ROHL Global Networks
Erosion and Sediment Control Plan
Northwest Territories
Dempster Fibre Project

Submitted to MVLWB
Files MV2019X0027 & MV2019L8-0013
All appendices are provided for information

Revision History	
Date Written	2022-02-23
Plan Owner	Engineering and Environmental
Date of Plan Review	2022-05-20
Date of Plan Revision	2022-06-10

Revision History

Date	Owner	Comments
April 14, 2022	ROHL Engineering and Environmental	V1.0 submitted to MVLWB for review
June 10, 2022	ROHL Engineering and Environmental	V2.0 Updated to incorporate recommendations from MVLWB public review

Conformity Table- Permits

LUP	WL	Requirement	Section of Plan
Part C, Condition 14	Part F, Conditions 9 & 10	Develop a plan to address the potential for in-stream sedimentation that may occur during vegetation clearing, and during the installation and maintenance of the fibre optic line.	2.0, 3.0, 4.0, 5.0

Conformity Table – Revisions

ID	Recommendation	Revision	Section of Plan
1	Revise section 4.0 to be specific to the Dempster Fibre Line Project, rather than a general list of preventative measures.	Preventative measures updated to be specific to the Dempster Fibre Line Project.	4.0, page 8
2	Note the specific times that will be prioritized for construction.	The principle of timing updated to state that construction will be timed to avoid the seasonal runoff.	6.0, page 10
3	Clarify how the results of site visits will be used to ensure that appropriate sediment and erosion control measures are in place prior to the start of construction.	Additional information included on the role of environmental monitors in conducting site visits to describe how site visits will aid in ensuring appropriate sediment and erosion control measures are in place.	6.0, page 10, 11
4	Provide additional details on all erosion prevention and sedimentation controls that may be used during construction and installation of the Fibre Line. The information should include the types of controls, specific areas where certain controls will be installed, and an outline of how the controls will be monitored/maintained during and after construction.	Introductory sentence added to provide clarity on the types of sediment and erosion controls typically used in fibre optic cable installation. Paragraph 3 following "Silt Fencing" subtitle added to provide information on how the controls will be monitored and maintained during and after construction.	7.0, page 11
5	Include at least one site map to outline sensitive or key areas of	Example site maps provided in Appendix C.	Appendix C

	concern, as well as the planned installation locations for erosion/sedimentation control measures.		
6	Provide a summary of drainage conditions to be encountered along the Dempster Highway.	Section 5.0 “Streams, Wetlands, and Waterbodies” added to discuss drainage conditions along the Dempster Highway.	Section 5.0, page 9, 10
7	To minimize ground disturbance and the project’s environmental footprint, only vibratory plows should be used for this project.	Section 2.0 “Conventional Bury” updated to remove “trencher”.	Section 2.0, page 7
8	Outline the potential environmental consequences of Surface Lay.	Section 2.0 updated to provide additional context to the Surface Lay methodology.	Section 2.0, page 7

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1.0 PROJECT BACKGROUND

Company Name, Location, and Mailing Address

ROHL Global Networks Inc. (RGN)
11211 266 Street Acheson, AB
T7X 6E1

Primary Contact: Gary Seed – Project Manager, Field Operations
Phone: (867) 332-8124
Email: GSeed@rohlglobal.com

Purpose & Scope

The purpose of this plan is to outline the erosion and sediment control activities to be implemented throughout the duration of the Dempster Fibre Project (DFP). Erosion and sediment control activities will be conducted as part of all installation activities for the duration of the Project to minimize the effect on the surrounding landscape. Sediment and erosion control will support the continuation of a healthy environment and any future human activities that will occur in the project area. This plan is applicable to all construction crew personnel on the Project.

Effective Date

This plan will be effective from the date of approval by the Mackenzie Valley Land and Water Board and will expire on the date that the permit is closed.

Revisions

Any revisions to the plan will be submitted to the Mackenzie Land and Water Board for approval and regulating agencies prior to implementing any changes.

Distribution

This plan and the most recent revisions will be distributed to all staff and contractors working on the project. The Plan will be presented and reviewed during an orientation prior to the start of construction. The Erosion and Sediment Control Plan will be included as part of new staff orientation activities.

Licenses, Permits, and Fees

All sediment and erosion control activities associated with the construction, operation, and maintenance of the DFP will be done in accordance with this plan, and all applicable federal, territorial, and municipal laws and regulations.

2.0 CONSTRUCTION METHODOLOGIES

Construction of this project will require the followings activities:

Conventional Bury:

Use vibratory plow to cut and create trench at a target depth of 1.0 m.
Appropriate plow train or tandem tractor configurations are allowed as necessary to complete work; configurations must ensure minimal ground disturbance.

Shallow Bury:

Use trencher (i.e. chain-wheel and/or rock-wheel) or vibratory plow to cut and create shallow trench at a depth >300 mm ‑ 1.0 m. Appropriate plow train or tandem tractor configurations are allowed as necessary to complete work; configurations must ensure minimal ground disturbance.

Sub-Surface Lay:

Use trencher (i.e. chain-wheel and/or rock-wheel) or vibratory plow to cut and create shallow trench at a depth >150 mm ‑ <300mm. Appropriate plow train or tandem tractor configurations are allowed as necessary to complete work; configurations must ensure minimal ground disturbance.

Surface Lay:

In ponds and waterbodies where means of burial are not feasible the facility will be laid in the surface, allowed to settle to the bottom, and secured with cable weights. Only applicable in non-flowing waters. The cable being used in the application of Surface Lay is a project specific cable designed to eliminate environmental consequences. Due to its armoured coating, it is secifcially designed to eliminate potential degredation caused by animals or by natural elements. The Surface Lay methodlogy will only occur in water, and cable weights will be placed to secure the conduit in place, so it will not be visible and will limit impact to wildlife passing through waterbodies. The Project will take every effort to limit Surface Lay installation and will review all locations where Surface Lay is designed to review alternative installation methods where suitable. Surface Lay is a final resort installation when there is no other suitable method.

Horizontal Directional Drilling (HDD):

HDD of all fish bearing-bearing streams, rivers, and other water bodies or challenging sections.

New Aerial:

New aerial cable installations will be installed in sensitive terrain or challenging conditions to minimized ground disturbance.

3.0 EROSION AND SEDIMENTATION

Erosion is the process that gradually wears away soil and rock by wind, water and/or ice. The deposition and accumulation of detached soil particles in other areas is called sedimentation. Sedimentation can have a detrimental effect on watercourses, water bodies and wetlands by:

- Altering oxygen concentrations;
- Clogging pore spaces between gravels used for fish spawning;

- Smothering fish eggs and fry;
- Suffocating aquatic insects;
- Clouding water, affecting predator-prey relationships;
- Transporting pollutants;
- Increasing water temperatures to uninhabitable levels;
- Altering hydrology of wetlands; and
- Degrading drinking water quality.

Water is the most common cause of erosion in construction activities. Construction activities and large earthmoving projects can accelerate erosion dramatically by exposing large areas of soil to rain and running water. To minimize potential erosion and sedimentation issues during construction, implement best management practices for permafrost protection, erosion and sedimentation control. A minimum standard will be to follow the practices for erosion and sediment control detailed in the Government of Northwest Territories guidance document Erosion and Sediment Control Manual (Government of Northwest Territories 2013), a copy of which is included in *Appendix B*.

4.0 PREVENTATIVE MEASURES

A key goal for the Dempster Fibre Line Project is to, wherever possible, minimize the removal and disturbance to natural vegetation, both above ground and the roots. While larger vegetation such as trees will need to be cleared, in most cases, shorter vegetation can be retained. While equipment will disturb the smaller vegation, minimizing disturbance to the root beds is possible with the exception of the narrow trench required for fibre line.

Limiting disturbance of vegetation and root beds is one of the most effective and cheapest tools that a developer can employ to prevent erosion and sediment mobilization. Vegetation prevents rain drop erosion, holds sediment in place, detains and reduces the velocity of surface water, and filters runoff water. Just as important, retaining as much natural vegetation as possible can reduce the amount and cost of reclamation work after the project is completed.

Key mitigations for the Dempster Fibre Project include:

- Minimizing the size of the disturbed area (i.e. project footprint).
- Use of existing trails and roads as much as possible.
- Maximizing retention of natural vegetation cover and rootbeds—it is the best and cheapest defence against erosion.
- Maintaining reserve zones and riparian buffers as outlined in the Riparian Plan.
- Minimize compaction at all sites by selecting proper equiment.
- Avoid working on unstable areas and steep slopes.
- Minimize water crossings and directionally drill under streams and open water wetlands.
- Sequence and schedule construction to take advantage of drier weather.
- Avoid disturbing permafrost layer.
- When brushing/mulching avoid clearing to soil, cut trees and shrubs off near ground level leaving the root mass in the ground. Willows and most other northern shrubs in previously disturbed right-of-ways are very hardy and will regrow after being cut off and driven on if most of the roots are kept intact.

- Avoid rutting by using appropriate equipment for ground conditions. Low ground pressure equipment will be used in wet areas that would be sensitive to conventional equipment (e.g. non-open-water wetlands)

5.0 STREAMS, WETLANDS, AND WATERBODIES

There are many drainages that cross the Dempster Highway within the Yukon and Mackenzie River watersheds. This includes streams of various sizes and orders, many of which are surrounded by wetlands riparian areas. The Highway intersects these streams and has a variety of crossing structures including single culverts, multiple culverts, and bridges. The fibre line will intersect these streams, lakes, wetlands and waterbodies. Stream, wetland and waterbody (lake) classification and mapping has been completed and mitigations including machine free and riparian management zones will be established to avoid impacts to these features. Implementing these zones will go a long way to prevent sediment delivery to these features. Example site maps outlining these classifications, sensitive and key areas of concerns, and locations planned for erosion/sediment control measures can be found in *Appendix C*. Some drainages consist of multiple features, such as a stream or lake surrounded by a wetland. In addition, there are instances where watercourse and wetland buffers overlap. In these cases, both buffers are displayed on the map. Riparian zone management/classification of multiple, overlapping features will default to the feature with the bigger buffer or reserve zone.

The riparian zones identified along the route are guidelines for protection of riparian values. The Right of Way (ROW) runs along the Dempster Highway and is positioned within the previously cleared area of the Highway. Due to previous disturbance, some of the riparian values are already impacted. For example, trees are rarely present within the riparian zone in the ROW; however, it will be important to eliminate or reduce machine disturbance in areas that are sensitive to degradation and changes in water quality. As such, a multifaceted approach is planned to ensure that riparian values are protected during the conduct of the project.

Streams and Waterbodies

All streams and waterbodies will be protected from machine use by incorporating Reserve Zones around each. Specific management is proposed and detailed below:

- All stream and waterbody Riparian Management and Reserve Zones will be marked in the field as per the widths associated with the classification
- Machine Free Reserve Zones will be established at least 20m from known fish bearing streams or streams with the potential to be fish bearing. These machine free zones will be increased up to the total width of the Riparian Management Zone if the environmental monitors deem necessary. This assessment will be based on the riparian vegetation types and moisture levels. Environmental monitors will be trained by experienced biologists and technologists acting in the capacity of the Project's Qualified Environmental Professionals.

Wetlands

Given the geophysical properties of the regions of the fibre line intersects, there are many wetlands identified along the ROW. While riparian guidance is based on wetland size, it does not account for the sensitivity of the wetland. For example, a wetland with areas of open water is expected to be more sensitive to disturbance than one without open water. As such, it is proposed that wetlands will be treated using the following measures:

- All stream Riparian Management and Machine Free Reserve Zones will be marked in the field as per the widths associated with all classifications.
- Wetlands with open water or areas that would be sensitive to machine operation will be marked as Machine Free Reserve Zones. Machine Free buffers will be established either 5 m or 20 m from open water wetlands, based on their classification. These machine-free zones may be increased if environmental monitors deem it necessary.

6.0 EROSION PREVENTION AND PLANNING

Preventing erosion is the primary strategy of this Erosion and Sediment Control Plan. Moreover, it is often easier and less expensive to control erosion at the source than it is to deal with sediment after it has been mobilized. Activities which greatly increase the risk of erosion, and which require planning include:

- Clearing/grubbing vegetation;
- Handling and moving soil during construction;
- Erecting water diversions;
- Destabilizing slopes;
- Disturbing and melting permafrost;
- Conducting in-stream work; and
- Building temporary roads.

If it is not possible to eliminate erosion at a particular site, ROHL will develop a plan to minimize and manage them using the following principles:

- Installation of the cable in sensitive areas will be timed to avoid the seasonal runoff to minimize the potential for erosion along the Project route. This period of seasonal runoff is typically completed by mid-June. Construction activities will begin following the end of seasonal runoff period until the seasonal freeze-up occurs.
- Time the mobilization and demobilization of equipment and camps to minimize erosion. Avoid mobilization efforts during spring runoff. During the spring and fall when temperature falls below zero at night, ground can be much more stable during the morning than during the heat of the day. If necessary, time moving equipment for when the ground is frozen.
- Visit the site before the work and identify site-specific erosion issues and sediment release problems that may arise based on work-site factors such as:

  - Slope, aspect, and elevation
  - Soil texture and percolation characteristics
  - Areas with little vegetation cover that are likely to erode
  - Local climatic factors (e.g., rain shadows)
  - Proximity to sensitive water and potential for sedimentation

- A Qualified Environmental Professional (QEP) will visit known or suspected problem sites and other sites will be visited by environmental monitors. Environmental monitors are typically two working days ahead of construction. If areas where erosion and sediment control would be required are identified, the information from the environmental monitor will be shared with the site supervisor. The construction crew, with assistance from the environmental monitor and

QEP, will complete mitigation in the identified locations to prevent erosion and sedimentation from occuring. Such mitigation could include avoidance, use of a tool to prevent erosion (mud mats or mulches or soil covers) or sediment control methods such as silt fencing. The environmental monitors will be instructed by a Qualified Environmental Professional on the proper installation techniques for silt fencing.

- Consider the expected type, intensity, and duration of the disturbance, remembering that a small disturbance in a sensitive area or at the wrong time can be just as worrisome as a major disturbance in a resilient area.

7.0 SEDIMENT CONTROLS

In fibre optic cable installation where there is mimimal removal of the protective vegetative layer, typically the only sediment control measures that are used are silt fencing or sandbags.

Silt Fencing:

Silt fences are used to pond sheet flow runoff on mildly sloped areas, thus allowing heavy sediment particles to settle out while water and lighter particles slowly pass through the fence material. When properly designed and installed, silt fences are very effective at removing sediment from runoff.
In addition to creating sediment traps, another common application of silt fencing is for constructing perimeter barriers that prevent loose material from falling into watercourses.

The primary material used to construct silt fencing is geotextile cloth. Geotextile comes in two types: woven and nonwoven. Woven cloth is smooth, whereas nonwoven cloth has a rougher, woolly finish. The two products function differently and have different applications. The woven type is stronger and allows water to seep through but is impervious to sediment. Woven geotextile should be used for silt fencing. Nonwoven geotextile is more porous but tends to clog up quickly with sediment and is not stiff enough to stand upright on a fence and resist water pressure (i.e., it sags and rips). The Silt Fence Product Sheet is included in *Appendix A.*

Monitoring of the installed silt fences will be conducted by environmental monitors who will be trained by Qualified Environmental Professionals on the installation, inspection, and monitoring of silt fencing as an erosion control measure. Silt fences will be inspected at least once a week and after each rainfall. Any necessary repairs will be done when bulges occur or when sediment accumulation reaches 50 per cent of the fabric height. Any areas of collapse, decomposition or ineffectiveness will be immediately replaced. Sediment deposits will be removed as necessary to continue to allow for adequate sediment storage and to reduce pressure on the silt fence. The construction crews and environmental monitors will ensure that the sediment is removed to a secure area. Silt fence materials and sediment deposition will not be removed until the catchment area has been appropriately stabilized. The area of the removed silt fence will also be stabilized.

The design life of a silt fence typically is only around six months or less. Silt fences are frequently installed incorrectly. Successful performance is highly dependent on proper installation.

Installation:

- Place the fence at the bottom of a slope or on a slope bench. Install it at right angles to the slope, following the slope contour.

- The filter cloth should be keyed into the surrounding earth to hold it in place. Otherwise, runoff and sediment will flow beneath the fence. To do this, dig a shallow trench and key the fabric in the ground. Cover the trench and compact the loose soil. Then pound the stakes into the ground.

- Posts should be spaced so that the geotextile cloth does not develop major sags and can support the weight of sediment and water. The cloth should be securely attached to posts on the uphill side, so fasteners are not pulled out by the weight of sediment and water.

- Where a joint in the geotextile is necessary, ensure that there is sufficient overlap.

- Silt fences should not be used in locations with concentrated flow, including streams or other storm water conveyances, as they will not hold up to the flow.

8.0 PROCEDURE SIGNOFF

I have received a copy of all relevant documents related to the **Erosion and Sediment Control Plan** for the **Dempster Fibre Project**. I have received answers to any questions and will complete the activities per the plan and as directed by ROHL.

Name	Signature	Date of Review

APPENDIX A

Silt Fence Product Sheet

EROSION &
SEDIMENT CONTROL

PRODUCT OVERVIEW

Silt Fence

Nilex Silt Fence helps prevent sediment and other contaminants carried in sheet flow from being transported off-site. Silt fence protects streams, rivers, lakes, storm drainage systems, and other water resources from pollution by silt, sediment, and construction debris.

Nilex Silt Fence is designed and manufactured to meet and exceed industry standard sediment control requirements.

Nilex also offers a wire backed silt fence which is constructed of 16 guage wire mesh, covered with a woven geotextile fabric. The wire mesh provides additional support during substantial loads of silt and water

Silt Fence should:

- Be considered as a component of a comprehensive erosion and sediment control best management plan
- Be carefully maintained and inspected
- Be installed on a slope where sheet flow runoff can be stored behind barriers
- Push fabric against the posts
- Not be used in areas of concentrated flow; across streams, ditches, and waterways

Advantages:

- Quick and easy installation
- Fabricated with UV stabilized geotextile and premium wooden stakes
- Custom fabrics and posts available

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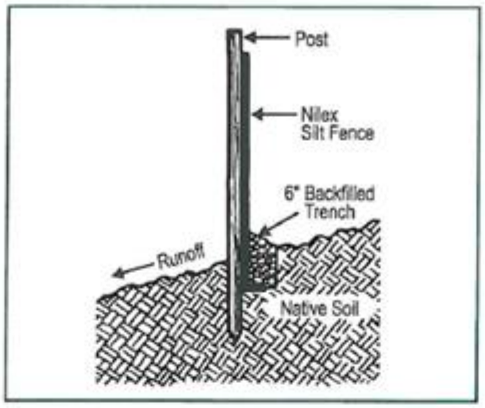
INSTALLATION GUIDELINES

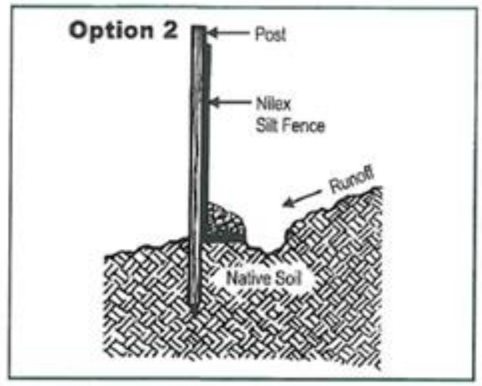
Option 1 (Preferred)



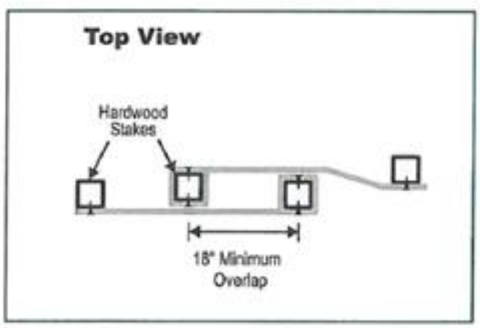
To ensure optimal performance, silt fence is best installed in an excavated 6" x 6" (15 cm x 15 cm) trench. Stakes should be pounded in until the fabric reaches the bottom of the trench.

Always install with the posts facing downhill, so runoff pushes the fabric against the posts, not away from them. The trench should be backfilled by a backhoe or other earth moving equipment.

Option 2



The second option is to pound in the stakes until the fabric is snug on the soil surface. Earth moving equipment should be used to cut and blade at least 6" (15 cm) of fill against the fabric edge. This method of installation is less labour intensive, but may allow water to undercut the silt fence in areas of high runoff.



When installing several lengths of silt fence end to end, overlap the edges of the fabric at least 18" (45 cm).

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APPENDIX B

Government of Northwest Territories Erosion and Sediment Control Manual

GOVERNMENT OF THE NORTHWEST TERRITORIES, DEPARTMENT OF TRANSPORTATION - EROSION AND SEDIMENT CONTROL MANUAL

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VERSION HISTORY

Version No.	Date	Description

PREFACE

This manual provides guidelines for analysis, design, construction, and maintenance of erosion and sediment control systems for transportation construction projects in the Northwest Territories (NWT). This document was developed with the intent that it would provide a convenient and comprehensive resource and a rational basis for the design of erosion and sediment control systems. It is intended primarily for use by design consultants but also provides valuable information for contractors and field personnel. It is intended to assist and provide direction in the analysis and design of erosion and sediment control structures, but is not intended to preclude innovative or alternative designs.

This manual was adapted for use in the NWT from the Alberta Ministry of Transportation's Erosion and Sediment Control Manual (Alberta Transportation 2011). The intent is for the manual to reflect the climatic and biophysical conditions that influence the processes of erosion and sedimentation in the NWT, in order to design and implement erosion and sediment control in a way that reflects conditions in the territory.

Continuing comment is essential to the regular updating of this document and feedback is welcome. Periodic updates and revisions will be undertaken in response to user feedback, changes in technology, regulatory requirements and many other factors. The most current version of this document will be posted on the Government of the Northwest Territories Department of Transportation (GNWT-DOT) website (www.gov.nt.ca). Inquiries, suggestions for revisions or additions, and comments may be sent to the Planning, Policy and Environment Division, Government of the Northwest Territories, Transportation, PPE, P.O. Box 1320, Yellowknife, NT X1A 2I9.

GNWT-DOT thanks all those who have contributed to the development of this document. Special thanks are expressed to Alberta Transportation and Don Snider, Manager of Transportation Projects and Environmental Services, in particular, who agreed to provide the Alberta ESC manual to the GNWT to form the basis of the current volume. GNWT-DOT also extends its gratitude to the Department of Fisheries and Oceans for its willingness to review and comment on this document during development. The manual was adapted for the GNWT-DOT by Summit Environmental Consultants Inc. of Yellowknife, NT.

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1.0 INTRODUCTION

1.1 Background

Erosion and sedimentation are naturally occurring processes of loosening and transporting soil through the action of wind, water, or ice, and the subsequent transport and deposition of sediment particles. Construction activities can result in increased erosion and sedimentation where soil surfaces are exposed to rainfall and runoff. If uncontrolled, these processes may result in adverse effects on the environment. This includes loss of soil productivity, degradation of surface water quality, damage to adjacent land, and degradation of aquatic habitat. Erosion and sediment control techniques are activities or practices, or a combination of practices, which are designed to:

- Protect an exposed soil surface;
- Prevent or reduce the release of sediment to environmentally sensitive areas;
- Minimize impacts to permafrost; and
- Promote revegetation establishment.

The purpose of this document is to develop a set of guidelines and standard procedures to minimize erosion and sediment transport in transportation construction activities in the Northwest Territories (NWT). The document focuses on minimizing potential impacts to environmentally sensitive areas.

Erosion and Sediment Control (ESC) combines two terms: erosion control, and sediment control. In this document, the term **erosion control** means the prevention of erosion, while **sediment control** refers to preventing or minimizing the transport of eroded sediment away from the construction site.

1.2 Objectives

The objectives of this document are to:

- Outline the regulatory requirements related to ESC in NWT;
- Clarify the roles and responsibilities of the owner [Government of the Northwest Territories – Department of Transportation (GNWT-DOT)], their consultants, and contractors;
- Provide guidelines and standard procedures for selecting, designing and implementing ESC measures for transportation construction and maintenance;
- Provide details of ESC measures commonly required on the NWT construction sites as well as their applications and limitations; and
- Provide a means for the GNWT-DOT to educate consultants and contractors in proper ESC procedures.

1.3 Document Disclaimer

This document is intended for use in the design, construction and maintenance of ESC measures for terrestrial (land-based) infrastructure. The information, guidelines and reference material presented in this document are intended to complement the experience and judgement of the individual or firm responsible for preparing an ESC Plan.

A Field Guide titled "Erosion and Sediment Control Field Guide" has been prepared as a companion to this document. The field guide contains information derived from the ESC Manual for use by field personnel, and includes the following:

- Introduction,
- Objectives
- Regulatory Requirements
- Erosion and Sediment Control Process
- Inspection and Maintenance
- Tables, BMPs, and Inspection Form, and
- Best Management Practices (BMPs) details.

ESC measures for in-stream (water-based) works are provided in this document. This includes works near streams and lakes. In addition to this document, Fisheries and Oceans Canada (DFO) has published a series of Operational Statements guiding in-stream works in the NWT. The Operational Statements and the ESC Manual should be used together when planning and designing work in and near streams, lakes and wetlands.

It is the responsibility of project owners, consultants, and contractors to ensure that they have the appropriate environmental authorizations and regulatory approvals in place for all upland and in-stream works. It is likewise their responsibility to carry out construction works with due diligence and using appropriate procedures to protect the environment.

1.4 Selected Key Terms and Acronyms

There are a number of terms and acronyms from ESC practices that are used throughout this manual. They are defined here to assist the reader.

Active layer	The layer of soil or rock underlain by permafrost that thaws in summer.
BMP	Best Management Practices.
Erosivity	The potential ability of rain to cause erosion. It is a function of the physical characteristics of rainfall including rainfall intensity and duration.
Erodibility	The vulnerability or susceptibility of the soil to erosion. It is a function of both a soil's physical characteristics and the management of the soil.
Ground ice	Ice formed in freezing and frozen ground. It occurs in pores, voids, and other openings in soils and rocks.
Permafrost	Ground that is perennially (all year) frozen.
RUSLE	Revised Universal Soil Loss Equation. An equation used to predict annual soil loss. RUSLE gets employed in ESC planning to assess erosion risk and compare control options.

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2.0 REGULATORY REQUIREMENTS

There are several federal and territorial Acts and Regulations in force that direct construction, maintenance, and closure activities undertaken by or on behalf of the Department of Transportation. These Acts and Regulations contain legal measures designed to mitigate adverse environmental effects associated with various works or undertakings. Of particular relevance to the ESC Manual are those measures intended to limit erosion and/or sedimentation as a result of transportation construction activities.

Most legislation and other types of regulatory instruments make reference to preventing the release of harmful or deleterious substances, including sediment, to the environment. A summary of the Acts and Regulations guiding responsible development and environmental protection in the Northwest Territories is provided below in Sections 2.1, 2.2 and 2.3.

2.1 Federal Legislation

2.1.1 Navigable Waters Protection Act

The *Navigable Waters Protection Act* (NWPA) protects the public right of navigation by regulating works over waterways such as bridges, dams and docks to minimize the overall impact on navigation. NWPA applies to in-stream work involving construction or placement in, on, over, under, through, or across navigable water. The original definition of “navigable water" captured any body of water capable of accommodating any type of floating vessel for transportation, recreation or commercial purpose. The body of water can be navigable periodically, historically, or by facilitating public access.

In 2009, NWPA was amended, in part to narrow the class of works to which it applies. The amendments also granted the Minister of Transportation and Cabinet more power to exempt classes of works and waterways, while increasing the level of inspection and enforcement of the Act.

The Government of Canada is currently (2012) proposing further amendments to the NWPA. The bill is still before Parliament at the time of this report, so a summary of the changes is not possible at this time. It appears likely that the new legislation will change the definition of water bodies that are protected under the Act. However, it is likely that major structures (e.g. bridges, outfalls) will require authorization under the Act.

Subsection 22 of the NWPA contains prohibitions related to the deposition of organic and non-organic materials (e.g., sediment or rubbish) into navigable waters.

2.1.2 Fisheries Act

The Federal *Fisheries Act* is intended to protect fish and fish habitat. The *Fisheries Act* is the most comprehensive piece of environmental legislation in Canada and comes with serious penalties for violators, including substantial fines and/or imprisonment. Subsection 36 (3) of the Act is of most relevance to this manual. This states that no one shall deposit or permit the deposit of a **deleterious substance** of any type in water frequented by fish or in any place under any conditions where the deleterious substance may enter water. Sediment eroded from a construction or development site is considered a deleterious substance under the Act. Under subsection 38 (5) anyone who owns, manages or controls a deleterious substance has a duty to report any deposit out of the normal course of events to a Fishery Inspector or regulatory authority. Under subsection 38(6) these people are also responsible to counteract, mitigate, and as soon as possible, remedy any adverse effects that results or may result from the occurrence. Environment Canada is responsible for the administration and enforcement of the pollution prevention provisions of the *Fisheries Act*. The Department of Fisheries and Oceans Canada (DFO) is responsible for the administration and enforcement of the remaining portions of the *Fisheries Act*.

Transportation construction activities must also take into consideration the protection of fish habitat and sensitive environmental areas. Subsection 35 (1) of the Act prohibits the carrying on of any work or undertaking that results in the **serious harm to fish that are part of a commercial, recreational or Aboriginal fishery, or to fish that support such a fishery,** unless authorized by the Minister [Note: This subsection used to prohibit any harmful alteration, disruption or destruction of fish or fish habitat (HADD), but was revised in 2012 to its current reading].

The removal of fish habitat from the clause may indicate less control over activities in or around water. However, under subsection 38(4), developers or responsible agents are still responsible for notifying authorities about unauthorized harmful alterations, disruptions or destructions of fish habitat. As with deleterious substance deposits, subsection 38 (6) also requires responsible agents to prevent the occurrence or to counteract, mitigate or remedy any adverse effects that result from the occurrence or might reasonably be expected to result from it. Practically speaking, people undertaking transportation construction activities are still responsible for preventing harm to fish habitat and for addressing adverse environmental effects.

Changes to the *Fisheries Act* in 2012 have cast some confusion over what responsible measures one must take when working around water. In the Northwest Territories the changes will need to be considered with respect to the Aboriginal Treaty and Land Claims that cover the entire territory. With fishing a recognized traditional activity amongst Aboriginal beneficiaries, harm to any fish could trigger subsection 35 (1). The harm of non-commercial or non-sport/harvest fish could also violate the modified Act as these ‘other’ fish constitute an important part of the diet for more economically viable fish.

Additional sections of the *Fisheries Act* relevant to transportation construction activities include that the maintenance of fishways; keeping fish passages free; and maintaining sufficient water flow in watercourses.

The condition (Subsection 30) to have an appropriately sized fish screen for all water intakes was repealed in the 2012 changes to the Act. Also repealed was subsection 32, preventing the unauthorized killing of fish by means other than fishing.

2.1.3 Canada National Parks Act

The *National Parks Act* designates and maintains national parks and national park reserves in Canada. The Act guides management decisions in Canada’s National Parks relating to capital re-development of facilities, accommodation and infrastructure. Proposed activities in National Parks must commit to high standards of ecological integrity and be authorized by Parks Canada.

Highway Number 5, the Fort Smith Highway, travels through Wood Buffalo National Park in the Northwest Territories. New road works or renewal of existing licenses or permits along the Park section of Highway 5 will require the authorization of Parks Canada.

2.2 Territorial Legislation

2.2.1 Mackenzie Valley Resource Management Act

The *Mackenzie Valley Resource Management Act* (MVRMA) came into effect in 1998. It governs land and water use in throughout the Northwest Territories. The Inuvialuit Settlement Region (ISR) and Wood Buffalo National Park are excluded from the MVRMA. Other Acts and Regulations, described below, regulate land and water use in the ISR. The Canada National Parks Act guides activities in Wood Buffalo National Park.

The MVRMA establishes public boards to regulate the use of land and water, to prepare regional land use plans to guide development, and to carry out environmental assessment and reviews of proposed projects in the Mackenzie Valley. The Act also makes provisions for monitoring cumulative impacts on the environment, and for periodic, independent environmental audits.

As institutions of public government, the land and water boards regulate all uses of land and water while considering the economic, social and cultural well-being of residents and communities in the Mackenzie Valley.

Through the MVRMA, an integrated co-management structure was created for public and private lands and waters throughout the Mackenzie Valley. Part IV of the Act came into effect in 2000, establishing the Mackenzie Valley Land and Water Board (MVLWB). The MVLWB screens projects for their social and environmental affect and issues water licences and land use permits accordingly.

2.2.2 Mackenzie Valley Land Use Regulations

Section 90 of the *Mackenzie Valley Resource Management Act* established the *Mackenzie Valley Land Use Regulations* (MVLUR). The MVLUR facilitates use of land in the Mackenzie Valley by setting the conditions for land use permits. There are three types of permits under the Regulations: “Type A”, “Type B”, and “Type C”. “Type A” permits are reserved for projects with a greater perceived environmental risk and resource demand. “Type B” permits encompass projects with a lower perceived risk and resource demand. “Type C” permits are reserved for activities occurring on T’licho Government lands for which neither a Type ‘A’ nor ‘B’ permit is required (MVLWB, 2012).

The following activities may require a land use permit:

- Use of explosives
- Use of vehicles
- Drilling
- Hydraulic prospecting
- Earth moving and clearing
- Campsites
- Fuel caches
- Preparation of lines, trails or rights-of-way

The Department of Aboriginal Affairs and Northern Development Canada is responsible for inspecting and enforcing land use permits issued in the NWT.

2.2.3 Northwest Territories Waters Act

The *Northwest Territories Waters Act* (NWTWA) was established in 1992 to regulate the use and disposal of water in special management areas in the NWT that fall **outside of the Mackenzie Valley**. Effectively, the NWTWA governs the use of water in the Inuvialuit Settlement Region (ISR). The NWTWA can also be used to manage trans-boundary waterways: water bodies that flow into or out of the NWT and a neighboring province or territory.

Section 10 of the NWTWA established the NWT Water Board. This Board is tasked with optimizing the conservation, development and utilization of waters for Canadians and NWT residents living within its management areas. The Board accomplishes this by screening development proposals and issuing Type “A” or Type “B” water licences.

2.2.4 Northwest Territories Water Regulations

The *Northwest Territories Water Regulations* (NWTWR) guides the use, disposal, and licensing of water in the Inuvialuit Settlement Region (ISR) of the NWT. Water licences are administered by the NWT Water Board. Water licences include terms and conditions to prevent an adverse impact on waters within a prescribed water management area (AANDC, 2009). The NWTWR are more technical in nature, and provide guidance to NWT Land and Water Boards on when to issue a Type “A” versus a Type “B” water licence.

2.2.5 Type A and Type B Water Licences

Water licences are issued by Land and Water Boards in the Mackenzie Valley, and by the NWT Water Board in the ISR and in special management areas. Some of the activities that require a Water Licence are (MVLWB, 2012):

- 100 m^3 or more of direct water use per day;
- A municipality or camp that uses more than 50 m^3 of water per day;
- Construction of a structure across a water course five or more metres wide at ordinary high water mark;
- Channel and bank alterations, erosion control, diversion of water, alteration of flow or storage of water (dam or storage reservoir);
- Draining or infilling of a water course;
- Any deposit of waste (solid waste, sewage, oil drilling etc.); and
- Industrial or mining and milling activities that use more than 100 m3 of water per day.

Similar to Land Use Permits, Type “A” water licences are required for activities of broad scope, having significant potential for adversely affecting human health or the environment, and/or requiring substantial volumes of water. Type “B” water licences are required for activities of generally limited scope, having less potential for adversely affecting human health or the environment (AANDC, 2009). All development projects that require licences undergo preliminary screenings by the responsible regulatory board. The screening determines if the project must proceed to an environmental assessment (see Section 2.2.1) or go directly into the regulatory phase, which includes a detailed review of the water licence application.

The NWTWA and NWTWR form part of the legal and administrative framework that was established for managing land and water use under the MVRMA (AANDC, 2009). As with the NWTWB, the Minister of AANDC is responsible for approving all Type “A” water licences. Inspectors employed by AANDC are responsible for enforcing the provisions of the NWTWA, NWTWR, and MVRMA (*ibid)*.

2.2.6 Environmental Protection Act

The *Environmental Protection Act* (EPA) was established in 1988 and promotes responsible environmental stewardship in the NWT. The EPA gives the NWT Minister of the Environment and Natural Resources the authority to research knowledge gaps and establish boards, committees, or other bodies to provide advice relating to the preservation, protection or enhancement of the environment. The Minister can also appoint a Chief Environmental Protection Officer for the NWT. The EPA empowers the Chief Environmental Protection Officer (CEPO) to uphold the Act, including authorizing certified members of the Royal Canadian Mounted Police and certified wildlife officers identified under subsection 76(1) of the *Wildlife Act* to be inspectors tasked with upholding the Act.

The EPA makes it an offence to discharge contaminants into the environment that endangers the health of animal life or is likely to cause damage to plant life or property. Sediment eroded from a construction site may be considered a “contaminant”. Officers have the authority to direct persons to put in safeguards to avoid contamination, to cease operations and to repair damage to the environment caused by the contamination. Persons have a duty to report all contaminations and are required to take all reasonable measures to stop and/or contain the contamination.

The EPA also empowers the Minister to appoint a Controller with the authority to issue and revoke permits and licences under this Act. The EPA also establishes the penalties, and identifies the right to reclaim costs and expenses associated with contaminations.

2.3 Due Diligence

Most environmental legislation provides for "due diligence" as a defence to the majority of environmental offences. GNWT-DOT is working to meet its due diligence obligations with respect to erosion and sediment control by taking the following steps:

- Publication of this document for implementation in the transportation construction industry by in-house forces, contractors and consultants;
- Publication of a plain language field manual for workers involved in GNWT-DOT transportation construction activities;
- Increasing awareness of the adverse effects of erosion and sedimentation, regulatory requirements, and penalties for contravention; and
- Requiring the proper use of best management practices for erosion and sediment control for the transportation construction industry through contracts and regulatory terms and conditions.

3.0 EROSION AND SEDIMENT CONTROL MANAGEMENT STRATEGY

3.1 Government of the Northwest Territories – Department of Transportation (GNWT-DOT) Requirements

Erosion and Sediment Control Plans should be prepared by qualified firms or individuals for all GNWT-DOT transportation construction projects. Submitted plans and construction works must comply with the specifications set out in this manual. Construction monitoring is provided as part of the work. Interim audits shall be conducted by the qualified person of record for the construction project or GNWT-DOT.

Parties undertaking phases of works or entire projects for the GNWT-DOT are required to fulfil various requirements concerning environmental protection. Responsibilities pertaining to erosion and sediment control measures form an important part of these requirements. Within the project planning phase, the development of an effective ESC plan is a requirement for GNWT-DOT project managers and contractors, as outlined below.

3.1.1 Design Engineer/Technician Responsibility – Permanent Erosion and Sediment Control (PESC) Plans (Design Phase)

Construction projects should have three levels of development for ESC including: the planning strategies and procedures and the two levels of ESC plans: temporary (construction) and permanent (post-construction).

Planning Strategies and Procedures (Table C-5) in Appendix C are often called minimum requirements which are non-structural methods or procedures that can reduce erosion and sediment transport. Proper planning generally constitutes the minimum requirement for preparing an ESC strategy. The minimum requirements for planning strategies and procedures for an erosion and sediment control plans are presented in Table 7.1.

A **permanent erosion and sediment control** (PESC) plan must be established to minimize erosion and sedimentation once a project is operational. The designer is required to prepare a Permanent Erosion and Sediment Control Plan (PESC Plan) for the project as part of the detailed planning and design phase of a project. The requirements for the PESC are detailed in Section 9.0.

To ensure that erosion is controlled during construction, the PESC is provided to the contractor to guide them in designing the **temporary erosion and sediment control plan** (TESC) plan. The TESC plan becomes part of the Environmental Management Plan (EMP) implemented during construction.

The TESC plan would apply during construction operations, and provide appropriate mitigations when soils are typically exposed to the elements and newly disturbed areas. It is called “temporary” because it focuses on preventing erosion and sediment processes for a short period of time.

During the execution of the contract, the contractor, as the party having ‘care and control’ of the site, will be responsible for environmental protection and minimization of potential environmental hazards resulting from construction activities. The contractor is required to develop and implement an EMP detailing environmental protection measures. The EMP includes an ESC Plan as a core element.

Both the EMP and PESC Plan must be completed by individuals or firms with appropriate training and experience in both construction and ESC practices. Ideal training and designations for the PESC Plan reviewer include:

- Registered Professional Engineer or Geoscientist with appropriate expertise and licenced to practice in the NWT;
- Certified Professional in Erosion and Sediment Control (CPESC); and/or
- Registered Professional Agrologist with expertise in soil and water conservation.

3.2 Overview of Preparation of Erosion and Sediment Control Plans

The process of preparing an erosion and sediment control strategy as well as maintaining and revising the measures contained therein is presented in Figure 3.1. The figure outlines general steps involved in preparing permanent and temporary erosion and sediment control plans for each phase of a transportation construction project.

Design Phase (Pre-construction)

Permanent Erosion & Sediment Control Plan

May Include:
- Soils information
- Environmental and hydrotechnical information
- Identification of erosion and sediment control issues
- Design of permanent erosion and sediment control measures

⇩

Tender Phase

Contract Specifications & Special Provisions may include:
- Specific requirements related to Erosion & Sediment Control

⇩

Construction Phase

Contract Awarded

⇩

EMP Prepared by Contractor
(including the TESC Plan)
Based on:
- Contract Specifications & Special Provisions
- Environmental Management Plan (EMP) Framework
- Erosion and Sediment Control Manual
- Permanent Erosion & Sediment Control Plan
- Design information
- Contractor experience
- Proper construction planning - Scheduling

⇩

Implementation and Maintenance of Measures Contained in EMP

- Update EMP to include information obtained during construction
- Maintain records for interim audits
- Ensure implemented measures result in compliance with environmental regulations

⇩

Implementation of Measures Contained in Permanent Erosion and Sediment Control Plan

- Designer to update permanent measures to include information obtained during construction
- Contractor to implement permanent measures as part of construction as early as possible

⇩

Post-Construction Phase

Post-Construction Monitoring

- GNWT-DOT and maintenance contractor(s) to verify permanent measures implemented result in compliance with environmental regulations

Figure 3.1: GNWT-DOT Management Strategy for Erosion and Sediment Control on Transportation Construction Projects

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4.0 EROSION AND SEDIMENTATION PROCESS

4.1 Mechanics of Erosion

Erosion is the displacement of surface soil by naturally occurring processes that cause the detachment (entrainment) and transport of soil materials from one location to another. The natural processes (e.g., rain, flowing water, wind, and frost) responsible for erosion can be considerably accelerated through human activities.

