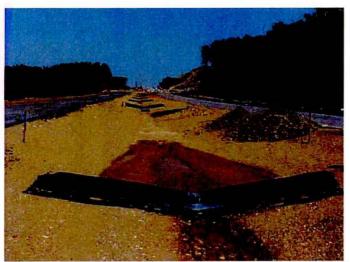


Figure 24 Silt dike, adopted from [34]

Description:

A barrier used to dissipate flow energy and reduce velocity, which allows some sediment to settle out upstream of the barrier structure.

A Longevity:

Used as a temporary measure.

* Application:

- May be placed across the ditch along steep to dissipate flow energy and reduce flow velocities.
- Usually used as grade breaks along ditch (3 to 7% grade) in combination with RECP or non-woven geotextile as soil covering mattings;
- Usually used in combination with permanent gabion structure (i.e., gabion) at steep grade (+6%) areas.
- It is a reusable design.

❖ Maintenance:

- Should inspect frequently.
- Buildup sedimentation should be removed before it reaches one half the structure height.
- Remove the sediment without damaging the barrier structure.
- Suitable repairs should be made if erosion noted at toe or upslope of the structure.
- The structure should be removed at least 1 year after stabilization.

Slope Drains.



Figure 25 Slope drains, adopted from [30]

Description:

Flexible tubing or pipe used to convey concentrated runoff from the top to the bottom of a cut or fill slope without causing significant erosion along the slope.

* Longevity:

Used for both temporary and permanent measures.

* Application:

- Used on cut or fill slopes where there is a high potential for erosion caused by concentrated runoff flow over the face of the slope
- Used in combination with other BMPs such as diversion channels, berms, or barriers, to convey flow direct toward the slope drain.

❖ Maintenance:

- Should inspect frequently.
- Any damages should repair immediately.
- Should install additional stakes in case of pipe movement.
- After each storm water, sediment should be removed from upslope inflow apron area.

Slope Texturing. [8]



Figure 26 Roughening, adopted picture from [25]

❖ Description:

Texturing of slopes, either by roughening the surface, tracking the surface, or installing grooves or benches. Texturing reduces the runoff velocity, traps sediment, and increases the infiltration of water into the soil.

* Longevity:

Used as a temporary measure.

Application:

- Used to roughen the exposed soils on the slope surface to minimize erosion and reduced the water flow velocity.
- May be used on fresh cut or fill slopes with 3H:1V or 2H:1V slopes in cohesive soils.
- May be used on slope that other BMPs not applied immediately.
- May be combined with benching to reduced erosion on long slope.
- Benching is a permanent slope design and should design by geotechnical engineer.

Sodding. [8] [30]



Figure 27 Sodding, adopted from [35]

Measures which rapidly establish vegetative cover by use of grass sod to cover and stabilize disturbed areas of bare soil in environmentally sensitive areas where complete cover of the disturbed soil surface is essential and conventional or hydroseeding and mulching may not be effective to erosion protection.

Longevity:

Used as a temporary or permanent measure.

* Application:

- Used to immediate protect of soil surface from water and wind erosion where adequate topsoil and fertilizer can be provided
- Irrigation is required after placement

* Maintenance:

- Should inspect frequently.
- Washout or damaged area should be regraded and re-sodded immediately.
- For rill or gullied areas additional BMPs is required.
- Should be maintained by fertilizing, irrigating, weed control and mowing, depending on location and plan.
- Should not moved within one month of installation. And residue from moving should be left on the sod unless it has more than 1 cm depth.

Stabilized Worksite Entrances. [8]



Figure 28 Stabilized worksite entrance, adopted from [30]

Description:

Gravel pads located at site access points (entrances) that are used to reduce the amount of sediment carried off construction sites by vehicles.

A Longevity:

Used as a temporary measure.