Water is the predominant agent of erosion on transportation construction sites and on operational infrastructure sites. Wind erosion is not a major contributing factor to erosion on most transportation projects because of the localized nature of the exposed areas and relatively short construction time periods. Thus, methods of controlling water erosion are the principal focus of this manual. However, effective erosion control measures will mitigate both water and wind forces.

The prevention of erosion is critical to the success of the overall ESC Plan. Undisturbed or un-displaced soils behave predictably, are stable, and represent no environmental risk. Once sediment becomes displaced, controlling it becomes very difficult, imprecise and costly. Sediment suspended in flowing water, for example, is difficult to remove. For this reason, the need for prevention through erosion controls cannot be over emphasized. In many cases though, soil disturbance is unavoidable. Thus sediment controls are installed on a construction site to promote sedimentation before being carried off-site.

Sedimentation is the deposition of soil particles by moving water. Sedimentation occurs at locations where the velocity of the water slows down or stops. As the water slows down, energy is taken out of the water, allowing the sediment to settle and come out of suspension. The larger particles such as gravel and sand settle out first. As the flow velocity reduces further, the smaller particles such as fine sand and silt settle, eventually leaving only the clay sized particles as the last to be deposited. In general, the silt and clay particles only settle out in still water bodies likes ponds, lakes, and wetlands; or in treatment facilities such as storm water or sediment control ponds.

Sediment fencing installed across a long slope, slows the water and allows sediment to deposit. Commonly used sediment fencing, with woven material, will filter larger particle sizes such as sand and gravel. Silts and clays are fine enough to pass through the small holes in the woven fabric of this type of fencing. Where the removal of fine silts and clays are required, settling ponds may be necessary to allow water to be still or near still for a period of time.

Two common units are employed when measuring the presence of suspended solids in water: Total Suspended Solids (TSS) and turbidity. TSS is the mass of suspended solids per volume of water (standard units: mg/L). Turbidity is an indication of the ability of light to pass through the water, measured in Nephelometric Turbidity Units (NTU). Turbidity can be measured in the field with portable instruments, while TSS must be analyzed in a lab. TSS and turbidity are correlated but the relationship tends to be site specific. For example, if the suspended material includes fine organic material, analysis can indicate low TSS concentrations but relatively high turbidity. Elevated TSS and turbidity can both have detrimental effects on an aquatic environment. Smothering fish eggs or aquatic plants, gill abrasion, increasing risk of predation, reducing oxygen, or blocking light are some of the adverse aquatic environmental effects posed by fine sediments.

Clay particles will only settle out after extended periods of time (days to weeks) due to their fine particle size. As a result, settling by gravity alone is often ineffective or impractical for clay size particles. Again, this points to the importance of preventing the erosion of fine-grained soils in the first place.

4.2 Types of Water Erosion

There are generally four types of erosion that result from water which are illustrated in Figure 4.1.

1. **Raindrop (Splash) Erosion:** Movement of soil particles caused by the direct impact of raindrops on unprotected exposed soil surfaces.
2. **Sheet Erosion:** Movement of soil particles by runoff flowing over the ground surface as a broad thin sheet layer. Erosion is caused by shear stresses associated with water flow.
3. **Rill and Gully Erosion**: Movement of soil particles due to a concentration of runoff in depressions (rills) in the ground surface. Erosion potential in this situation is greater than with sheet flow due to the greater velocity and depth of flow. Further increases in the velocity and depth of flow will escalate the erosion potential which may gradually enlarge the rills into gullies. Conventionally, rills are defined as small channels on a hill slope that are 75 mm or less in depth. Once the depth exceeds 75 mm, then the eroded channels are referred to as gullies (Fifield 2001).
4. **Stream and Channel Erosion:** Movement of soil particles on the bed and banks of streams and channels due to concentration of runoff. Scouring, another facet of channel erosion, occurs along channels where eddies form as a result of sudden expansion, contraction or change in flow direction. Scouring may lead to rapid soil loss from the channel bed or side slopes.

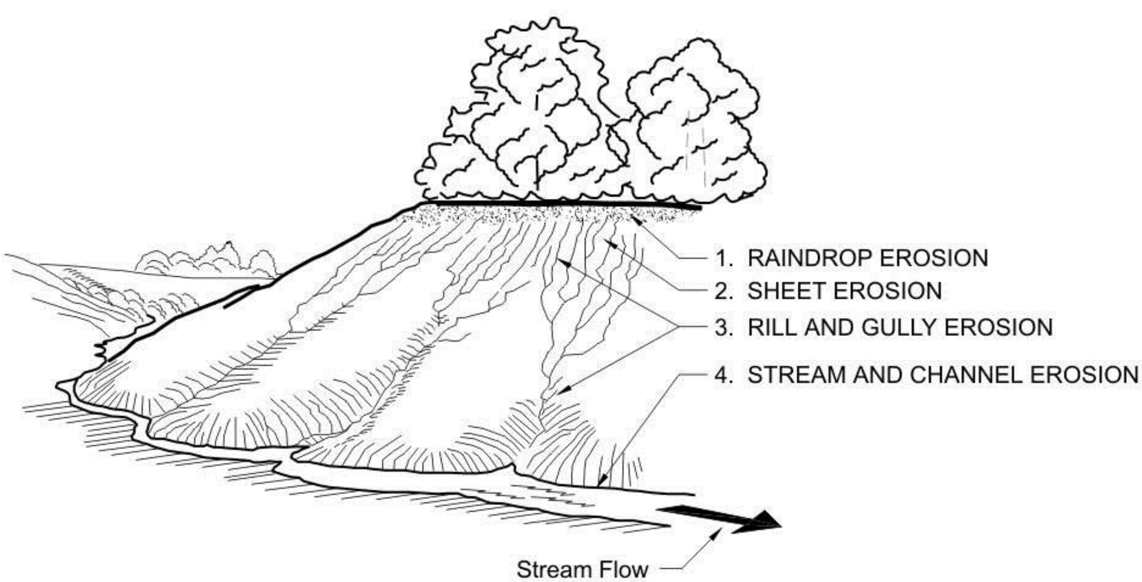


Figure 4.1: Types of Water Erosion

Erosion potential is reduced by minimizing rainfall impact and by reducing the velocity and depth of surface water flow. The erosion potential increases with increasing flow velocity and depth.

4.3 Factors Affecting Erosion

4.3.1 General

Erosion occurs as a result of a number of interacting factors and processes. Four broad factors that affect erosion are as follows:

- Climate;
- Soil characteristics including texture (particle size), structure, and organic matter content
- Vegetative cover; and
- Topography (slope angle, length, aspect and shape).

Each of these factors is described in the following sections.

4.3.2 Climate

The erosive potential of rainfall depends on the intensity (amount per unit of time) and duration of the rainfall event. In general, erosion risk is highest from intense but short duration storms. However, extended periods of less intense rainfall can also create significant erosion because saturated soils have lower strength to resist erosion.

The climate of a location affects the amount and type (rain, snow) of precipitation, the duration of frozen conditions, the length of the growing season, and other factors that affect plant growth and hence the vegetative cover. The climate may have a long term effect on topography, especially in reference to the growth and persistence of permafrost. The climate also affects soil characteristics, where cooler climates have thinner topsoil and deeper weathering.

Climate data are available through Environment Canada, Agriculture Canada, territorial environment agencies, and local communities. Environment Canada is the agency that produces Intensity-Duration-Frequency (IDF) curves from precipitation data[1]. IDF curves are the key climate data tools for ESC planning, especially for the design of sedimentation structures.

The regional climate varies across the NWT. As such, the intensity and duration of precipitation events varies from location to location, as does the erosion hazard.

Rainfall data can be used as a general guideline when considered with other site specific factors such as soil texture and slope gradient and slope length. Table 4.1 provides annual rainfall, snowfall, days with temperature >0°C, and rainfall intensity data for NWT climate stations where there are IDF curves. The rainfall intensity data are given for the 2-year and 25-year return interval one-hour and six-hour storms. Although these numbers provide an indication of the spatial variation in rainfall erosivity, care should be taken in extrapolating between sites. Values from sites in Alberta and Saskatchewan are included in Table 4.1 for comparison.

[1] See http://www.climate.weatheroffice.gc.ca/prods_servs/index_e.html

Station*	**Region**	**Normal** Annual Rainfall (mm)**	**Normal Annual Snowfall (cm)**	**Normal Days with Minimum Temp. >0°C**	**2-year Return Interval Intensity (mm/hr.)**		**25-year Return Interval Intensity (mm/hr.)**	
					1 hour	6 hours	1 hour	6 hours
Yellowknife	Mackenzie Slave Lowlands, Taiga Plains	165	152	143	9.5	3.0	21	6.8
Fort Reliance	Low Subarctic; Taiga Shield	172	147	133	7.2	2.3	17	4.5
Fort Simpson	Mackenzie Slave Lowlands, Taiga Plains	224	170	140	11	3.6	27	7.4
Hay River	Mackenzie Slave Lowlands, Taiga Plains	203	125	144	9.2	3.1	21	6.4
Inuvik	High Subarctic Taiga Plains	117	168	107	5.6	1.9	12	4.1
Norman Wells	Great Bear Plains, Low Subarctic Taiga Plains	166	153	133	7.9	2.7	18	5.4
Tungsten	Cordillera	214	261	n/a	6.9	2.3	11	3.6
Comparison to sites in central and northern Alberta and Saskatchewan								
Fort Chipewyan		252	145	144	12	3.6	27	6.9
Edmonton		375	121	162	16	4.5	30	7.8
Saskatoon		265	97	166	16	n/a	46	n/a

* All sites located at airport
** Normal is the 1971-2000 average, except Tungsten (1961-1990)

Source: Environment Canada (2012)

Table 4.1: Precipitation and Rainfall Intensity Data for Selected Sites in the NWT

4.3.3 Soil Characteristics

Soil characteristics that primarily affect soil erodibility are as follows:

- Particle size distribution (soil texture);
- Soil structure (i.e., how well soil particles are held together)
- Permeability;
- Frozen or unfrozen condition;
- Presence of ground ice in areas with continuous or discontinuous permafrost; and
- Fibrous organic matter content (structure).

A classification of soil erodibility in relationship to soil texture is presented in Figure 4.2. In general, soils containing high proportions of silt and very fine sand are usually the most easily eroded. Soils containing high proportions of clay are usually the least erodible.

In order to use Figure 4.2 to determine erodibility, estimate the amount of sand and clay within the soil sample by hand testing (Figure 4.3) or use laboratory soil texture results. Using the soil texture triangle, locate the percent of clay and sand contained within the sample. Follow the lines until they intersect to locate the soil texture class in the triangle (e.g. 30% sand on horizontal axis, 50% clay on vertical axis is a clay). Once the soil texture class is identified, locate it on the Erodibility Chart to determine the estimated erodibility of the soil (e.g. the erodibility rating for clay is Low). The erodibility factor for clay loam is medium. The large numerals on the texture nomograph are soil texture groups (outlined by the thicker lines on the soil texture triangle), and are not used in the soil erodibility method.

Once eroded, clays are readily transported over potentially long distances in flowing water, even if the velocity is slow. Coarse textured soils (sands and gravelly sands) with little silt content are the least erodible soils.

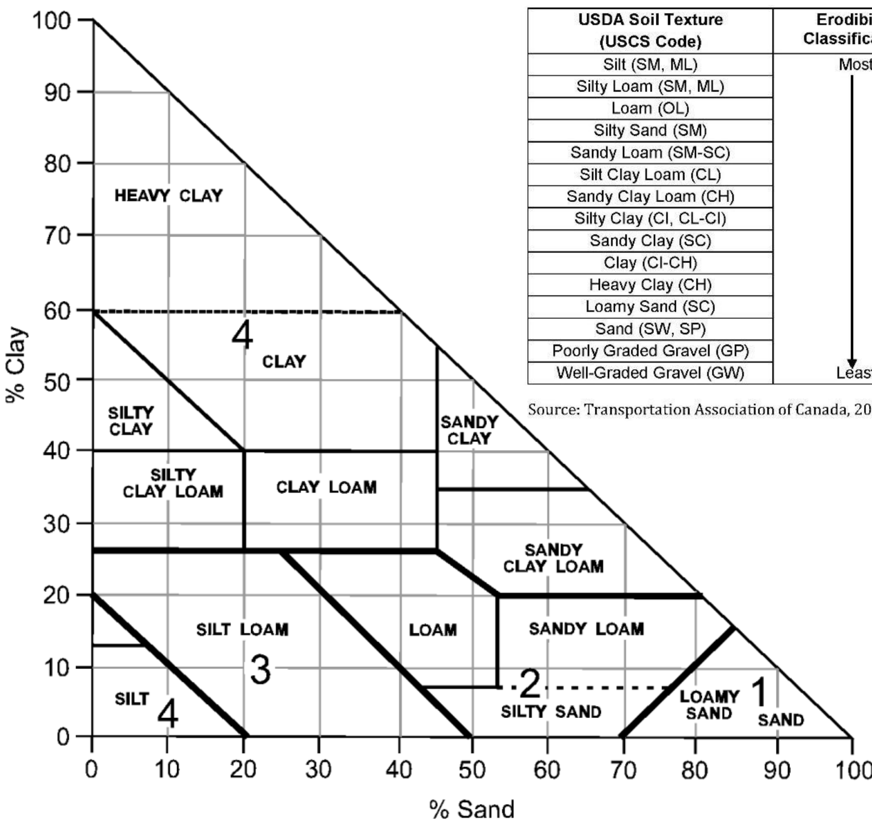
The ability of a soil to absorb rainfall or surface runoff is best characterized by its permeability, which influences the ability of water to infiltrate into the ground. The potential for erosion is smaller in soils that readily absorb rainfall or surface runoff, as this decreases the volume of water available to cause sheet, rill and gully erosion.

A general relationship between soil type and the runoff generated by precipitation is presented in Figure 4.4. This graph indicates the amount of runoff that can be expected for each general soil type in relation to the amount of precipitation during a specific event. This graph provides the user with a quick visual reference as to what they may expect for runoff on their site area.

In general, the presence of topsoil (i.e., the relatively high organic matter upper horizon of a soil) reduces erosion compared to subsoil with similar texture. This observed behaviour is mainly due to the permeability and fibrous nature of the organic material in the topsoil. An organic rich soil placed in an unsaturated condition generally has the ability to absorb a significant amount of water. Furthermore, the various rootlets and fibres present in topsoil act as reinforcement that minimizes the effect of raindrop, sheet or rill and gully erosion.

The presence of permafrost influences soil erodibility. Although a frozen soil is resistant to erosion, infiltration is restricted leading to increased runoff which can affect down-gradient non-frozen soils. Exposure of a frozen soil (e.g., in a road cut) can lead to permafrost melt, soil saturation, and increased erosion potential if rainfall or runoff occurs. Additional information on permafrost and erosion is provided in Section 6.2.

Examples of soil data for typical NWT soil types are presented in Appendix A to illustrate typical textural and organic matter characteristics. This information is included for the purpose of illustrating the variety of soils that could be encountered on the NWT construction sites. It is not intended as a comprehensive list of soil types, nor should it be used to replace or supplement soil testing data for a specific construction sited.



USDA Soil Texture (USCS Code)	Erodibility Classification	Soil Erodibility Rating
Silt (SM, ML)	Most	High
Silty Loam (SM, ML)		High
Loam (OL)		High
Silty Sand (SM)		High
Sandy Loam (SM-SC)		Medium
Silt Clay Loam (CL)		Medium
Sandy Clay Loam (CH)		Medium
Silty Clay (CI, CL-CI)		Medium
Sandy Clay (SC)		Low
Clay (CI-CH)		Low
Heavy Clay (CH)		Low
Loamy Sand (SC)		Low
Sand (SW, SP)		Low
Poorly Graded Gravel (GP)		Low
Well-Graded Gravel (GW)	Least	Low

Source: Transportation Association of Canada, 2005

Figure 4.2: Soil Texture Nomograph and Erodibility Rating

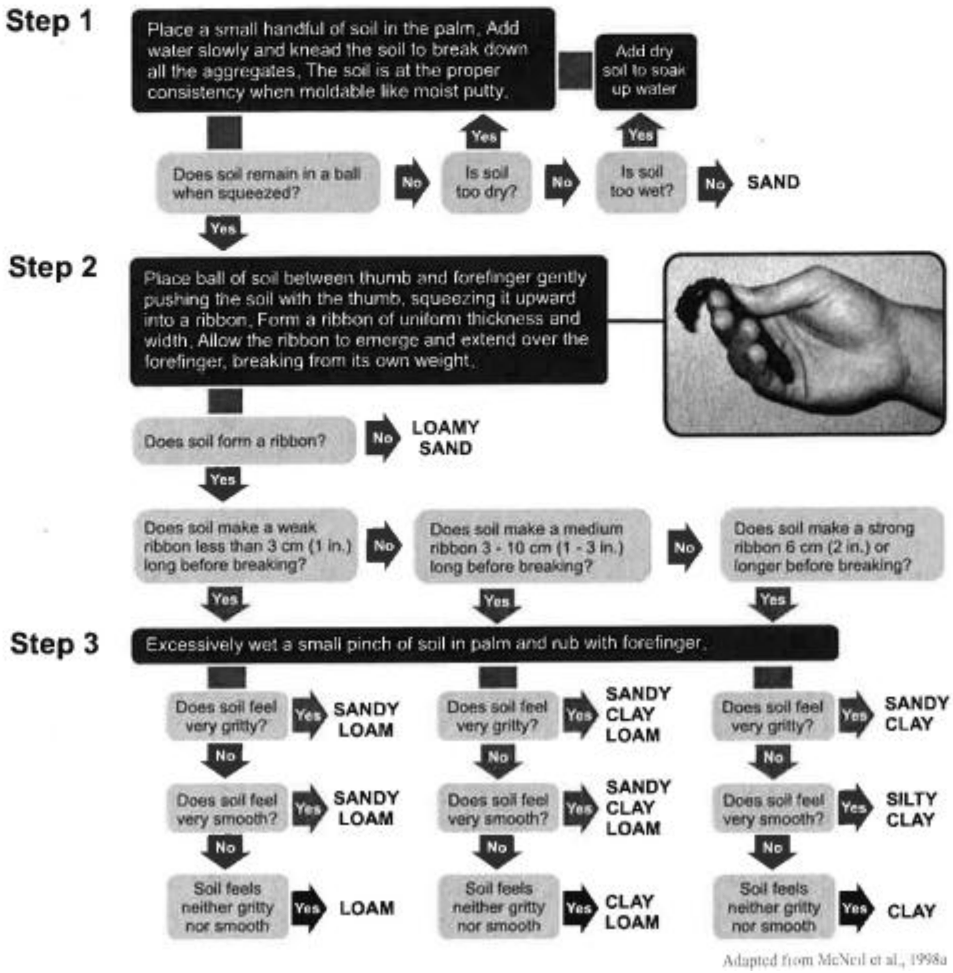


Figure 4.3: Manual Method for Determining Soil Texture[2]

[2] Alberta Agriculture: Nutrient Management Planning Guide, Figure 3.1.5 (Undated)

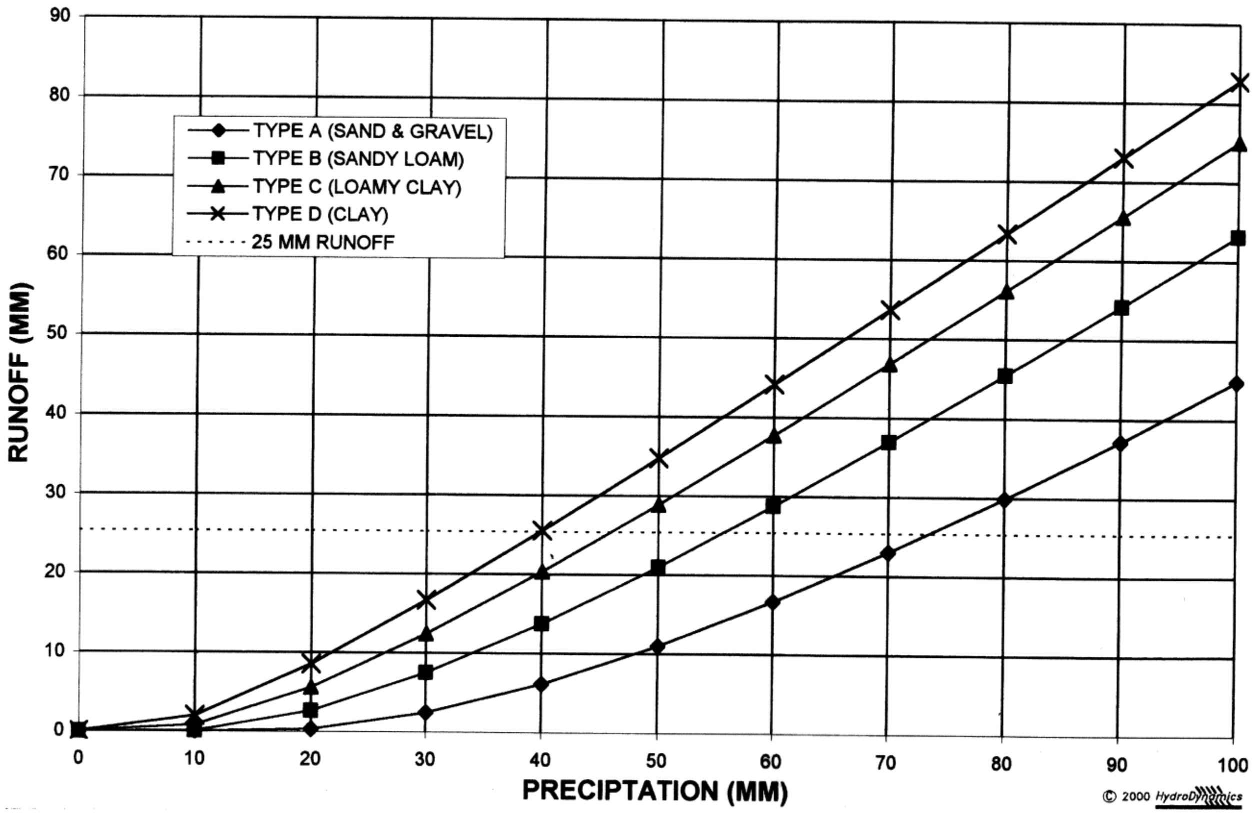


Figure 4.4: Estimated Runoff from Precipitation for Different Soil Types

Source: Fifield, 2001

4.3.4 Vegetative Cover on Soil

Under natural conditions, the amount of vegetation cover is perhaps the major factor controlling natural erosion rates. Vegetative cover is a very durable and a highly effective erosion control measure. Vegetation minimizes erosion by:

- Shielding the ground from direct rainfall impact;
- Improving the soil permeability;
- Reducing velocity of runoff; and
- Holding soil particles in place with the root structure from living and dead vegetation.

Because of its effectiveness in controlling soil erosion, vegetation is usually the primary choice for long-term erosion control (unless there are reasons for doing otherwise). Given the relatively short growing season in the NWT, it can take several years for vegetative cover to be established. ESC Plans should therefore:

- Minimize the removal of vegetation on sloping ground during construction to what is absolutely necessary; and

- Specify plant species for re-vegetation that are climatically suited to the specific ecological region and site characteristics. Indigenous plant species should be considered and some may be transplanted from local areas, if approved by the GNWT-DOT, such as in sod placement treatments, in conjunction with seeding treatments using non-native species (refer to Grass Seed Mix). Caution should be used to ensure low growing species are used where “line-of-sight” is necessary along linear corridors to avoid the need for intense maintenance. Some examples of indigenous species which may be suitable include:
  - Cotton-grass for wet areas;
  - Black Current for moist woody areas;
  - Bog Rosemary for damp or muskeg zones;
  - Crowberry for sandy or rocky areas;
  - Willows or dwarf birch, low growing varieties in most areas;
  - Alder in most disturbed areas. Seed can be easily collected in fall and planted just before snowfall; and
  - Other potential species may include: dogwood, raspberry, rose, Saskatoon, snowberry, kinnikinnick, high-bush cranberry, cinquefoil, blue-jointed reed grass, fowl bluegrass, meadow foxtail, and slender wild rye, any native sedge or rush species depending on the site location and local availability.

4.3.5 Topography

Topography refers to the shape, length, gradient and aspect of a slope. The length and gradient (slope angle) are critical factors, with longer and steeper slopes producing greater soil erosion. The aspect of the slope also affects soil erosion. For example, south-facing slopes tend to thaw more quickly in the spring and the soils can become drier than north-facing slopes in the summer. On north-facing slopes in the NWT, the ground may remain frozen beneath a relatively thin active layer well into the summer.

The shape of a slope also influences the potential extent of erosion; concave slopes with lower gradients at the base are generally less erodible than convex slopes with steeper slopes at the base.

5.0 SITE ASSESSMENT

5.1 General

ESC Plan development begins with a site assessment. The project site assessment provides information needed to assess the erosion potential of a roadway construction site and to identify beneficial features or problem areas on the site. The project site includes the construction area and peripheral areas including temporary roads, quarries, material storage, material disposal, staging and field office areas. The proximity of the site to streams, lakes and other water bodies must be assessed since the consequences of impacting these water bodies play a role in determining the risk of erosion and sedimentation.

The crossing of a water body or other type of encroachment may require Authorization under the *Fisheries Act*. It may also trigger the need for a broader environmental effects analysis under territorial or federal legislation. In cases where works will occur around water, DFO should be contacted to ensure activities are in compliance with the *Fisheries Act*. Submitting a Notification form suffices for works that can be done in conformance with a DFO-approved *Northwest Territories Operational Statement.* For works with a higher risk level or where *Operational Statements* do not apply, DFO should be consulted early in the planning process for project-specific advice. Where works will occur around other sensitive environments or encroach on valued ecosystem components, the appropriate Regulatory Agencies should be consulted.

Identifying the erosion potential of a site and the sensitivity of any downstream values will determine the relative risk represented by the project (see the Risk Assessment section 5.1.8). The project manager can then establish an appropriate level of effort for site specific erosion and sediment control management. An effective ESC Plan will minimize the site disturbance and prevent off-site sediment transport and protect sensitive areas.

Background information for the proposed construction site should be assembled to permit a preliminary assessment of the drainage and erosion potential of the site as well as for identification of environmentally sensitive areas and the presence of fish species for in-stream work windows. Identifying these areas will assist in evaluating the ESC measures to be implemented on and downstream of the proposed construction site.

The key information sources for use in preparing a site assessment are discussed in the following sections. This section is not intended to be an exhaustive list of information sources; it is the responsibility of the individual or firm preparing an erosion control strategy to ensure they have considered the appropriate relevant information.

5.1.1 Review of Construction Drawings

Design drawings will provide some of the information necessary for the preparation of an ESC Plan. This information includes, but is not limited to, the location, size and gradient of grubbing areas and stripping areas, vertical and horizontal road alignments, length and gradient of cut slopes and embankment slopes, ditch lines, culverts, bridges and watercourse crossings, riparian zones, and special sites such as borrow pits, gravel pits, and spoil areas.

5.1.2 Geotechnical Investigation Reports

Geotechnical information such as borehole logs, test pit logs, and accompanying reports are available for some areas in which transportation construction projects may take place in the NWT. This information will likely indicate the type of soils encountered in the area, detailed soil descriptions, the thickness of each unit, moisture content, soil strength values, the presence and type of ground ice associated with permafrost, and water table levels from discrete locations. In some cases, topsoil assessments or slope stability assessments may have been conducted.

Geotechnical investigations for many project designs may include review of aerial photographs, terrain assessment and soil survey investigation for both gradeline and borrow sources where available. An assessment of difficult/adverse site conditions (i.e., highly erodible soils, unstable slopes, soft subgrade, and high groundwater table) may also be conducted.

Current geotechnical investigation requirements are provided in Geotechnical Site Investigation Guidelines for Building Foundations in Permafrost (I. Holubec Consulting Inc., 2010) and may be implemented by the GNWT-DOT for some construction projects. In general, the depths of soil sampling should extend beneath the design grade for cut slopes, ditch bottoms, and to the maximum depths of proposed borrow source areas. Site assessment of riparian and other water bodies, floodplains and river crossings may be undertaken to evaluate stability of fills as well as to identify possible ESC concerns.

For a typical earthwork grading project, the following soil testing information is provided on the design drawings:

- Soil classification according to USCS;
- Moisture content (%);
- Estimated optimum moisture content (%); and
- Estimated maximum dry density from moisture density relationship testing (kg/m^3).

Depending on the scope of work, the geotechnical report may include the following additional information related to ESC concerns:

- A review of the gradeline design from a geotechnical and erosion perspective;
- Laboratory grain size analysis and Atterberg Limit testing results for fine-grained soils;
- Soil permeability; and
- Stability of large cuts and thick fill areas.

Further, additional reports prepared for environmental and hydrotechnical aspects of the project may contain the following information:

- Identification of environmentally sensitive areas including permafrost, riparian zones, wetlands and fish bearing water bodies;
- Identification of recreational, commercial or traditional fisheries; and

- Construction timing restrictions related to fish and wildlife considerations.

5.1.3 Aerial Photography/Imagery Review

A review of available aerial photographs can provide an overview of landforms, drainage and surface features in and adjacent to the construction site. Overlaying a proposed project alignment on the aerial photos may allow the viewer to locate areas of potential high risk conditions such as historical slope instability. Further, a review of aerial photographs is useful in evaluating drainage patterns, such as drainage catchment size, historic drainage features, ephemeral streams and lowlands.

Web-based aerial image technology provides additional information such as type and extent of soil cover, and type and extent of vegetation.

Sources of aerial photographs in the NWT include the following:

- GNWT Environment and Natural Resources (GNWT-ENR) (www.**enr**.gov.nt.ca/*)*;
- GNWT Department of Transportation (GNWT-DOT) (*www.**dot**.gov.nt.ca/);*
- Natural Resources Canada *(www.nrcan.gc.ca);* and
- GNWT Municipal and Community Affairs (MACA) (*www.**maca**.gov.nt.ca/)*: and
- GNWT Industry, Tourism and Investment (ITI) (*www.**iti**.gov.nt.ca/)*

Local communities such as Hay River, Fort Simpson, Fort Liard, Nahanni Butte, Tulita, Fort Good Hope, Fort McPherson, Aklavik and Tuktoyaktuk, may have information on flooding or other local events within their archives that may be beneficial when developing ESC Plans.

5.1.4 Surficial Geology Maps

Surficial geology maps are another soil information source that may be employed during construction. These maps may be used to interpolate soil conditions between drill holes or test pits (with inherent uncertainty) and can assist in delineating boundaries of various soil types.

The type of information found on surficial geology maps may include type and extent of soil, thickness and bedding characteristics of each soil type, stratigraphy, depth to bedrock, and in some instances, the erodibility rating.

Sources for surficial geology maps include:

- Natural Resources Canada *(www.nrcan.gc.ca);* and
- Geological Survey of Canada. *(www.nrcan.gc.ca/earth-sciences/about/organization/organization-structure/geological-survey-of-canada/)*

5.1.5 Vegetative Cover Maps

Vegetative cover maps typically include the dominant plant species as well as information on moisture and nutrient regimes. They can provide information about the type of vegetation that should be used for re-vegetation, considering the drainage class and soil texture.

Information on vegetative cover will help identify the rooting conditions that may be encountered during grubbing and stripping operations. The existing vegetation will provide the designer with a basis for successful revegetation by defining which species are currently growing on the site and indications of the limitations of the site (e.g., arid versus wet conditions).

Vegetative cover maps come in various forms. Some are developed to address specific concerns such as new development and others are developed for inventory purposes. For the purpose of erosion and sediment control planning, site level vegetative cover maps (scale 1:10,000 or less) are the most useful and provide the level of detail required for characterizing a construction site and developing specific erosion and sediment control measures. Overview maps of larger scale may not provide enough detail to plan specific measures, but may be useful for characterizing general site conditions.

Sources for vegetative cover maps include:

- GNWT Environment and Natural Resources (GNWT-ENR) (*www.**enr**.gov.nt.ca)*;
- Natural Resources Canada *(www.nrcan.gc.ca);* and
- Environment Canada (*www.ec.gc.ca/default.asp?lang=en)*.

5.1.6 Floodplain Information

Floodplain information including frequency, duration, and flood levels is important data to identify erosion and deposition processes associated with natural flooding as opposed to sedimentation caused by construction activities. Sources for floodplain information include:

- GNWT Environment and Natural Resources (*www.**enr**.gov.nt.ca/)*;
- GNWT Municipal and Community Affairs (*www.**maca**.gov.nt.ca/*); and
- Environment Canada (*www.ec.gc.ca/default.asp?lang=en)*;

Floodplain information should be shown on the drawings that accompany the documentation for an erosion and sediment control strategy.

5.1.7 Site Inspection (Data Collection)

A site inspection of the proposed construction site is a fundamental step in the preparation of an ESC strategy. Observations of the existing site conditions, such as drainage patterns, existing vegetation and signs of wildlife use, will provide the greatest level of detail for identifying potential erosion and sediment sources and location of drainage structures for temporary diversions and post-construction alignment. A site inspection should be conducted at the time of year with no snow cover and not immediately following a rainfall event, if possible.

Site inspections should be conducted after the background information, such as flood pattern and frequency, climate data, vegetation mapping, and historical aerial photography, is reviewed. A site inspection should involve a reconnaissance of the project footprint to assess and document the following information:

- Soil Properties: The soil properties in an area to be disturbed by construction activities should be described according to the USCS in conjunction with Agriculture Soil Structure Code in the Soil Erodibility Rating table as presented in Figure 4.2. This information may be assessed by inspecting existing soil exposures or by conducting shallow test pits in the area. The focus should be on areas of anticipated high erosion potential.

  Watercourses: Potential areas of concentrated drainage and areas of surface flow or groundwater outflow should be noted on the site plans. The field inspection should focus on determining the potential for sedimentation and associated consequences downstream and downslope of the construction site. Depending on the nature of the construction, an estimate of the bank full elevation of streams may be required. Baseline water quality sampling will be conducted prior to the start of construction and at intervals during the project determined by site activities and outlined in the ESC Plan.

- Water Crossings: Water crossings, including watercourses and drainage ditches, should be noted.
- Fish Habitat Assessments: All water bodies adjacent to work sites should undergo a fish habitat assessment to account for the presence and importance of fish. If fish are present, care must be taken to prevent blocking fish passage, harming fish or their food (e.g. riparian habitat), or allowing sediment to reach the water. Under section 35(1) of the *Fisheries Act,* it is illegal to seriously harm or kill valued fish species.
- Riparian Zones: The location, width from the high water mark, and general descriptions of riparian zones should be noted and marked in the field. For guidance, vegetated riparian areas should be at least 15 m to 30 m wide to reduce sediment delivery potential. Furthermore, the presence of watercourses originating from or passing through the construction site that are buffered by these zones and their respective gradients should be noted. Intrusion into the riparian zone may require approvals from the GNWT-ENR.
- Vegetation: Existing and adjacent vegetation should be noted in terms of location, type and extent.
- Slope Failures: Signs of recent or historic slope failures or evidence of instability should be noted. Assessment by a geotechnical engineer may be required to determine the cause of slope failure.
- Eroded Sites: Areas of recent or past erosion and sedimentation events should be noted.
- Sensitive Sites: Potentially sensitive sites such as permafrost and icing areas, drinking water source areas, fish and wildlife habitat, private property, utilities, and recreational areas should be noted.

5.1.8 Risk Assessment

After the information has been reviewed and a site inspection completed, an erosion and sedimentation **Risk Assessment** is completed. The purpose of the Risk Assessment is to identify and prioritize areas requiring erosion and sedimentation control and to determine the types of Best Management Practices (BMPs) that should be considered as mitigation measures when developing the ESC Plan.

The Canadian Standards Association (CSA) (2009) has prepared a general risk management decision procedure (CAN/CSA Q850-97), including preliminary analysis, and risk assessment. This procedure may be applied to many activities, including erosion and sedimentation risk assessment. Risk is a quantitative or qualitative expression of possible loss that incorporates both the **probability that a hazard will cause harm** (human injury, property damage, environmental damage and/or other things of value) and the **consequences (the damage, loss or change) to the elements affected** (CSA 2009). The probability of erosion and sedimentation above natural levels, due to construction activities, is affected by the factors discussed in Chapter 4, and can be reduced by properly implementing the practices discussed in Chapter 7 of this manual.

ESC failures can result in four types of potential consequences:

- Ecological consequences related to the introduction of sediment to the aquatic environment;
- Project consequences related to the need to respond to and repair erosion damage and the implications for the project schedule and costs;
- Legal consequences associated with the deposition of sediment in receiving water bodies; and
- Professional and social consequences such as loss of reputation and confidence from nearby communities and other government agencies.

Land management practices during construction can significantly influence the risk of erosion. Removal of vegetation, soil compaction, and slope changes can all increase the rate of erosion. The lack of effective ESC measures can result in significant erosion and sediment transport.

Sedimentation can adversely affect the aquatic environment, including fish and fish habitat. These effects can range from behavioural effects (e.g., avoidance behaviour, decreased foraging success) to outright mortality, depending upon the concentration and duration of exposure (Newcombe and Jensen 1996). Depositing fine sediment in spawning areas can smother eggs and make streambed material unusable for spawning.

Erosion at construction sites can affect project costs and timelines. For example, repair or damage due to large soil movement or gully formation may require resources to be diverted from other construction activities. Damage to neighboring property or receiving water bodies, caused by soil leaving the site, can be costly to repair. In extreme cases, this can also affect project completion schedules.

There are legal consequences related to the release of sediment to the aquatic environment. Sediment is considered a deleterious substance under the *Fisheries Act* and a contaminant under the EPA. Any sediment release could result in charges laid under subsection 36(3) of the *Fisheries Act* or subsection 5(1) of the EPA. Substantial penalties may be attached to convictions for the release of sediment into waters frequented by fish (see subsection 40(1) of the *Fisheries Act* and subsection 12.1 of the EPA).

In addition to fines for environmental offences, stop work orders may be issued by regulatory officials. These can require all work to cease until appropriate mitigation measures are properly implemented and incorporated into a development plan.

All of these potential consequences must be considered in determining the best approach to developing ESC plans. Risk assessment is a key element in assessing the degree to which ESC measures are integrated into a development plan.

Integrating risk assessment with ESC planning also demonstrates that reasonable care was taken in addressing ESC issues and can be a consideration in litigation as part of a due diligence defense. If a risk assessment is not included in the ESC Plan development and a HADD or an uncontrolled release of sediment into a watercourse occurs, it will be difficult to prove that reasonable care was taken.

5.1.9 Consultation with Regulatory Agencies

There are several territorial and federal Regulatory Agencies (RAs) that may have specific and/or detailed information or concerns about the construction site. Gathering site specific baseline information is a challenge in northern Canada, and many sources may need contacting for the original site assessment. Information from regulatory agencies may include general fish and wildlife habitat information, historical data (e.g. rainfall records or past slope failures), revegetation limitations or requirements, information on previously implemented erosion and sediment control measures, and permitting requirements. For site specific information, consider contacting local communities and governments for local and traditional knowledge.

Some RAs have guidelines for specific types of works or undertakings. These guidelines can be found on the RA websites. These documents offer proven and accepted mitigation measures for specific low risk activities. Consider the following agency websites as a resource for project planning:

- Fisheries and Oceans Canada (*www.dfo-mpo.gc.ca/regions/central/habitat/os-eo/provinces-territories-territoires/nt/index-eng.htm).*
- AANDC (*www.aandc-aadnc.gc.ca*)*;*
- Environment Canada (*www.ec.gc.ca/default.asp?lang=en)*;
- GNWT Environment and Natural Resources (*www.enr.gov.nt.ca/)*;
- GNWT Water Board *(www.nwtwb.com/*); and
- Regional Boards with responsibility for environmental management.

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6.0 SITE EROSION POTENTIAL AND EVALUATION

6.1 General

Construction activities can increase erosion rates and the transfer of sediment away from the site. Many activities that are undertaken during construction can directly affect erosion and sediment transport. Activities may be linked or can influence more than one of the factors that can affect erosion rates. Using roadway construction as an example, these linkages are shown in Figure 6.1 below.

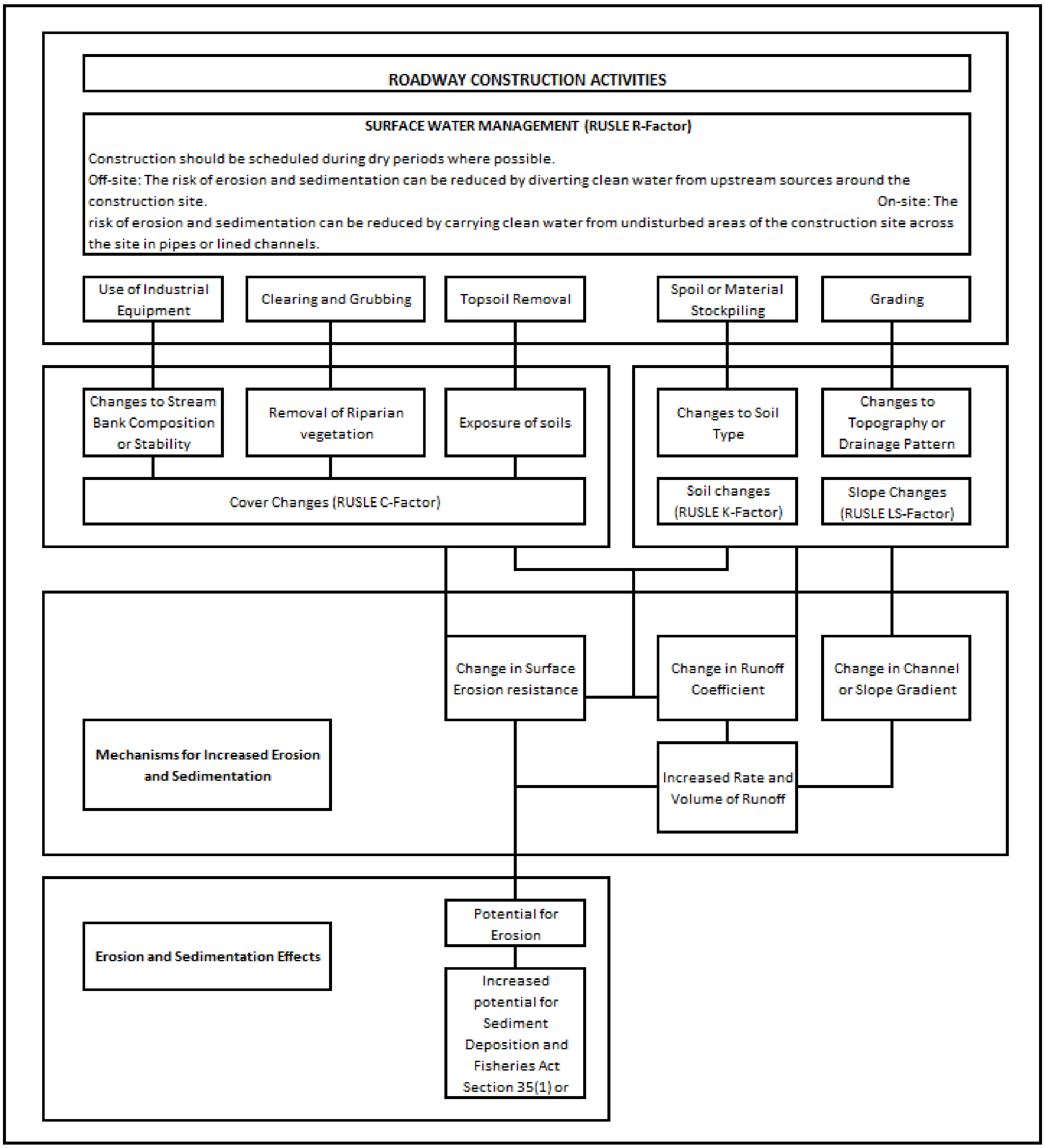

Figure 6.1: Linkage Diagram Relating Construction Activities to Risk of Erosion and Sedimentation

It is important to understand how each type of construction activity affects site erosion potential and the methods for addressing erosion or sediment control, when preparing an ESC Plan. A methodical approach to assessing potential for erosion and sedimentation due to construction activities involves a series of screening evaluations. The following information is required to assess the erosion potential: soil texture, structure, and permeability; topography; climate (e.g. rainfall erosivity and growing season); presence or absence of ground ice or permafrost; cover characteristics (i.e., vegetative, paved, rock etc.), shallow groundwater conditions; and receiving environment sensitivity.

The major challenge facing the designer is to correctly assess the erosion potential resulting from the construction activities. The site erosion potential is an estimate of the quantity of soil that could be removed from the construction site due to erosion and transportation by surface water flow. Soil loss evaluation methods used in agricultural practice have been successfully adapted to construction practices. The estimates produced by using these methods should be supplemented with judgement and experience so that the assessment of site erosion potential is appropriate for the construction site and reflects the level of environmental risk.

6.2 Regional Erosion Potential Issues

This section has been adapted from the Transportation Advisory Committee TAC National Guide to Erosion and Sediment Control for Roadway Projects, May 2005 (TAC Manual). Portions are directly quoted from the TAC Manual.

The NWT has several unique biophysical characteristics that influence ESC planning and practice. The NWT – Protected Area Strategy (PAS) has detailed information on ecoregions which offers the user more specific local information. It is important to be familiar with, and to address, site specific issues when developing an ESC Plan. This section outlines the key differences in ESC in the NWT compared to other parts of Canada.

The NWT is home to a number of flora and fauna species that may be considered at risk or endangered. Lists of species protected by regulations are available through the GNWT - Environment and Natural Resources. That department should be consulted for additional information on the implications for construction projects. Consultation with local First Nations or communities may be a good information source.

Emphasizing proper design of ESC measures, early revegetation of exposed surfaces, protection of impacted permafrost areas, and proactive maintenance programs will help reduce the impacts in these areas. To identify specific regional issues related to ESC, the physiographic regions within the NWT should be considered. These include the Cordillera, Interior Plains, Arctic Canada (Lowlands), Arctic Canada (Innuitian) and the Canadian Shield. A map of the Physiographic Regions of Canada is presented in Figure 6.2. The overview presented here is a brief introduction to regional issues that may be encountered. Local knowledge and additional relevant information should be applied to specific project sites.

Cordillera: The topography of the Cordillera Region is dominated by mountains, plateaus and steep valleys. Erosion potential in the Cordillera is affected by high gradient slopes, large annual rainfall and high runoff resulting from snowmelt and rain-on-snow events. Debris flows should be considered as an important design consideration.

The diverse topography in the Cordillera Region creates a variety of site-specific challenges for ESC. ESC Plan designers should be prepared for rainfall/runoff events, minimize the extent and duration of exposed soil, consider stabilizing temporary stockpiles (seeding or mulching) and be attentive to site sensitivities.

Interior Plains: The Interior Plains Region has an arid climate, low relief and relatively fine-grained soils that are highly susceptible to erosion. Agriculture in this region, limited to the southern portion of the NWT, has created tilled and disturbed soils that are highly susceptible to erosion. Vegetation establishment can be difficult due to arid climate and nutrient poor soils.

Wind erosion may be an issue in the southern plains area due to soil dryness.

Beaver dams may be a common feature on smaller watercourses and they provide critical late summer flows and overwintering habitat to sustain fish. Beaver dam removal should be approached with caution. Dams provide natural ESC and the rapid release of water from a breached dam can cause catastrophic erosion. Proposed beaver dam removal should be reviewed by DFO and GNWT – Environment and Natural Resources.

Canadian Shield: The Canadian Shield is the largest physiographic region in Canada and is a region of exposed rock and glacial features. The Shield is known for its rolling, undulating terrain and its numerous lakes. Some of the biggest challenges in ESC could be intense summer storms and winter storms. Emergency response planning should be incorporated into the ESC. A key consideration in ESC planning should be to minimize the extent and duration of exposed soil and to stabilize temporary stockpiles.

Arctic Canada: The Arctic physiographic region (tundra) generally believed to lie north of the treeline. The short growing season and harsh climate result in short, slow growing vegetation. A large portion of the surface in this region is bare rock and is covered in snow for the majority of the year. The largest runoff events are associated with spring melt.

Typically, large-scale tundra polygons, thaw lakes and depressions, and widespread mass-wasting and patterned-ground phenomena characterize these landscapes. The tundra environment is characterized by the general presence of permafrost (except beneath some lakes and rivers); short summers with almost continuous daylight; long winters and arctic "nights"; low annual precipitation (hence the name polar desert); strong winds and winter blizzards; discontinuous vegetation; unstable, wet SOIL conditions resulting from permafrost and frost action. Tundra plants have developed many adaptations for survival. Their low stature exploits the more favourable microclimate near the ground; small, leathery, hairy leaves prevent desiccation by evaporation.

Perennial life habit, vegetative propagation, short reproductive cycle and effective seed dispersal by wind are common among tundra plants (e.g. lichens, mosses, grasses, and low shrubs). [3]

[3] The Canadian Encyclopedia / Geography / Geography, General/ Physiographic Regions/ Arctic and Sub-Arctic Lands

Major erosion issues related to construction in the arctic are permafrost degradation due to excavation and ditch construction. Constructed infrastructure can change the reflectivity of the ground surface, which affects permafrost by increasing the amount of absorbed solar radiation. The harsh climate may also inhibit revegetation efforts.

Northern Canada: Permafrost degradation is a concern in many of Canada's northern physiographic regions. Refer to Figure 6.3 Permafrost Regions of the Northwest Territories. Construction activities and linear cuts in particular, can remove or disturb insulating soil and vegetation, expose dark soils to reduce the ground surface melt and cause water to flow against frozen ground. These can produce an unfrozen and saturated soil that is susceptible to slope failure and erosion. Proper northern construction techniques and reclamation efforts are required to prevent significant thawing of permafrost soils. For sites constructed on permafrost, available thaw-control BMPs include insulated thermal blankets, gravel buttresses and controlled ablation.

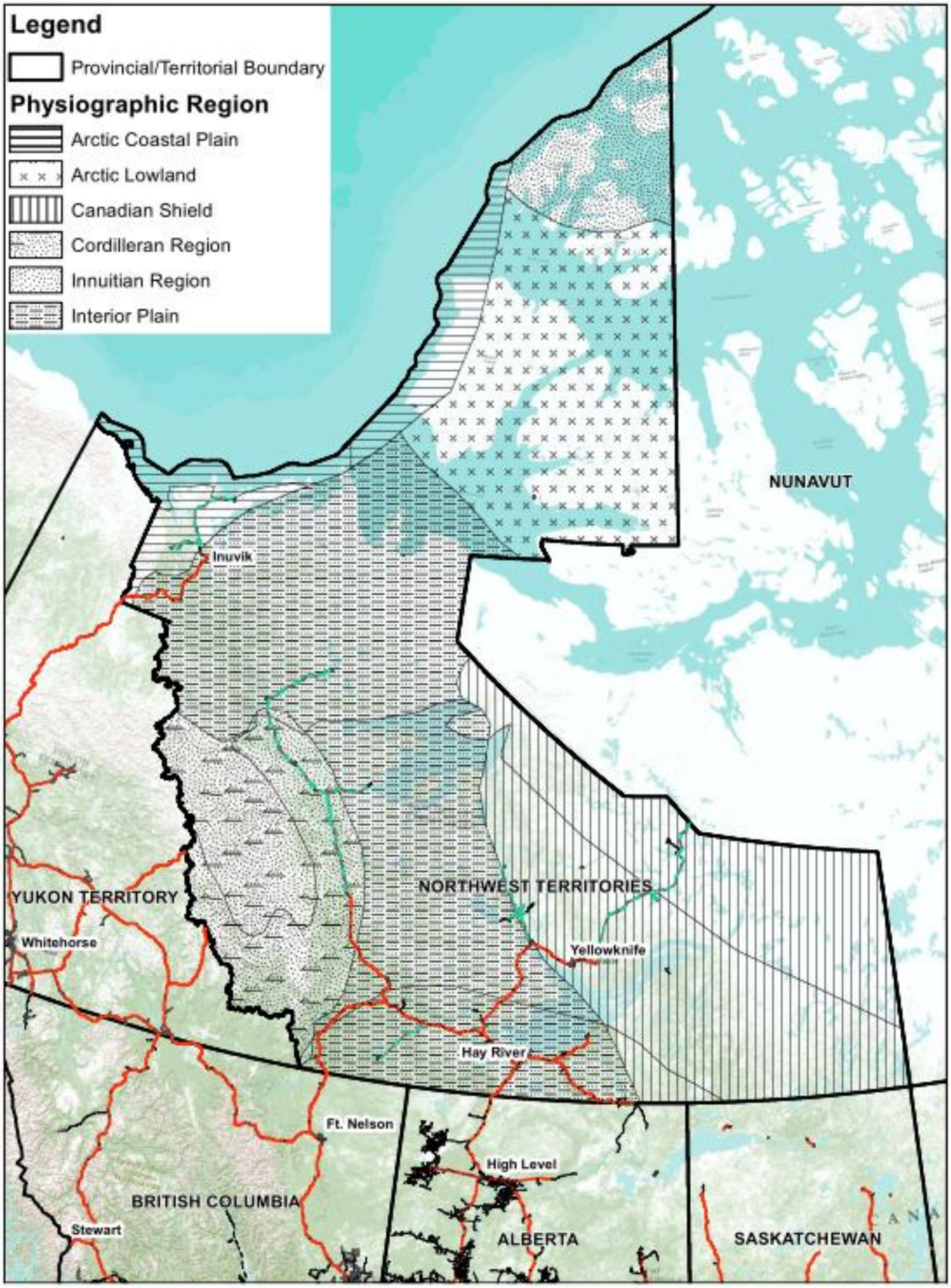

Figure 6-2: Physiographic Regions within the Northwest Territories

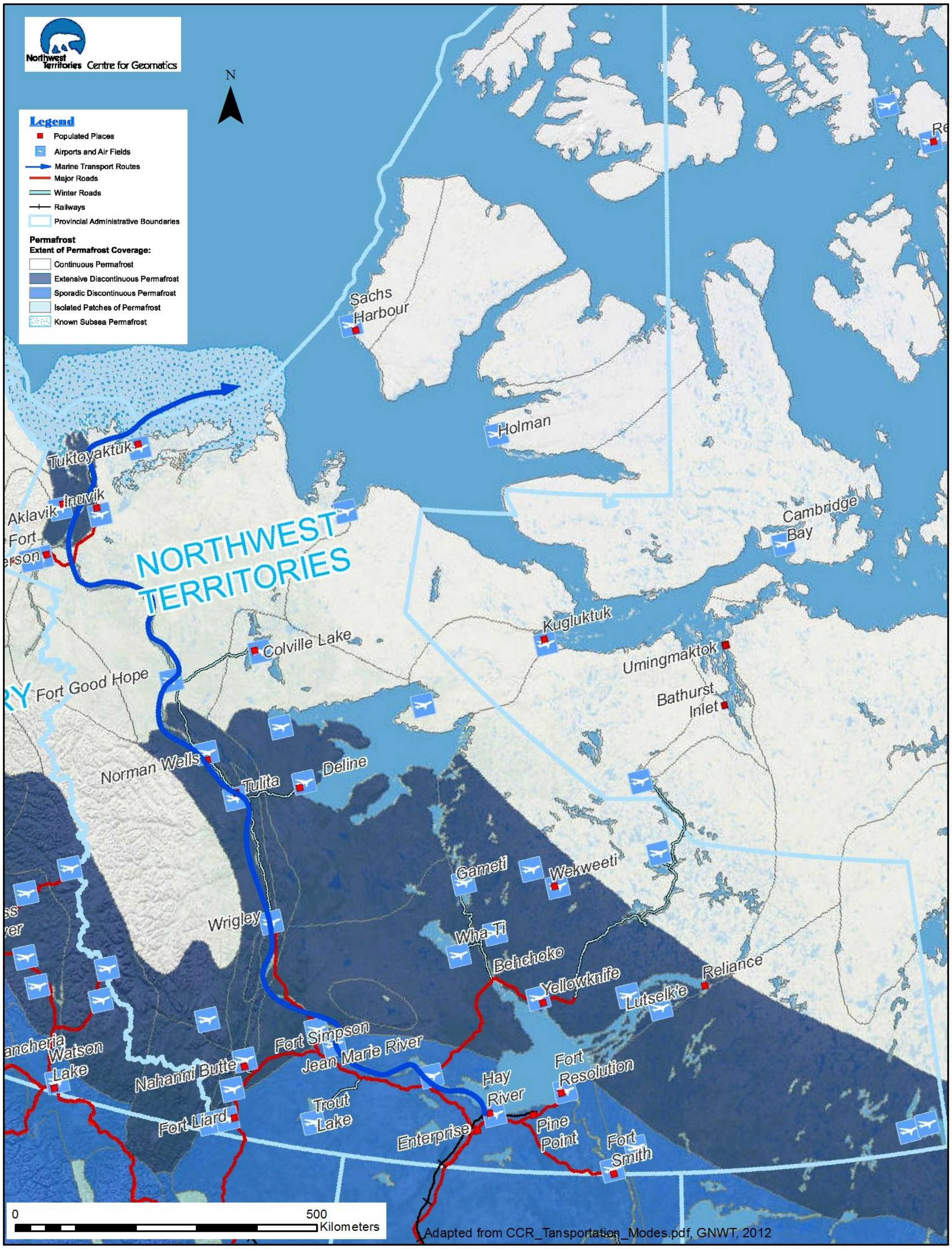

Figure 6-3: Permafrost Regions of the Northwest Territories

In addition to deep organic deposits, northern sites must also contend with very thin topsoil overlaying tills, silts and volcanic ash deposits. Vegetation establishment can be challenging due to the very short growing season, the arid climate, and nutrient poor soils in portions of the north.

Many northern streams, which are very sensitive to sediment deposition, support diverse populations of fish upon which traditional and recreational users rely.

6.3 Revised Universal Soil Loss Equation (RUSLE)

A number of approaches can be used for estimating transportation construction site erosion potential. The primary quantitative tool is the Revised Universal Soil Loss Equation (RUSLE), which is an update of the original Universal Soil Loss Equation (USLE) that was developed in the 1970s. The RUSLE calculations are available in an on-line software package that includes databases of soil erodibility (K) and climate (R) data for all major soils and cities across the United States. As this program was developed in the United States, no data was included for Canadian locations and it should not be used for NWT construction sites. The most recent version is known as RUSLE2 is in Windows format[4].

Agriculture Canada, working with other public agencies and universities, adapted RUSLE so it could be used in Canada, taking into account the factors that influence erosion in Canada. The document Revised Universal Soil Loss Equation for Application in Canada (RUSLE–FAC) (Wall *et al.* 2002) is available online and is the best guide for RUSLE use in Canada. RUSLE-FAC is not currently available in a computerized software and data package.

It is important to note that USLE/RUSLE only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, or wind erosion. Nor does it calculate sediment yield (i.e. the mass of sediment delivered from a watershed). Its primary value is to provide a consistent method of assessing erosion hazard and for determining the potential for specific ESC practices to reduce that hazard to an acceptable level.

For the remainder of this manual, references and examples will focus on RUSLE-FAC, which will be simply referred to as RUSLE for consistency.). For calculating a detailed analysis of soil loss on a project site, the designer should refer to the RUSLE-FAC document (*http://sis.agr.gc.ca/cansis/publications/manuals/2002-92/index.html*).

4 Available from the National Sedimentation Laboratory; http://www.ars.usda.gov/main/site_main.htm?modecode=64-08-05-00

The RUSLE formula is as follows:

$$A = R \times K \times LS \times C \times P \qquad \text{(Equation 6.1)}$$

Where:
- A = Annual soil loss (tonnes ha^{-1} $year^{-1}$)
- R = Rainfall factor (MJ mm ha^{-1} $hour^{-1}$ $year^{-1}$)
- K = Soil erodibility factor (tonne hour MJ^{-1} mm^{-1})
- LS = L and S are the slope length and steepness factors, respectively (dimensionless)
- C = Vegetation and Management Factor (dimensionless)
- P = Support Practice Factor (dimensionless)

Supporting information to assist in the selection of these factors is presented in Appendix B.

6.3.1 Rainfall Factor, R

The rainfall factor, R, is a measure of the total annual erosive rainfall for a specific location, combined with the distribution of erosive rainfall throughout the year. The rainfall factor is the average annual sum of the products of the two variables most critical to a storm's erosivity:

- Volume of rainfall and runoff (E); and
- Prolonged-peak rates of detachment and runoff (I) (Wischmeier and Smith, 1978).

EI is the total kinetic energy of a storm multiplied by the maximum 30-minute intensity.

In Canada R is estimated through the use of the following three primary methods:

1. Measured rainstorm EI values. This method is suitable if 22 or more years of rainfall intensity data are available (Wischmeier and Smith, 1978).
2. Equations which rely on an empirical relationship between R and the one-in-two year, 6 hour storm (Canadian adaptations are described in the RUSLE-FAC manual of Wall et al. 2002).
3. Hourly precipitation records, where available to predict R (e.g., Wigham and Stolte 1986).

Estimated R Values have been calculated for Selected Sites in the NWT. (Appendix B: Table B-1 or Section 6 - Table 6.1, Page 6-9)

These three methods have been used to estimate R and produce reference materials for Canadian conditions:

- In southern Canada, isoerodent[5] maps have been developed that indicate annual R values for an area and can be used to calculate average annual soil losses (Refer to the RUSLEFAC Handbook available at: http://sis.agr.gc.ca/cansis/publications/manuals/2002-92/index.html);

5 Isoerodent Maps: A map showing lines of equal soil erosivity which were developed through interpretation of long-term recording-rain gauge records. Maps for lower Canada are available as a result of the development of the RUSLE program in the United States.

- Monthly distribution of R which indicates the proportion of annual erosive rainfall that falls during each month (Table B-2, Appendix B); and
- Mean annual rainfall on frozen soil maps, which may indicate areas where rain falling on frozen soil could pose an erosion risk.

At present, the isoerodent maps are only available for southern Canada (Wall et al. 2002). Climate stations with rainfall intensity data in the NWT are spaced too far apart to generate reliable isoerodent lines, and R values need to be calculated from the best available climate data for a particular site.

Following are estimates of R values for the Environment Canada climate stations in the NWT where there are available Intensity-Duration-Frequency (IDF) data, specifically the rainfall from the 1-in-2 year 6-hour storm. The R estimates were generated using the empirical equation developed by Ateshian (1974) based on directions in the RUSLE-FAC Manual (Wall et al. 2002). The equation is:

$$R = 0.417\ p^{2.17}$$

where p is the normal, one-in-two year, 6 hour storm. The R values in Table 6.1 provide an indication of the spatial variation of erosive rainfall in the NWT. For example, based on the R-value estimates, the annual erosivity in Fort Simpson is almost four times that in Inuvik.

Location*	**Normal 1-in-2 year 6-hr intensity (mm/hr.)**	**Normal 1-in-2 year 6 hr. storm (mm)**	**R - the Erosivity Index (MJ mm/ha/hr.)**
Yellowknife	3.0	18.0	**221**
Fort Reliance	2.3	13.8	**124**
Fort Simpson	3.6	21.6	**328**
Hay River	3.1	18.6	**237**
Inuvik	1.9	11.4	**82**
Norman Wells	2.7	16.2	**176**
Tungsten	2.3	13.8	**124**

*All locations are at the local airport.

Table 6.1: Estimated R Values for Selected Sites in the NWT

It is important to note that the R factor is an index of rainfall erosivity that is used within the RUSLE to estimate annual soil loss. The RUSLE is most useful for comparing the relative effectiveness of conservation of practices rather than for developing precise estimates of soil loss. The lack of more site-specific R values for the NWT is not a serious constraint if the RUSLE is used as intended in this manual, which is to develop an ESC plan. The R values listed above should be used cautiously for any other purpose. For larger projects with significant potential consequences of erosion, users may wish to develop an R value based on local data and the methods specified in the most recent USDA RUSLE Manual (currently Renard et al. 1997)

6.3.2 Soil Erodibility Factor, K

6.3.2.1 Estimation of K

The K factor is a quantitative measure of a soil's inherent susceptibility to erosion. Generally, on the basis of soil characteristics alone, soils with a high percent content of silt and very fine sand particles, as well as low fibrous organic matter content, will be most erodible. A preliminary assessment of soil erodibility was presented earlier in Figure 4.2. K values estimated using the methods detailed herein is appropriate for soils encountered in agricultural practice. As such, a soil erodibility adjustment factor ($Ø_K$) is proposed to facilitate application of the estimated K values to construction sites and is discussed in Section 6.3.2.2.

A K value can be calculated for a specific soil, using the following empirical equation (Wischmeier and Smith, 1978).

$$\mathbf{K = [2.1x10^{-4}(12-a)M^{1.14} + 3.25(b-2)+2.5(c-3)]/100} \qquad \text{(Equation 6.2)}$$

Where: M = (% silt + very fine sand) x (100 - % clay)

a = % organic matter

b = the soil structure code used in soil classification (Figure B-2), and

c = the profile permeability class (Figure B-3)

The input parameters for the aforementioned equation are routinely characterized through standard soil profile descriptions and laboratory analyses. These parameters are listed as follows:

- % silt plus very fine sand (soil particle sizes between 0.05 and 0.10 mm);
- % sand greater than 0.10 mm;
- Soil structure;
- Permeability; and
- Organic matter content.

Of these variables, organic matter content can usually be assumed to be zero in road embankments or deep cuts.

The soil erodibility nomograph (Figure B-1, Appendix B) provides a graphical solution for determining a soil's K value, and can be used if the percent sand and organic matter fractions in a particular soil are known.

The soil erodibility potential is low for high plasticity clayey soil and coarse to medium grained granular soils; therefore, gradation analysis including hydrometer testing of these soils would not usually be required for an erodibility assessment. The soil erodibility can be high to medium for low to non-plastic soil and soil with significant amounts of silt and fine sand. Therefore gradation analysis including hydrometer testing is required.

Where the soil fractions are not known, K factors have been estimated for a number of surface textures and for approximate organic matter content. Major textural groups and their corresponding K values are listed (Table B-3, Appendix B).

6.3.2.2 Soil Erodibility Adjustment Factor ($Ø_K$)

It should be noted that the soil erodibility factor (K) was developed for an agricultural setting where soil are routinely tilled. The level of consolidation and/or compaction of soils encountered on cut and fill areas in a transportation construction setting is usually much greater than that encountered in an agricultural setting, which reduces erodibility for some construction periods. With the possible exception of winter road building, cut slopes in construction will usually or optimally consist of consolidated material and fill slopes that have undergone significant compaction effort and moisture conditioning. For fill embankments, compaction energy was exerted on the soils at thin lifts with moisture conditioning (to moisten or dry the soil to an optimum moisture content) to achieve a maximum dry density (Standard Proctor Density).

Most transportation related fills are constructed with mineral soils with minimal organic content. This situation differs greatly from an agriculture setting where soils have been cultivated to produce loose conditions that promote plant growth. Despite efforts to improve soil strength in a construction setting by compaction, silty and low plasticity fine-grained soils remain highly erodible and must be managed accordingly. The installation of rolled erosion control products (RECP) (e.g. coconut mat) or the replacement of fibrous organic material (Sodding) over highly erodible sites may be beneficial in these areas where feasible. Refer to Sections 7 and 8 of this manual for choosing erosion control measures which may be suitable to the construction site.

Based on the observed differences in the erodibility of construction and agricultural soils, the soil encountered in an industrial scenario would typically have a lower K value. Thus, a modification factor ($Ø_K$) should be applied to lower the K factor for use in RUSLE on construction sites. $Ø_K$ values ranging from 0.5 to 1.0 have been used elsewhere (with an average value of 0.8) to adjust K on construction sites. However, the selection of $Ø_K$ should be done carefully by the qualified person preparing the ESC Plan based on site conditions and the presence or absence of permafrost. If permafrost is not present, a modification factor of 0.8 is reasonable in most situations. If permafrost is present, the K value should <u>not</u> be modified since permafrost melting may increase soil erodibility.

6.3.3 Topographic Factor, LS

6.3.3.1 Estimation of LS

The topographic factor, LS, is a combined factor that accounts for the effect of slope length (L) and slope steepness (S) factors on the site erosion potential. It adjusts the erosion prediction for a given slope length and slope angle to account for differences from slope conditions present at the standard erosion monitoring plot on which the original USLE was based (LS=1 for slopes 22 m long with 9% grade).

For consolidated soil conditions, such as freshly prepared construction sites with minimal vegetative cover, values of LS can be evaluated from the Topographic Factor Chart (Table B-4, Appendix B) for slope lengths varying from 2 to 300 m, and slopes ranging from 0.2 to 60%.

The upper end of a slope can be defined as the top of the slope, or the divide down a ridge in the field. The lower end of a slope can be located by moving down the slope, perpendicular to the contours, until a broad area of deposition or a natural or constructed waterway is reached. Reducing either the length or steepness of a slope can reduce soil loss. However, reducing the steepness of a slope results in an increased slope length, thus the overall reduction of soil erosion may not be significant. Another way to reduce soil loss is to place intercepting berms along the contours. While this procedure will effectively reduce the cross-section to a series of simple slopes, costly earthworks may be required to establish the berms, which may not be justified unless fill material is readily acquired at a nearby location.

Estimation of the LS factor for uniform slopes and irregular slopes is discussed in the following paragraphs.

Uniform Slopes

The equation of the LS factor for a uniform slope is given as follows:

$$\mathbf{LS = (sl/22.13)^m \times S} \qquad \text{(Equation 6.3)}$$

The slope factor "S" in RUSLE is given as follows (McCool et al., 1989):

$S = 10.8\sin(\theta) + 0.03$

when slope is <9%, length ≥ 5 m

$S = 16.8\sin(\theta) + 0.50$

when slope ≥ 9%, length ≥ 5 m

$S = 3.0\sin(\theta)^{0.8} + 0.56$

when length <5 m

Where: sl is the slope length of the site (m)

θ is the angle of the slope (in degrees)

m is a coefficient related to the ratio of rill to inter-rill erosion presented in Table B-5.

Irregular Slopes

The RUSLE provides a procedure for separating an irregular slope into segments. This procedure recognizes and adjusts for differences in the type of slope. For example:

- A **convex slope** will have a greater effective LS factor (i.e., a higher erosion estimate) than a uniform slope with the same average gradient; conversely
- A **concave slope** will generally have a lower effective erosion rate than a uniform slope of the same average gradient.

The irregular slope should be divided into a two to five segments that describe varying conditions down slope (i.e., soil type, practices, etc.).

Design examples illustrating evaluation of LS for irregular slope are presented in Appendix H as Examples H.4 and H.5.

6.3.3.2 Topographic Adjustment Factor ($Ø_{LS}$)

The RUSLE Topographic factor (LS) was developed for typical agricultural slopes with loosened surficial soils for most soil types of moderate to low erodibility. For linear construction applications, slopes are generally much steeper than this and the surficial soils are much denser. Typical slopes for a linear construction site in the Northwest Territories range from 3H:1V (33%) to 6H:1V (16%). Using RUSLE for a typical linear construction slope results in a relatively high LS value and subsequently high site erosion potential. Although it steeper slopes are more prone to erosion as a result of increased runoff velocities, the RUSLE classifications for site erosion potential are calibrated or standardized to a much lower slope gradient and therefore should be modified for use on linear construction sites. In the agriculture practice of assessing the erodibility for slope with loose surficial soils, a gentle slope (9% slope, 22 m length) was chosen to calibrate a baseline value for slope factor (LS=1 in RUSLE) with other slope configurations of steepness and length (Wischmeier and Smith, 1978). As a result, the LS factor is dependent on soil conditions, even though it is intended as a modifier for varying slope steepness. In linear construction slopes with compacted soils, the same baseline slope configuration will yield a lower slope (LS) value due to the higher density in linear construction soils.

Based on the differences between a linear construction and agricultural setting, the soils encountered in a linear setting should have a lower slope factor rating. Thus a Topographic Adjustment Factor ($Ø_{LS}$) is applied to lower the LS factor determined as part of the RUSLE approach to estimating soil loss. An $Ø_{LS}$ of 0.8 is suggested to address the inherent differences between transportation construction and agricultural settings. However, the selection of $Ø_{LS}$ is to be conducted at the discretion of the individual or firm estimating soil loss potential based on site conditions, experience and judgement. The adjustment factor has been developed based on judgement for this document and represents a transportation construction specific factor to be used in the RUSLE.

In the NWT where permafrost is encountered, the $Ø_{LS}$ should not be applied due to the melt process and loose soil condition encountered once the water saturation levels dissipate.

6.3.4 Vegetation and Management Factor, C

The C-factor is used to determine the relative effectiveness of soil including natural vegetation, crops, grasses, and/or artificial protection cover (such as mulch, synthetic erosion protection matting) to prevent or reduce soil loss. For bare soil, C=1 is always used (i.e. no reduction in erosion); whereas for soil surface protected by mulch C=0.1 to 0.2 is common. Some construction site C-factor values are shown in Tables B-6a and B-6b (Appendix B).

6.3.5 Support Practice Factor, P (Practice Factor)

The P-factor is a measure of the effects of practices designed to modify the contouring flow pattern, grade, or direction of surface runoff and thus reduce the amount of erosion. Generally, a support practice is most effective when it causes eroded sediments to be deposited far upslope, very close to their source. In the absence of any support practices, P is given a value of 1.0 in the RUSLE formula. With the use of appropriate construction practice, the P factor can be reduced. For example, the practice of track roughening of bare slope (up/down slope) can reduce the P factor from 1.0 to 0.9.

Estimation of P may well be the least accurate and most subject to error of the RUSLE factors, because there are less field data to support the P values compared to other factors in the RUSLE, and because it depends on the practice being implemented properly. The additive effect of multiple ESC practices is also not well understood.

Some construction site P-factor values are provided in Table B-7, Appendix B.

6.4 Empirical[6] Methods for Sediment Storage/Impoundment Design

Sedimentation basins or traps are best designed by a qualified person using local precipitation data and site-specific soils information. For smaller projects or if the supporting data are unavailable, it is reasonable to size ponds using general guidelines based on empirical evidence. For smaller drainage areas (i.e. less than 10 ha), there is a general relationship between the required storage capacity for sediment laden runoff from the construction site and the area of disturbed or exposed soil. Disturbed areas greater than 10 ha or those on long steep slopes must utilize estimating procedures such as the RUSLE to estimate how much sediment could be delivered to the pond. It is important to note that various site specific factors affecting soil erosion rate are taken into account. Therefore, the empirical method should be used with caution. The main advantage of the empirical approach is its simplicity and ease of application.

Other jurisdictions utilize storage volume requirements ranging from 40 to 250 m^3 per hectare of disturbed area. Sediment storage/impoundment ponds are normally designed at 1 m depth with a design volume ranging from 150 m^3 per hectare of disturbed area (minimum) to 250 m^3 per hectare (recommended). It is assumed that vegetation will be established within one to two years of land disturbances or that there will be at least one clean out of the sedimentation facilities per year. If neither is performed, a storage volume of 250 m^3/ha (whenever possible) is recommended for sensitive areas. If 250 m^2/ha cannot be achieved due to restricted space availability, the minimum storage that should be considered in the absence of site-specific design information is 150 m^3/ha. Smaller ponds may be feasible in those parts of the NWT will low rainfall erosivity (see Table 6.1), but the design should be supported by runoff estimates using the Rational Method (Appendix E) or another suitable method.

6.5 Examples for Estimating Site Erosion Potential

Examples using the RUSLE for determining the soil erosion potential are presented in Appendix H as Examples H.1, H.2 and H.3.

6.6 Site Evaluation

Once a site assessment has been completed, the information should be summarized to provide a complete summary evaluation of the slope and drainage conditions. The site evaluation is a critical step in the preparation of an erosion and sediment control plan and the summary information should be clearly indicated on drawings and supporting documents.

[6] Empirical: Information acquired by means of observation or experimentation

6.6.1 Slope Analysis Summary

The slope conditions to be exposed should be assessed to estimate the potential sediment loss from a site. Exposed areas generally include all cut and fill slopes as well as large stockpiles and non-dugout borrow sources. It may be necessary to divide a slope area by drainage breaks and/or soil type. A representative value for each of the following parameters should be indicated on the ESC Plan drawings and supporting documents:

- Soil Type: Each distinctly separate soil type should be delineated by area on the site plan. Where distinct soil type boundaries are not known or cannot be inferred, estimations of soil type areas are acceptable. Information from the site assessment is helpful in defining the various soil types by area. Additional information gathered during construction can be used to update the soil type areas.
- RUSLE Factors: The RUSLE factors (R, K, LS, C, and P) as defined in Section 6.2 should be summarized for the general conditions of the site and for the specific conditions for each distinctly separate soil/ slope area to be encountered on the site.
- Site Erosion Potential / Hazard Class: Using the RUSLE factors, the soil erosion potential (tonnes/ha/year) should be estimated for each distinct area and period of anticipated construction activity. For the soil loss estimated for a particular site, the associated hazard classification can be obtained from Table 6.2.
- Permafrost: Areas with permafrost should be shown on the site plan.
- Special Sites: Any sites of special consideration should be indicated on the site plan, such as locations of potential slope instability, seepage, or borrow sources.

6.6.2 Drainage Analysis Summary

As a minimum, proponents should complete a summary of the drainage conditions to be encountered and included as information on the ESC Plan drawings and support documents.

- Drainage Catchment Areas: A topographic site plan of the construction site and contributing drainage catchment area(s) needs to be divided into smaller drainage areas based on topographic breaks in slope. Then, for each drainage area identified, an estimate of size in hectares (ha) should be provided. Where the site has to be re-graded to final elevations, the direction of sediment-laden flow could change. Overland flow routes, for both initial and final site grade conditions, should be checked to ensure that appropriate on-site and downstream environmental effects have been evaluated.
- Watercourses: If not already shown on the topographic site plan, all watercourses should be identified and labelled. Watercourses consist of all areas of channelized flow (i.e., rivers, streams, creeks, ditches), as well as drainage collection features such as swamps, ponds and lakes. Design drawings should show all proposed ditch lines, catchments and crossings in addition to the natural drainage features including swales. Information on watercourses should extend beyond the limits of the construction site. As a minimum, drainage connectivity should be established to the nearest body of sensitive water downstream of the construction site.

- Floodplain Information: Where applicable, a clear definition of the floodplain limits should be shown on the drawings.
- Special Sites: Sites of special consideration (e.g., permafrost) should be indicated on the drawings.

6.6.3 Site Hazard Classification

Site hazard classification can be obtained from Table 6.2 below based on the estimate of site erosion potential (tonnes / ha / year).

Site Erosion Potential (tonnes / ha / year)	**Hazard Class**
< 6	Very Low
6-11	Low
11-22	Moderate
22-33	High
> 33	Very High

Source: Wall et al, 2002*

Table 6.2: Site Hazard Classification (RUSLE-FAC *)

6.6.4 Connectivity to Downstream Aquatic Resources

The location of the construction site with respect to downstream aquatic resources is a very important factor in preparing an ESC Plan. Establishing the connectivity of the construction site to downstream water supplies, flood control, fish habitat, navigation, and recreational activities can be conducted using information from the drainage analysis summary.

For the purposes of site evaluation, the most damaging, and therefore monitored, consequences from erosion and sedimentation are 1) the degradation of water quality and 2) the impact on fish habitat. The connectivity rating for each distinct segment on a construction site should be shown on the ESC Plan drawings.

The following table provides ratings based on connectivity to aquatic resources:

Connectivity Rating	Criteria[1]
Direct	Any sediment from a construction site may be transported directly downstream to locations where it may result in adverse effects to water quality or aquatic resources.
Indirect	Sediment laden water from a construction site empties into a secondary watercourse (i.e., stream, ditch, swale) before connecting with any stream with water quality or aquatic resource values. The secondary watercourse may be a non-fish habitat watercourse or a wetland with significant ecological value.
No Connectivity	For no connectivity, the sediment laden runoff flows into a non-significant[*] depressional area and sediment is trapped where water quality or aquatic resources are not a concern, or must terminate before connecting with any stream, or secondary stream, that may have water quality or aquatic resource values.

1 Criteria adapted from British Columbia Ministry of Forests (2001).

Table 6.3: Connectivity Rating to Aquatic Resources

[*] Assessment of the significance of a wetland or pond should be undertaken by an environmental specialist.

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7.0 EROSION AND SEDIMENT CONTROL METHODS

7.1 General

It is important to distinguish between erosion control measures and sediment control measures when preparing an effective erosion and sediment control plan. The difference between erosion and sediment control methods is defined and summarized for the purposes of this document and all related activities on construction sites as follows:

- **Erosion Control** is the process whereby the potential for erosion (displacement of solids by wind, water or ice), is minimized; and
- **Sediment Control** is the process whereby the potential for eroded soil being transported and/or deposited beyond the limits of the construction site is minimized. In this document, the term "sediment control" is synonymous with sedimentation control.

Erosion control is the primary means for preventing the displacement of soils and the subsequent degradation of downstream aquatic resources; sediment control should be viewed as the contingency plan. Most erosion control measures are initiated to implement early re-vegetation as the erosion control method. Primary emphasis must be placed on erosion control, particularly in areas of elevated erosion potential where fine particles are exposed during construction that will not readily settle out in a practical time frame. However, measures to address both erosion control and sediment control are required for most sites.

The design of erosion and sediment control measures should be viewed as a flexible process that responds to new information that is obtained throughout the construction phase and changes to the construction environment. As such, the design of temporary and permanent erosion and sediment control measures should be expected to evolve throughout construction to varying degrees based on site conditions and field performance of the implemented measures.

Erosion and sediment control measures are classified into the following categories:

- Planning Strategy and Procedures ;
- Temporary measures;
- Permanent measures; and
- Best Management Practices (BMP).

Each of these categories and BMPs are described in the following sections.

7.1.1 Temporary and Permanent Control Measures

Erosion and sediment control measures can be classified into two broad categories:

- Temporary Measures: Those measures implemented during the construction phase that will be removed once permanent measures are installed and/or vegetative cover is established; and
- Permanent Measures: Measures incorporated into the overall design to address long-term, post-construction ESC.

Temporary ESC measures should be installed at the start of the construction phase. Additional measures will likely need to be installed throughout the construction phase. Permanent ESC measures can be installed during or at the end of the construction phase.

A listing of ESC control BMPs are presented in Tables C-1, C-2 and C-3 in Appendix C. Examples of temporary measures include top-soiling, seeding, slope texturing, synthetic permeable barrier, mulching, Rolled Erosion Control Product (RECP) coverings, silt fence, rolls, wattles, and straw bale barriers. Examples of permanent measures include diversion ditches, energy dissipaters, berm interceptors, gabions, rock check dams, sediment ponds/basins, etc. Dependent on site conditions, some temporary measures will be retained for a longer time to increase its life span to near permanent. Stream bank protection BMPs are included (Table C-4) in Appendix C.

7.2 Planning Strategy and Procedures

Planning Strategies and Procedures (Table C-5) in Appendix C are often called minimum requirements which are non-structural methods or procedures that can reduce erosion and sediment transport. Proper planning generally constitutes the minimum requirement for preparing an ESC strategy. Proper construction planning includes implementing erosion or sedimentation control BMPs early in construction and recognizing the impact of different seasons on construction sites (e.g., rainfall, snow melt, and freeze-thaw). Various methods of scheduling construction activities can provide the first, best opportunities to help minimize the potential for erosion and sedimentation. However, the minimum requirements are generally not sufficient on their own. As such, many construction projects require site specific ESC measures to be implemented as site conditions dictate. The effectiveness of the ESC measures on a site is highly dependent on proper implementation of a well prepared ESC Plan.

The minimum requirements for planning strategies and procedures for an erosion and sediment control plans are presented in Table 7.1.

7.2.1 ESC Management Based on Diligence and Understanding

Project managers must recognize that successfully implementing ESC measures requires a good understanding of ESC principles and process by design and field staff. Selecting ESC mitigation measures to match the specific site, installing BMPs correctly, and conducting routine maintenance of ESC mitigation measures are essential aspects of ESC management. The planning strategies and procedures and the BMPs presented in this document are as important as the understanding of the implementation principles to achieve good construction performance and protect the environment.