❖ Application:

- Used anywhere vehicles and equipment enter or exit a construction site
- Retains sediment on construction site, and reduces deposition of sediments on public roads

* Maintenance:

- Should inspect frequently.
- Granular material should be regraded when required
- May add material to fill large voids to maintain a minimum pad thickness of 0.30m
- Public roads should be cleaned as soon as possible if material accidentally deposited in them

Straw Mulching and Crimping. [8]



Figure 29 Straw Mulching and Crimping, adopted from [36]

Description:

Uniform layers of straw incorporated into the soil with a studded roller or anchoring it with stabilizing emulsion. Used as a temporary measure to protect against the impact of rain drops. Also known as Straw Anchoring.

A Longevity:

Used as a temporary measure.

* Application:

- Used as a surface cover on disturbed areas until soils can be prepared for revegetation and permanent vegetation is established
- Used in combination with seeding strategies to enhance plant establishment

Maintenance:

- Should inspect frequently.
- Straw mulching should reapply in areas where erosion observed, and other BMPs may be required to prevent erosion.
- Should inspect and maintain all slopes to prevent erosion after any rainfall event.

Topsoiling. [8]

❖ Description:

Applications of topsoil to provide a medium for vegetation to grow by covering of exposed mineral soils with soils of high organic content to minimize.

A Longevity:

Used as temporary or permanent measure.

* Application:

- Provided bedding for seeding and cover the exposed areas that is not suitable to promote vegetation.
- May be used on slope up to 2H:1V

- May be used prior to seeding, mulching, hydromulching, hydroseeding and installation of any RECP.

* Maintenance:

- Should inspect frequency.
- Should repair any damages caused by washout immediately with regraded and re-topsoiling to prevent further erosion.

Suggested ESC categories summary

Effective ESCP would not possible unless appropriate BMPs related to the construction site has chosen. Proper BMPs category makes the process of selection easier. This document has employed two different methods to achieve the appropriate BMPs category, interview with engineers and professionals of this field and systematic literature review of available Erosion and Sediment Control manuals, handbooks, journal papers to identify the current problem and present the rational and understandable categories for BMPs. The provided BMPs list on this document is the BMPs list typically used by ODOT consist of 24 methods.

One of the categories of ESC Best Management Practices provided in this study is based on the construction activities and construction phase. Selected BMPs should be proportional to the experience and judgment of the designer from construction site erosion potential and effectiveness of BMPs. In the following construction activities phase and their effects on erosion and sediment, would briefly be described.

Site preparations. Must be considered early in the planning phase within a construction site. Site preparations are valuable to the designer, technicians, and contractors in preserving and maintaining the site conditions [22].

Clearing and Grubbing. Clearing operations include slashing, cutting, stockpiling, and removal (or burning) of trees and brush. May leave the stump and root mass intact. In grubbing operations, the residues left behind during clearing operations would be removed and may cause soil exposure. During this phase, topsoil and most of the organic mat would remain in place.

Stripping. By removing the organic mat from the site and expose the underlying mineral soil increased the erosion potential.

Borrow Excavations. The excavation and removing borrow material for roadway subgrade construction, or the construction of a dam, canal, dike, and other structure of erosion protection. Borrow excavations can either be landscape borrows or dugout borrows. Development of borrow excavations may include clearing, stripping, grubbing, and excavation which may cause soil disturbance and exposed the soil surface; it also changes the natural drainage.

Stockpiles. Include material removed from excavations, stripping, clearing, and borrow pits. It may disturb the vegetated, and exposed soil surface and slopes and change the natural drainage.

Cut Slope. Creating slopes through the excavation and removal of native soil. It may increase the slope angle, disturb the soil surface, create exposed slopes, and change the natural drainage.

Fill Slope. Constructed by placing and compacting fill material, may create disturbed exposed slopes, create steep slope angles and change the natural drainage.

Ditch and channels. Constructed to direct and transport water along or transverse to the highway alignment. May change the original drainage pattern and increased the flow concentration velocity and erosion potential.