The objectives of the ESC measures begin with education and interaction amongst them project team. This iterative process continues throughout the planning, design, construction and post construction stage of the project.

Table 7.1: Planning Strategies and Procedures for ESC Plans

Planning Strategy or Procedure	Applications: Slopes	Applications: Ditches & Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
Minimize Exposed Soils	✓	✓	✓	✓	• Decreases erosion potential; • Decreases area of erosion and sediment control measures required, thus decreasing costs.	• Requires planning and organization of sub-contractors (project phasing); • May require permanent controls be completed on some areas prior to new areas being stripped.
Observe Environmental Timing Restrictions	✓	✓	✓	✓	• Minimizes potential negative impacts on fish and wildlife. • May minimize permitting requirements (e.g. remaining outside of spawning or other critical periods) • Avoid nesting periods	• May affect project schedule.
Maximize Work During Favourable Weather	✓	✓	✓	✓	• Minimizes work in wet soil conditions; • Minimizes amount of storm water to handle or treat on disturbed portion of site; • Promotes seeding (vegetation establishment before wet season and allow establishment in fall for erosion control in late spring).	• May require additional labour and resources to increase scale of production / construction.

Table 7.1: Planning Strategies and Procedures for ESC Plans

Planning Strategy or Procedure	Applications				Comments	
	Slopes	Ditches & Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
Protect Permafrost	✓	✓	✓	✓	• Minimizes saturated soils and runoff water; • Reduces long term melting and potential structural damage or slope failure; • Reduces long-term maintenance costs; • Minimizes slope failures along ditches and side cuts.	• Room required to stockpile fibrous organic material (insulation) for redistribution; • Minimizes amount of construction area exposed at one time; • Requires pre-planning and scheduled construction operations; • May require increased drainage structure planning.
Scheduling of Work	✓	✓	✓	✓	• Sets targets for: good housekeeping; earliest construction and installation of erosion and sediment controls; the most preferred work period (dry versus rainy seasons, outside of fisheries windows); preferred timing for topsoil stripping to minimize soil exposure and for protection of permafrost, where applicable; and, opportunities for topsoil and seeding to be completed during rather than following the end of construction; • Avoids conflicts and delays in construction operations and set timeframes for sub-contractors; • Sets target deadlines.	• May require construction to be completed in one area before starting in another.
Implement BMPs Early	✓	✓	✓	✓	• Minimizes erosion and reduces soil loss and potential impacts downslope during construction.	• May need scheduling to avoid conflicts with machine activities.
Avoid Wet	✓	✓	✓	✓	• Minimizes erosion potential;	• Shutdowns may prolong/delay

Table 7.1: Planning Strategies and Procedures for ESC Plans

Planning Strategy or Procedure	Applications: Slopes	Applications: Ditches & Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
Weather Periods					• Minimizes soil disturbance and mud tracking.	construction activities.
Direct Surface Water Flow Around Site	✓	✓	✓	✓	• Keeps clean water clean; • Keeps surface water off-site and from causing erosion and sedimentation; • Minimizes the amount of water to be handled on site.	• New diversion structures may require erosion and sediment control measures to be implemented; • Need to be identified and planned for prior to main construction start-up.
Avoid Ponding Water		✓	✓	✓	• Minimizes saturated soils; • Minimizes permafrost melt; • Reduces erosion and potential sedimentation downslope.	• Increased drainage controls (structures) required.
Topsoil and Seed	✓	✓	✓		• Covers exposed soil and reduces erosion potential; • Promotes early revegetation efforts. Use of local native seed will promote revegetation with endemic plants able to survive local conditions; • May provide nutrient source for soils.	• Revegetation is seasonal and erosion may occur before plant growth; • Topsoil supplies may be limited in some areas; • Imported (hauled from other sites) topsoils may contain weed seeds.
Surface Roughening (Slope Texturing)	✓		✓	✓	• Reduces erosion: on fine grained soils, estimated 12% for a dozer ripping on the contour, 52% for track walking up and down the slope, 54% for sheep's foot rolling, and 76% for imprinting (Mike Harding, 2010).	• Equipment may need to be scheduled specifically for this task.

Table 7.1: Planning Strategies and Procedures for ESC Plans						
Planning Strategy or Procedure	**Applications**				**Comments**	
	Slopes	**Ditches & Channels**	**Large Flat Surface Areas**	**Borrow and Stockpile Area**	**Advantages**	**Limitations**
Preserve and Use Existing Drainage Systems	✓	✓	✓	✓	• Minimizes exposed soils and potential erosion in drainage system; • Helps keep clean water clean.	• Requires planning; • May affect scheduling of certain construction activities.
Control Construction Traffic				✓	• Avoids unnecessary heavy traffic in sensitive areas or areas with increased disturbance; • Avoids unwanted soil compaction.	• Forcing traffic into localized areas may increase disturbance or compaction in high-traffic areas.
Signage	✓	✓	✓	✓	• Clearly labelling sensitive zones or areas not to be disturbed identifies restrictions/boundaries for machine operators and other workers; • Helps avoid damages to protected areas or clean water areas; • Identifies hazards for machines and equipment.	• Signage methods and locations will need planning to avoid conflict with operations.
Stockpile Control				✓	• Stockpiles are protected from wind and water erosion, and kept separate to avoid mixing of soils; • Watercourses and environmentally sensitive areas are protected, while piles are close enough to minimize cost for re-application.	• May result in longer haul distances; • Planned for location, number of piles and separation methods; • Planned for reduced erosion and sedimentation.

7.3 Water Management Measures

Water management measures are those which can be implemented on-site or off-site to meet ESC Plan objectives. These measures are intended to control water and reduce erosion potential by following these general principles:

- Keep clean water clean, by temporarily or permanently diverting clean water around the construction or maintenance site and by conveying clean water from undisturbed areas within the site to natural receiving streams;
- Minimize the velocity of any flowing water on site (the erosive power of flowing water increases exponentially with velocity);
- Minimize watercourse disturbance by using existing undisturbed drainages where possible and by integrating on-site drainage into the project design;
- Anticipate and manage groundwater as required;
- Avoid ponding water and plan for increased drainage structures in wet areas;
- Identify areas where icing has previously occurred and anticipate new locations. Plan for multi-level drainage structures where icing is anticipated; and
- Identify permafrost in sub-soils, minimize exposure, plan for additional drainage structures and anticipate required protection strategies.
- If new drainage channels are needed to accommodate design discharges, consider the use of Natural Channel Design (NCD) principles for watercourse diversions. This approach to watercourse restoration and realignment reconstructs channels to match the natural physical form of the stream or drainage that would be appropriate for that location (Toronto and Region Conservation Authority 2009).

Commonly used water management measures are listed in Table 7.2, where the applicability of each to construction site ESC Plans is noted.

Table 7.2: Surface Water Management Measures for ESC Plans

Name	Slopes	Natural Channels	Drainage Channels	Pipes and Culverts	Large Flat Surface	Borrow / Stockpile	Comments and Measures	Temporary	Permanent
Divert Clean Water Around the Site	✓	✓	✓	✓	✓	✓	Clean water drainages from upstream areas should be diverted around the construction site wherever practical to reduce the quantity of water that must be managed on site. This can be done using lined ditches, berms, pipes or culverts.	✓	✓
Keep Clean Water on the Site Clean	✓	✓	✓	✓	✓	✓	Clean water drainages from undisturbed areas within the construction site should be collected and allowed to discharge to receiving streams using lined ditches, pipes and culverts as required, and protect drainage from sediment laden runoff.	✓	✓
Use Existing Drainage		✓	✓	✓			Existing watercourses that are well-vegetated have natural low rates of erosion. Discharges from the construction site containing minimum (close to natural) levels of sediment can be conveyed to existing, undisturbed watercourses. Care must be taken to ensure that peak flows in existing watercourses are not exceeded, as this may cause erosion damage and/or bank failure.	✓	✓
Integrate New Drainage into the Project Design		✓	✓	✓			Where necessary to construct new ditches or use pipes or culverts for on-site surface water management, integrate these features into the permanent project design, where appropriate, to prevent future disturbance due to removal of temporary measures.	✓	✓
Keep Drainage Areas Small	✓	✓	✓	✓	✓	✓	Smaller drainage areas generally require less complex erosion control measures and smaller drainage channels, so they are preferred if local topography permits. By discharging from a number of small discharge points rather than a few large ones, the size of sediment control measures is reduced and the magnitude of potential risk due to failure is reduced.	✓	✓
Design Drainage Channels Appropriately	✓	✓	✓				Drainage channels should be designed with appropriate depths, slopes, cross-sections and linings (armoured or vegetated). NCD is recommended for watercourse diversions.	✓	✓
Manage Shallow Groundwater	✓	✓				✓	Slopes, excavations and areas around retaining walls or tall cuts in fine-grained soil, may be sensitive to piping failure or erosion due to high porewater pressures. These can be managed by temporary dewatering or by incorporating permanent drains to reduce porewater pressures. Gravel blankets can also be installed to protect the ground surface. Dewatering wells, if properly screened, may produce clean water and be suitable for direct discharge to receiving streams.	✓	✓

Source: Modified from Transportation Association of Canada, 2005

7.4 Erosion Control BMPs

BMPs for erosion control are measures that have been proven to work on construction sites when these measures were properly planned and constructed. These measures reduce erosion potential by avoiding exposed soil duration, stabilizing exposed soil or reducing surface flow velocity. There are generally two types of erosion control BMPs included with the minimum requirements:

- Source Control BMPs for protecting exposed surfaces; and
- Runoff Control BMPs for controlling water.

Experience is an important component in the successful selection of the appropriate BMP(s) and in the design and implementation of an ESC plan. It is the designer's responsibility to select BMPs which are appropriate for site conditions.

7.4.1 Controlling Erosion at the Source

The protection of exposed surfaces from the erosive energy of rain splash and surface flows should be the primary goal when selecting appropriate control measures. The maintenance or establishment of vegetative ground cover is the single most effective method of erosion control. Ground cover can include placing topsoil in conjunction with one or more of the following common erosion control methods: seeding, mulching, hydro-seeding, sodding, erosion control blankets, turf reinforcement matting (TRM), and riprap or gabion mats.

Protection of permafrost is a required component of erosion control in northern sites. A covering layer of vegetation and fibrous organic matter naturally creates an insulating thermal layer to minimize permafrost melt and protect the soils from erosive factors of water. Removal of vegetation and the organic protective layer (stripping) should be minimized in permafrost zones. If surface organic material must be removed for construction, it should be stockpiled and re-applied where possible. Melting of permafrost may be detrimental to slope stability and soil structural integrity, resulting in slope or ground failure, and high maintenance and infrastructure costs.

An overview of appropriate BMPs for the protection of exposed surfaces with their respective advantages and limitations is presented in Table 7.3.

7.4.2 Runoff Control

During construction it is not possible or practical to provide surface cover for all disturbed areas. Commonly used methods for runoff control include: the diversion of water which is entering the site; the modification of slope surfaces; the reduction of slope gradients; controlling flow velocity; providing adequate or increased drainage;, diverting flows away from exposed soil areas; and providing adequate containment systems (ponds) for managing sediment laden runoff.

An overview of appropriate BMPs for the runoff control is presented in Table 7.4 with their respective advantages and limitations.

7.4.3 Biotechnical Erosion Control

Erosion control BMPs may involve the use of bio-technical erosion control methods, (sometimes referred to as “bio-engineering”) in combination with other BMPs; however it takes time for woody species to become established (usually 2-3 yrs.) and effective. Bio-technical erosion control methods are best considered as permanent erosion control measures that involve using the roots, stems and leaves of vegetation to reduce the potential for erosion. This is achieved by introducing plants with foliage that decreases impact erosion of rain drops, and plant rooting which anchor (bind) the soil and increase infiltration of moisture into the soil. As the plants grow, the strength of the bio-technical erosion control system strengthens and improves. Typically bio-technical erosion control is used to prevent erosion where there are environmental or aesthetic enhancement requirements; however, if properly selected and implemented, it will provide a simple and cost-effective measure for controlling long-term erosion problems.

Revegetation of exposed soil with local native grasses or plants combined with approved grass seed mixes is the main bio-technical erosion control method utilized in construction. Although native species are preferred the seed may be in short supply and alternative seed sources will need to be addressed.

For transportation projects, the designer should identify the need to establish the appropriate type of vegetation, whether trees/willows/shrubs or grasses/low height plants, since most transportation projects will have a safety/line of sight factor that must be considered. Planting tall plants will have maintenance implications, and the revegetated species may need to be mowed to maintain line-of-sight. There may also be concerns with wildlife foraging, migratory birds or riparian shade requirements which will need to be addressed on a site specific basis by the ESC Plan designer.

Table 7.3: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
18	Topsoiling (The application of topsoil over mineral soils to provide a growing medium for seeded vegetation and protect from surface erosion)	✓	✓	✓	✓	• Placing topsoil provides excellent medium for vegetation root structure development; • Organic content promotes plant growth; • Placing stockpiled organic material back on surfaces allows the reuse of these materials (topsoil or peat) stripped from the site at start of grading; • Absorbs raindrop energy to minimize erosion potential; • Insulates frozen soils and may reduce the amount or speed of the thawing process.	• Cannot be effective without seeding and allowing time for plant growth; Not appropriate for slopes steeper than 2H:1V (steep slopes will require geotextile, fabric or rolled erosion control product covering over topsoil and specialized design); • Dry topsoil is particularly susceptible to wind erosion; • Topsoil is susceptible to erosion prior to establishment of vegetation. • Areas with invasive species should be avoided if collecting topsoil.
15	Seeding (Introduction of seed for establishment of vegetation for permanent erosion protection)	✓	✓	✓	✓	• Inexpensive and effective erosion control measure once established; • Promotes even cover and controls seed distribution for higher plant densities as quickly as possible following construction; • Planting locally appropriate species helps reduce weed species establishment. • May be conducted as the project commences without waiting until the	• Requires a prepared surface; • May require soil amendments (topsoil, fertilizers) to be added to poor quality soils; • Grasses may require periodic maintenance (mowing); • Uncut dry grass may be a fire hazard; • Seeding on long steep slopes may be difficult; • Invasive species should be avoided; • Seasonal limitations for seed germination; • Preferred growing periods may not coincide

Table 7.3: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
						end of the job; • Effectiveness increases with time as vegetation develops; • Aesthetically pleasing; • Enhances terrestrial and aquatic habitat; • Can be used in conjunction with other permanent soil stabilization practices; • Can be applied by installing cocoa matting with embedded seed.	with a delayed construction schedule; • Freshly seeded areas are susceptible to runoff erosion until vegetation is established; • Reseeding may be required to achieve adequate densities; • May attract wildlife thereby creating hazards for the travelling public
16	Mulching (Protective covering applied to protect exposed soils from erosion and protect seed during germination)	✓	✓	✓	✓	• Used alone to protect exposed areas for short periods; • Protects soil from rain splash erosion; • Preserves soil moisture and protects germinating seed from temperature extremes; • Relatively inexpensive measure of promoting plant growth and providing slope protection; • Can utilize vegetative material through on site chipping/mulching and spreading.	• Application of mulch on long steep slopes may be difficult; • May require additional specialized equipment to apply; • Some mulch types may deplete available soil nitrogen; • Slow release fertilizer may need to be added.

Table 7.3: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
17a 17b	Hydroseeding / Hydromulching (Seed and mulch mixed with water for application by truck for revegetation and protection of exposed soils)	✓	✓	✓	✓	• Economical and effective on large areas; • Conforms to uneven surfaces; • Retains moisture; • May contain added soil amendments to promote germination and establishment of vegetation; • Mulch with tackifier may be used to provide immediate soil protection until seed germination and vegetation is established; • Allows vegetation of steep slopes where conventional seeding/mulching techniques are very difficult; • Relatively efficient to operate; • Provides wind erosion control.	• Site must be accessible to hydro-seeding / hydromulching equipment (usually mounted on trucks with a maximum hose range of approximately 50 m); • May require subsequent application (reseeding) in areas of low densities as part of maintenance program. • Invasive species should be avoided
19	Soil and Root Mat Replacement (Sodding) (Used where sod mat has been harvested during stripping to be re-applied to protect sensitive sites and insulate soils in permafrost areas.	✓	✓	✓	✓	• Immediate protection for sensitive areas from water and wind erosion; • Aesthetically pleasing. • May contain local seed within fibrous mat	• Expensive due to time required for removing, retaining and replacing the soil and root mat; • Labour intensive to remove and replace; • Soil and root mat may not be readily available; • Soil and root mat cannot be stored on-site for long periods of time. • Harvesting soil and sod in areas with invasive species should be avoided

Table 7.3: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
9	Riprap Armouring (Application of rock lining to provides protection to soils in ditch lines, down-drains, stream channels and slopes)	✓	✓	✓		• Most applicable as a surface soil lining for drainage ditches and down-drains with underlay, and in stream channels without use of fabric underlay • Used for soils where vegetation not easily established or where permanent protection is immediately required; • Effective for high velocities or concentrations; • Permits infiltration; • Dissipates energy of flow from culvert inlets/outlets or other water discharge points; • Easy to install and repair; • Very durable and virtually maintenance free. •	• Expensive; • May require heavy equipment to transport and place rock; • May not be feasible in areas where rock is not readily available; • May be labour intensive to install; • Riprap is usually thicker than gabion mattress requiring additional depth in the channel to be considered in planning.
8	Rolled Erosion Control Products (RECP) (manufactured product used to protect soils from raindrop erosion, and protect seed	✓	✓			• Provides an immediate protective covering to bare soil or topsoil applied to a surface; • Can be used in conjunction with seeding; • Can be more uniform and longer lasting than mulch; • Wide range of commercially available	• Labour intensive to install; • Not suitable for rocky slopes; proper site preparation is required to seat RECP onto soil correctly (requires good soil contact); • Temporary (degrades over time) dependant of type and quality; • Temporary blankets may require removal prior to restarting construction activities.

Table 7.3: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
	during germination)					products; • Natural product choices available; • May be used for temporary cover protection.	
10	Cellular Confinement System (manufactured product applied to soil surface to reduce rill erosion and provide stabilization of surface soils)	✓	✓			• Lightweight; • Easily installed; • Uses locally available soils for fill to reduce costs.	• Not commonly used in transportation construction projects; • Expensive; • Installation is labour intensive (hand installation); • Not suitable for slopes steeper than 1H:1V.
22	Crushed Rock Buttress for Slopes (Permafrost) (Application of crushed rock to support slope surface material during melt events)	✓				• The cut slope can be rapidly prepared and buttressed to provide support and ensure continued thermal insulation; • Local rock and aggregate materials can be used, if crushing facilities are available; • When ground ice melting occurs, the wetted soils will be held by the buttress and drainage can occur, to increase overall soil stability.	• Obtaining sufficient crushed rock or coarse aggregate for the buttress may be difficult in permafrost areas; • The buttress will require maintenance and replacement of failed buttress material.

Table 7.3: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
23	Controlled Melt of Cut Slope (Permafrost) (controls natural melting of ice within a slope until slope stabilizes)	✓				• Where no other project configuration is possible to avoid permafrost with high ground ice, this BMP allows controlled melting of the ground ice and stabilization of the cut slope over the long term; • The separation berm can be constructed of local materials if available.	• Construction of the separation berm requires consideration and use of an overflow drainage feature (armoured notch) for extreme rain events or high runoff from snowmelt. Other drainage systems, such as standpipes, may be considered; • Light coloured crushed rock or aggregate will be required for the separation berm to limit thermal degradation of permafrost; • The receding soil failure at the cut slope will require time to come to a slope gradient in balance with water, soil and thermal conditions.
24	Insulated Thermal Blanket on Cut Slope (Permafrost) (application of thermal materials over slope or ground section to reduce/prevent permafrost melt while allowing natural drainage)	✓				• The thermal blanket material can be obtained locally; • The cut slope may regress back from ground ice melt over time but the blanket material will shift and conform to the underlying slope surface, providing support and thermal protection; • For cut slopes with ground ice and in permafrost areas, the cut slope can be prepared at a steep gradient, preserving the natural vegetation and organic deposit cover, and a thermal blanket can be placed over the cut	• Melting of ground ice and permafrost is usually progressive, resulting in loss of soil strength and volume, and may cause retrogressive slope failure behind the blanket; • Climate change with a slow increase in average air temperature, is causing general increase of ground temperatures, melt of permafrost, especially along the belt of discontinuous permafrost where the permafrost is thin, at shallow depth and at a temperature not far below freezing.

Table 7.3: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications: Slopes	Applications: Ditches and Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
						slope to reduce ground ice melting and allow water drainage.	
20a	Live Staking (Planting of live cuttings to promote growth of woody vegetation for the purpose of promoting fast establishment of leafy woody vegetation to protect exposed soils from raindrop erosion and bind soils through rooting networks)	✓		✓		• Establishes vegetative cover and root mat; • Once established, vegetation may reduce flow velocities; • May trap sediment laden runoff; • Aesthetically pleasing once established; • Grows stronger with time and root structure development; • Usually has deeper root structure than grass; • Rooting promotes water infiltration; • Planting conducted without large equipment; • Available local native species may be used; • May be used in conjunction with other practices for riparian remediation and stream bank stabilization on water crossings.	• Expensive to install if stock not readily available; • May be labour intensive to install; • Not commonly used in linear construction projects; • Revegetated areas are subject to erosion until plants are established; • Plants may be damaged by wildlife; • Watering may be required during dry season until plants are established. • May interfere with sight lines for linear projects. • Matured staked species may be considered a liability on some sites (airport lands) • May become protected habitat under Migratory Birds Convention Act. • May provide habitat for wildlife close to areas used by traffic.

Table 7.3: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
21	Riparian Zone Preservation (Retention of natural vegetation within a riparian area to provide natural filtration of sediments and reduce runoff velocity)	✓	✓	✓	✓	• Natural vegetation buffer to filter and reduce runoff velocity by dissipating flow; • Most effective natural sediment control measure; • Promotes infiltration which may reduce volume of runoff.	• Planted vegetation requires substantial periods of time before they are as effective as established vegetation at controlling sediment; • Not intended for heavy sediment load filtration, high volume discharge or as a sole source for construction runoff control. • May not be deemed to be an acceptable addition to the highway right of way (line of sight obstruction at maturity of staked species). • May become protected habitat when vegetation matures and provides habitat for wildlife and/or migratory birds.
25	Scheduling (Used to promote the scheduling of events to minimize the exposure of soils to unfavourable weather conditions, plan site activities including the installation of BMPs)	✓	✓	✓	✓	• Promotes efficient, orderly construction of BMPs; • Identifies potential protection issues related to construction timing and seasonal climatic conditions; • Identifies fish sensitive periods which may be avoided; • May minimize the amount of soil exposure thereby reducing erosion potential; • Identifies need for early installation of perimeter control for sediment	• Needs to be flexible and revisited as construction progresses; • May require amendment in the event of delays in construction.

Table 7.3: Erosion Control Measures – Source Control							
BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
						entrapment and runoff control measures; • Provides timelines for permitting, in-stream works, and early vegetation establishment; • Allows for scheduling of equipment, delivery of supplies, and subcontractor deployment	
28	Compost Blanket (application of composted materials as a blanket to cover exposed soils to protect form erosion)	✓		✓	✓	• Economical if readily available; • Appropriate on slopes 2H:1V to level surface; • Provides nutrient base as soil amendment.	• Application on steep slopes (>2H:1V) may be difficult; • Treatment area should be accessible to blower trucks. • May not be readily available; • May not be authorized for use near or upslope of watercourses
2	Gabions (Manufactured metal basket or blanket which can be filled with cobbles for the construction of slope structures, velocity reduction structure and channel or ditch bed stabilization)	✓	✓			• Provides stabilization for steep slopes or reinforced channels in streams, rivers or creeks; • Can be used as mats for run out below ditch blocks or culvert inlets/outlets; • Can be designed to be used with compacted soil fill for areas requiring vegetation walls	• Should be used with caution within stream beds. Not a preferred treatment for fisheries sensitive areas. • May require design by Qualified Professional; • May be expensive and labour intensive • May have limited lifespan dependent on the quality and coating applied to the materials used.

Table 7.3: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
38	Stream Diversion Channel (Man-made channel constructed to divert a stream around or through a construction site to protect water quality and provide a dry work area)		✓			• Protects environmentally sensitive areas; • Conveys flow consistency better than a dam, impoundment and pumping; • Not at risk of power failure or malfunction (e.g. pumps); • Maintains fish passage; • Diverts surface flows from entering the site or limits flow to specific area of the site	• Requires erosion protection; • Risk of export of sediment downstream if not properly staged; • Requires fish exclusion and fish salvage if working on a known or suspected fish-bearing stream. Permits may be required; • In-stream work windows are regulated by agencies and must be adhered to.
39	Coffer Dam (Man-made dam structure used to direct water around or out of a work area [e.g. metal sheet piling, sand bags, straw bales, aqua dam, etc.) to provide a dry work area and protect water quality.		✓			• Protects environmentally sensitive areas by limiting the work site area; • Diverts all or a portion of a stream or surface water flows around a site to maintain downstream flows; • Permits work to be conducted "in the dry" to minimize downstream sedimentation • May divert up to 2/3 of watercourse without significant impact to fish passage • Used to control erosion by keeping water out of the work site	• Used only to divert water- not used as a barricade which causes ponding; • Requires monitoring and maintenance; • Risk of export of sediment downstream • Used in areas of shallow flow depth (usually less than 1.2 m unless designed by an engineer); • Height of the dam should provide protection for a 1 in 10 year event, if possible (height of dam to be less than 1.2 m unless designed by an engineer); • All debris and accumulated sediment inside the work area must be cleared away before removal of the coffer dam; • Operations within the work area must be capable of withstanding flooding without risk

Table 7.3: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications: Slopes	Applications: Ditches and Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
							to life and equipment damage; • May require authorization for in-stream works, fish exclusion and fish salvage on fish-bearing streams. Permits may be required; • In-stream work windows are regulated by agencies and must be adhered to. • Requires contingency planning for flooding or groundwater infiltration.

2 Adapted from Alberta Transportation (2011).

Table 7.4: Erosion Control Measures – Runoff Control

BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
27	Slope Texturing (the roughening of surface soils to promote infiltration of water, trap seed, and reduce velocity and rill development on slopes through contouring or the use of horizontal machine track patterns)	✓		✓	✓	• Roughens slope surface to reduce potential erosion and sediment yield and promotes infiltration; • Suitable for clayey soils; • Contouring and roughening (tracking) of slope face reduces runoff velocity and increases infiltration rates; • Reduces erosion and collects sediment better than smooth surfaces; • Captures and holds water, seed and mulch, which promotes vegetation growth.	• Must be planned cost included in grading; • May cause sloughing in sensitive (wet) soils, • Tracking may compact soil, • Provides limited erosion control and should not be used as primary control measure; • Not suitable for silty and sandy soils; • Not practical for slope length <8 m for bulldozer operation up/down slope; • Not suitable for permafrost areas.
14	Diversion Ditch (Used to divert water from entering a construction site or through a site, may be used to divert water out of a ditch line)	✓	✓	✓	✓	• Intercepts and diverts water from the top of a slope away from disturbed soil areas to reduce downslope erosion; • May be incorporated into permanent project drainage systems using natural channel design. • May be used to temporarily divert a stream to permit culvert installation	• Channel must be sized appropriately to accommodate anticipated flow volumes and velocities; • Lining may be required; • May require design by qualified personnel; • Must be graded to minimize ponding.

Table 7.4: Erosion Control Measures – Runoff Control							
BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
11	Energy Dissipater (structure used to reduce the speed at which the water flows to reduce erosion and/or promote sediment deposit)	✓	✓			• Slows runoff velocity and dissipates flow energy to minimize erosion potential in relatively short distances; • May collect sediment due to reduced runoff velocities;	• Small diameter rocks can be dislodged; • May be expensive if rock has to be hauled in; • Grouted riprap armouring may breakup due to hydrostatic pressures, frost heaves, or settlement; • May be labour intensive to install; • May require design by qualified professional.
13	Slope (Down) Drains (Pipe structure which directs water from the top to the base of a slope)	✓				• Directs surface water runoff into drain pipe or lined channel and delivers to base of slope; • Protects exposed soils on the slope face from erosion causing rilling or gullying.	• Must be sized appropriately to accommodate anticipated flows; • Erosion can occur at inlet/outlet if protection is not installed; • Requires incorporation into permanent design; • Slope drain pipe must be anchored to slope.

Table 7.4: Erosion Control Measures – Runoff Control

BMP #	BMP Name	Applications: Slopes	Applications: Ditches and Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
2	Gabions (Gabion Baskets may be used beneath a perched culvert or steep drop to protect the soils from erosion as it drops from a height above, Gabion blankets may also be required to protect the run-out area beneath the structure)		✓			• Relatively maintenance free, permanent drop structure; • Long lasting; • May be less expensive than riprap; • Allows smaller diameter rock/stones to be used; • Relatively flexible; • Commercially available products; • Suitable for resisting high flow velocity.	• Construction may be labour intensive (hand installation); • Extra costs associated with gabion basket materials; • May be expensive if rock is not available in local area.
3	Berm Interceptor (Soil berm constructed of local material to intercept and redirect water flows, or build containment ponds)	✓		✓	✓	• Easy to construct; • Relatively inexpensive as local soil and material is used.	• Qualified Professional design required for fill heights in excess of 3 m; • May not be suitable for all soil types or sites; • Riprap spillway and/or permeable outlet may be required.

Table 7.4: Erosion Control Measures – Runoff Control

BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
5	Rock Check Dam (Structure constructed of rock to slow water usually within a ditch line. May be used on slopes <9% with angular rock large enough to withstand velocity of the water flow)		✓		✓	• Permanent or temporary small, velocity control structure for steep (<9%) drainage channels; • Reduces grade length between structures; • Cheaper than gabions or armouring entire channel; • Easily constructed;	• Can be expensive in areas of limited rock source; • Not appropriate for channels >8% slope or draining areas larger than 10 ha; • Requires ongoing maintenance (particularly after high flow storm events); • Can fail if water undermines or outflanks structure or rock is not sized correctly for water velocity and volume; • May cause flooding during spring melt or when combined with icing conditions; • Maintenance costs increase for ditches when permanent
6	Synthetic Permeable Barriers (Manufactured product used to reduce flow velocity in small areas and for low flow situations, Re-usable and/or moveable)		✓			• Reusable/moveable; • Reduces flow velocities and dissipates flow energy which reduces some sediment; • Used as grade breaks in conjunction with sturdy permanent drop structures along steep grades.	• Not to be used as check structures; • Only suitable for small drainage areas (< 0.8 ha) and low-flow velocity; • Must be installed by hand in conjunction with RECP; • May become brittle in winter and are easily damaged by construction equipment or recreational vehicles; • Only partially effective in

Table 7.4: Erosion Control Measures – Runoff Control

BMP #	**BMP Name**	**Applications: Slopes**	**Applications: Ditches and Channels**	**Applications: Large Flat Surface Areas**	**Applications: Borrow and Stockpile Area**	**Comments: Advantages**	**Comments: Limitations**
							retaining sediment. • Must be maintained and, eventually, removed, so may require an extra mobilization to site. •
29 30	Rolls (Coir) Wattles (Manufactured materials or natural) (Used on fill or cut slopes to reduce runoff velocity, provide small slope breaks to permit infiltration and promote vegetation establishment.)	✓				• Function well in freeze-thaw conditions; • Low-cost solution to sheet flow and rill erosion on slopes; • Low to medium cost flow velocity control and silt trap; • Can be used on slopes too steep for silt fences or straw bale barriers; • Biodegradable manufactured types available. • Wattles can be made of willow or other local vegetation	• Labour intensive to install (hand installation); • Designed for slope surfaces with low flow velocities; • Designed for short slope lengths with a maximum slope of 2H:1V;

7.5 Sediment Control Best Management Practices (BMPs)

BMPs for sediment control are measures that are included have been used under various conditions throughout North America and are proven measures which minimize impact to the environment from construction sites, when the measures were properly planned and constructed. These measures reduce off-site sediment delivery by promoting the reduction of sediment before surface water is allowed to leave the construction site. There are generally two types of sediment control methods that can be used:

- Filtering and entrapment; and
- Impoundment.

An overview of appropriate sediment control BMPs is presented in Table 7.5 with their respective advantages and limitations. As with erosion control BMPs, experience plays an important role in the selection of appropriate BMPs, and the design and implementation of an erosion and sediment control plan. It is the designer's responsibility to select the sediment control BMPs that match site conditions.

7.5.1 Filtering and Entrapment

Soil particles suspended in surface water can be filtered through porous media consisting of natural and artificial materials (i.e., vegetative strips, stone filters, man-made fibre filters). Filtering can be effectively applied to concentrated small volumes of flow at inlets of permanent or temporary drainage systems and outlets of sedimentation ponds. This application requires careful maintenance to ensure continued effectiveness as sediment can clog these filters during storm events and/or during prolonged use.

Filtering is most effective when applied to non-concentrated (dispersed) sheet flow as a linear measure placed perpendicular to the direction of flow. Stream banks and the perimeter of regions of high-erosion potential are typical sites where filtering BMPs are employed for sediment control.

The most commonly used entrapment method is a silt fence. Sediment fencing is more effective for trapping particle sizes of fine and medium sand to coarse silt, depending on the mesh size used, and for low flow velocity (<1.0 m/sec) and gentle grades (<3%). Sediment fencing does not capture silt or clay sized particles as they are too small and will pass through the weave of the fabric. This method should only be used when there are **low runoff flow rates and volumes**; otherwise, its effectiveness will decrease and the system can be undermined, overtopped, or breached on the sides. Too much flow volume or velocity or too much sediment buildup may cause the fence to fail and fall over under the pressure.

Check dams constructed from coarse granular material may be used on a steeper gradient (3% to 8%) where high flow velocity or volumes are anticipated. These larger structures should be designed by a qualified person.

A sediment control plan may involve the use of bio-technical erosion control methods (bioengineering) for filtering. Bio-technical erosion control methods are considered permanent sediment control measures that involve using vegetation to reduce flow velocities. This strategy promotes controlled sedimentation by slowing the flow velocity which allows the sediment to settle out and allow it to be retained within the construction site. The denser the vegetation cover and the larger the stems or leaf size (obstructions) within the flow path, the greater the reduction in the flow velocity will be.

7.5.2 Impoundment BMPs

The temporary impoundment of sediment-laden surface water reduces flow velocity which allows sedimentation. However, sedimentation may take a long time if the suspended sediments contain a significant portion of clay/colloidal or organic particles. This technique is normally applied to **concentrated flow** within the permanent or temporary drainage system of a construction or maintenance site.

Permanent basins and traps should be avoided in areas of permafrost as ponding of water will contribute to increased rates of permafrost melt or degradation.

Common types of impoundment structures are:

- Sediment basins are designed for a large (>2.0 ha) runoff area;
- Sediment trap is designed for a small (<2.0 ha) runoff area; and
- Temporary barriers (synthetic weave barrier, rock check) along ditches or the toe of a slope.

The design of sediment containment is discussed in Section 12. A number of variations to the basic design can be used ranging from relatively small single basins to multiple interconnected basins. Containment basins and traps are to be designed by a Professional Engineer if the consequences of failure warrant (e.g., if there are risks to ecological values, property, or human health).

Ideally, impoundment basins should be located within the site near the sediment source. Roadside ditches and old drainage channels can also be used as sediment impoundment areas upon installation of permeable or impermeable berms. Sediment traps/basins should be installed near the perimeter of the site to prevent off-site sediment delivery. Sedimentation traps/basins may be constructed by excavation and/or earth dyke construction, together with installation of a granular berm as an outlet flow structure.

Where at all possible, the height of dykes or dams constructed to form impoundments should be kept as low as possible to assist in mitigating potential hazards due to a failure. If correctly constructed and well maintained, sediment basins and traps can be an effective means of minimizing the quantity of sediment that is transported off-site. Regular maintenance and sediment removal will be required to ensure that adequate capacity and drainage is maintained.

Extended detention ponds allow runoff to be detained through slow release rates. Detention allows the finer sediment to settle out. Due to the slow release, these ponds are generally designed to be dry between runoff events. Clogging of the outlet is a real potential due to the slow release rate and should be designed with a protective device, regularly monitored and maintained.

Table 7.5: Sediment Control Measures

	BMP Name	BMP #	Applications: Slopes	Applications: Ditches and Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
Filtering and Entrapment	Riparian Zone Preservation	21	✓	✓	✓	✓	• Well established vegetation buffer will filter and slow runoff; • Most effective natural sediment control measure.	• May not be feasible to retain; • Not practical for large flow volumes, high velocities, or too much sediment • Damage to riparian vegetation may occur if too much sediment is deposited; • Not able to be cleaned or maintained; • Newly planted riparian zones require substantial periods of time before they are effective at controlling sediment. • Within a right of way, riparian areas can become areas where wildlife will stage before crossing the highway.
Filtering and Entrapment	Straw Bale Barrier	7		✓	✓	✓	• Biodegradable; • Less expensive; and • Easier to install than other barriers.	• Labour intensive to install; • Short service life due to biodegradation; • Straw bales are not readily available across most of the NWT; • Maximum barrier height of one straw bale; • May require extensive maintenance after high flow storm events; • Require proper keying and staking.

Table 7.5: Sediment Control Measures

BMP Name		BMP #	Applications				Comments	
			Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
	Rolls (Fibre) Coir or Wattles (Manufactured materials)	29	✓				• Function well in freeze-thaw conditions; • Low cost solution to sheet flow and rill erosion on slopes; • Low to medium cost flow control and silt trap; • Can be used on slopes too steep for sediment fences; • Biodegradable.	• Labour intensive to install (hand installation); • Designed for slope surfaces with low flow velocities; • Designed for short slope lengths with a maximum slope of 2H:1V;
	Wattles (Live) (Usually collected live local material is used and bundled to make rolls or wattles)	30	✓				• Function well in freeze thaw conditions; • Solution for sheet flow and rill erosion near water bodies; • Can be used on slopes too steep for sediment fences; • Materials for construction may be immediately available; • Biodegradable – Live; • Improved strength over time; • Flow control and sediment trap; • Aesthetically pleasing once established.	• Labour intensive to install; • Designed for low flow velocities; • Designed for short slope lengths; • May cause visual obstruction.

Table 7.5: Sediment Control Measures

BMP Name	BMP #	Applications: Slopes	Applications: Ditches and Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
Sediment Fence (manufactured fencing used to slow flow velocity, promote settling and sediment detention)	1	✓		✓	✓	• Economical; • Readily available from suppliers; • Easy to install; • Slows water to settle out coarse grained sediment; • More effective than straw bale barriers.	• May fail during high runoff events; • Applicable for sheet flow erosion only; • Limited to locations where adequate space is available; • Maintenance to remove sediment build up is required on a regular basis; • Damage to sediment fence may occur during sediment removal; • Usable life of approximately one year, after which removal and disposal is required.
Storm Drain Inlet/Sediment Barrier	4			✓		• Temporary measure; • Easy to install and remove.	• Limits drain inlet capacity; • Very limited sediment entrapment capacity; • Requires regular clean-out and maintenance; • May increase intake flows downslope or at next storm drain or cause flooding.

Table 7.5: Sediment Control Measures

	BMP Name	BMP #	Applications: Slopes	Applications: Ditches and Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
	Compost Blanket (compost spread in a layer over exposed soils to protect the site from raindrop erosion)	28	✓		✓	✓	• Economical if product readily available; • Appropriate on slopes 2H:1V slope or flatter • Natural fibers used to protect the site from raindrop erosion and protect seed during germination. • Provides nutrients for vegetation establishment • May be made from vegetation on site	• Application on steep slopes may be difficult; • Treatment area should be accessible to blower trucks. • May not be readily available if accessible material (vegetation) is not present • Trucking in material may make it too expensive
All BMPs	Scheduling (Planning of construction site activities including installation and maintenance of ESC measures)	25	✓	✓	✓	✓	• Identifies anticipated product requirements prior to start of construction (facilitates ordering and early delivery of necessary ESC products); • Identifies protection issues such as seasonal weather impacts (avoidance of heavy precipitation periods); • Identifies fish and wildlife restrictions (e.g. spawning periods and nesting) • Permits planning for efficient, early and orderly construction of BMPs; • Promotes early installation of perimeter control for sediment entrapment such as sediment ponds and sediment fencing.	

Table 7.5: Sediment Control Measures

	BMP Name	BMP #	Applications: Slopes	Applications: Ditches and Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
	Stream Diversion Channel (Diverts stream flow around a work site to re-enter the channel below the site)	38		✓			• Protects environmentally sensitive areas; • Conveys flow consistency better than a dam, impoundment and pumping; • Not at risk of power failure or malfunction (e.g. pumps); • Maintains fish passage. • Keeps clean water clean • May use plastic culvert for temporary water passage • Used to provide dry work area within a channel temporarily (e.g. culvert installation)	• Requires erosion protection; • Risk of export of sediment downstream if not properly staged; • Requires fish exclusion and fish salvage if working on a known or suspected fish-bearing stream. Permits may be required; • In-stream work windows are regulated by agencies and must be adhered to.
Impoundment	Sediment Traps/Basins (Constructed ponds which may be temporary or permanent in design. May require design by a qualified person)	12		✓			• May be constructed of a variety of materials; • Collects sediment laden runoff and reduces velocity of flow to allow deposition of sediment; • Can be cleaned and may be expanded if required; • Capable of being designed to handle large volumes of sediment laden runoff.	• “Last resort” measure; • Normally requires 250 m³ storage volume per ha of contributing area; • Can require large amount of area; • Requires monitoring of sediment in outflowing water and in sediment level; • Requires maintenance to remove sediment build up; • Requires design by qualified person; • Usually requires 'back-up' control measures in case trap/basin overflows or system becomes overloaded • May require back-up measures to address fine clays and silt sediment

7.6 Selection Considerations for Bio-technical Erosion Control Methods

The following should be evaluated when bio-technical erosion control methods are considered for use in an ESC Plan:

- Availability of Suitable Plants Suitable plants for use in bio-technical erosion control methods must be local and biologically appropriate for the proposed construction site.
- Mechanical and Hydrological Benefits of Plant Root Systems The root systems increase in depth and density with time and promote infiltration of surface moisture; however, when initially installed the plants used in bio-technical erosion control are usually in seed form or dormant and provide no immediate mechanical or hydrological benefit. The process of benching during installation may help reduce erosion and promotes plant growth by capturing moisture and nutrients.
- Use of Indigenous Materials The plants used must be biologically appropriate to the site climate, soil and moisture conditions. Harvest sites should have similar characteristics to the planting site. Large differences in growth conditions such as precipitation, temperature, elevation, slope aspect, drainage and soil type may decrease the effectiveness of the bio-technical erosion control system through plant mortality or poor growth.
- Transport of Weeds The qualified person and contractor responsible for design and implementation of bio-technical erosion control methods must minimize the risk of damaging existing vegetation and introducing invasive or foreign species into a new area. A qualified person should be consulted to confirm the suitability of plant species for use in bio-technical erosion control methods.
- Labour / Skill Requirements Crews can be easily trained to install bio-technical erosion control systems and the capital requirements are typically low. Bio-technical erosion control can be installed using heavy equipment, however the harvesting and installation of the living plant material is conducive to hand planting on sensitive sites that limit heavy equipment use.
- Costs The majority of bio-technical erosion control costs are associated with labour. Labour costs can be substantial because plant material must be harvested, prepared, installed and tended, and this is usually done by hand. Transportation and storage, if required, of living plants is also a cost consideration. In some cases, large refrigerated facilities are required to properly store living plant material for extended periods between harvesting and planting.
- Environmental Compatibility Selected properly, the plants provide non-intrusive systems that enhance fish and wildlife habitat as well as aesthetics. It is important to recognize the site sensitivities before selecting plants to be used in bio-technical erosion control. Harvesting plant species that are well acclimatized and appropriate to the installation site will provide the most effective bio-technical erosion control results.

- Access Bio-technical erosion control methods can be the most appropriate choice for sites with poor access such as riparian zones or sensitive stream banks. Difficult sites can be accessed on foot with minimal impact, however poor site access will increase costs associated with transportation and handling since machinery may not be able to support the labour force. For sites where access is good, heavy equipment can support bio-technical erosion control installation by transportation of supplies and equipment and preparation of earthworks.
- Timing Bio-technical erosion control methods are most effective when the plant stock is harvested during the dormant seasons (late fall or early spring). Nutrients and water stored within the plant during dormancy provides the best opportunity for the plant to establish roots when it is placed in soil. Plants that are harvested while in a growth period suffer higher mortality since the plant has already gone into leaf production and harvesting shocks the plant system. Plants can be harvested during a dormant period, cold stored and then planted when the soil has warmed.
- Maintenance Requirements Depending on the site, certain levels of maintenance are required. Supplemental plant stock may be required if minimum coverage of plant growth is not achieved by a certain time in the project schedule. Conversely, bio-technical erosion control systems that experience heavy growth may require trimming or mowing maintenance particularly on projects where sight lines are important.

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8.0 SELECTION OF BMP FOR EROSION AND SEDIMENT CONTROL

8.1 Preliminary Tasks

The following tasks should be completed before erosion and sediment control measures are selected for a given site:

- Conduct the Site Assessment (Section 5.0);
- Conduct the Site Evaluation (Section 6.6);
- Site Hazard Classification (Section 6.6.3); and
- Connectivity to Downstream Resources (Section 6.6.4).

The order in which these tasks should be completed is presented as a flow chart in Figure 8.1.

Conduct Site Assessment
(Section 5.0)

- Gather background information

⇩

Conduct Site Evaluation
(Section 6.6)

- Prepare slope analysis summary (Section 6.6.1)
- Prepare drainage analysis summary (Section 6.6.2) Determine the presence/absence and extent of permafrost or icing areas.
- Estimate soil loss for each drainage catchment on the construction site (Section 6.3)
- Prepare site hazard classification for each drainage catchment on the construction site (Section 6.6.3)
- Prepare connectivity rating to aquatic resources (Section 6.4.4)

⇩

Select Appropriate Erosion and Sediment Control Measures
(Section 8.2)

- Based on results of Site Evaluation

Figure 8.1: Steps in Preparing the Erosion and Sediment Control Pan

8.2 Guidelines for Selecting Appropriate Erosion and Sediment Control Measures

Failure of erosion and sediment control measures can result in three types of potential consequences:

- Ecological consequences related to the introduction of sediment to the aquatic environment. This is related to the connectivity to aquatic resources (see Table 6.3).
- Project consequences related to the need to repair erosion damage and the implications for project schedule and cost; and
- Legal consequences associated with the deposition of sediment in receiving water bodies or other environmentally sensitive sites.

The aim in selecting, designing, and constructing the appropriate erosion and sediment control measures is to reduce the risk of these negative consequences.

Following the site assessment and evaluation, the information required to adequately select the ESC measures for preparing an ESC Plan will be available. Selection of BMPs and other measures should be guided by a combination of the site erosion potential, the consequences of erosion and sediment control, and the experience and judgement of the designer.

A summary of the BMPs and other measures required based on site erosion potential and consequences of erosion and sedimentation is presented in Table 8.2.

Erosion Potential	Consequences of Erosion and Sedimentation	Level of Erosion and Sediment Control (BMPs and Other Measures)					
		Planning Strategies and Procedures	ESC Plans and Structural BMPs	Water Management	Staged Construction and Progressive Rehabilitation	More Intensive Sediment Control BMPs	Water Quality Monitoring
Low	Low	Recommended[b]	-	-	-	-	-
	High	Required	Required	-	-	-	-
Moderate	Low[a]	Required	-	-	-	-	-
	High	Required	Required	Recommended[b]	Recommended[b]	Recommended[b]	Recommended[b]
High	Low[a]	Required	Required	Required	Required	Required	Recommended[b]
	High	Required	Required	Required	Required	Required	Required[c]
Reference in Manual		7.2	7.3, 7.4, 8.0	7.3	7.2, 7.2.1	7.5	9.9

Source: Transportation Association of Canada, 2005

Table 8.1: Required Levels of Erosion and Sediment Control

Notes:

(a) If economically justified, it may be acceptable to limit ESC measures for low-consequence projects, including those distant from sensitive areas, to procedural BMPs only.

(b) This level of ESC should be implemented where practical. For example, a small, short-duration project may not require staged construction and progressive rehabilitation. Recommended actions may be necessary to demonstrate due diligence in the event of the release of sediment due to an extreme runoff event.

(c) Water quality monitoring provides a quantitative measurement of the effectiveness of ESC measures. Monitoring may be required by regulatory agencies.

The information presented in Table 8.2 must be supplemented with the designer's experience and judgement during the preparation of the ESC strategy. Those responsible for the design and implementation of BMPs and other measures should continue to utilize innovative approaches which best address specific situations. Advances in technology will also continue to improve the methods and materials that are currently employed. Reference should be made to the suppliers for the most up-to-date approved products.

Specific measures and BMPs are published in many manuals and standards, which describe criteria and specifications in detail. Many of the BMPs most commonly used in the Northwest Territories are presented in Appendix C. The BMPs are listed in terms of erosion control and sediment control, and the description, typical applications, advantages and limitations for each are provided. For each BMP, installation information and construction, maintenance and inspection considerations are provided, and where applicable, similar measures are noted to provide the designer with options and flexibility in choice.

Other factors affecting the selection of erosion and sediment control BMPs include:

- Site Specific Design Requirements;
- Specific Construction Requirements including available space and requirements to address the presence of permafrost;
- Regulatory laws and guidelines; and
- Cost.

8.3 Construction Phase Activities

Erosion control considerations for various construction phase activities are presented as follows. These construction-related activities must be addressed in the contractor's ESC Plan. Other aspects of environmental protection for these activities are to be addressed in the Environmental Management Plan (EMP).

Clearing and Grubbing

Clearing operations include slashing, cutting, stockpiling, and removal (or burning) of trees and brush. Clearing operations leave the stump and root mass intact, as well as the organic mat in the soil. Grubbing operations include the removal of the tree stumps and root masses left behind during clearing operations, however, the topsoil and the majority of the organic mat remains in place. Grubbing operations may cause localized soil exposure in areas where roots and stumps were removed. Clearing and grubbing may have an impact (melting) on permafrost areas, thus in the permafrost zones these activities should be carefully managed.

Stripping

Stripping is the removal of the organic mat from the construction site to expose the underlying mineral soil. The exposed soil will be disturbed during the stripping operation, thereby increasing the erosion potential.

In permafrost areas, the stripping of the organic mat and topsoil likely result in the melting of the permafrost layer, further increasing the erosion potential and the potential structural failure of the sub-soils. If it is necessary to strip this material, the area of stripping should be minimized and the material should be removed and stockpiled in a manner that makes it suitable for retrieval and reapplication.

Borrow Excavations

Borrow excavations may be located outside of the construction site boundaries and used for the purposes of removing borrow material for:

- Roadway subgrade construction, or
- The other site construction activities including dams, channels, berm structures or other erosion protection works associated with the transportation infrastructure project, or
- Purposes other than transportation infrastructure as outlined in the Quarry Permit.

Borrow excavations can be topographical highs such as hills or ridges, or on relatively flat terrain, or are large excavations utilized for the extraction of construction material. The borrow pit (quarry) area is to be restored as required by the GNWT-MACA Quarry Permit (Pursuant to subsection 3 (4) of the Commissioner's Land Act) or the relevant Land Use Permit. This may include restoring or remediating holding water areas. In northern areas where permafrost is present or may develop (temporary zones), borrow pits should be designed in a manner that does not permit the holding (ponding) of water as this increases the melt within the permafrost layer. Melting of the permafrost layer is known to contribute to subsequent infrastructure damage and may continue for an extended period of time.

Development of borrow excavations may include clearing, grubbing, stripping and excavation. The development of borrow excavations and haul roads may cause soil disturbance, create exposed slopes and/or alter the natural drainage courses in the vicinity of the borrow excavation. Borrow excavations and infrastructure construction within a permafrost zone should be designed by a qualified person.

Stockpiles

Stockpiles may include material removed from excavations, stripping, clearing, and from borrow pits. The creation of stockpiles may disturb the vegetated soil surface, create exposed slopes, and/or temporarily alter the natural drainage courses. Avoid ponding water in stockpile areas and provide sufficient drainage as required.

Cut Slope Construction

Cut slopes are slopes created through the excavation and removal of native soil. Cut slopes may increase the slope angle, disturb the soil surface, create exposed slopes, and/or alter the natural drainage courses. Cut slopes may expose soil with ground ice with resultant melting and drainage of water and soil slurries.

Fill Slope Construction

Fill (embankment) slopes are constructed by placing and compacting fill material. Fill slope embankments create large areas of disturbed exposed soils, may require steep slope angles and/or they may alter the natural drainage courses which impacts the overall erosion risk.

Ditch Construction

Where channels or ditches are constructed to direct and transport water along or transverse (crosswise) to the linear alignment, the original drainage pattern may be altered and concentration of flows created, thereby increasing flow velocity and erosion potential. Ditch construction creates exposed slopes which can be eroded.

In areas of permafrost and ground ice, melting can be expected. Ditches within the permafrost zone will require a wider base as the melting of the upper slope will allow fluid movement of soils into the ditch line. In permafrost zones, the ditch line should be wider than in non-permafrost areas, the slope cuts should be made near vertical, the vegetation and fibrous organic matter retained on the upslope side and the bank allowed to self-stabilize. The vegetative mat will relax over the slope as the soil flows to stabilize the slope, providing an insulating layer which will minimize further melting. During the self-stabilization period, the soil in the ditch needs to be monitored and removed only enough to allow water passage to resume as per the remainder of the ditch line. The material immediately at the base of the slope should not be removed as it provides stabilization for the area upslope.

Culvert Installation

Culverts are installed to provide surface drainage from the road prism and upslope ditches, and to connect natural drainage courses. Installation of culverts may cause flow concentrations, create cut slopes, disturb the soil surface on slope faces, and create scour zones at the culvert inlet or outlet. Areas known to have “icings” may require multiple drainage structures at differing levels (stacking). These should be designed by a qualified person. Ponding of water should be avoided and extra structures installed as necessary to provide adequate drainage, especially in areas where melting of permafrost is a concern.

Temporary Access Road Construction

Temporary access roads are constructed to accommodate construction equipment on the project site. Construction of temporary haul roads may alter drainage courses and may include the construction of cut slopes, fill slopes, ditches or culvert installation.

8.4 Selection of Best Management Practice (BMP) According to Construction Activity

A large number of ESC BMPs are available for use in an ESC Plan. The BMPs presented in this section are proven to be effective when properly implemented. Since the effective implementation of control measures is a site-specific operation, the BMPs have been grouped by typical construction activities that occur on transportation construction sites in Table 8.2. BMPs (Appendix C) typically used for stream bank stabilization applications are summarized in Tables 8.3 and 8.4.

When selecting BMPs, consideration must be given to site specific conditions. For example, a site with rocky sites and embankments where rock is solid will enable sediment fencing to be used as an ESC measure. An alternative method of controlling water or run-off from the site such as berms or diversion ditches may be required. As such, customized methods and techniques may be required to meet the specific requirements of any given construction site. Innovative ideas or variations of the ESC control measures may be developed and implemented on site, which may work as well as or better than the “standard method”. In such cases, the erosion and sediment controls should still be designed to be straightforward to implement, maintain, and inspect for effectiveness. If the intended result is achieved and can be maintained, the control measure should be acceptable for that specific site condition.

BMP Name		Construction Activity								
		Clearing and Grubbing	**Stripping**	**Borrow Pits**	**Stockpiles**	**Cut Slopes**	**Fill Slopes**	**Ditches/Channels**	**Culverts**	**Temporary Haul Roads**
1.	Sediment Fence	✓	✓	✓	✓	✓	✓		✓	✓
2.	Gabions					✓	✓	✓	✓	
3.	Berm Interceptor	✓	✓	✓	✓	✓	✓			✓
4.	Storm Drain Inlet							✓	✓	
5	Rock Check							✓		
6.	Synthetic Permeable Barrier							✓		
7.	Straw Bale Barrier			✓	✓	✓	✓			✓
8.	Rolled Erosion Control Products (RECP)				✓	✓	✓	✓		
9.	Riprap Armouring					✓	✓	✓	✓	
10.	Cellular Confinement System					✓	✓	✓		
11.	Energy Dissipaters							✓	✓	
12.	Sediment Traps and Basins		✓					✓		
13.	Slope Drains					✓	✓			
14.	Diversion Ditches		✓	✓	✓	✓	✓			
15.	Seeding			✓	✓	✓	✓	✓		
16.	Mulching			✓	✓	✓	✓	✓		
17a	Hydroseeding			✓	✓	✓	✓	✓		
17b	Hydromulching			✓	✓	✓	✓	✓		
18.	Topsoiling		✓	✓	✓	✓	✓	✓		
19.	Soil and Root Mat Replacement (Sodding)	✓	✓	✓	✓	✓	✓	✓		
20a	Live Staking					✓	✓	✓		
21.	Riparian Zone Preservation	✓	✓	✓	✓	✓	✓	✓	✓	✓
22.	Crushed Rock Buttress for Slopes (Permafrost)					✓	✓			
23.	Controlled Ablation (Melt) of Cut Slope (Permafrost)					✓				
24.	Insulated Thermal Blanket on Cut Slope (Permafrost)					✓				
25.	Scheduling	✓	✓	✓	✓	✓	✓	✓	✓	✓
26.	Stabilized Worksite Entrances	✓	✓	✓	✓	✓	✓	✓	✓	✓
27.	Slope Texturing			✓	✓	✓	✓			✓
28.	Compost Blanket				✓	✓	✓			✓
29.	Rolls (Fibre- Coir, Wattles)			✓	✓	✓	✓			
30	Wattles (Live Facine)					✓				

Table 8.2: Application for BMPs Based on Construction Activities

BMP #	BMP Name	Category	Also Known As
29	Rolls (Fibre)	Bank Armour and Protection	• Coir Rolls • Coir Mats • Wattles
30	Wattles (Live)	Bank Armour and Protection	• (Live Facine)
20a	Live Staking	Bank Armour and Protection	• Live Staking
20b	Brush layering	Bank Armour and Protection	• Live Brush Layering
31	Brush Mattress	Bank Armour and Protection	• Live Brush Mattress • Brush Mat
32	Live Siltation	Bank Armour and Protection	• Vertical Brush layering
33	Willow Posts & Poles	Bank Armour and Protection	• Pole Planting • Dormant Live Posts
34	Rock Vanes	Bank Armour and Protection	• Rock Vanes • Upstream Angled Spurs
35	Longitudinal Stone Toe	Bank Armour and Protection	• Longitudinal Peaked Stone Toe Protection (LPSTP) • Stone Toe • Rock Toe • Stone Toe Buttress • Weighted Riprap Toe • Longitudinal Fill Stone Toe Protection (LFSTP)
36	Vegetated Mechanically Stabilized Earth (VMSE)	Bank Armour and Protection	• Vegetated Geogrids • Brush layering with Soil Wraps • Vegetated Geotextile Fabric Wrapped Soil
37	Vegetated Riprap	Bank Armour and Protection	• Vegetated Rock Revetment • Vegetated Rock Slope Protection (VRSP) • Face Planting • Joint Planting
38	Stream Diversion Channel	Diversion of Stream	• Diversion Ditching • Stream Diversion
39	Coffer Dam (Small Streams)	Diversion of Stream	• Coffer Dam • Dam • Stream Barrier

Note: Adapted from E-SenSS Software, 2005, Salix Applied Earthcare

Table 8.3: BMPs for Stream bank Applications

	BMP 29 Roll (Fibre)	BMP 20a Live Staking	BMP 20b Brush layering	BMP 31 Brush Mattress	BMP 32 Live Siltation	BMP 33 Willow Posts & Poles	BMP 34 Rock Vanes	BMP 35 Longitudinal Stone Toe	BMP 36 VMSE	BMP 37 Vegetated Riprap	BMP 38 Stream Diversion Channel	BMP 39 Coffer Dam
Erosion Process												
Toe erosion with upper bank failure	✓				✓		✓	✓		✓		
Scour of middle and upper banks by currents		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Local scour	✓	✓	✓	✓	✓	✓	✓			✓		
Erosion of local lenses or layers of non-cohesive sediment	✓	✓	✓	✓	✓	✓			✓	✓		
Erosion by overbank runoff			✓									
General Bed Degradation												
Erosion by navigation waves	✓	✓			✓	✓				✓	✓	✓
Erosion by wind waves	✓	✓			✓	✓				✓		
Erosion by ice and debris gouging	✓							✓		✓		
General bank instability or susceptibility to mass slope failure		✓	✓					✓	✓			
Spatial Application												
In-stream							✓				✓	✓
Toe	✓			✓	✓		✓	✓		✓		
Mid-bank		✓	✓	✓		✓			✓	✓		
Top of bank				✓						✓		
Hydrologic / Geomorphic Setting												
Resistive	✓			✓				✓	✓	✓		
Redirective							✓				✓	✓
Continuous				✓	✓			✓	✓	✓	✓	✓
Discontinuous							✓		✓			
Outer Bend	✓			✓	✓		✓	✓	✓	✓		
Inner Bend				✓					✓			
Incision								✓				
Lateral Migration	✓						✓			✓		
Aggradation					✓		✓					
Complexity												
Low					✓	✓		✓				
Moderate	✓	✓	✓	✓			✓			✓	✓	✓
High									✓		✓	✓

Note: Adapted from E-SenSS Software, 2005, Salix Applied Earthcare

Table 8.4: BMPs for Stream bank Applications Based on Erosion Process

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9.0 PERMANENT EROSION AND SEDIMENT CONTROL PLAN (PESC PLAN)

9.1 General

The Permanent Erosion and Sediment Control (PESC) Plan constitutes the measures designed by a qualified person to be constructed to address long term post-construction erosion and sedimentation hazards. In many cases it builds on the ESC Plan that guides the construction period. For example, a temporary pond during construction could be modified to become a permanent storm water retention pond. The PESC Plan should be designed using acceptable engineering and vegetation management approaches, and forms part of a project detailed design. The PESC Plan will also be referenced by the construction contractor in the development of the Environmental Management Plan (EMP).

A PESC Plan should be prepared as part of the design for all construction projects. For sites smaller than two ha (and not connected to an environmentally sensitive area), this consists of identifying minimum requirements for an erosion and sediment control strategy, and where practical, incorporating erosion and sediment controls into the detailed design to reduce on-site runoff and erosion. Sites larger than two ha require the development of a comprehensive PESC Plan and associated documents. During construction, the PESC Plan should be reviewed by a qualified person and modified as required as field conditions change.

A checklist for the development of the ESC Plans is included in Appendix D.

9.2 7Qualified Persons Responsibility

The qualified person is required to prepare and submit:

- A PESC Plan Report;
- Design and Construction Drawings showing PESC measures where appropriate;
- Contract special provisions which may be necessary to identify and address special areas of concern or types of work; and
- As-Built drawings showing the type, quantity and location of PESC measures installed.

A qualified person is responsible to monitor construction and confirm that the permanent erosion control works are installed according to the requirements of the PESC Plan.

The required qualifications of the Qualified Person are provided in Section 3.1.3.

9.3 PESC Plan Documentation

The PESC Plan must include a report and drawings. Reference should be made to GNWT DOT's guidelines for transportation projects. As a minimum the following should be addressed in the PESC Plan:

- Site Assessment;
- Design of the PESC Plan including highlighting procedural or minimum requirements, required BMPs and site specific designs;

- Shut Down considerations;
- Inspection, Monitoring and Maintenance Requirements; and
- Emergency Response Plan and incident reporting requirements.

9.4 Design and Construction Drawings

The Design and Construction Drawings must show the PESC measures (where appropriate) and reference the PESC Plan report.

9.5 Contract Special Provisions

Contract Special Provisions shall discuss other special or site specific items not included in the standard specifications for transportation construction. Information which may be included in the Special Provisions are design location of the devices, quantities and special regulatory requirements, or reference to special instructions on installing the erosion and sediment control devices.

9.6 Site Inspection during Construction

Once the PESC measures have been installed, it is important that their effectiveness is monitored and necessary maintenance be carried out through the remainder of the construction phase. The success of the entire erosion and sediment control strategy will depend upon this, and its importance cannot be overemphasized.

All temporary and permanent ESC measures must be inspected by the contractor daily and following heavy rainstorms or snowmelt events during the construction phase. Immediate action must be taken by the contractor when the need for maintenance or repair of PESC measures is identified for the ongoing performance of the measures.

A qualified person should inspect the PESC measures every seven days and following heavy rainstorms or snowmelt and advise the contractor immediately of any areas of concern. As site work progresses, the PESC Plan should be modified when necessary by the Qualified Person to reflect changing site conditions or new information which has been identified during construction.

A copy of the PESC Plan, along with a copy of the Construction Drawings, must be kept by the Contractor at the construction site for use by construction workers and inspection personnel.

9.7 Inspection and Incident Records

The Contractor and Qualified Person must both maintain separate records of their inspection of all ESC measures at the frequencies noted above, including notes regarding damage and deficiencies observed. The same document can be used to record maintenance and repairs undertaken after the inspection.

The Qualified Person must submit their inspection report of ESC measures to the GNWT - DOT on a weekly basis. The contractor must maintain records of their daily inspection and provide copies to the qualified person, if and when requested.

A sample inspection report form is presented in Appendix D. Inspection Report Forms may be developed or modified for the specific site.

9.8 As-Built Drawings and Project Records

A complete summary of the PESC measures installed must be documented by the Qualified Person during construction and updated as various measures modified. As-built drawings and supporting records must include a plan view drawing showing the type, quantity and location of PESC measures installed.

Supplemental information which should be included in the Final Details includes:

- Inspection and Maintenance Reports;
- Modifications to the PESC Plan;
- Photos of the installed PESC measures; and
- Incident Reports.

9.9 Post Construction

After final acceptance, the inspection and maintenance responsibilities of the PESC measures will be transferred from the construction contractor to the Maintenance Contract Inspector (MCI) and the GNWT-DOT's Maintenance Contractor.

The respective maintenance responsibilities at the Construction Phase and Post Construction Phase are described in the GNWT-DOT maintenance contract. Inspection and maintenance of PESC measures must continue regularly so that the measures remain effective in the long term. The following circumstances and conditions will permit BMPs to be removed:

- Revegetation of bare soil is successful;
- No obvious erosion scour is observed;
- No obvious bed load of silt and sediment laden runoff is observed;
- Inspection and maintenance report indicates satisfactory performance; and
- GNWT-DOT maintenance staff will assess and decide on performance of the structures and the requirement for necessary removal.

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10.0 TEMPORARY EROSION AND SEDIMENT CONTROL PLAN (TESC PLAN)

10.1 General

The temporary erosion and sediment control plan (TESC Plan) constitutes the measures designed and installed by the qualified person to address matters of erosion and sediment control which the contractor anticipates during the construction contract and includes activities up to the point of final acceptance of the construction work. The TESC Plan is prepared by the contractor and forms one component of the EMP which is also prepared by the contractor.

Sample checklists for the development of the TESC and PESC Plans are included in Appendix D. These forms may be modified to reflect changing requirements.

10.2 Contractor's Responsibility

The contractor is required to prepare and submit an Environmental Management Plan (EMP) to the Qualified Person prior to construction. In order to develop a TESC Plan, the contractor should incorporate recommendations of the Qualified Person's PESC Plan and Environmental Risk Assessment.

Responsibilities of the Qualified Person and Contractor as well as the guidelines provided by the GNWT-DOT for preparing an EMP are used in preparing the TESC Plan Documentation.As a minimum, the following should be addressed in the TESC Plan:

- Design of the TESC Plan including addressing procedural or minimum requirements, required BMPs and site specific designs;
- Shut Down considerations;
- Inspection, Monitoring and Maintenance requirements; and
- Emergency Response Plan and incident reporting requirements.

10.3 Site Inspection during Construction

During construction, before final acceptance of the construction contract works, the responsibility for the inspection, maintenance and repair of all TESC measures lies with the contractor. A schedule of planned maintenance activities is required with the submission of the EMP. When implemented controls are insufficient or not working as intended, changes to the TESC Plan component must be made by the contractor to ensure continued compliance.

All erosion and sediment control measures must be inspected daily by the contractor and following heavy rainstorms or snowmelt events. Some measures will require periodic replacement and/or removal of accumulated sediment.

Damage or deficiencies to control measures should be corrected immediately.

Details on inspection, maintenance and repair activities shall be recorded on the "Inspection and Maintenance Form". A sample form is presented in Appendix D.

10.4 Shutdown Considerations

The TESC Plan must include provisions for erosion and sediment control during shutdown periods. Shutdowns are considered any extended period of time during which the contractor is not actively developing the project site and may no longer have personnel or equipment on-site. Shutdowns may or may not be planned and may result from seasonal work stoppages, adverse weather events, or contractual disagreements. During a shutdown, erosion and sediment control measures must still be inspected and maintained. This will include during winter shutdown and more importantly, during spring snow melt prior to construction re-start when the contractor must provide timely, regular monitoring and maintenance as well as install additional measures as necessary.

10.5 Emergency Response Plan

The TESC Plan must show preparedness for an emergency response to erosion and sediment related problems. The contractor should reference the most current versions of the Environmental Management Plan (EMP), GNWT-DOT ESC Manual and should also reference the Qualified Person's PESC Plan for information on requirements and procedures.

10.6 Inspection and Incident Reports

All inspection, maintenance and repairs performed on erosion and sediment control measures should be recorded on the "Inspection and Maintenance Form". A sample form is presented in Appendix D. Inspection and maintenance report and repair records must be kept at the construction site for review by construction personnel, inspectors, Qualified Person and GNWT-DOT personnel.

10.7 Post Construction

After final acceptance, the inspection and maintenance responsibilities of any installations that must remain in operation may be transferred from the construction contractor to the Maintenance Contract Inspector (MCI) and the GNWT-DOT's Maintenance Contractor in the post construction phase as outlined in the contract agreement. The respective maintenance responsibilities at the Construction Phase and the Post Construction Phase are described in the GNWT-DOT maintenance contract. Inspection and maintenance must continue until the BMP is no longer required, at which time the BMP will have to be removed. The contractor may be responsible for the inspection and maintenance of the BMPs for a period following the end of construction. The following circumstances and conditions will permit BMPs to be removed:

- Revegetation of bare soil is successful;
- No obvious erosion scour is observed;
- No obvious bed load of silt and sediment laden runoff is observed; and
- GNWT-DOT maintenance staff will assess and decide on performance of the structures and requirement for necessary removal.

11.0 GUIDELINES FOR ESTIMATING RUNOFF FROM SMALL WATERSHEDS AND DESIGN OF OPEN CHANNELS

11.1 General

The design of erosion and sediment control measures should consider the peak flow rate of surface runoff to ensure channels and sedimentation containment systems are adequately sized. Furthermore, these structures must be protected from erosion due to concentrated water flow.

Channelized flow requires provision of erosion control measures to prevent concentrated water flow from causing erosion. The amount of runoff laden with sediment will influence the design requirements for sediment control. The estimate of runoff from small watersheds and the design of channel lining are presented below.

11.2 Estimating Runoff from Small Watersheds

The amount of runoff from each catchment on a transportation construction project site is related to the design rainfall storm and the catchment area affected by construction. A linear drainage design generally includes ditches and cross-drainage culverts as well as storm water storage/treatment areas and floodplain considerations.

For the design of erosion and sedimentation protection measures, runoff estimation is an important design consideration. The runoff assessment should be provided by a qualified hydrology professional or engineer. For small catchment areas, the guidelines for the estimate of runoff are presented in Appendix E. These guidelines should only be used in conjunction with professional judgement and experience. For major watercourse crossings, the drainage assessment is generally provided by a qualified engineer.

11.3 Design of Open Channels

Open channels are the system of ditches and swales that convey concentrated drainage on a transportation construction site. Culverts are pipes, either completely closed or arched, which also convey ditch or channel water. These channels and culverts must be designed to contain design runoff flow without overtopping. Furthermore, open channels must be able to convey the concentrated flows without promoting additional erosion within the channel. Open channel design should be provided by a qualified hydrology professional or engineer.

The use of permissible tractive resistance[7] has been adopted for the design of channel lining instead of the permissible velocity concept[8] which was historically used by some designers. For linear ditch/channel and a simplified flow regime, the channel design is a function of runoff, geometric channel properties and channel roughness (n).

[7] Tractive resistance: The resistance to motion due to friction per unit weight hauled.(Webster's Online Dictionary)
[8] Permissible velocity: The highest velocity at which water is permitted to pass through a structure or conduit without excessive damage (McGraw-Hill Science & Technology Dictionary)

The channel roughness (n) is dependent on the degree of irregularity of the **wetted** perimeter of open channel flow which may be influenced by erosion control BMPs in the channel. The protective linings for channels can include soft armour linings of different materials (e.g. vegetation, soil coverings or erosion protection matting, etc.) and hard armour linings (e.g. gabions, riprap, concrete linings, pipes, etc.), all of which will affect "n".

Simplified guidelines for design of linear channels and channel roughness (n) values for various protective channel lining materials are presented in Appendix F. These guidelines should only be used in conjunction with professional judgement and experience.

12.0 GUIDELINES FOR THE DESIGN OF SEDIMENT CONTAINMENT

12.1 General

The function of a sediment containment system is to provide storage capacity to runoff volume and to slow the flow velocity of runoff to allow the sedimentation of suspended soil particles (silt, clay) to occur. When designed correctly, most sediment containment systems do one or more of the following:

- Provide containment storage volume for incoming runoff waters;
- Create uniform flow zones, increased flow path length and width and increased sedimentation times to facilitate sedimentation of suspended particles; and
- Discharge water at a controlled rate that permits adequate detention time for sedimentation of suspended particles.

It is important to note that removal of all incoming suspended particles is not feasible due to the practical limits of water storage volume and available settling time. Therefore, the efficiency of a containment system is based on the efficiency of sedimentation of a target grain size.

The sediment containment system should be designed so that the outflow rate during the design rainfall event is equal to or smaller than the inflow rate of sediment-laden runoff. Coarse to medium size silt particles (particle size range 75 μm to 20 μm) can be realistically targeted for sedimentation. Finer size particles (i.e., clay and fine silt) will require a long time to settle and therefore may not be deposited in the sediment containment facility during the time of retention. As such, targeting clay, fine silt particles and organic silts for sedimentation is generally not practical.

The design capacity of a sediment containment system should be sufficient to impound the runoff volume collected from an area of disturbed land (bare soil) for a 1:2 year storm event of 24 hour rainfall intensity or a recommended runoff volume of 250 m^3 per hectare of disturbed land. Under conditions of land constraints, a minimum runoff volume of 150 m^3 per hectare can be considered. The designer of a sediment containment system should consider the flow rate at which sediment laden runoff enters the system and ensure that sufficient time exists to permit adequate sedimentation to occur before the water exits the system.

12.2 Containment Systems (Type I, II and III)

The type of containment system should be selected based on site specific conditions. The selection should generally be based on the following:

- Site erosion potential classification;
- Area of upstream soil exposure;
- Terrain conditions in the contributing area;
- Area and soil depth constraints in the planned containment system site; and
- Method of construction.

Construction of the containment system should be completed at high risk areas prior to any land disturbance and construction.

The selection of the location and type of sediment containment system should be based on the experience and judgement of the designer. The criteria for selection of the type of sediment containment systems are presented in Table 12.1.

Containment System *	Site Erosion Potential Classification	Design Particle Size *	Affected Land Area *
Type I (Sediment Basin)	High to Very High	Particle size ≤ 0.045 mm (medium silt and finer)	>2.0 ha
Type II (Sediment Trap)	Moderate	Particle size between 0.045 mm and 0.014 mm (fine sand, coarse to medium silt)	≤2.0 ha
Type III (Sediment Barrier)	Low to Very Low	Particle size >0.14 mm (medium to fine sand, coarse silt)	Grade break and velocity retarder for construction and intermediate areas

*Source: Fifield, 2001

Table 12.1: Containment System Types

The three types of sediment containment systems are discussed in the following sections. Ponding of water should be avoided in areas of underlying frozen soil condition where possible. Sediment ponds should be designed by a qualified person.

Type I (Sediment Basin)

Type I sediment containment system requires development of a structure to capture coarse to medium silt and a portion of smaller suspended particles. Since particles of this size have low settling velocities, large storage volumes, long flow-path lengths, and controlled discharges are required. As such, the containment basin will be configured accordingly to provide sufficient retention time and flow velocity reduction to permit sedimentation. Type I systems are designed to have the highest possible net efficiency and are best represented by the traditional sediment basin.

In general, sediment basins should be sized for a minimum recommended storage volume of 250 m³/ha where possible over the contributing disturbed bare soil area. Length (L) to width (W_e) ratio should be between 4:1 and 8:1. A practical width (W_e) can be 6 to 8 m. Generally, a practical pond depth is 1.2 m. The maximum pond depth should not exceed 1.5 m. An illustration of the Type I structure is presented in Figure 12.1.

Type II (Sediment Trap)

The Type II sediment containment system will capture suspended particles (fine sand to coarse silt) having higher settling velocities than particles requiring Type I structure.

Consequently, small storage volumes and shorter flow-path lengths in comparison to widths can be used. As with a Type I structure, these sediment control systems will also have controlled discharges. Whereas their net effectiveness for the inflow and sedimentation of all suspended particles may be low, Type II systems will still have an effective sediment control measure.

In general, sediment traps should be sized for a recommended storage volume of 250 m³/ha over the contributing area where possible or a minimum storage volume of 150 m³/ha under conditions of land constraints. Length (L) to width (W_e) ratio should be between 2:1 and 3:1. A practical pond depth can be 1 m and the maximum pond depth should not exceed 1.5 m. Illustrations of Type II structures are presented in Figure 12.1 and Figure 12.2.

Type III (Sediment Barrier)

The least effective method to control suspended particles in runoff waters is represented by the Type III sediment containment systems. These are not necessarily design structures, as found with Type I and Type II systems, but are often BMPs (such as drainage ditch check structures). Whenever significant runoff occurs, all Type III systems have very low net and apparent effectiveness to control suspended particles. However, when runoff is low, the Type III sediment control systems can be effective in reducing flow velocity and suspended particles (coarse silt to fine sand) along gentle grade areas as long as they are regularly maintained.

12.3 Design Considerations

The design of a sedimentation pond can be a challenge as design parameters are difficult to define (e.g., storm events, runoff, soil erodibility and distribution of erodible soil). Thus, the evaluation of the effectiveness of pond performance is difficult to quantify. Therefore, the design of a sediment pond or the review of its performance should be undertaken by a qualified engineer with practical experience and professional judgement. A suggested design rationale for the design of sediment containment systems is presented in Appendix G.

The focus of sediment control is capturing silt and larger sized soil particles. It is not practical to design for clay particles or colloidal organic particles due to the significant amount of time required for these to settle. Therefore, erosion control should be emphasized for preventing release of water containing clay particles or colloidal organic particles from a construction site.

Methods that estimate the efficiency of a given sediment containment system should be used with caution as there are several variables that affect the effectiveness of these systems. Estimating the efficiency of a sediment containment system should be used as a preliminary means of evaluating various options. However, the final selection should be based on the site conditions and the experience and judgement of the designer.

Care should be taken when designing embankments, since these may have to be designed according to dam design guidelines and regulatory requirements. Regardless of the height of an embankment, the consequences of failure will determine the level of effort during design and construction. A qualified engineer should design the foundation and embankment, and provide inspection during and after construction. Similarly, the optimization of pond areas and depth to obtain maximum efficiency should be undertaken by a qualified engineer.

12.4 Design Examples

A design example for a sediment pond is presented in Appendix H as Example H.16.