Culvert. Installed to connect drainage courses and surface drainage flow. It may cause flow concentrations, create cut slopes, disturb the soil surface on slope faces, and create scour zones at the culvert inlet or outlet.

Temporary Access Road. Constructed to provide construction equipment access on the project site. It may change drainage courses and may include the construction of cut slopes, fill slopes, ditches or culvert installation [8].

Soil stabilization. As a construction project progresses, completed areas and areas of inactivity must be stabilized. It is one of the BMPs to stabilize areas as quickly as possible to avoid erosion problems [22].

The other categories which is presented on this document is based on ESCs BMPs application such as slope, ditches and channels. Also, in this category the life longevity of BMPs practices showed as a temporary and permanent category. Proper construction planning should include temporary ESC BMPs early in the construction life cycle. Permanent ESC measures should also be installed during or at the end of the construction phase.

The following two tables summarize the procedures and BMPs for selecting ESC. Table 3 describe the application of BMPs based on the site construction activities and Table 4 describe the application of BMPs based on their spatial location (i.e., slope, channel and flat area, or stockpile). It should be noted that sites condition might be different from place to place, selected BMPs should meet specific requirements of any given construction site. Considered BMPs should be easy to design, implement, maintain and inspect.

In addition, Appendix one provides a list of different manufacture's product and pay items and their specification charts. An enormous number of ESC products exists, and according to demand, the new product would be introduced. This document can only present a part of available products. This information gathered based on the internet search and provided specification by the production companies on their website or their brochures.

ESC Best Management Practices	Construction Activities													
													Construction	
	Site Preparations	Clearing and Grubbing	Stripping	Borrow Pits	Stockpiles	Cut Slopes	Fill Slope	Ditches/Ch annels	Culverts	Temporary Haul Roads	Soil Stabilization	Sediment Containment	Post Construction Monitoring	
Reinforced Silt Fence	1	1	✓	✓	1	✓	✓		✓	√		1		
Gabions								✓	✓				✓	
Compost Blanket					✓	1	1			1			1	
Fiber Rolls and Wattles				✓	✓	✓	✓					✓		
Berm interceptor		1	1	1	1	1	1			1			/	
Storm Drain Inlet								✓	✓				✓	
Rock Check Dam								1				1	1	
Silt Dike								1				1		
Rolled Erosion Control Products (RECP)					1	1	✓	1					1	
Riprap Armoring								1	1				✓	
Cellular Confinement System						1	1	1					/	
Energy Dissipators								1	✓				✓	
Sediment Traps and Basins			1					1				1	1	
Slope Drains						1	√						✓	
Seeding				1	1	1	1	1			1		/	
Mulching				1	1	1	1	1			1		1	
Straw Mulching and Crimping (Straw Anchoring)				1		1	1				✓		V	
Hydroseeding				1	1	1	1	1			1		1	
Hydromulching			1	1	1	1	1				1		1	
Topsoiling				√	1	1	1	1					1	
Sodding				1	1	1	/	1			1		/	
Riparian Zone Preservation		1	1	1	1	1	1	1	1	1	5.5///		✓	
Stabilized Worksite Entrances	1	1	1	1	1	1	1		1	1	L I WELL		1	
Slope Texturing				1	1	1	1			1			/	

ESC Best Management Practices	S	IPs based on Application			F	Functi onal longevity					
	Slope	Ditches and Channels	Large Flat Surface	Borrow and Stockpile	Erosion Control - Source Control	Erosion Control Runoff Control	Sediment Control Filling and Entrapment	Sediment Control Impoundment	Temporary	Permanent	
Berm Interceptor							1			/	~
Cellular Confinement System					V						V
Compost Blanket					_		1			/	
Energy Dissipator							,				V
Gabions						,	/	i i i i i i i i i i i i i i i i i i i			V
Hydroseeding		74			~					_	
Hydromulching					~					V	
Mulching					V				1	/	
Riparian Zone Preservation			199		V		1			/	10
Riprap Armoring					V						V
Rock Check Dam							1			/	V
Rolled Erosion Control Product (RECP)					~				85	/	V
Fiber Rolls and Wattles							/			/	
Sediment Traps/ Basins								✓			V
Seeding			ATTE		~					/	V
Reinforced Silt Fence							✓			/	
Slope (Down) Drains						~				/	V
Slope Texturing					V	V				/	
Sodding					V					/	V
Storm Drain Inlet/Sediment Barrier							1			/	
Straw Mulching and Crimping (Straw Anchoring)					,					V	
Silt Dike						V	✓ ✓		9	/	
Topsoiling					V				TE ST	/	