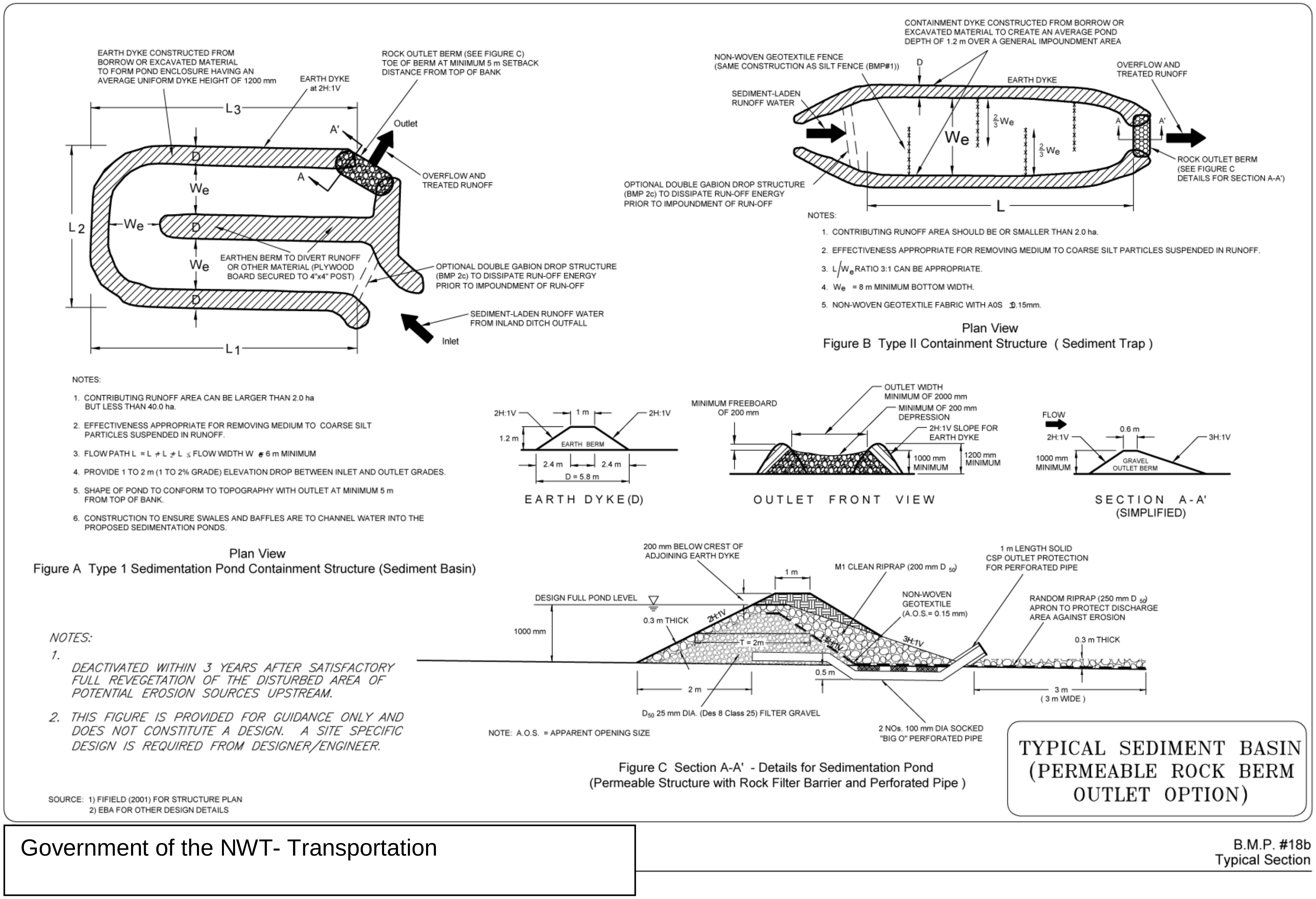

Figure 12.1: Type I and II Typical Sediment Containment Systems (Source: Fifield 2001)

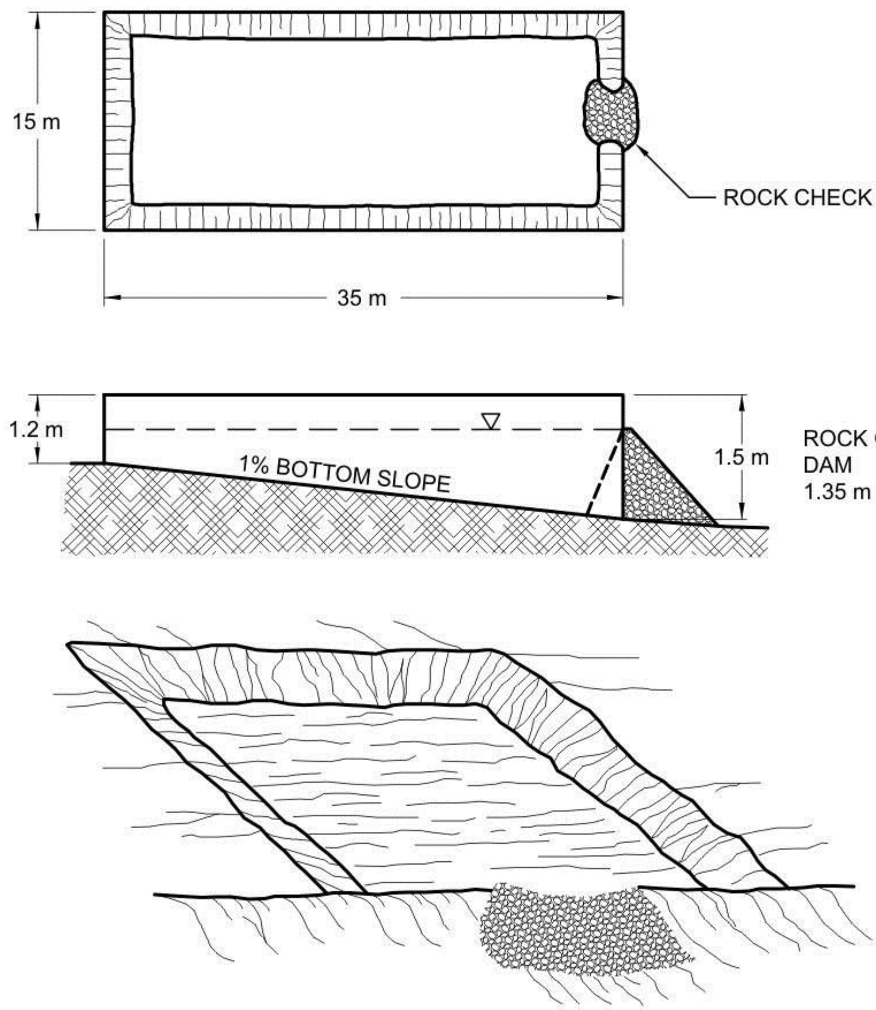

Figure 12.2: Type II Sediment Containment System (Sediment Trap) – Excavation Option

Source: City of Calgary, 2001

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Northwest Territories Transportation

GOVERNMENT OF THE NORTHWEST TERRITORIES, DEPARTMENT OF TRANSPORTATION - EROSION AND SEDIMENT CONTROL MANUAL,

APPENDICES A - H

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APPENDIX A

EXAMPLES OF SOIL TEST DATA AVAILABLE FOR THE NORTHWEST TERRITORIES

Examples of Soil Test Data available for the Northwest Territories

Soil Series/ Association	Depth (cm)	Where found	Organic Matter (%)	Texture Class	Particle Sizes			Drainage	Source
					Sand*	Silt	Clay		
Antoine	0 - 22	Martin River area	0.3 – 0.6	Loamy Sand	85*	8	7	Poorly Drained	JH Day (1966)
Arrowhead	0 - 60	Either side of the Liard, Mackenzie and Muskeg Rivers	0.3 - 0.6	Silty**	6.5 - 7.3	78.7 -83.5	10 – 14	Well Drained	Rostad, White and Acton (1976)
Berens	0 - 16	Terraces near Jean-Marie Creek and Rabbitskin River	1.2 – 2.4	Silty Clay Loam	10*	55	33	Well Drained	JH Day (1966)
	16 +		1.3	Loam	42*	39	18		
Betalamea	0 - 12	Between 60^{O} parallel and the Flett Rapids and between Nahanni Butte and the Birch River	2.8 – 11.7	Loam	42*	28.3 - 37.2	18	Poorly Drained	JH Day (1966)
	12 - 23		0.6	Clay Loam	32*	35	32		
Blackstone River	0 - 15	Between the Netla and Poplar Rivers	1.9	Loam	42*	38	18	Poorly Drained	JH Day (1966)

Soil Series/ Association	Depth (cm)	Where found	Organic Matter (%)	Texture Class	Particle Sizes			Drainage	Source
					Sand*	Silt	Clay		
Bluebill	0 - 7	Liard River	3.1	Clay Loam**	40.0	41.1	18.9	Well to Poorly Drained	Rostad, White and Acton (1976)
	7-36		1.2 – 1.8	Loam**	27.2 – 33.4	31.9 – 38.8	34.0 – 34.8		
Bluefish	0-70	Liard river, Fort Simpson,	0.5 – 1.4	Sandy Loam**	6.0 – 16.8	75.1 – 78.6	8.1 – 17.0	Well to Poorly Drained	Rostad, White and Acton (1976)
Bovie Lake	0-20	Throughout Mackenzie Valley area	1.0	Silt Loam**	9.2	73.7	17.2	Well to Poorly Drained	Rostad, White and Acton (1976)
Bulmer	0 - 35	Southeast of Liard river	3.4	Sandy Loam**	65.3	25.3	9.5	Well to Poorly Drained	Rostad, White and Acton (1976)
	35 - 50		0.2	Clay Loam**	32.2	40.5	27.3		
Celibeta	0 - 10	Fisherman Lake area	1.3	Silt Loam**	7.8	78.4	13.8	Well Drained	Rostad, White and Acton (1976)
	10 - 20		1.2	Silty Clay**	2.7	53.3	44.0		
	20 - 40		1.0	Heavy Clay**	1.6	35.6	62.8		

Soil Series/ Association	Depth (cm)	Where found	Organic Matter (%)	Texture Class	Particle Sizes			Drainage	Source
					Sand*	Silt	Clay		
Clewi	0-2	North of Salt River, East bank of Slave River north of mouth of Salt River	28.5	Loam	45*	38	14	Well Drained	Day and Leahy (1957)
	2-28		1.0 - 1.5	Silty Clay Loam	10*	55	35		
Flett	0 - 7	Abandoned floodplains along Liard River	7.1	Clay Loam	32*	29	32	Poorly Drained	JH Day (1966)
Fort Smith	0-6	Fort Smith, Slave and Salt Rivers	1.6	Silt loam	22*	64	14	Well Drained	Day and Leahy (1957)
	6-22		1.4	Sand	92*	4	4		
Grand Detour	0-16	North of Salt River, south of Great Slave Lake, east bank of Slave River north of the mouth of Salt River	9.4 - 26.1	Silty Clay	5*	48	47	Well Drained	Day and Leahy (1957)
	16+		7.1	Clay Loam	32*	34	34		

Soil Series/ Association	Depth (cm)	Where found	Organic Matter (%)	Texture Class	Particle Sizes			Drainage	Source
					Sand*	Silt	Clay		
Gros Cap	0 – 12	West end of Mackenzie River area and Liard River	1.1	Silt Loam**	6.1	79.3	14.6	Well Drained	Rostad, White and Acton (1976)
	12 – 32		1.2	Silty Clay**	3.0	54.2	42.8		
	32 - 56		2.0	Silty Clay Loam**	3.9	61.9	34.2		
Kotaneelee	0 - 2	Fort Simpson area	9.3	Loam	42*	31	18	Poorly Drained	JH Day (1966)
	2 - 40		1.4 – 1.6	Silty Clay Loam	10*	56	33		
Liard	0 - 20	West of Meridian Island, valley of Redknife and Trout Rivers, Along the Liard and Mackenzie Rivers	4.0	Silty Clay Loam**	8.4	64.0	27.5	Well to Moderately Well Drained	Rostad, White and Acton (1976)
Liard	0 - 24		5.9 – 8.7	Fine Sandy Loam	65*	20	8	Well to Moderately Well Drained	JH Day (1966)
Liard (2)	0 - 20		12.2	Silt Loam**	6.4	71.3	22.4	Well to Moderately Well Drained	Rostad, White and Acton (1976)

Soil Series/ Association	Depth (cm)	Where found	Organic Matter (%)	Texture Class	Particle Sizes			Drainage	Source
					Sand*	Silt	Clay		
Martin River	0 - 80	SW of Mackenzie River to Martin River and south to Jean-Marie Creek	0.3 – 1.5	Heavy Clay**	84.4 – 92.4	4.3 – 12.2	2.9 – 4.3	Well to Moderately Well Drained	Rostad, White and Acton (1976)
Netla	0 - 24	Abandoned floodplains of the Liard River between big Island and the Matou River	1.1 – 2.4	Silty Clay Loam**	8.2 – 11.8	53.3 – 58.2	29.9 – 38.5	Well to Moderately Well Drained	Rostad, White and Acton (1976)
Petitot	0 - 70	Along Liard river from Dehdjida Creek to Birch River, and Fisherman Lake area	0.7 – 3.2	Silty Clay	0.1 – 1.0	40.3 – 58.8	40.2 – 59.4	Well to Poorly Drained	Rostad, White and Acton (1976)
Pointed Mountain	0 - 40	Fisherman Lake, west of Liard River and south to BC border	1.0 – 2.1	Clay**	24.7 – 25.8	28.8 – 31.5	43.7 – 45.4	Well to Poorly Drained	Rostad, White and Acton (1976)
Rabbit Creek	0 – 4	Uplands areas north of Liard	1.5	Silty Sand	45.0	48.6	6.4	Well to Moderately Well	Rostad, White and Acton (1976)
	4 - 22		1.0	Loam	39.0	41.3	19.7		

		River						Drained	
Soil Series/ Association	**Depth (cm)**	**Where found**	**Organic Matter (%)**	**Texture Class**	**Particle Sizes**			**Drainage**	**Source**
					Sand*	**Silt**	**Clay**		
Slave-Portage	0 - 18	North of Salt River, south of McConnell Island, east of Little Buffalo River, and west of Taltson and Tethul Rivers	3.1 - 7.7	Clay	27*	23	50	Imperfectly to Poorly Drained	Day and Leahy (1957)
	20 - 26+		1.1-1.3	Silty Clay	5*	48	47		
Slave- Long Island	0-20		9.8 - 16.8	Silty Clay Loam	10*	55	35	Imperfectly Drained	Day and Leahy (1957)
Trout Lake	0 - 4	Southeast of Fort Liard and throughout Mackenzie Valley	2.7	Silt Loam**	21.5	63.8	14.7	Well to Poorly Drained	Rostad, White and Acton (1976)
	4 - 68		1.3 – 2.2	Clay Loam**	28.1 – 33.5	32.7 – 36.6	30.0 – 39.2		

*Indicates that particle sizes were estimated from textural classes and the textural triangle in The Canadian System of Soil Classification (Agriculture and Agri-Food Canada 1998).
** Indicates that soil textures were determined from particle percentages and the textural triangle in The Canadian System of Soil Classification (Agriculture and Agri-Food Canada 1998).

APPENDIX B

SUPPORTING INFORMATION FOR RUSLE

Supporting Information for RUSLE

GUIDANCE FOR USING THIS APPENDIX

This appendix provides information that can be used for estimating average annual soil loss using the Revised Universal Soil Loss Equation (RUSLE). For calculating a detailed analysis of soil loss on a project site, the designer should refer to the RUSLE-FAC document (http://sis.agr.gc.ca/cansis/publications/manuals/2002-92/index.html).

1. Table **B-1** provides R values for selected sites in the NWT. There are relatively few climate stations in the NWT with the data needed to calculate R, therefore caution should be applied when extrapolating between locations.
2. Figure **B-1** is the soil nomograph that is used to calculate the K factor (soil erodibility factor). The data inputs that are used for calculating K are soil texture (%silt + % very fine sand), soil organic matter (%), soil structure, and soil permeability. It is not uncommon to only have soil texture data. If this is the case, Figure B-2 (soil structure), Figure B-3 (permeability), and Table B-3 (organic matter) should be used to estimate the other inputs to the K calculation.
3. If soil structure data are not available, the soil structure code in the K calculation can be estimated from Figure **B-2**.
4. If soil permeability data are not available, the soil permeability code in the K calculation can be estimated from Figure **B-3**.
5. Table **B-2** is provided for information only. It shows the spatial and month-to-month variations in rainfall erosivity at sites across Canada. Similar data are not available for the NWT. Sites like Gimli. MB and Beaverlodge, AB are indicative of monthly variations likely in the NWT. Note how R values compare to the R values in Table B-1.
6. If soil organic matter data are not available, the soil organic matter content in the K calculation can be estimated from Table **B-3**.
7. Use Table **B-4** to determine the LS factor from slope angle and length measurements.
8. Table **B-5** is used to adjust the LS factor when a detailed estimation of soil loss is needed. May not be needed for Erosion and Sediment Control planning on most sites.
9. Table **B-6a** and **B-6b** provide examples of C factors (conservation practices).
10. Table **B-7** provides P factors (soil conservation practices) for construction sites.

Section 6.3 of the main body of this report provides information on using RUSLE for construction sites in the NWT.

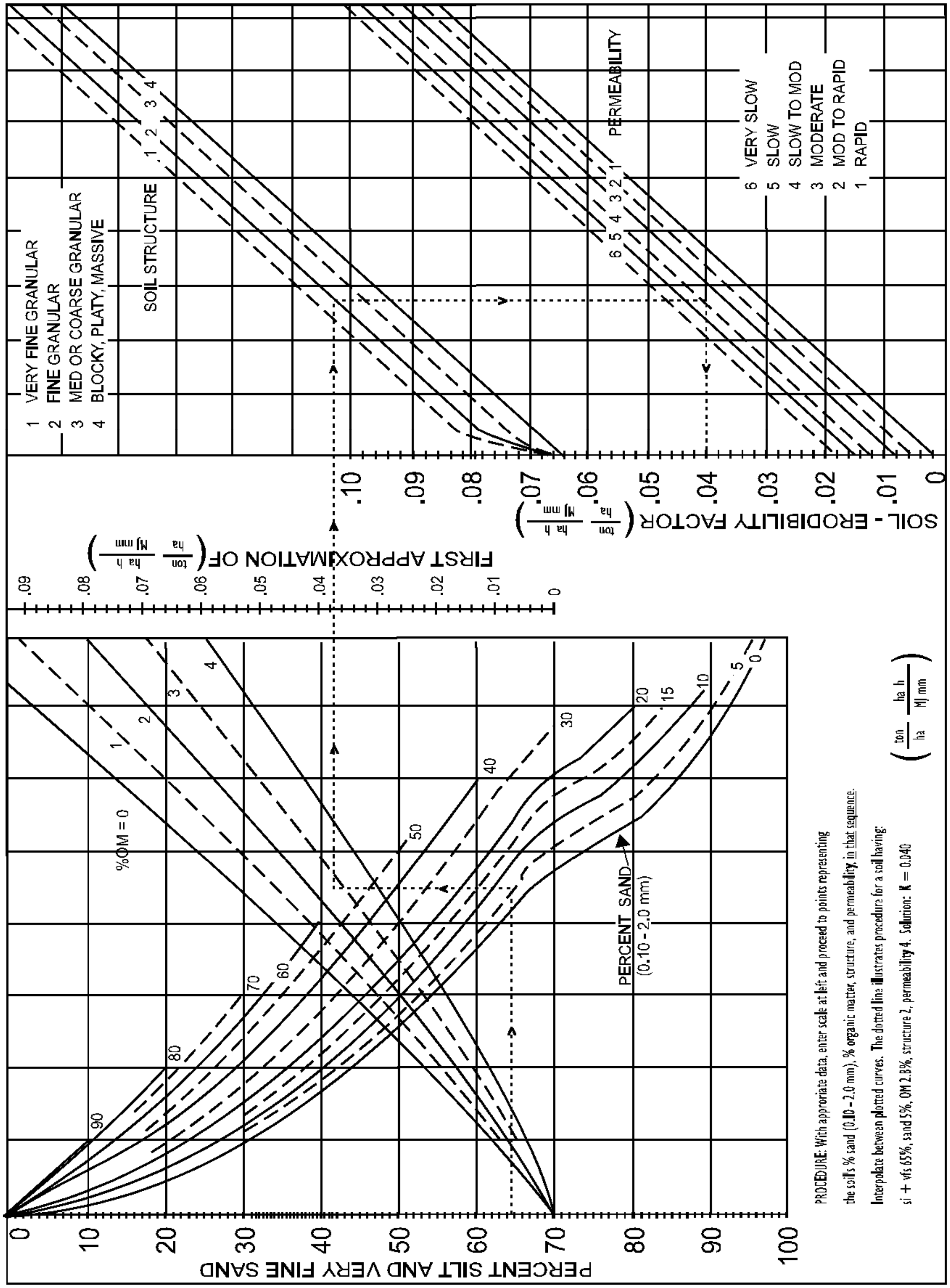

Figure B-1: The soil erodibility nomograph (Foster et al, 1981)

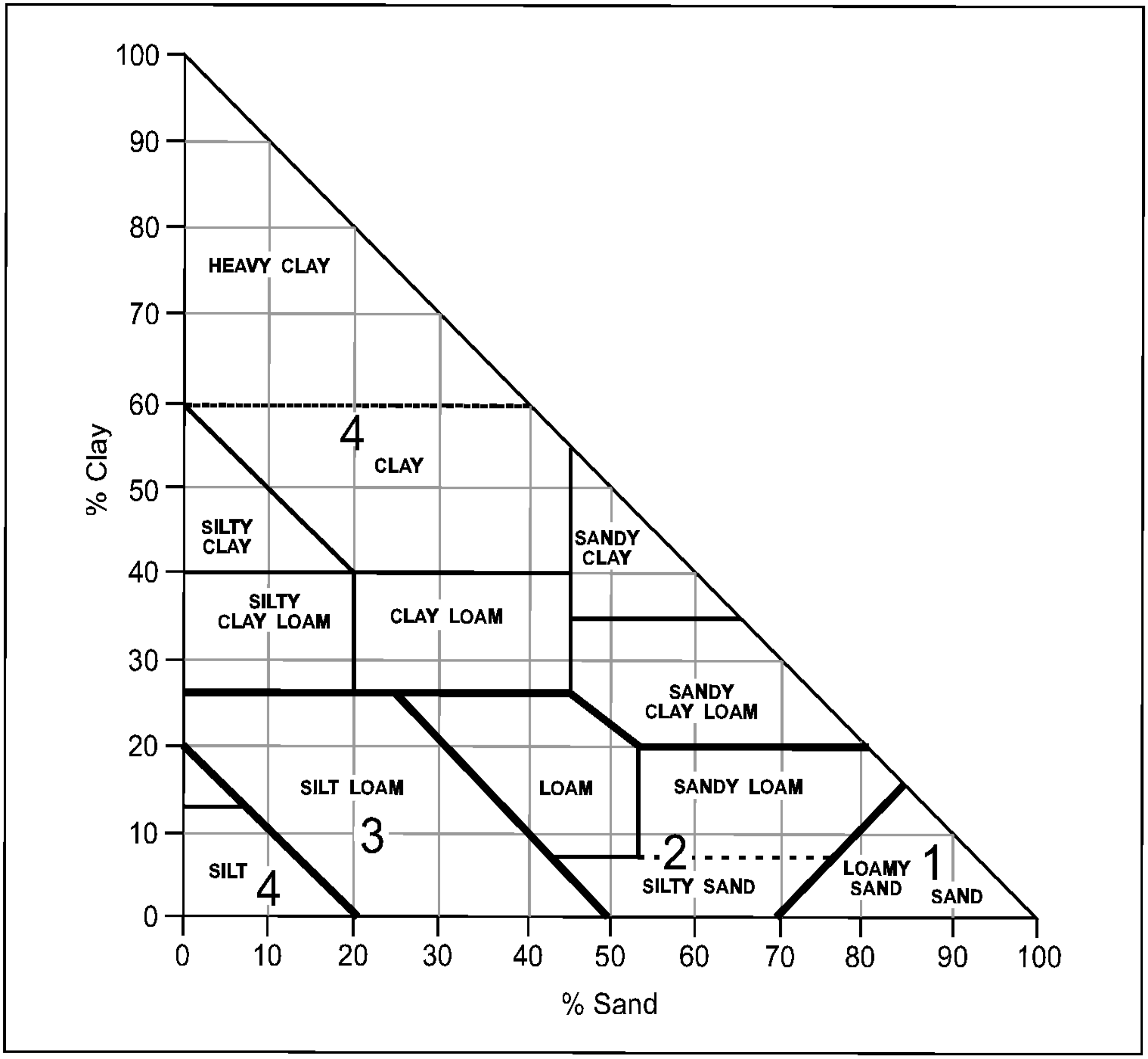

Figure B-2: Structure code based on textural classification

Note: For use in calculating the K value when soil structure information is not available but texture data are available.

Source: 1) Ontario Centre for Soil Resource Evaluation, 1993
2) Wall et al, 1997

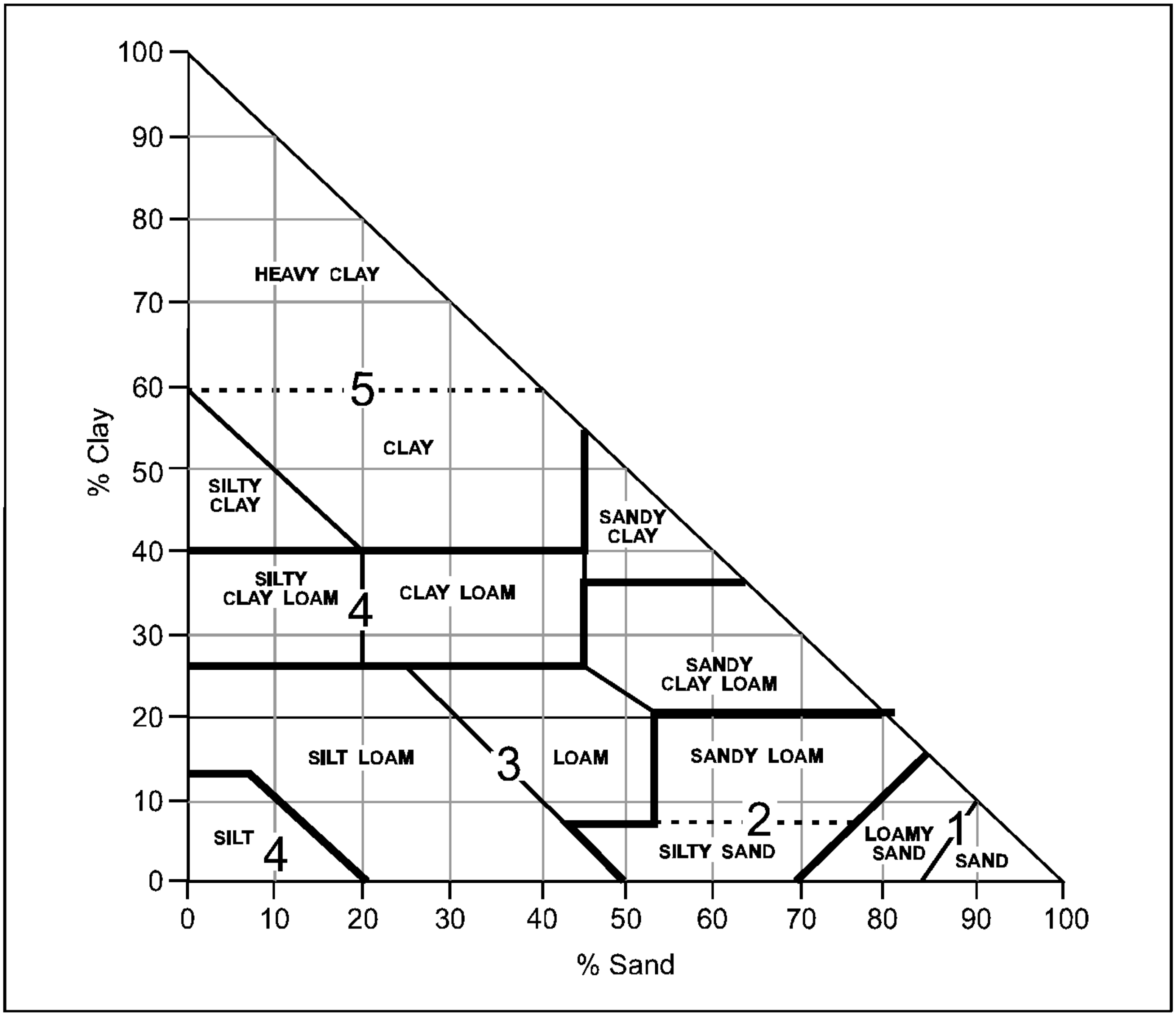

Figure B-3: Permeability code based on textural classification

Note: For use in calculating the K value when soil permeability information is not available but texture data are available.

(Source: Ontario Centre for Soil Resource Evaluation, 1993)

Location*	Normal 1-in-2 year 6-hr intensity (mm/hr.)	Normal 1-in-2 year 6 hr. storm (mm)	R - the Erosivity Index (MJ mm/ha/hr.)
Yellowknife	3.0	18.0	**221**
Fort Reliance	2.3	13.8	**124**
Fort Simpson	3.6	21.6	**328**
Hay River	3.1	18.6	**237**
Inuvik	1.9	11.4	**82**
Norman Wells	2.7	16.2	**176**
Tungsten	2.3	13.8	**124**

*All locations are at the local airport.

Table B-1: Estimated R values for selected sites in the NWT

Note: This is the same as Table 6.1 (Page 6-9) in the main manual.

Site	R_t	Monthly percentage of erosivity index (R)											
		J	F	M	A	M	J	J	A	S	O	N	D
Beaverlodge, B.C.	378	0	0	4	9	3	20	23	34	7	0	0	0
Lethbridge, Alta.	346	0	0	1	4	11	22	37	16	10	0	0	0
Peace River, Alta.	226	0	0	4	10	5	17	41	17	7	1	0	0
Vauxhall, Alta.	270	0	0	2	13	9	24	24	16	11	0	0	0
Broadview, Sask.	342	0	0	2	7	8	12	24	31	15	2	0	0
Estevan, Sask.	680	0	0	1	2	8	22	41	18	9	1	0	0
Outlook, Sask.	261	0	0	1	4	8	39	32	12	5	0	0	0
Saskatoon, Sask.	348	0	0	2	6	13	38	33	5	3	0	0	0
Swift Current, Sask.	268	0	0	1	3	7	43	25	16	5	0	0	0
Wynyard, Sask.	572	0	0	1	2	13	18	39	22	4	1	0	0
Yorkton, Sask.	663	0	0	1	2	7	23	26	28	10	2	0	0
Hudson Bay	510	0	0	2	5	5	22	37	18	10	1	0	0
Glenlea	1029	0	0	2	5	11	23	31	20	6	3	0	0
Gimli, Man.	848	0	0	1	4	6	25	24	27	11	3	0	0
Winnipeg, Man.	1093	0	0	1	3	12	18	21	32	12	2	0	0
White River, Ont.	1075	0	0	0	2	8	16	17	26	23	5	3	0
Windsor, Ont.	1615	2	3	5	9	6	15	20	18	9	5	4	4
London, Ont.	1330	3	3	3	9	7	14	18	15	11	7	6	4
Montreal, Que.	920	0	0	0	6	5	17	19	22	15	9	7	0
Moncton, N.B.	1225	3	4	4	4	8	10	14	15	10	12	11	5
Halifax, N.S.	1790	*	*	*	2	11	16	19	24	19	8	1	0
Kentville, N.S.	1975	4	6	7	6	3	12	12	15	10	10	7	8
Nappan, N.S.	1900	3	3	3	9	7	14	18	15	11	7	6	4
Truro, N.S.	2000	4	8	5	5	5	7	6	13	11	11	15	10
Charlottetown, P.E.I.	1520	4	4	4	9	7	13	17	14	11	7	5	5
St. John's, Nfld.	1700	4	8	5	5	5	7	6	13	11	11	17	8

* Data not available
Units for R = $MJ\ mm\ ha^{-1}\ h^{-1}$

Table B-2: Erosivity index and monthly distribution for sites in the Western and Eastern Canada

(Source RUSLEFAC)

TEXTURAL CLASS	ORGANIC MATTER CONTENT		
	< 2 %	> 2 %	AVERAGE
Clay	0.032	0.028	0.029
Clay Loam	0.044	0.037	0.040
Coarse Sandy Loam	-	0.009	0.009
Fine Sand	0.012	0.008	0.011
Fine Sandy Loam	0.029	0.022	0.024
Heavy Clay	0.025	0.020	0.022
Loam	0.045	0.038	0.040
Loamy Fine Sand	0.020	0.012	0.015
Loamy Sand	0.007	0.005	0.005
Loamy Very Fine Sand	0.058	0.033	0.051
Sand	0.001	0.003	0.001
Sandy Clay Loam	-	0.026	0.026
Sandy Loam	0.018	0.016	0.017
Silt Loam	0.054	0.049	0.050
Silty Clay	0.036	0.034	0.034
Silty Clay Loam	0.046	0.040	0.042
Very Fine Sand	0.061	0.049	0.057
Very Fine Sandy Loam	0.054	0.044	0.046

Table B-3: Soil erodibility values (K) for common surface textures

These K estimations are based on the information obtained on approximately 1600 soil samples.

If the organic matter content of a soil is unknown, use the value in the ‘average’ column. The other two columns refer to the values which can be used if the approximately organic matter content of a particular texture is known to be either greater or less than 2 percent.

(Source: Wall et al, 1997)

Slope (%)	Slope length in meters											
	2	5	10	15	25	50	75	100	150	200	250	300
0.2	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
0.5	0.07	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09
1	0.11	0.12	0.13	0.13	0.14	0.15	0.15	0.16	0.16	0.16	0.17	0.17
2	0.18	0.20	0.22	0.23	0.25	0.28	0.29	0.30	0.32	0.33	0.35	0.35
3	0.23	0.27	0.31	0.33	0.36	0.41	0.44	0.47	0.50	0.53	0.55	0.57
4	0.27	0.33	0.39	0.42	0.47	0.55	0.60	0.64	0.70	0.74	0.78	0.81
5	0.31	0.39	0.47	0.52	0.59	0.70	0.77	0.83	0.92	0.99	1.05	1.10
6	0.35	0.45	0.54	0.61	0.70	0.84	0.94	1.02	1.14	1.24	1.32	1.39
8	0.41	0.55	0.69	0.78	0.92	1.15	1.31	1.43	1.63	1.79	1.92	2.03
10	0.48	0.66	0.84	0.96	1.15	1.47	1.69	1.87	2.15	2.38	2.57	2.74
12	0.61	0.86	1.11	1.29	1.57	2.03	2.37	2.64	3.07	3.42	3.72	3.99
14	0.70	1.01	1.33	1.56	1.91	2.52	2.96	3.31	3.89	4.36	4.77	5.12
16	0.79	1.16	1.54	1.82	2.25	3.00	3.55	4.00	4.74	5.33	5.85	6.31
20	0.96	1.44	1.96	2.34	2.94	4.00	4.79	5.44	6.51	7.39	8.16	8.85
25	1.15	1.77	2.45	2.96	3.77	5.22	6.31	7.23	8.74	10.01	11.12	12.11
30	1.33	2.08	2.92	3.56	4.57	6.42	7.84	9.03	11.01	12.68	14.15	15.47
40	1.64	2.64	3.78	4.67	6.08	8.72	10.76	12.50	15.43	17.91	20.12	22.11
50	1.91	3.13	4.55	5.66	7.45	10.83	13.47	15.73	19.57	22.85	25.77	28.43
60	2.15	3.56	5.22	6.54	8.67	12.71	15.91	18.65	23.34	27.36	30.95	34.23

Table B-4: Values for topographic factor, LS, for low ratio of rill:interill erosion, such as consolidated soil conditions with cover and rangeland (applicable to thawing soils where both inter-rill and rill erosion are significant

(Source: Wall et al, 1997)

Slope Steepness (%)	Slope Length Exponent, m Rill/Interrill Ratio â		
	Low*	Moderate†	High‡
0.2	0.02	0.04	0.07
0.5	0.04	0.08	0.16
1	0.08	0.15	0.26
2	0.14	0.24	0.39
3	0.18	0.31	0.47
4	0.22	0.36	0.53
5	0.25	0.40	0.57
6	0.28	0.43	0.60
8	0.32	0.48	0.65
10	0.35	0.52	0.68
12	0.37	0.55	0.71
14	0.40	0.57	0.72
16	0.41	0.59	0.74
20	0.44	0.61	0.76
25	0.47	0.64	0.78
30	0.49	0.66	0.79
40	0.52	0.68	0.81
50	0.54	0.70	0.82
60	0.55	0.71	0.83

* Conditions where rill erosion is slight with respect to interill erosion; generally C factors would be less than 0.15

† Conditions where rill and interill erosion would be about equal on a 22.1 m long slope in seedbed condition on a 9% slope

‡ Conditions where rill erosion is great with respect to interill erosion; generally C factors would be greater than 7.0

Table B-5: Slope length exponents (m) for a range of slopes and rill/interill erosion classes

(Source: McCool et al, 1989)

Type of mulch	Mulch rate tons/acre	Land slope percent	C Factor	Length limit (feet)
None	0	all	1	-
Straw or hay, tied down by anchoring and tacking equipment	1	1.5	0.20	200
	1	6-10	0.20	100
	1.5	1.5	0.12	300
	1.5	6-10	0.12	150
	2	1.5	0.06	400
	2	6-10	0.06	200
	2	11-15	0.07	150
	2	16-20	0.11	100
	2	21-25	0.14	75
	2	26-33	0.17	50
	2	34-50	0.20	35
Crushed stone, 1/4 to 1 1/2 inch	135	<16	0.05	200
	135	16-20	0.05	150
	135	21-33	0.05	100
	135	34-50	0.05	75
	240	<21	0.02	300
	240	21-33	0.02	200
	240	34-50	0.02	150
Wood chips	7	<16	0.08	75
	7	16-20	0.08	50
	12	<16	0.05	150
	12	16-20	0.05	100
	12	21-33	0.05	75
	25	<16	0.02	200
	25	16-20	0.02	150
	25	21-33	0.02	100
	25	34-50	0.02	75

Table B-6a: C-Factors for mulch placement and respective slope length limits

(Source: Wall et al, 1997)

Treatment	C-Factor
Sod Grass	0.01
Temporary Vegetation/Cover Crop	0.45[1]
Hydraulic Mulch at 4.5 tonnes/ha	0.10[2]
Soil Sealant	0.10 – 0.60[3]
Rolled Erosion Control Products	0.10 – 0.30[3]

Notes: [1] Assumes planting occurs within optimal climatic conditions

[2] Some limitation on use in arid and semiarid climates

[3] Value used should be substantiated by documentation (e.g. manufacturer's specifications).

Table B-6b: C-Factors for Other Treatments

Treatment			P- Factor
Bare Soil			
Packed and smooth			1.00
Freshly disked or rough, irregular			0.90
Sediment Containment Systems (a.k.a. Sediment Trap / Basin)			0.10-0.90[A]
Bale or Sandbag Barriers			0.90
Rock (Diameter = 25 - 50 mm) Barriers at Sump Location			0.80
Silt - Fence Barriers			0.60
Contour Furrowed Surface			
Must be maintained throughout construction activities, otherwise P-Factor =1.0, Maximum length refers to downslope length			
	Slope (%)	**Max. Length (m)**	
	1 to 2	120	0.60
	3 to 5	90	0.50
	6 to 8	60	0.50
	9 to 12	40	0.60
	13 to 16	25	0.70
	17 to 20	20	0.80
	>20	15	0.80
Terracing			
Must contain 2-year runoff volumes without overflowing, otherwise P-Factor = 1.00			
	Slope (%)		
	1 to 2		0.12
	3 to 8		0.10
	9 to 12		0.12
	13 to 16		0.14
	17 to 20		0.16
	>20		0.18
Grass Buffer Strips to Filter Sediment-laden Sheet Flows			
Strips must be at least 15 m (50 ft) wide and have a groundcover value of 65% or greater, otherwise P-Factor =1.00			
	Basin Slope (%)		
	0 to 10		0.60
	11 to 24		0.80

A. Should be constructed as the first step in over lot grading.

Note: Use of P-Factor values not in this table must be supported by documentation.

Table B-7: P-Factor Values for Construction Sites

(Sources: Fifield 2001 and Wall et al, 1997)

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APPENDIX C

EROSION AND SEDIMENTATION CONTROL BEST MANAGEMENT PRACTICES (BMPs)

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INTRODUCTION

The 2012 GNWT- Department of Transportation ESC Manual includes BMPs designed for:

- Crushed Rock Buttress for Slopes (Permafrost)
- Controlled Melt of Cut Slope (Permafrost)
- Insulated Thermal Blanket on Cut Slope (Permafrost)

All BMPs adapted from the Alberta Transportation Erosion and Sediment Control Manual (2011) had a general review and was modified to be applicable in the northern climate where necessary.

Users of this manual are cautioned that these BMPs are for guidance only and that a specific site design is required by the engineer or designer.

LIST OF TABLES

LIST OF BMPs

Erosion and Sediment Control

BMP #	BMP Description	BMP #	BMP Drawing
1.	Sediment Fence	1.	**a.** Sediment Fence - Trench **b.** Sediment Fence - Mechanical **c.** Sediment Fence - Configuration Plan
2.	Gabions	2.	**a.** Gabions **b.** Gabion - Drop Structure **c.** Gabion - Energy Dissipater
3.	Berm Interceptor	3.	Berm Interceptor
4.	Storm Drain Inlet	4.	**a.** Storm Drain Drop Inlet **b.** Storm Drain Curb Inlet Barrier **c.** Curb Inlet **d.** Storm Drain Inlet Barrier - Sandbags **e.** Storm Drain Drop Inlet Barrier - Straw bale **f.** Strom Drain Drop Inlet - Sediment Fence
5	Rock Check	5	Rock Check Dam
6.	Synthetic Permeable Barrier	6.	Synthetic Permeable Barrier
7.	Straw Bale Barrier	7.	Straw Bale Barrier
8.	Rolled Erosion Control Products (RECP)	8.	**a.** Rolled Erosion Control Product (RECP) Channel **b.** Rolled Erosion Control Product (RECP) Slope
9.	Riprap Armouring	9.	**a.** Riprap Armouring for Slope **b.** Riprap Armouring for Channel
10.	Cellular Confinement System	N/A	N/A
11.	Energy Dissipaters	11.	**a.** Energy Dissipaters for Culvert Outlet **b.** Energy Dissipater for Semi-Circular Trough Drain terminal Protection for Bridge Headslope
12.	Sediment Traps and Basins	12.	**a.** Typical Sediment Basin (Riser Outlet Option) **b.** Typical Sediment Basin (Permeable Rock berm Outlet Option)
13.	Slope Drains	13.	**a.** Slope Drain **b.** Overside Drain
14.	Diversion Ditches	14.	Diversion (Intercept) Ditch
15.	Seeding	N/A	N/A

16.	Mulching	N/A	N/A
17a	Hydroseeding	N/A	N/A
17b	Hydromulching	N/A	N/A
18.	Topsoiling	N/A	N/A
19.	Soil and Root Mat Replacement (Sodding)	N/A	N/A
20a	Live Staking	20	**a.** Live Staking **b-1.** Brushlayering **b-2.** Brushlayering **b-3.** Brushlayering
21.	Riparian Zone Preservation	N/A	N/A
22.	Crushed Rock Buttress for Slopes (Permafrost)	22.	Gravel Buttress for Cutslopes in ice-Rich Permafrost
23.	Controlled Ablation (Melt) of Cut Slope (Permafrost)	23.	Natural Buttress for Cutslopes in Ice-Rich Permafrost
24.	Insulated Thermal Blanket on Cut Slope (Permafrost)	24.	Insulated Thermal Blanket for Cutslopes in Ice-Rich Permafrost
25.	Scheduling	N/A	N/A
26.	Stabilized Worksite Entrances	26.	Construction Entrance / Exit
27.	Slope Texturing	27.	**a.** Surface Roughening **b.** Grooved or Serrated Slope **c.** Benched Slope
28.	Compost Blanket	N/A	N/A
29.	Rolls (Fibre- Coir, Wattles)	29.	**a.** Coir Roll with Brushlayering **b.** Coir Roll / Coir Mats **c.** Straw Rolls
30	Wattles (Live)	N/A	N/A

Streambank Stabilization Techniques

BMP#	BMP Description	BMP#	BMP Description
29	Rolls (Fibre- Coir, Wattles)	29	**a.** Coir Roll with Brushlayering **b.** Coir Roll / Coir Mats **c.** Straw Rolls
30	Wattles (Live)	N/A	N/A
20a	Live Staking	20a	Live Staking
20b	Brushlayering	20b	Brushlayering
31	Brush Mattress	31	Brush Mattress
32	Live Siltation	32	Live Siltation
33	Willow Posts & Poles	33	Willow Posts & Poles
34	Rock Vanes	34	**a.** Rock Vane - Typical **b.** Rock Vane – Typical with Pole Planting

35	Longitudinal Stone Toe	35	Longitudinal Stone Toe
36	Vegetated Mechanically Stabilized Earth (VMSE)	36	Vegetated Mechanically Stabilized Earth (VMSE)
37	Vegetated Riprap	37	**a.** Vegetated Riprap **b.** Vegetated Riprap **c.** Vegetated Riprap **d.** Vegetated Riprap
38	Stream Diversion Channel	38	Temporary Stream Diversion
39	Coffer Dam (Small Streams)	N/A	N/A

Table C-1: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
18	Topsoiling (The application of topsoil over mineral soils to provide a growing medium for seeded vegetation and protect from surface erosion)	✓	✓	✓	✓	• Placing topsoil provides excellent medium for vegetation root structure development; • Organic content promotes plant growth; • Placing stockpiled organic material back on surfaces allows the reuse of these materials (topsoil or peat) stripped from the site at start of grading; • Absorbs raindrop energy to minimize erosion potential; • Insulates frozen soils and may reduce the amount or speed of the thawing process.	• Cannot be effective without seeding and allowing time for plant growth; Not appropriate for slopes steeper than 2H:1V (steep slopes will require geotextile, fabric or rolled erosion control product covering over topsoil and specialized design); • Dry topsoil is particularly susceptible to wind erosion; • Topsoil is susceptible to erosion prior to establishment of vegetation. • Areas with invasive species should be avoided if collecting topsoil.
15	Seeding (Introduction of seed for establishment of vegetation for permanent erosion protection)	✓	✓	✓	✓	• Inexpensive and effective erosion control measure once established; • Promotes even cover and controls seed distribution for higher plant densities as quickly as possible following construction; • Planting locally appropriate species helps reduce weed species establishment. • May be conducted as the project commences without waiting until the	• Requires a prepared surface; • May require soil amendments (topsoil, fertilizers) to be added to poor quality soils; • Grasses may require periodic maintenance (mowing); • Uncut dry grass may be a fire hazard; • Seeding on long steep slopes may be difficult; • Invasive species should be avoided; • Seasonal limitations for seed germination; • Preferred growing periods may not coincide

Table C-1: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications: Slopes	Applications: Ditches and Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
						end of the job; • Effectiveness increases with time as vegetation develops; • Aesthetically pleasing; • Enhances terrestrial and aquatic habitat; • Can be used in conjunction with other permanent soil stabilization practices; • Can be applied by installing cocoa matting with embedded seed.	with a delayed construction schedule; • Freshly seeded areas are susceptible to runoff erosion until vegetation is established; • Reseeding may be required to achieve adequate densities; • May attract wildlife thereby creating hazards for the travelling public
16	Mulching (Protective covering applied to protect exposed soils from erosion and protect seed during germination)	✓	✓	✓	✓	• Used alone to protect exposed areas for short periods; • Protects soil from rain splash erosion; • Preserves soil moisture and protects germinating seed from temperature extremes; • Relatively inexpensive measure of promoting plant growth and providing slope protection; • Can utilize vegetative material through on site chipping/mulching and spreading.	• Application of mulch on long steep slopes may be difficult; • May require additional specialized equipment to apply; • Some mulch types may deplete available soil nitrogen; • Slow release fertilizer may need to be added.

Table C-1: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
17a 17b	Hydroseeding / Hydromulching (Seed and mulch mixed with water for application by truck for revegetation and protection of exposed soils)	✓	✓	✓	✓	• Economical and effective on large areas; • Conforms to uneven surfaces; • Retains moisture; • May contain added soil amendments to promote germination and establishment of vegetation; • Mulch with tackifier may be used to provide immediate soil protection until seed germination and vegetation is established; • Allows vegetation of steep slopes where conventional seeding/mulching techniques are very difficult; • Relatively efficient to operate; • Provides wind erosion control.	• Site must be accessible to hydroseeding / hydromulching equipment (usually mounted on trucks with a maximum hose range of approximately 50 m); • May require subsequent application (reseeding) in areas of low densities as part of maintenance program. • Invasive species should be avoided
19	Soil and Root Mat Replacement (Sodding) (Used where sod mat has been harvested during stripping to be re-applied to protect sensitive sites and insulate soils in permafrost areas.	✓	✓	✓	✓	• Immediate protection for sensitive areas from water and wind erosion; • Aesthetically pleasing. • May contain local seed within fibrous mat	• Expensive due to time required for removing, retaining and replacing the soil and root mat; • Labour intensive to remove and replace; • Soil and root mat may not be readily available; • Soil and root mat cannot be stored on-site for long periods of time. • Harvesting soil and sod in areas with invasive species should be avoided

Table C-1: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications: Slopes	Applications: Ditches and Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
9	Riprap Armouring (Application of rock lining to provides protection to soils in ditchlines, downdrains, stream channels and slopes)	✓	✓	✓		• Most applicable as a surface soil lining for drainage ditches and downdrains with underlay,and in stream channels without use of fabric underlay • Used for soils where vegetation not easily established or where permanent protection is immediately required; • Effective for high velocities or concentrations; • Permits infiltration; • Dissipates energy of flow from culvert inlets/outlets or other water discharge points; • Easy to install and repair; • Very durable and virtually maintenance free.	• Expensive; • May require heavy equipment to transport and place rock; • May not be feasible in areas where rock is not readily available; • May be labour intensive to install; • Riprap is usually thicker than gabion mattress requiring additional depth in the channel to be considered in planning.
8	Rolled Erosion Control Products (RECP) (manufactured product used to protect soils from raindrop erosion, and protect seed during germination)	✓	✓			• Provides an immediate protective covering to bare soil or topsoil applied to a surface; • Can be used in conjunction with seeding; • Can be more uniform and longer lasting than mulch; • Wide range of commercially available products;	• Labour intensive to install; • Not suitable for rocky slopes; proper site preparation is required to seat RECP onto soil correctly (requires good soil contact); • Temporary (degrades over time) dependant of type and quality; • Temporary blankets may require removal prior to restarting construction activities.

Table C-1: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
						• Natural product choices available; • May be used for temporary cover protection.	
10	Cellular Confinement System (manufactured product applied to soil surface to reduce rill erosion and provide stabilization of surface soils)	✓	✓			• Lightweight; • Easily installed; • Uses locally available soils for fill to reduce costs.	• Not commonly used in transportation construction projects; • Expensive; • Installation is labour intensive (hand installation); • Not suitable for slopes steeper than 1H:1V.
22	Crushed Rock Buttress for Slopes (Permafrost) (Application of crushed rock to support slope surface material during melt events)	✓				• The cut slope can be rapidly prepared and buttressed to provide support and ensure continued thermal insulation; • Local rock and aggregate materials can be used, if crushing facilities are available; • When ground ice melting occurs, the wetted soils will be held by the buttress and drainage can occur, to increase overall soil stability.	• Obtaining sufficient crushed rock or coarse aggregate for the buttress may be difficult in permafrost areas; • The buttress will require maintenance and replacement of failed buttress material.
23	Controlled Melt of Cut Slope (Permafrost) (controls natural melting of ice within	✓				• Where no other project configuration is possible to avoid permafrost with high ground ice, this BMP allows controlled melting of the ground ice and stabilization of the cut slope over	• Construction of the separation berm requires consideration and use of an overflow drainage feature (armoured notch) for extreme rain events or high runoff from snowmelt. Other drainage systems, such as

Table C-1: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications: Slopes	Applications: Ditches and Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
	a slope until slope stabilizes)					the long term; • The separation berm can be constructed of local materials if available.	standpipes, may be considered; • Light coloured crushed rock or aggregate will be required for the separation berm to limit thermal degradation of permafrost; • The receding soil failure at the cut slope will require time to come to a slope gradient in balance with water, soil and thermal conditions.
24	Insulated Thermal Blanket on Cut Slope (Permafrost) (application of thermal materials over slope or ground section to reduce/prevent permafrost melt while allowing natural drainage)	✓				• The thermal blanket material can be obtained locally; • The cut slope may regress back from ground ice melt over time but the blanket material will shift and conform to the underlying slope surface, providing support and thermal protection; • For cut slopes with ground ice and in permafrost areas, the cut slope can be prepared at a steep gradient, preserving the natural vegetation and organic deposit cover, and a thermal blanket can be placed over the cut slope to reduce ground ice melting and allow water drainage.	• Melting of ground ice and permafrost is usually progressive, resulting in loss of soil strength and volume, and may cause retrogressive slope failure behind the blanket; • Climate change with a slow increase in average air temperature, is causing general increase of ground temperatures, melt of permafrost, especially along the belt of discontinuous permafrost where the permafrost is thin, at shallow depth and at a temperature not far below freezing.
20a	Live Staking (Planting of live cuttings to promote growth of woody	✓		✓		• Establishes vegetative cover and root mat; • Once established, vegetation may reduce flow velocities;	• Expensive to install if stock not readily available; • May be labour intensive to install; • Not commonly used in linear construction

Table C-1: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications: Slopes	Applications: Ditches and Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
	vegetation for the purpose of promoting fast establishment of leafy woody vegetation to protect exposed soils from raindrop erosion and bind soils through rooting networks)					• May trap sediment laden runoff; • Aesthetically pleasing once established; • Grows stronger with time and root structure development; • Usually has deeper root structure than grass; • Rooting promotes water infiltration; • Planting conducted without large equipment; • Available local native species may be used; • May be used in conjunction with other practices for riparian remediation and streambank stabilization on water crossings.	projects; • Revegetated areas are subject to erosion until plants are established; • Plants may be damaged by wildlife; • Watering may be required during dry season until plants are established. • May interfere with sight lines for linear projects. • Matured staked species may be considered a liability on some sites (airport lands) • May become protected habitat under Migratory Birds Convention Act. • May provide habitat for wildlife close to areas used by traffic.

Table C-1: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
21	Riparian Zone Preservation (Retention of natural vegetation within a riparian area to provide natural filtration of sediments and reduce runoff velocity)	✓	✓	✓	✓	• Natural vegetation buffer to filter and reduce runoff velocity by dissipating flow; • Most effective natural sediment control measure; • Promotes infiltration which may reduce volume of runoff.	• Planted vegetation requires substantial periods of time before they are as effective as established vegetation at controlling sediment; • Not intended for heavy sediment load filtration, high volume discharge or as a sole source for construction runoff control. • May not be deemed to be an acceptable addition to the highway right of way (line of sight obstruction at maturity of staked species). • May become protected habitat when vegetation matures and provides habitat for wildlife and/or migratory birds.
25	Scheduling (Used to promote the scheduling of events to minimize the exposure of soils to unfavourable weather conditions, plan site activities including the installation of BMPs)	✓	✓	✓	✓	• Promotes efficient, orderly construction of BMPs; • Identifies potential protection issues related to construction timing and seasonal climatic conditions; • Identifies fish sensitive periods which may be avoided; • May minimize the amount of soil exposure thereby reducing erosion potential; • Identifies need for early installation of perimeter control for sediment entrapment and runoff control measures;	• Needs to be flexible and revisited as construction progresses; • May require amendment in the event of delays in construction.

Table C-1: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications: Slopes	Applications: Ditches and Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
						• Provides timelines for permitting, in-stream works, and early vegetation establishment; • Allows for scheduling of equipment, delivery of supplies, and subcontractor deployment	
28	Compost Blanket (application of composted materials as a blanket to cover exposed soils to protect form erosion)	✓		✓	✓	• Economical if readily available; • Appropriate on slopes 2H:1V to level surface; • Provides nutrient base as soil amendment.	• Application on steep slopes (>2H:1V) may be difficult; • Treatment area should be accessible to blower trucks. • May not be readily available; • May not be authorized for use near or upslope of watercourses
2	Gabions (Manufactured metal basket or blanket which can be filled with cobbles for the construction of slope structures, velocity reduction structure and channel or ditch bed stabilization)	✓	✓			• Provides stabilization for steep slopes or reinforced channels in streams, rivers or creeks; • Can be used as mats for runout below ditch blocks or culvert inlets/outlets; • Can be designed to be used with compacted soil fill for areas requiring vegetation walls	• Should be used with caution within stream beds. Not a preferred treatment for fisheries sensitive areas. • May require design by Qualified Professional; • May be expensive and labour intensive • May have limited lifespan dependent on the quality and coating applied to the materials used.
38	Stream Diversion Channel (Man-made channel constructed to divert		✓			• Protects environmentally sensitive areas; • Conveys flow consistency better than a dam, impoundment and	• Requires erosion protection; • Risk of export of sediment downstream if not properly staged; • Requires fish exclusion and fish salvage if

Table C-1: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
	a stream around or through a construction site to protect water quality and provide a dry work area)					pumping; • Not at risk of power failure or malfunction (e.g. pumps); • Maintains fish passage; • Diverts surface flows from entering the site or limits flow to specific area of the site	working on a known or suspected fish-bearing stream. Permits may be required; • In-stream work windows are regulated by agencies and must be adhered to.
39	Coffer Dam (Man-made dam structure used to direct water around or out of a work area [e.g. metal sheet piling, sand bags, straw bales, aquadam, etc) to provide a dry work area and protect water quality.		✓			• Protects environmentally sensitive areas by limiting the work site area; • Diverts all or a portion of a stream or surface water flows around a site to maintain downstream flows; • Permits work to be conducted “in the dry” to minimize downstream sedimentation • May divert up to 2/3 of watercourse without significant impact to fish passage • Used to control erosion by keeping water out of the work site	• Used only to divert water- not used as a barricade which causes ponding; • Requires monitoring and maintenance; • Risk of export of sediment downstream • Used in areas of shallow flow depth (usually less than 1.2 m unless designed by an engineer); • Height of the dam should provide protection for a 1 in 10 year event, if possible (height of dam to be less than 1.2 m unless designed by an engineer); • All debris and accumulated sediment inside the work area must be cleared away before removal of the coffer dam; • Operations within the work area must be capable of withstanding flooding without risk to life and equipment damage; • May require authorization for instream works, fish exclusion and fish salvage on fish-bearing streams. Permits may be

Table C-1: Erosion Control Measures – Source Control

BMP #	BMP Name	Applications: Slopes	Applications: Ditches and Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
							required; • In-stream work windows are regulated by agencies and must be adhered to. • Requires contingency planning for flooding or groundwater infiltration.

Table C-2: Erosion Control Measures – Runoff Control								
BMP #	**BMP Name**	**Applications**				**Comments**	
		Slopes	**Ditches and Channels**	**Large Flat Surface Areas**	**Borrow and Stockpile Area**	**Advantages**	**Limitations**
27	Slope Texturing (the roughening of surface soils to promote infiltration of water, trap seed, and reduce velocity and rill development on slopes through contouring or the use of horizontal machine track patterns)	✓		✓	✓	• Roughens slope surface to reduce potential erosion and sediment yield and promotes infiltration; • Suitable for clayey soils; • Contouring and roughening (tracking) of slope face reduces runoff velocity and increases infiltration rates; • Reduces erosion and collects sediment better than smooth surfaces; • Captures and holds water, seed and mulch which promotes vegetation growth.	• Must be planned cost included in grading; • May cause sloughing in sensitive (wet) soils, • Tracking may compact soil, • Provides limited erosion control and should not be used as primary control measure; • Not suitable for silty and sandy soils; • Not practical for slope length <8 m for bulldozer operation up/down slope; • Not suitable for permafrost areas.
14	Diversion Ditch (Used to divert water from entering a construction site or through a site, may be used to divert water out of a ditchline)	✓	✓	✓	✓	• Intercepts and diverts water from the top of a slope away from disturbed soil areas to reduce downslope erosion; • May be incorporated into permanent project drainage systems using natural channel design. • May be used to temporarily divert a stream to permit culvert installation	• Channel must be sized appropriately to accommodate anticipated flow volumes and velocities; • Lining may be required; • May require design by qualified personnel; • Must be graded to minimize ponding.
11	Energy Dissipator (structure used to reduce the speed at	✓	✓			• Slows runoff velocity and dissipates flow energy to minimize erosion potential in relatively short distances;	• Small diameter rocks can be dislodged; • May be expensive if rock has to

Table C-2: Erosion Control Measures – Runoff Control							
BMP #	**BMP Name**	**Applications**				**Comments**	
		Slopes	**Ditches and Channels**	**Large Flat Surface Areas**	**Borrow and Stockpile Area**	**Advantages**	**Limitations**
	which the water flows to reduce erosion and/or promote sediment deposit)					• May collect sediment due to reduced runoff velocities;	be hauled in; • Grouted riprap armouring may breakup due to hydrostatic pressures, frost heaves, or settlement; • May be labour intensive to install; • May require design by qualified professional.
13	Slope (Down) Drains (Pipe structure which directs water from the top to the base of a slope)	✓				• Directs surface water runoff into drain pipe or lined channel and delivers to base of slope; • Protects exposed soils on the slope face from erosion causing rilling or gullying.	• Must be sized appropriately to accommodate anticipated flows; • Erosion can occur at inlet/outlet if protection is not installed; • Requires incorporation into permanent design; • Slope drain pipe must be anchored to slope.

Table C-2: Erosion Control Measures – Runoff Control							
		Applications				Comments	
BMP #	BMP Name	Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
2	Gabions (Gabion Baskets may be used beneath a perched culvert or steep drop to protect the soils from erosion as it drops from a height above, Gabion blankets may also be required to protect the run-out area beneath the structure)		✓			• Relatively maintenance free, permanent drop structure; • Long lasting; • May be less expensive than riprap; • Allows smaller diameter rock/stones to be used; • Relatively flexible; • Commercially available products; • Suitable for resisting high flow velocity.	• Construction may be labour intensive (hand installation); • Extra costs associated with gabion basket materials; • May be expensive if rock is not available in local area.
3	Berm Interceptor (Soil berm constructed of local material to intercept and redirect water flows, or build containment ponds)	✓		✓	✓	• Easy to construct; • Relatively inexpensive as local soil and material is used.	• Qualified Professional design required for fill heights in excess of 3 m; • May not be suitable for all soil types or sites; • Riprap spillway and/or permeable outlet may be required.

Table C-2: Erosion Control Measures – Runoff Control							
BMP #	**BMP Name**	**Applications**				**Comments**	
		Slopes	**Ditches and Channels**	**Large Flat Surface Areas**	**Borrow and Stockpile Area**	**Advantages**	**Limitations**
5	Rock Check Dam (Structure constructed of rock to slow water usually within a ditchline. May be used on slopes <9% with angular rock large enough to withstand velocity of the water flow)		✓		✓	• Permanent or temporary small, velocity control structure for steep (<9%) drainage channels; • Reduces grade length between structures; • Cheaper than gabions or armouring entire channel; • Easily constructed;	• Can be expensive in areas of limited rock source; • Not appropriate for channels >8% slope or draining areas larger than 10 ha; • Requires ongoing maintenance (particularly after high flow storm events); • Can fail if water undermines or outflanks structure or rock is not sized correctly for water velocity and volume; • May cause flooding during spring melt or when combined with icing conditions; • Maintenance costs increase for ditches when permanent
6	Synthetic Permeable Barriers (Manufactured product used to reduce flow velocity in small areas and for low flow situations, Re-usable and/or moveable)		✓			• Reusable/moveable; • Reduces flow velocities and dissipates flow energy which reduces some sediment; • Used as grade breaks in conjunction with sturdy permanent drop structures along steep grades.	• Not to be used as check structures; • Only suitable for small drainage areas (< 0.8 ha) and low-flow velocity; • Must be installed by hand in conjunction with RECP; • May become brittle in winter and are easily damaged by construction equipment or recreational vehicles; • Only partially effective in

Table C-2: Erosion Control Measures – Runoff Control							
BMP #	**BMP Name**	**Applications**				**Comments**	
		Slopes	**Ditches and Channels**	**Large Flat Surface Areas**	**Borrow and Stockpile Area**	**Advantages**	**Limitations**
							retaining sediment. • Must be maintained and, eventually, removed, so may require an extra mobilization to site.
29 30	Rolls (Coir) Wattles (Manufactured materials or natural) (Used on fill or cut slopes to reduce runoff velocity, provide small slope breaks to permit infiltration and promote vegetation establishment.)	✓				• Function well in freeze-thaw conditions; • Low-cost solution to sheet flow and rill erosion on slopes; • Low to medium cost flow velocity control and silt trap; • Can be used on slopes too steep for silt fences or straw bale barriers; • Biodegradable manufactured types available. • Wattles can be made of willow or other local vegetation	• Labour intensive to install (hand installation); • Designed for slope surfaces with low flow velocities; • Designed for short slope lengths with a maximum slope of 2H:1V;

Table C-3: Sediment Control Measures

	BMP Name	BMP #	Applications: Slopes	Applications: Ditches and Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
Filtering and Entrapment	Riparian Zone Preservation	21	✓	✓	✓	✓	• Well established vegetation buffer will filter and slow runoff; • Most effective natural sediment control measure.	• May not be feasible to retain; • Not practical for large flow volumes, high velocities, or too much sediment • Damage to riparian vegetation may occur if too much sediment is deposited; • Not able to be cleaned or maintained; • Newly planted riparian zones require substantial periods of time before they are effective at controlling sediment. • Within a right of way, riparian areas can become areas where wildlife will stage before crossing the highway.
Filtering and Entrapment	Straw Bale Barrier	7		✓	✓	✓	• Biodegradable; • Less expensive; and • Easier to install than other barriers.	• Labour intensive to install; • Short service life due to biodegradation; • Straw bales are not readily available across most of the NWT; • Maximum barrier height of one straw bale; • May require extensive maintenance after high flow storm events; • Require proper keying and staking.

Table C-3: Sediment Control Measures

BMP Name		BMP #	Applications: Slopes	Applications: Ditches and Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
	Rolls (Fibre) Coir or Wattles (Manufactured materials)	29	✓				• Function well in freeze-thaw conditions; • Low cost solution to sheet flow and rill erosion on slopes; • Low to medium cost flow control and silt trap; • Can be used on slopes too steep for sediment fences; • Biodegradable.	• Labour intensive to install (hand installation); • Designed for slope surfaces with low flow velocities; • Designed for short slope lengths with a maximum slope of 2H:1V;
	Wattles (Live) (Usually collected live local material is used and bundled to make rolls or wattles)	30	✓				• Function well in freeze thaw conditions; • Solution for sheet flow and rill erosion near water bodies; • Can be used on slopes too steep for sediment fences; • Materials for construction may be immediately available; • Biodegradable – Live; • Improved strength over time; • Flow control and sediment trap; • Aesthetically pleasing once established.	• Labour intensive to install; • Designed for low flow velocities; • Designed for short slope lengths; • May cause visual obstruction.

Table C-3: Sediment Control Measures							
BMP Name	BMP #	Applications				Comments	
		Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
Sediment Fence (manufactured fencing used to slow flow velocity, promote settling and sediment detention)	1	✓		✓	✓	• Economical; • Readily available from suppliers; • Easy to install; • Slows water to settle out coarse grained sediment; • More effective than straw bale barriers.	• May fail during high runoff events; • Applicable for sheet flow erosion only; • Limited to locations where adequate space is available; • Maintenance to remove sediment build up is required on a regular basis; • Damage to sediment fence may occur during sediment removal; • Usable life of approximately one year, after which removal and disposal is required.
Storm Drain Inlet/Sediment Barrier	4			✓		• Temporary measure; • Easy to install and remove.	• Limits drain inlet capacity; • Very limited sediment entrapment capacity; • Requires regular clean-out and maintenance; • May increase intake flows downslope or at next storm drain or cause flooding.

Table C-3: Sediment Control Measures

	BMP Name	BMP #	Applications: Slopes	Applications: Ditches and Channels	Applications: Large Flat Surface Areas	Applications: Borrow and Stockpile Area	Comments: Advantages	Comments: Limitations
All BMPs	Compost Blanket (compost spread in a layer over exposed soils to protect the site from raindrop erosion)	28	✓		✓	✓	• Economical if product readily available; • Appropriate on slopes 2H:1V slope or flatter • Natural fibers used to protect the site from raindrop erosion and protect seed during germination. • Provides nutrients for vegetation establishment • May be made from vegetation on site	• Application on steep slopes may be difficult; • Treatment area should be accessible to blower trucks. • May not be readily available if accessible material (vegetation) is not present • Trucking in material may make it too expensive
	Scheduling (Planning of construction site activities including installation and maintenance of ESC measures)	25	✓	✓	✓	✓	• Identifies anticipated product requirements prior to start of construction (facilitates ordering and early delivery of necessary ESC products); • Identifies protection issues such as seasonal weather impacts (avoidance of heavy precipitation periods); • Identifies fish and wildlife restrictions (e.g. spawning periods and nesting) • Permits planning for efficient, early and orderly construction of BMPs; • Promotes early installation of perimeter control for sediment entrapment such as sediment ponds and sediment fencing.	

Table C-3: Sediment Control Measures								
BMP Name		BMP #	Applications				Comments	
			Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
	Stream Diversion Channel (Diverts stream flow around a work site to re-enter the channel below the site)	38		✓			• Protects environmentally sensitive areas; • Conveys flow consistency better than a dam, impoundment and pumping; • Not at risk of power failure or malfunction (e.g. pumps); • Maintains fish passage. • Keeps clean water clean • May use plastic culvert for temporary water passage • Used to provide dry work area within a channel temporarily (e.g. culvert installation)	• Requires erosion protection; • Risk of export of sediment downstream if not properly staged; • Requires fish exclusion and fish salvage if working on a known or suspected fish-bearing stream. Permits may be required; • In-stream work windows are regulated by agencies and must be adhered to.

Table C-3: Sediment Control Measures

BMP Name		BMP #	Applications				Comments	
			Slopes	Ditches and Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
Impoundment	Sediment Traps/Basins (Constructed ponds which may be temporary or permanent in design. May require design by a qualified person)	12		✓			• May be constructed of a variety of materials; • Collects sediment laden runoff and reduces velocity of flow to allow deposition of sediment; • Can be cleaned and may be expanded if required; • Capable of being designed to handle large volumes of sediment laden runoff.	• “Last resort” measure; • Normally requires 250 m³ storage volume per ha of contributing area; • Can require large amount of area; • Requires monitoring of sediment in outflowing water and in sediment level; • Requires maintenance to remove sediment build up; • Requires design by qualified person; • Usually requires 'back-up' control measures in case trap/basin overflows or system becomes overloaded • May require back-up measures to address fine clays and silt sediment.

Table C-4: Streambank Applications

BMP # and Name	Comments	
	Advantages	**Limitations**
#20a Live Staking	• Establishes vegetative cover and root mat • Reduces flow velocities on vegetative surface • Traps sediment laden runoff • Aesthetically pleasing once established • Grows stronger with time as root structure develops • Usually has deeper root structure than grass	• Expensive • May be labour intensive to install • Not commonly used in highway construction projects • Revegetated areas are subject to erosion until plants are established • Plants may be damaged by wildlife
#20b Brushlayering	• Provide immediate soil stability and habitat • Can be used with other toe protection such as, rootwads, coir rolls, and log toes • Combining live brush-layering with rock toes is an effective and relatively low cost technique for revegetating and stabilizing streambanks • Provides a source of shade and nutrients, while slowing velocities along the bank during flooding flows • Provides a flexible strengthening system to fill slopes • Act as horizontal drains and favourably modify the soil water flow regime	• Live cuttings are most effective when implemented during the dormancy period of chosen plant species • Brushlayers are vulnerable to failure before rooting occurs • Not effective at counteracting failure along very deep-seated failure planes
#31 Brush Mattress	• Provides a dense network of branches that quickly stabilize a slope or streambank • Will trap sediments during high water and eventual plant growth will enhance aquatic habitat • Well suited for combined installation with many other streambank or slope stabilization techniques such as Vegetated Riprap, Live Stakes, Live Fascines, Rootwad Revetment, Live Siltation, and Coconut Fibre Rolls • Provides immediate surface protection against floods, greatly reducing water velocity at the soil surface • Cuttings are usually available locally • Relatively economical technique • Captures sediment during floods, assisting in rebuilding of bank • Produces riparian vegetation rapidly and enhances wildlife habitat value	• Does not show high success on streams where basal ends cannot be kept wet for the duration of the growing season • They should be installed during the dormant season for woody vegetation and Installation is labour intensive
#32 Live Siltation	• A very effective and simple conservation method using local plant materials • Can be constructed in combination with rock toes, Rootwad Revetments, Coconut Fibre Rolls, Live Fascines, and Brush Mattresses • Valuable for providing immediate cover and fish habitat while other revegetation plantings become established • The protruding branches provide roughness, slow velocities, and encourage deposition of sediment	• If using a living system, cuttings must be taken during the dormancy period

Table C-4: Streambank Applications

BMP # and Name	Comments	
	Advantages	**Limitations**
	• The depositional areas are then available for natural recruitment of native riparian vegetation	
#33 Willow Posts and Poles	• Willow posts and poles are inexpensive to acquire, install, and maintain, provide long-term protection • May be inserted into stone or soil backfill and thus become incorporated with the structure as they root • Can be incorporated into many techniques during construction (e.g., Vegetated Riprap, Vegetated Gabions) • Can be planted in the keyways of many structures • Aquatic and terrestrial habitat is provided and/or improved • Willows act as pioneer species, and allow other plant species to colonize the area after the willows have become established	• Willow posts and poles have higher survival rates when planted during their dormant season, so planning should be adjusted accordingly • Optimum stabilization is not achieved until the willows become established, typically at least one season after installation, although they provide some reinforcement immediately following installation
#35 Longitudinal Stone Toe	• Willow posts and poles may be incorporated into key sections and used to revegetate the middle and upper bank above stone toe • May be combined with a number of other different techniques and the results enhance aquatic habitats • Longitudinal Stone Toe with Spurs is a variation on this technique. Bank grading, reshaping, or sloping is usually not needed (existing bank and overbank vegetation need not be disturbed or cleared), nor is a filter cloth or gravel filter needed • If stone is placed from the water side, existing bank vegetation need not be disturbed • Very cost-effective and is relatively easy to design, specify and construct • It is easily combined with other bank stability techniques that provide superior habitat compared to pure riprap	• Only provides toe protection and does not protect mid- and upper bank areas • Some erosion of these areas should be anticipated during long-duration, high energy flows, or until the areas become otherwise protected • Stone toe is not suitable for reaches where rapid bed degradation (lowering) is likely, or where scour depths adjacent to the toe will be greater than the height of the toe.
#29 Rolls (Coir)	• Durable with high tensile strength • Rolls and Mats accumulate sediment while plants grow and roots develop • Biodegradable • Can be combined with brushlayering to provide immediate shoreline or streambank protection.	• Coir Rolls are relatively expensive • Technique should be implemented during the dormancy period of the cuttings used for brushlayering and staking.

Table C-4: Streambank Applications

BMP # and Name	Comments	
	Advantages	**Limitations**
#34 Rock Vanes	• Rock vanes can successfully reduce near-bank velocities and shear stress, vegetation establishment is greatly improved • Vanes are often combined with other biotechnical soil stabilization measures for bank areas between the vanes • Provide aquatic habitats superior to resistive, continuous structures like Riprap and Longitudinal Stone Toe • Controlled scour at the vane tip, the creation of pool/riffle bed complexity, and increased deposition of the upstream end are the major environmental benefits of vanes • Vanes provide fish rearing and benthic habitat, creates or maintains pool and riffle habitat, provides cover and areas for adult fish, and velocity refugia. • Redirection of impinging flows away from the bank and the sedimentation on the upstream side of the vane creates areas where vegetation can effectively re-establish • Areas of active bank erosion become depositional, vegetate, and subsequently, become permanently stable • Appropriate under a range of flow conditions and bed materials and can be used in series to redirect flows around bends • Vane installation does not require extensive bank reshaping, and most heavy equipment work can be done from the top of the bank, further reducing site disturbance • Vanes require less rock and heavy equipment than riprap for a similar length of protected bank.	• Unintended impacts can result from improper design and construction • If the vane is not properly keyed into the bank, it is likely to fail, creating new localized erosion problems • Improper vane angle and crest elevation can redirect flow in unintended directions, triggering downstream erosion
#36 Vegetated Mechanically Stabilized Earth (VMSE)	• The presence of vegetation softens the stark visual appearance of conventional mechanically stabilized earth structures and provides potential habitat for riparian wildlife • Overhanging branches of the live brushlayers provide shade for fish and a substrate for insects and other organisms that the fish feed upon • They permit much steeper slopes to be constructed than would be possible with live brushlayers alone • Brushlayering treatment by itself is normally restricted to slopes no steeper than 1V:2H • VMSE can be constructed with a slope as steep as 1V:0.5H • The vegetation shields the fabric against damaging UV radiation, and	• A VMSE structure must be constructed during the dormancy period to insure good vegetative propagation and establishment • Alternatively, the live cuttings may be harvested during dormancy, and placed in temporary cold storage until they are ready for use during an out-of-dormancy period, viz., during the summer months (increases the cost) • Materials procurement is more demanding, and installation more complex, because of the blending of two distinct methods, viz., conventional MSE and live brushlayering, into a single approach • Costs will also be more than brushlayering used alone,

Table C-4: Streambank Applications

BMP # and Name	Comments	
	Advantages	**Limitations**
	provides visual and riparian habitat benefits • Brushlayers act as horizontal drains that favourably modify the groundwater regime in the vicinity of the slope face, thereby improving stability against mass slope failure	because of the added expense of the geotextile and the additional labour required to handle and construct the wraps • VMSE streambank structures must be constructed during periods of low water because of the need to excavate and backfill a trench with rock in the streambed to provide a stable foundation.
#37 Vegetated Rip-Rap	• When graded or "self-launching" stone are used, riprap is self-adjusting to small amounts of substrate consolidation or movement • The revetment can sustain minor damage and still continue to function adequately without further damage • Rough surface of the riprap dissipates local currents and minimizes wave action more than a smooth revetment (like concrete blocks) • Stones are readily available in most locations, and materials are less expensive than many other "hard armouring" techniques • Rock provides a large amount of aquatic habitat it's easily repaired • Fibrous roots of the chosen vegetation prevents washout of fines, stabilizes the native soil, anchors armour stone to the bank, and increases the lift-off resistance • Vegetation improves drainage of the slope by removing soil moisture for its own use. • More natural appearance, and is therefore more aesthetically pleasing, which is frequently a matter of great importance in high-visibility areas • Vegetation supplies the river with carbon-based debris, which is integral to many aquatic food webs, and birds that catch fish or aquatic insects will be attracted by the increased perching space next to the stream • Brushlayering methods reach out over the water, and provide shade and organic debris to the aquatic system.	• May be inappropriate as bank vegetation can reduce flow capacity, especially when in full leaf along a narrow channel • Large rocks may be difficult to obtain and transport • Increase costs if rock not readily available • Riprap may present a barrier to animals trying to access the stream.

Table C-5: Planning Strategies and Procedures for ESC Plans						
Planning Strategy or Procedure	Applications				Comments	
	Slopes	Ditches & Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
Minimize Exposed Soils	✓	✓	✓	✓	• Decreases erosion potential; • Decreases area of erosion and sediment control measures required, thus decreasing costs.	• Requires planning and organization of sub-contractors (project phasing); • May require permanent controls be completed on some areas prior to new areas being stripped.
Observe Environmental Timing Restrictions	✓	✓	✓	✓	• Minimizes potential negative impacts on fish and wildlife. • May minimize permitting requirements (e.g. remaining outside of spawning or other critical periods) • Avoid nesting periods	• May affect project schedule.
Maximize Work During Favourable Weather	✓	✓	✓	✓	• Minimizes work in wet soil conditions; • Minimizes amount of storm water to handle or treat on disturbed portion of site; • Promotes seeding (vegetation establishment before wet season and allow establishment in fall for erosion control in late spring).	• May require additional labour and resources to increase scale of production / construction.

Table C-5: Planning Strategies and Procedures for ESC Plans						
Planning Strategy or Procedure	**Applications**				**Comments**	
	Slopes	**Ditches & Channels**	**Large Flat Surface Areas**	**Borrow and Stockpile Area**	**Advantages**	**Limitations**
Protect Permafrost	✓	✓	✓	✓	• Minimizes saturated soils and runoff water; • Reduces long term melting and potential structural damage or slope failure; • Reduces long-term maintenance costs; • Minimizes slope failures along ditches and sidecuts.	• Room required to stockpile fibrous organic material (insulation) for redistribution; • Minimizes amount of construction area exposed at one time; • Requires pre-planning and scheduled construction operations; • May require increased drainage structure planning.
Scheduling of Work	✓	✓	✓	✓	• Sets targets for: good housekeeping; earliest construction and installation of erosion and sediment controls; the most preferred work period (dry versus rainy seasons, outside of fisheries windows); preferred timing for topsoil stripping to minimize soil exposure and for protection of permafrost, where applicable; and, opportunities for topsoil and seeding to be completed during rather than following the end of construction; • Avoids conflicts and delays in construction operations and set timeframes for sub-contractors; • Sets target deadlines.	• May require construction to be completed in one area before starting in another.
Implement BMPs Early	✓	✓	✓	✓	• Minimizes erosion and reduces soil loss and potential impacts downslope during construction.	• May need scheduling to avoid conflicts with machine activities.
Avoid Wet	✓	✓	✓	✓	• Minimizes erosion potential;	• Shutdowns may prolong/delay

Table C-5: Planning Strategies and Procedures for ESC Plans						
Planning Strategy or Procedure	**Applications**				**Comments**	
	Slopes	**Ditches & Channels**	**Large Flat Surface Areas**	**Borrow and Stockpile Area**	**Advantages**	**Limitations**
Weather Periods					• Minimizes soil disturbance and mud tracking.	construction activities.
Direct Surface Water Flow Around Site	✓	✓	✓	✓	• Keeps clean water clean; • Keeps surface water off-site and from causing erosion and sedimentation; • Minimizes the amount of water to be handled on site.	• New diversion structures may require erosion and sediment control measures to be implemented; • Need to be identified and planned for prior to main construction start-up.
Avoid Ponding Water		✓	✓	✓	• Minimizes saturated soils; • Minimizes permafrost melt; • Reduces erosion and potential sedimentation downslope.	• Increased drainage controls (structures) required.
Topsoil and Seed	✓	✓	✓		• Covers exposed soil and reduces erosion potential; • Promotes early revegetation efforts. Use of local native seed will promote revegetation with endemic plants able to survive local conditions; • May provide nutrient source for soils.	• Revegetation is seasonal and erosion may occur before plant growth; • Topsoil supplies may be limited in some areas; • Imported (hauled from other sites) topsoils may contain weed seeds.
Surface Roughening (Slope Texturing)	✓		✓	✓	• Reduces erosion: on fine grained soils, estimated 12% for a dozer ripping on the contour, 52% for track walking up and down the slope, 54% for sheep's foot rolling, and 76% for imprinting (Mike Harding, 2010).	• Equipment may need to be scheduled specifically for this task.

Table C-5: Planning Strategies and Procedures for ESC Plans

Planning Strategy or Procedure	Applications				Comments	
	Slopes	Ditches & Channels	Large Flat Surface Areas	Borrow and Stockpile Area	Advantages	Limitations
Preserve and Use Existing Drainage Systems	✓	✓	✓	✓	• Minimizes exposed soils and potential erosion in drainage system; • Helps keep clean water clean.	• Requires planning; • May affect scheduling of certain construction activities.
Control Construction Traffic				✓	• Avoids unnecessary heavy traffic in sensitive areas or areas with increased disturbance; • Avoids unwanted soil compaction.	• Forcing traffic into localized areas may increase disturbance or compaction in high-traffic areas.
Signage	✓	✓	✓	✓	• Clearly labelling sensitive zones or areas not to be disturbed identifies restrictions/boundaries for machine operators and other workers; • Helps avoid damages to protected areas or clean water areas; • Identifies hazards for machines and equipment.	• Signage methods and locations will need planning to avoid conflict with operations.
Stockpile Control				✓	• Stockpiles are protected from wind and water erosion, and kept separate to avoid mixing of soils; • Watercourses and environmentally sensitive areas are protected, while piles are close enough to minimize cost for re-application.	• May result in longer haul distances; • Planned for location, number of piles and separation methods; • Planned for reduced erosion and sedimentation.

Sediment Fence Sediment Control	B.M.P. #1

- Useable life of approximately one year dependent on regular maintenance

Construction

- Two methods of installation are commonly used
  - Trench method (common method)
  - Mechanical (slicing) installation method (e.g. Tommy Silt Fence Machine or equivalent) (used in areas where soil depth is not a concern, therefore has not been included in this manual)
- Trench Method
  - Select location of sediment fence (fence must be level - along contours)
  - Excavate a trench approximately 0.15 m deep by 0.15 m wide for entire length of fence along upstream side of posts;
  - With fabric on the upstream or upslope side toward the flow, drive support posts a minimum of 0.3 m into ground, spaced a maximum of 2 m apart;
  - Extend the loose flap of filter fabric the bottom to cover the base of trench (see figure);
  - Backfill and compact soil in trench, being careful not to damage fence or dislodge posts;
  - Where extra support is required, attach the wire mesh or snow fencing, as reinforcement, to upstream side of posts with staples or other type of ties. If using fencing material which is not stapled to the posts, place the wire mesh or snow fencing first and then line the upslope side with the fabric. Secure all tightly to the posts.

Construction Considerations

- Site Selection
  - Size of drainage area upslope of the sediment fence should be no greater than 0.1 ha for each 30 m length of sediment fence;
  - Maximum slope length above sediment fence should be no greater than 30 m;
  - Maximum slope gradient above the sediment fence should be no greater than 2H:1V;
- Fence should be placed on contour (level) to produce proper water detention;

- Fence should be placed far enough away from toe of slope to provide adequate retention area (minimum of 1.8 m away from toe of slope is recommended) which will also permit access by equipment to conduct maintenance;
- Fence should not be installed immediately adjacent to a stream. The fence should be as far from the stream edge as possible and at a minimum far enough (>1.0 m is recommended) from the stream bank to allow room for a second fence to be installed, should the first one fail or become damaged; Ends of fence should be angled upslope (smile) to collect runoff;
- Fence fabric should not extend more than 0.7 m above grade when installed correctly;
- Fence fabric (and wire mesh or snow fence, if used) should be dug into a trench at least 0.15 m deep (six inches) and lay across the bottom of the trench 0.15 m to prevent undercutting of fence by runoff; Fence stakes can be wood or metal material dependent on design and ground conditions;
- Stakes are to be placed on downstream side of fence, fabric on the same side as the material to be contained;
- Posts should not be spaced greater than 2 m apart;
- Wire mesh or standard snow fencing may be placed on the upslope side of the fencing to provide additional strength and support reinforcement;
- Fence material should be cut from a continuous roll to avoid joints. If joints are necessary, the wrapping of fabric around the fence post with a minimum overlap of 0.2 m and staples should be used to attach the fabric to the post);
- Fence material (and wire mesh or snow fence, if used) should be attached to posts with heavy duty staples, tie wires, or hog rings;
- Trench backfill should be compacted.
- Long sections of silt fence are more prone to failure than short sections.
  - Maximum length of each section of silt fence should be 40 m.
  - Sediment fence should be installed in 'J' hook or 'smile' configuration, with maximum length of 40 m, along contours (level). The J pattern allows for an escape path for detained water (minimizes pushing over or overtopping of the fence structure).

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans. Sediment fences should be inspected daily but at a minimum of once every 7 days, as well as after significant storm events and spring melt.

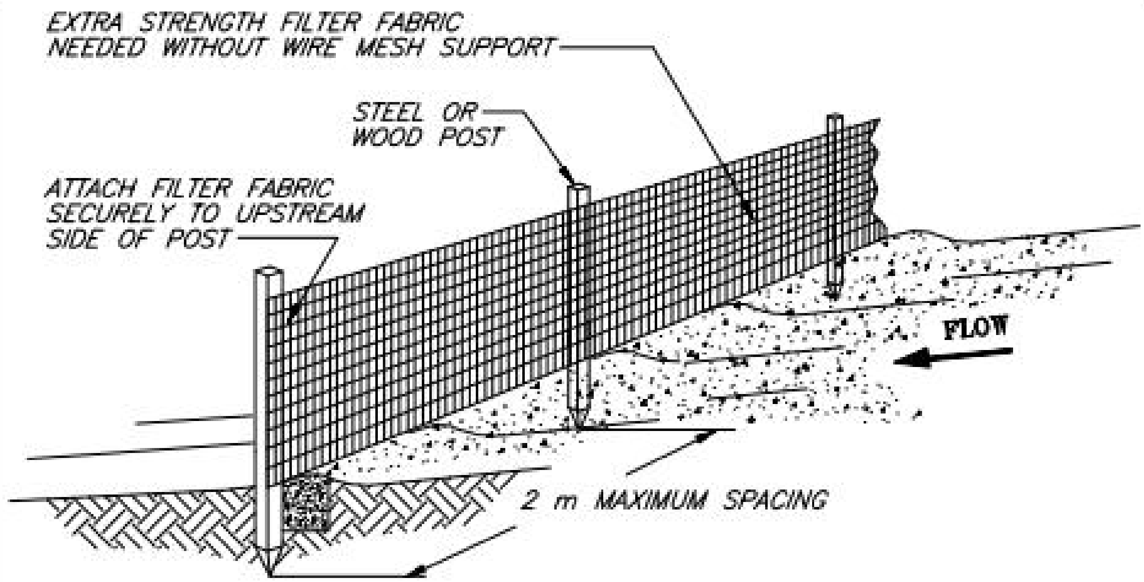
- Repair undercut fences. This is a sign that the fence was incorrectly installed or overloaded. Repair or replace damaged fencing (split, torn, loose or weathered) fabric immediately.
- Sediment build up should be removed once it accumulates to a depth of 0.3 m (one foot).
- Sediment should be removed and stored at a suitable stockpile location with no surface flow;
- Remove fence after vegetation is established;
- Deactivate fabric by cutting the fencing material between the stakes and pulling to remove; bottom trenched-in portion of fence fabric should be removed from the ground to avoid groundwater interception and potential for wildlife entanglement.