References

- [1] "Maine Erosion and Sediment Control Practices Field Guide for Contractors," Maine Department of Environmental Protection, 2003.
- [2] "United States Environmental Protection Agency," 11 March 2019. [Online]. Available: https://www.epa.gov/laws-regulations/summary-clean-water-act. [Accessed 3 9 2019].
- [3] D. E. Scott Kelting, "Implementation, Management, and Cost of the Clean Water Act and Storm Water Pollution Prentation Plan," *Procedia Engineering*, vol. 171, pp. 419-424, 2017.
- [4] "Storm Water Best Management Practices," U.S. Environmental Protection Agency, 2012.
- [5] D. E. Scott Kelting, "Implementation, Management, and Cost of the Clean Water Act and Storm Water Pollution Prentation Plan," *Procedia Engineering 171*, pp. 419-424, 2017.
- [6] "Iowa statewide urban design and specification design manual," Iowa state university institue of transportation, 2019.
- [7] "General Permit OKR10," Oklahoma Department of Environmental Quality Water Quality Division, 2017.
- [8] "Erosion and Sediment control manual," Government of Alberta transportation, 2011.
- [9] "Watershed management field manual, FAO Conservation Guide 13/5," Food and Agriculture Organization of the United Nations, 1998.
- [10] C. Copeland, "Stormwater Permits: Status of EPA's Regulatory Program," Congressional Research Service, 2012.
- [11] "Natinal Pollutant Discharge Elimination System (NPDES) Storm Water Pprogram Questions and Answers- Volume III," U.S. Environmental Protection Agency, 2004.
- [12] "ODOT Roadway Drainage Manual," Oklahoma Department of Transportation, 2014.
- [13] "Association of State Wetland Managers," 2019. [Online]. Available: https://www.aswm.org/aswm/58-wetland-programs/state-summaries/785-oklahoma.
- [14] K. Alsharif, "Construction and stormwater pollution: Policy, violations, and penalties," *Land Use Policy* 27, p. 612–616, 2010.
- [15] V. A. G. T. W. Y. Sheila Belayutham, "The dynamics of proximal and distal factors in construction site water," *Journal of Cleaner Production 113*, p. 54e65, 2016.
- [16] "Maine Erosion and Sediment Control Practices Field Guide for Contractors," Maine Department of Environmental Protection, Revision 2003.
- [17] "EROSION AND SEDIMENT CONTROL, LANDSCAPE DESIGN CRITERIA," ILLINOIS STATE TOLL HIGHWAY AUTHORITY, 2018.
- [18] "Ryerson University," [Online]. Available: http://www.civil.ryerson.ca/stormwater/menu_5/index.htm. [Accessed 07 09 2019].

- [19] "Food and Agriculture Organization of the United Nation," [Online]. Available: http://www.fao.org/3/u3160e/u3160e05.htm. [Accessed 8 9 2019].
- [20] "MASSACHUSETTS EROSION AND SEDIMENT CONTROL GUIDELINES FOR URBAN AND SUBURBAN AREAS," Massachusetts Department of Environmental Protection, 2003.
- [21] "Erosion and Sediment Control, Landscape Design Criteria," Illinois State Toll Highway Authority, 2019.
- [22] "Erosion and Sediment Control Design and Construction Manual," North Carolina Department of Transporation, 2015.
- [23] "Permanent Erosion and Sediment Control Design Guidelines," Montana Department of Transportation, 2018.
- [24] "Guidance Manual for Developing Best Managemet Practices (BMP)," United States Environmental Protection Agency, 1993.
- [25] "Storm Water Management Feild Guide," Indiana Department of Transportation, 2018.
- [26] "Products-Cellular Confinement," Geo Solution Company, 2019. [Online]. Available: https://www.geosolutionsinc.com/products/erosion-control-geoweb.html. [Accessed 09 09 2019].
- [27] "Energy Dissipators," Vaughan Concreate products, 2018. [Online]. Available: http://www.vaughnconcreteproducts.com/energy-dissipator. [Accessed 09 09 2019].
- [28] "Erosion Control," Enviromesh Co., 2018. [Online]. Available: https://enviromesh.com/applications/erosion-control/. [Accessed 09 09 2019].
- [29] Paris Texac Hydromulching, [Online]. Available: http://parishydromulching.weebly.com/what-is-hydromulching.html. [Accessed 15 09 2019].
- [30] "Erosion & Sediment Control Handbook," Tennessee Department of Environment and Construction, 2012.
- [31] "Watson Woods Riparian Preserve," Prescott Creeks Preservation Association, 2019. [Online]. Available: https://prescottcreeks.org/watson-woods-riparian-preserve/. [Accessed 16 09 2019].
- [32] "Erosion prevention practices Riprap," Minnesota Pollution Control Agency, 8 3 2019. [Online]. Available: https://stormwater.pca.state.mn.us/index.php?title=Erosion_prevention_practices_-_Riprap. [Accessed 16 9 2019].
- [33] "Seeding," Seedmasters, Inc, 2013. [Online]. Available: http://www.seedmasters.net/seeding-erosion-control.html. [Accessed 09 09 2019].
- [34] "10" Triangular Silt Dike Photo Gallery," Triangular Silt Dike Co., [Online]. Available: http://tri-siltdike.com/10-silt-dike-photo-gallery.html. [Accessed 16 9 2019].
- [35] "Sodding," Aaron's Lawn Care & Landscaping, 2019. [Online]. Available: http://www.aaronslawn.com/home-slider/sodding. [Accessed 16 9 2019].

- [36] Kyle, "Mulching and plant cover," Kyle lilly weblog, 28 11 2012. [Online]. Available: http://kylelilly.blogspot.com/2012/11/mulching-and-plant-cover.html. [Accessed 16 9 2019].
- [37] "Developing Your Stormwater Pollution Prevention Plan A Guide for Construction Sites," U.S. Environmental Protection Agency's Construction, 2007.
- [38] "Erosion AND Sediment Control, Landscape Design Criteria," Illinois State Toll Highway Authority, 2018.
- [39] C. L. Jeremy Hanson, "Recommendations of the Expert Panel to Define Removal Rates for Erosion and Sediment Control Practices," Chesapeake Research Consortium Tom Schueler and Chesapeake Stormwater Network, 2014.
- [40] "Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas," Massachusetts Department of Environmental Protection, 2003.
- [41] "New Hampshire Stormwater manual, Volume 3," Comprehensive Environmental Inc. and the New Hampshire Department of Environmental, 2008.
- [42] "Alaska Storm Water Pollution Prevention Plan Guide," Alaska Department of Transportation and Facilities, 2017.
- [43] "Proper Selection of Hydroseeding Mixtures and Components to Promote Rapid Revegetation of Disturbed Department of Defense Lands," Department Of The Army U.S. Army Corps of Engineers, 2009.
- [44] "Evaluation of ALDOT Ditch Check Practices Using Large-Scale Testing Techniques," Auburn University Highway Research Center, 2014.
- [45] K. Schiff, "Was the Clean Water Act Effective?," *Marine Pollution Bulletin 81*, pp. 1-2, 2014.

Appendix 1