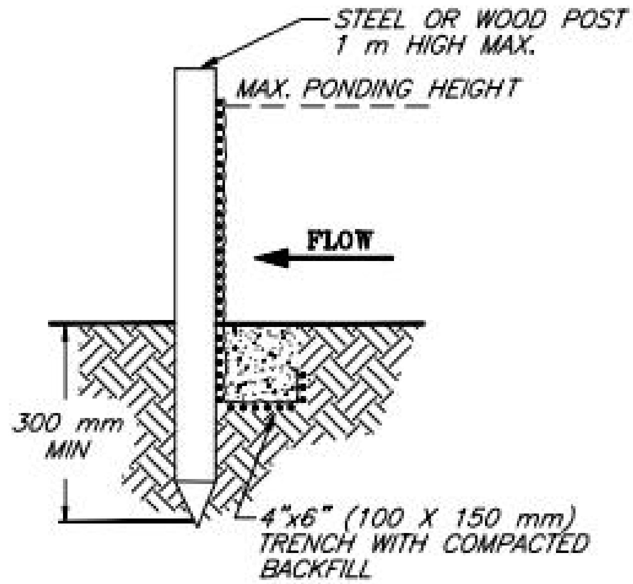
Similar Measures

- Straw Bales
- Rock Barrier
- Permeable/Synthetic Barriers

Design Considerations

- For sediment fence to work as a system, the following factors should be considered:
  a) quantity – adequate number, location, and spacing of fences for efficient detention and sedimentation
  b) installation – must be done correctly and on contour
  c) compaction – backfill and trenching of fabric
  d) support – posts adequately embedded, appropriate selection of post material and spacing
  e) attachment – secure fabric to post
- Install sediment fence in a 'J' hook or 'smile' configuration, so that the ends are higher than the fenceline to contain the water and sediment





TRENCH METHOD DETAIL

NOTES:

1. SILT FENCE SHALL BE PLACED ON SLOPE CONTOURS TO MAXIMIZE PONDING EFFICIENCY.
2. INSPECT AND REPAIR FENCE DAILY AND AFTER EACH STORM EVENT AND REMOVE SEDIMENT WHEN ACCUMULATED SILT REACHES 200 mm.
3. REMOVED SEDIMENT SHALL BE DEPOSITED TO AN AREA WILL NOT CONTRIBUTE SEDIMENT OFF-SITE.
4. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

NOT TO SCALE

Sediment Fence (Trench Method)

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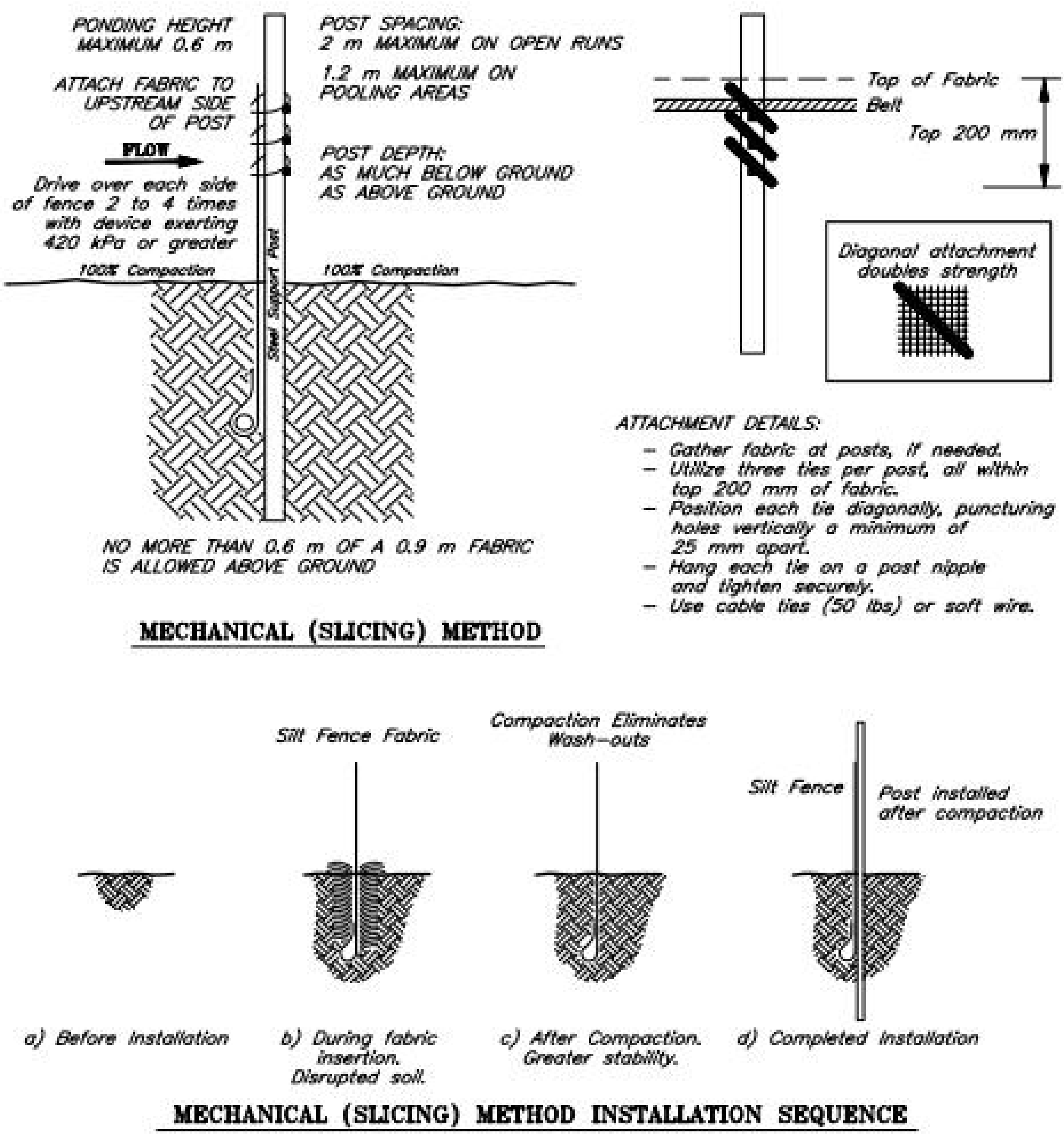


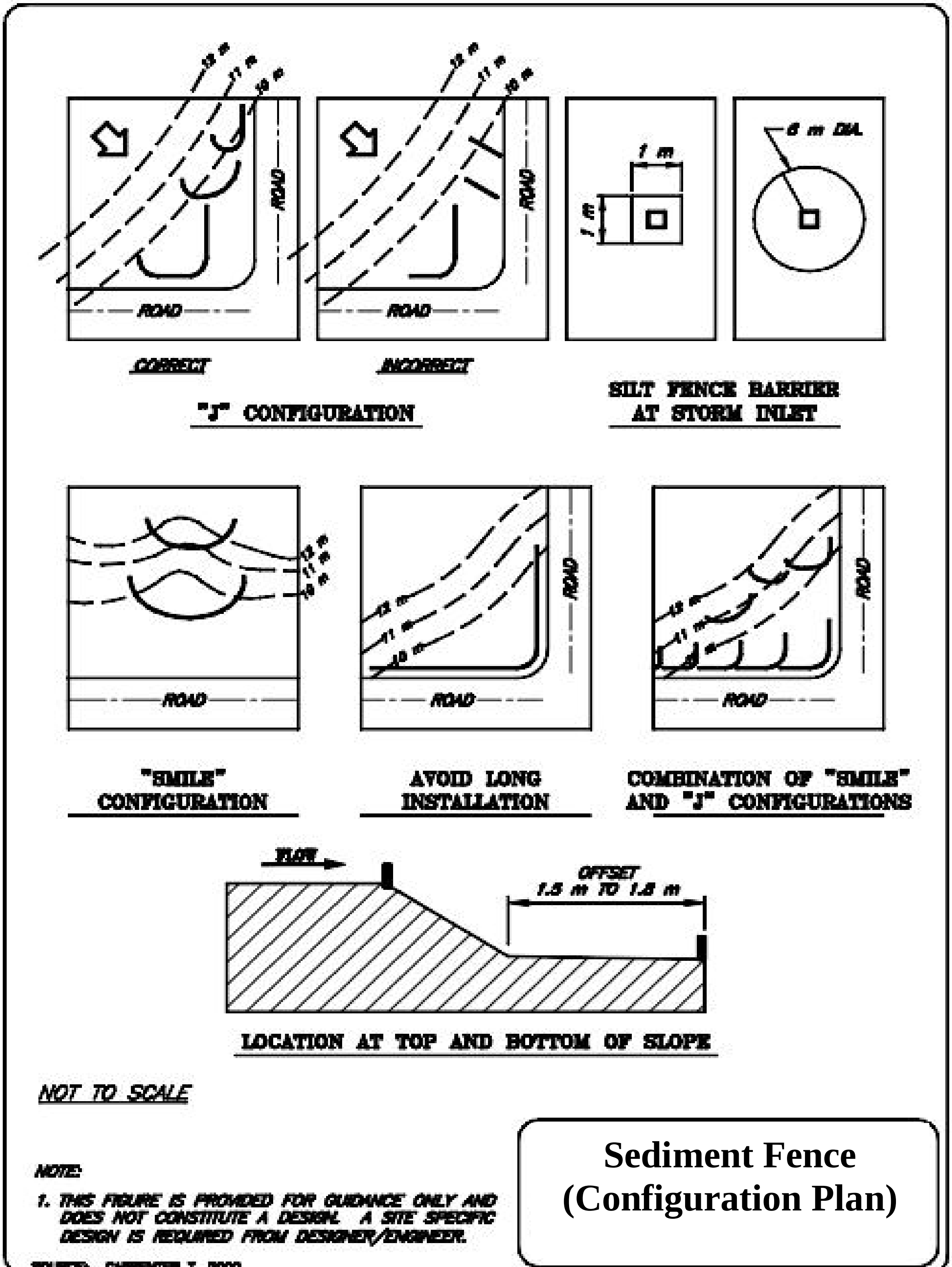
NOTES:

1. INSTALLATION MACHINE MUST ALLOW CONTINUOUS SLICING AND EMBEDMENT OF GEOTEXTILE INTO GROUND WITH MINOR GROUND DISTURBANCE.
2. INSTALLATION MACHINE TYPES WILL VARY WITH MANUFACTURER.
3. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

NOT TO SCALE

SOURCE: CARPENTER T. 2000

Sediment Fence (Mechanical Method)



Sediment Fence (Configuration Plan)

Gabions (a - c) Erosion Control	B.M.P. #2 (a-c)

Description and Purpose

- Consists of rock placed inside wire baskets to protect steep or erodible slopes from sheet flow erosion
- Protects erodible stream channel banks from potentially highly erosive concentrated flow velocities or high friction forces
- Use:

a) Slope and Banks (mats and baskets)

b) Single Gabion Drop (Check Dam) Structure for Ditch Channel

c) Double Gabion "Energy Dissipater" Drop (Check Dam) Structure for Ditch Channel

Applications

- Primarily used as an erosion control.
- Permanent measure
- May be used on stream banks where low flow velocities exist (do not exceed 6 m/s) and are designed by a Qualified Professional.
- 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 armouring of channels
- May be used to construct dikes or weirs
- Used as a check dam structure to reduce grade between structures and as velocity dissipator in channels
- Used as a splash pad to reduce flow velocity, dissipate flow energy and protect channel or ditchline bed

Advantages

- Relatively maintenance free
- Long lasting and sturdy structure.
- Will conform to shape of base and shift with settlement of the bed material Lower thickness requirement for gabion (can be 1/2 to 1/3 riprap thickness) compared with riprap thickness for identical severe hydraulic conditions.
- Allows smaller diameter rock material to be used where it would normally be erodible with riprap placement

- Gabions are porous, free-draining and flexible so they may be less affected by frost heaving and hydrostatic pressures
- Gabion check structures trap sediment and support plant growth to effect higher channel resistance to flow; however, cumulative build-up of silt may render gabions less effective with diminished height

Limitations

- Construction is labour intensive
- Expensive where rock is not readily available
- Extra costs associated with wire mesh cages and rock

Construction of Gabion Baskets and Mats

- Prepare subgrade at designated gabion location on mineral soil
- Excavate trench a minimum of 0.15 m deep to 'key-in' gabion structure. Construct gabion basket, as per design recommendations
- Line interior of basket with non-woven geotextile OR a gravely sand filter layer (if required by design) along areas where the basket is in contact with soil
  - Geotextile must be non-woven fabric to act as a separator (filter) between rock-and subgrade soils
  - Geotextile is not recommended within stream beds
- Backfill basket with rock with wire bracing at 1/3 points (or 0.3 m spacings)
- Install gabion basket top
- Construct a splash pad of rock or gabion mat underlain with geotextile fabric to reduce erosion on the downslope side of the installed structure.
- Backfill trench and compact soil around edges of completed basket
- Gabion mats are constructed by placing a layer of wire mesh, rock fill on mesh and place top layer of mesh. Attach the top and bottom layer with hooks, wire, or other connector to form a ‘blanket’. Blanket mesh may be partially joined and then filled with rock and then closing the opening to secure.

Construction Considerations

- Gabions should be placed on a properly graded surface
- Non-woven geotextile, where included in design, should be used to prevent loss of underlying material and infiltration of fine-grained particles into the gabion structure

- Rock in the baskets may be placed by hand to enhance dense pack ing of stones and decrease void spaces
- Construct gabion baskets with internal wire diaphragms to maintain structural stability and shape and restrict movement of internal rock pieces

Inspection and Maintenance

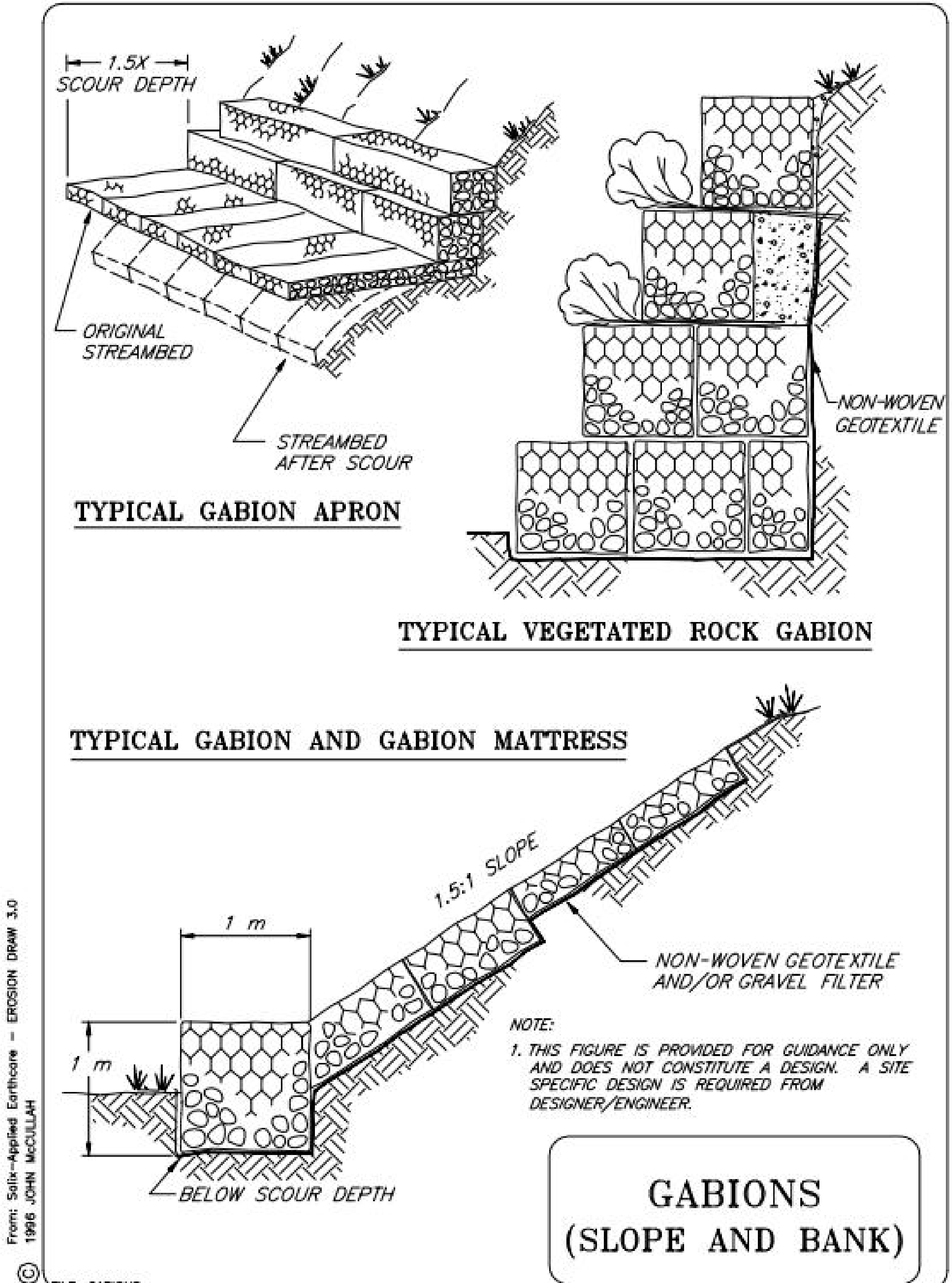
- Inspection frequency should be in accordance with the PESC and TESC Plans and should be inspected after major storm events, especially where undermining at the toe of the gabion is a concern
  - Repair as necessary; including hand grading and/or infilling of undermined areas with lined rocky material
- Timing for the removal of sediment should be determined based on depth of sediment collected, upslope channel erosion and the establishment of vegetation.

Similar Measures

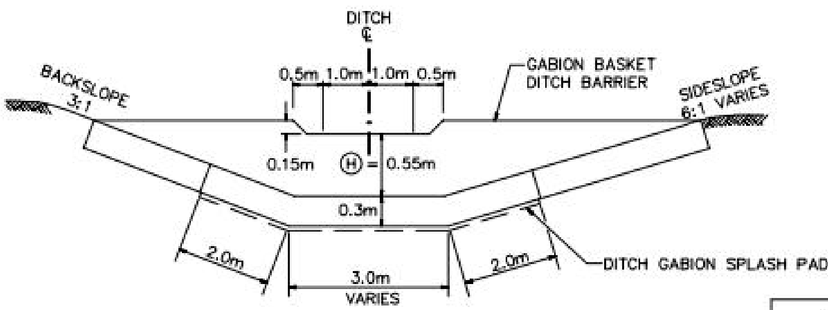
- Berms/Barriers
- Check Dams
- Permeable/Synthetic Barriers
- Rock/Brush barriers
- Sand/Gravel Bag Barriers

Design Considerations

- The gabion design should include an energy dissipater (i.e. a gabion mat as a splash pad) on the dow nstream side of gabion drop structure if overtopping of the gabion is anticipated

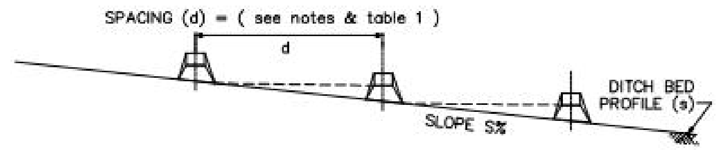


1.5X SCOUR DEPTH
ORIGINAL STREAMBED
STREAMBED AFTER SCOUR
TYPICAL GABION APRON
NON-WOVEN GEOTEXTILE
TYPICAL VEGETATED ROCK GABION
TYPICAL GABION AND GABION MATTRESS
1.5:1 SLOPE
1 m
1 m
NON-WOVEN GEOTEXTILE AND/OR GRAVEL FILTER
NOTE:
1. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.
BELOW SCOUR DEPTH
GABIONS
(SLOPE AND BANK)
From: Salix-Applied Earthcare – EROSION DRAW 3.0
© 1996 JOHN McCULLAH



FRONT VIEW FROM DOWNSTREAM
TYPICAL DITCH CROSS-SECTION
GABION BASKET DITCH BARRIER

N.T.S.

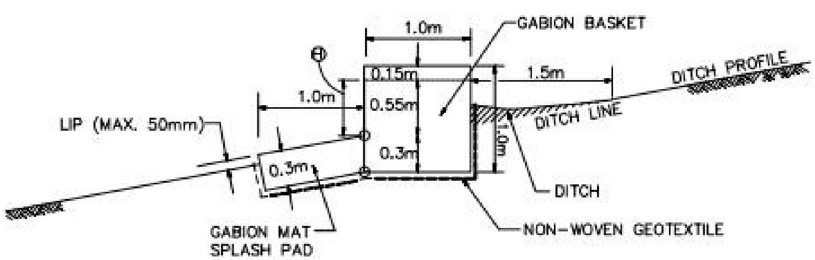


TYPICAL BARRIER SPACING

N.T.S.

SUGGESTED SPACING (d)		
S (%)	(m)	REMARKS
5–7	30	OPTION TO INSTALL A GRADE BREAK (s.a. WEAVE BARRIER) BETWEEN STRUCTURES.
7–8	25	A DOUBLE GABION FOLLOWS EVERY 2 SINGLE GABIONS.
>8%	≤15	DESIGN BY ENGINEER REQUIRED.

TABLE 1



CROSS-SECTION VIEW
"SINGLE GABION" BASKET DITCH BARRIER
& GABION MAT SPLASH PAD

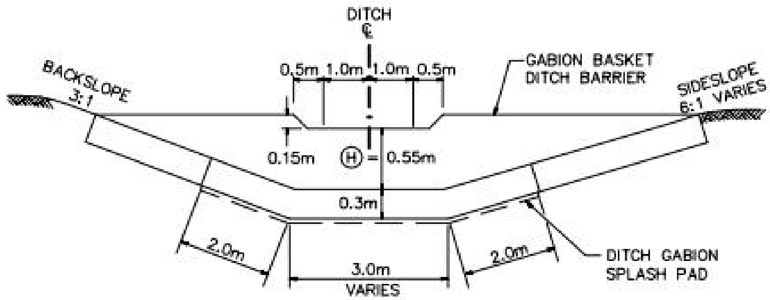
N.T.S.

NOTES:

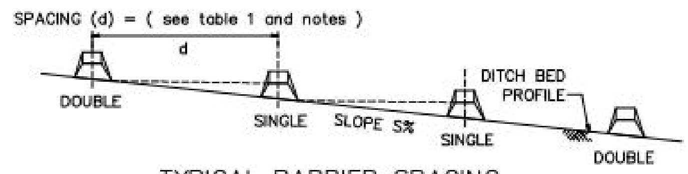
1. SUITABLE FOR MEDIUM TO STEEP GRADES AND CHANNELS LEADING TO WATER COURSE 4% < S < 10%.
2. i) SPACING TO BE DETERMINED BY ENGINEER BASED ON HYDRAULIC CONDITIONS.

   ii) USE IN CONJUNCTION WITH DOUBLE GABIONS OR OTHER BARRIER STRUCTURES.
3. SOIL COVERING BETWEEN STRUCTURES SUGGESTED FOR STEEP GRADE SOIL DITCH.
4. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

GABIONS
SINGLE GABION DROP STRUCTURE FOR DITCH CHANNEL



FRONT VIEW FROM DOWNSTREAM
TYPICAL DITCH CROSS–SECTION
GABION BASKET DITCH BARRIEP
N.T.S.



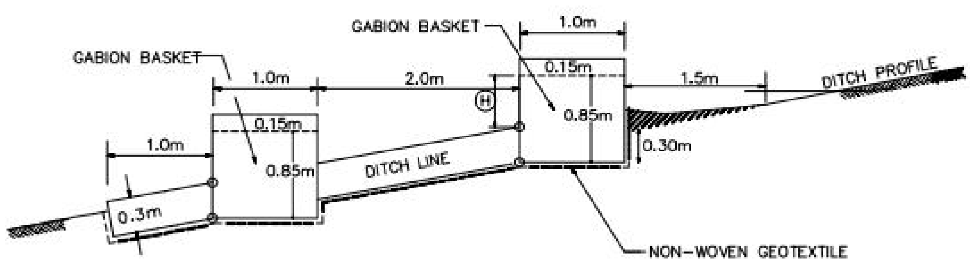
TYPICAL BARRIER SPACING
N.T.S.

SUGGESTED SPACING (d)		REMARKS
S (%)	(m)	
6–8	25	INTER–SPACED WITH 2 SINGLE GABIONS BETWEEN STRUCTURES
	35*	*SEE NOTES
>8%	≤15	DESIGN BY ENGINEER REQUIRED

TABLE 1

NOTES:

1. SUITABLE FOR STEEP GRADES (6%<S<12%) AND CHANNELS LEADING TO WATER COURSE
2. i) SPACING (d) TO BE DETERMINED BY ENGINEER BASED ON HYDRAULIC CONDITIONS.
   ii) USE IN CONJUNCTION WITH SINGLE GABION AND/OR OTHER GRADE BREAK STRUCTURES.
3. SUGGESTED TWO SINGLE GABIONS AT INTERVAL BETWEEN DOUBLE GABIONS.
4. SOIL COVERING BETWEEN STRUCTURES SUGGESTED FOR STEEP GRADE SOIL DITCH.
5. IF d* = 35 m at 7 to 8% GRADE
   – GRADE BREAK (s.a. PERMEABLE WEAVE BARRIER) SHOULD BE PLACED BETWEEN STRUCTURES.
   – LONG SPACING ALLOWABLE WHEN HYDRAULIC CONDITIONS NOT SEVERE.
6. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.



CROSS–SECTION VIEW
"DOUBLE GABION" ENERGY DISSIPATION GABION STRUCTURE
(TWO SINGLE GABIONS COMBINED)
N.T.S.

GABIONS
DOUBLE GABION "ENERGY DISSIPATOR" DROP STRUCTURE FOR DITCH CHANNEL

Berm Interceptor Erosion Control	B.M.P. #3

Description and Purpose

- Earth dike barrier constructed of compacted soil to intercept and divert flow of runoff water away from erodible slopes, sensitive areas or water bodies
- A spillway outlet of e rosion-resistant granular material constructed to allow exit of diverted water to less sensitive areas

Applications

- Primarily used as an eros ion control by diverting water away from the work site. May be used i n sediment control by being used for sedi ment pond construction or directing sediment laden water to sediment ponds.
- Temporary or permanent measure
- Used instead of, or in conjunction with, diversion ditches
- Perimeter control
- Placed along contours and/or at toe of slope to divert run-off from sensitive areas
- Used to divert water to sediment control structures

Advantages

- Easy to construct
- Can utilize on site soil material with a protective lining (e.g., poly sheeting or geotextile fabric)
- Can be converted to sedimentation/impoundment pond with the design of a permeable filter berm at the exit spillway area (see BMP #13)

Limitations

- Earth dike barriers may be require design by a qualified person may be required for earthen barriers in accordance with dam design guidelines and regulatory requirements. The consequences of fa ilure will influence the level of design and construction requirements

Construction

- Construct barrier from bottom up by placing and compacting subsequent lifts of soil
- Degree of compaction of each lift to be spec ified by the design engineer based on consequences of failure

Berm Interceptor Erosion Control	B.M.P. #3

Construction Considerations

- The barrier should be trapezoidal in cross-section
- When using soils a protective liner should be used
- Low barriers should have the slopes suited to the construction material used
  - 1.5H:1V for granular soils
  - 2H:1V or flatter for compacted mixed or fine-grained soils

Inspection and Maintenance

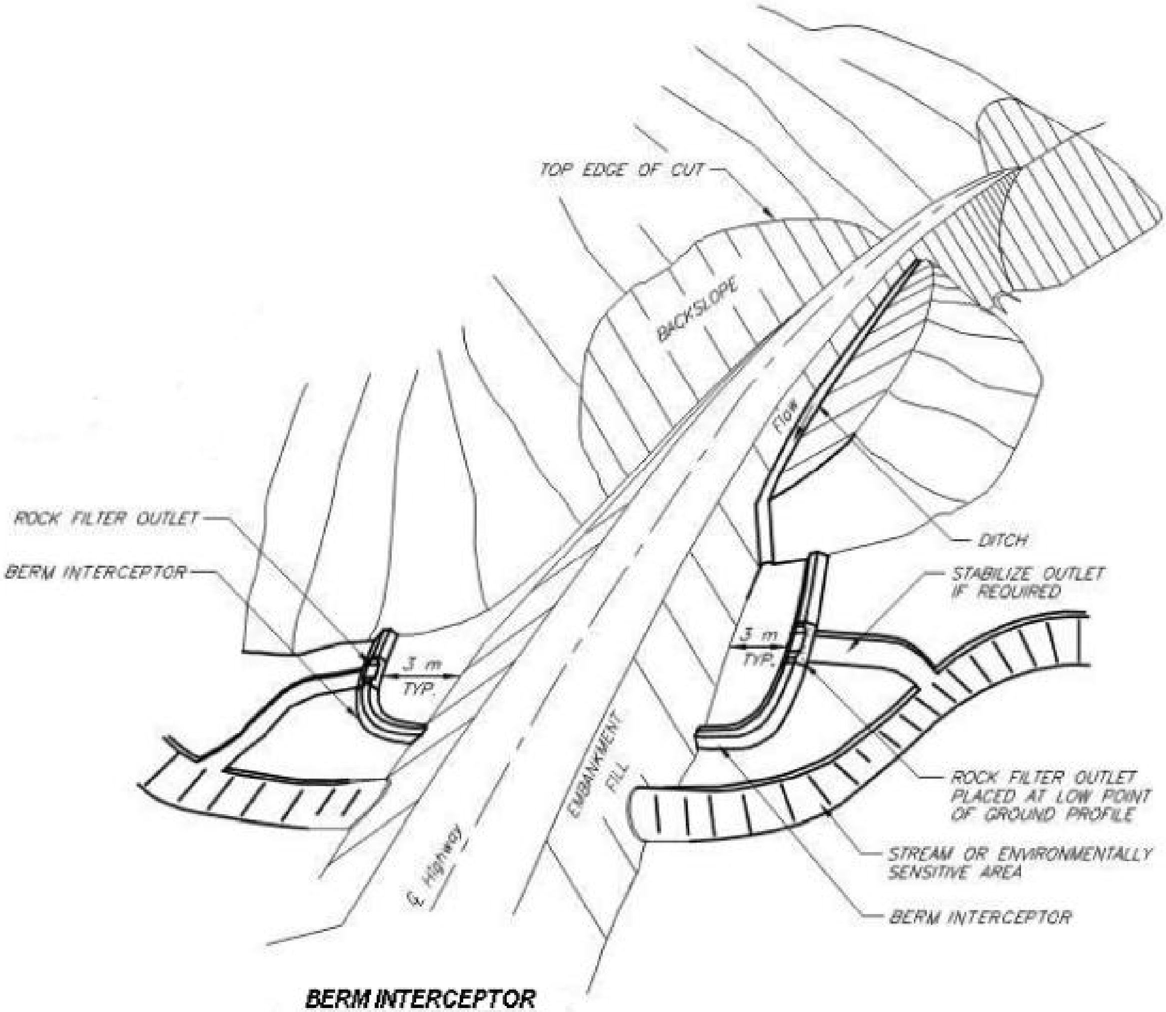
- The degree and extent of inspection and maintenance performed on an earth dike barrier is directly related to the consequences of failure. An engineer experienced in embankment design and inspection may be required for design, inspection, design of remedial measures, and supervision of their implementation
- Inspection frequency should be in accordance with the PESC and TESC Plans
- Piping failures may be remedied, under the guidance of the qualified person, by replacing saturated soils with drier compacted soil and/or by placement of geotextile over the failed area and placing a stabilizing toe berm constructed of granular materials
- Inspect a minimum of once per week and remove sediment when depths reach approximately one-half the barrier height, unless instructed otherwise by the designer.
- Deactivate and remove barrier once slope soils have been stabilized and return berm to an acceptable free-draining and stable condition

Similar Measures

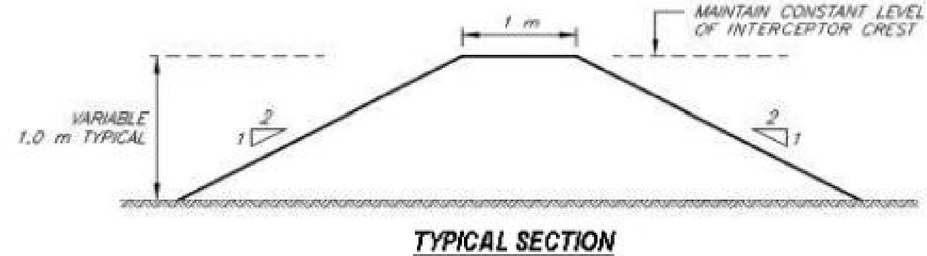
- Berms
- Sand/Gravel Bag Barriers

Design Considerations

- Qualified person design may be required for barriers constructed to hold back water (dike).



BERM INTERCEPTOR
TYPICAL LOCATION



TYPICAL SECTION
BERM INTERCEPTOR

NOTES:
1. SILT ACCUMULATION TO BE REMOVED WHEN HALF BERM INTERCEPTOR HEIGHT COVERED.
2. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

BERM
INTERCEPTOR

Storm Drain Inlet Sediment Barrier (a-f) Sediment Control	B.M.P. #4 (a-f)

Description and Purpose

- Temporary devices constructed to minimize the amount of sediment entering a storm drain by detaining or diverting runoff before the inlet to allow settling
- Storm Drain Inlet protection can consist of the following measures:

a) Block and Gravel Sediment Barrier – Option 1

b) Block and Gravel Curb Inlet Sediment Barrier – Option 2

c) Sand Bag Curb Inlet Sediment Barrier – Option 1

d) Sand Bag Curb and Gutter Sediment Barrier – Option 2

e) Straw Bale / Gravel Sediment Barrier - Option

f) Sediment Fence Sediment Barrier - Option

Applications

- Sediment control measure
- Temporary measure
- Used where storm drains are operational prior to establishing vegetation on disturbed drainage areas
- Can be effective where drainage enters municipal sewers or watercourses
- Used for small, nearly level (less than 5% grade) drainage areas
- Used as curb inlet barriers in gently sloping ditches and gutters
- Used where drainage area is 0.4 ha (1 acre) or less
- Used in open areas subjected to sheet flow and concentrated flows less than 0.014 m^3/s (0.5 cfs)
- Block and gravel bag barriers are applicable when sheet flows or concentrated flows exceed 0.014 m^3/s (0.5 cfs) and is necessary to allow for overtopping to prevent flooding
- Excavated drop inlet sediment traps are appropriate where relatively heavy flows are expected and overflow capacity is required

Storm Drain Inlet Sediment Barrier (a-f) Sediment Control	B.M.P. #4 (a-f)

Advantages

- Easy to install and remove
- Sand bags, blocks and gravel may be reusable

Limitations

- Detaining flow around inlet may result in excessive local flooding
- Use only when detained flow will not encroach into vehicular traffic, onto erodible surfaces and slopes, or beyond the limits of the construction site
- Frequent monitoring and removal of sediment is required

Construction

- Place inlet sediment barrier around entrance to drain/pipe. The option appropriate for use is dependent on site conditions.
- Sediment fence barrier can be used for soil surfaces
- Sand bags with clean fill material (e.g., washed sand, aggregate) should be used for asphalt or concrete surfaces
- Aggregate/sand filled bags
  - Fill bags ½ to ¾ full and place sand bags stacked and shingled one or two bags high around inlet. Partly filled bags will conform better to the surface and each other to provide a barrier
  - Place sandbags close together and pack in place to provide a tight seal
- Gravel barriers
  - Place concrete blocks stacked one or two blocks high, with cavities of blocks aligned with direction of flow, around inlet
  - Wrap 13 mm (1/2 inch) wire mesh or non-woven geotextile fabric around concrete blocks
  - Place 25 mm to 38 mm diameter rock around block and wire mesh assembly ensuring rock extends down from top of blocks to asphalt or concrete surfacing
- Gravel filter curb inlet
  - Place concrete blocks stacked one or two blocks high around inlet, with cavities of blocks aligned with direction of flow, forming a 'U' shape
  - Wrap 13 mm (1/2 inch) diameter wire mesh or non-woven geotextile fabric around concrete blocks

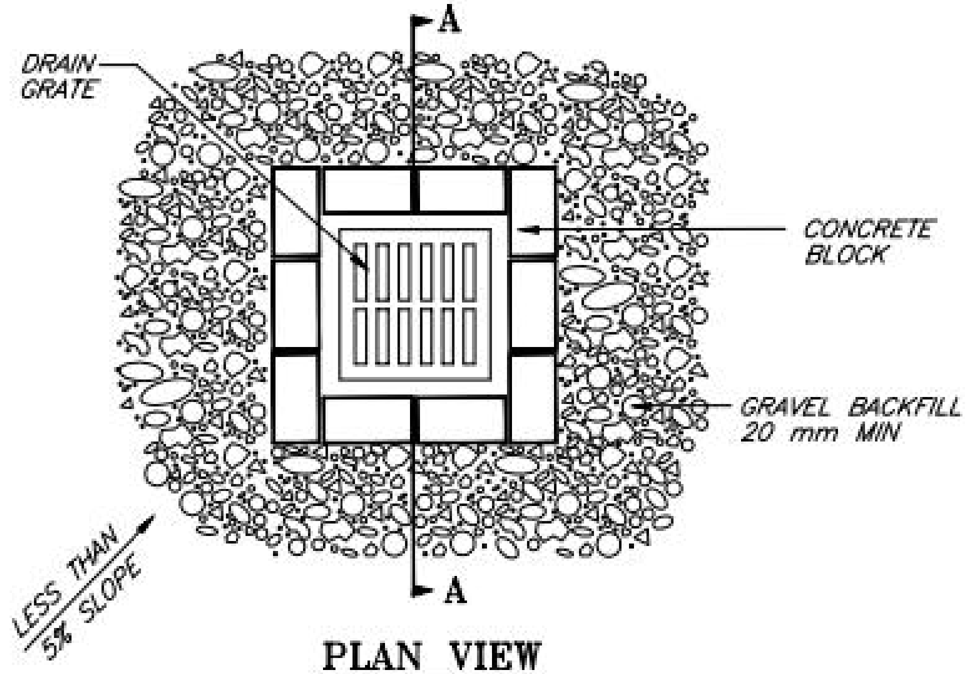
- Place 25 mm to 38 mm diameter rock around block and wire mesh assembly ensuring rock extends down from top of blocks to asphalt or concrete surfacing

Construction Considerations

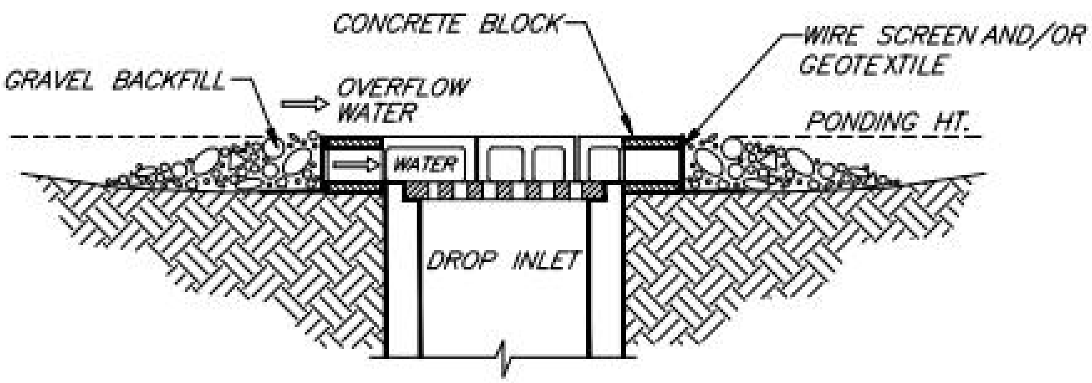
- Sand or aggregate filled sand bags should be used for asphalt or concrete surfaces
- Aggregate filled sand bags
  - Sand bags should be filled with pea gravel, drain rock, or other free draining material
  - Sand/aggregate filled sand bags should be filled only ¾ full to allow sand bag to be flexible to mould to contours, maintaining continuous contact with surface
  - Barrier should be placed at least 0.1 m from inlet to be protected
  - Several layers of sand bags should be overlapped and tightly packed against one another to provide a solid barrier
  - A one sand bag wide gap should be left in the lowest point of the upper layer to act as an emergency spillway
- Gravel filter inlet berm and gravel filter curb inlet
  - Slope gravel towards inlet at a maximum slope of 2H:1V
  - Maintain at least 0.3 m spacing between toe of gravel and inlet to minimize gravel entering inlet
  - 25 mm wire mesh may be placed over inlet to prevent gravel from entering inlet
- For drainage areas larger than 0.4 ha (1 ac), runoff should be directed towards a sediment retention device designed for larger flows before allowing water to reach inlet protection structure
- Use aggregate sand bags filled with 25 mm diameter rock in place of concrete blocks for gravel filter inlet berm or gravel filter curb inlet

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Remove sediment build up after each storm event
  - Sediment, gravel and water should not be allowed to accumulate on roads
- Divert flow and replace gravel if it becomes clogged with sediment
- Remove all inlet protection devices when inlet protection is no longer required



PLAN VIEW



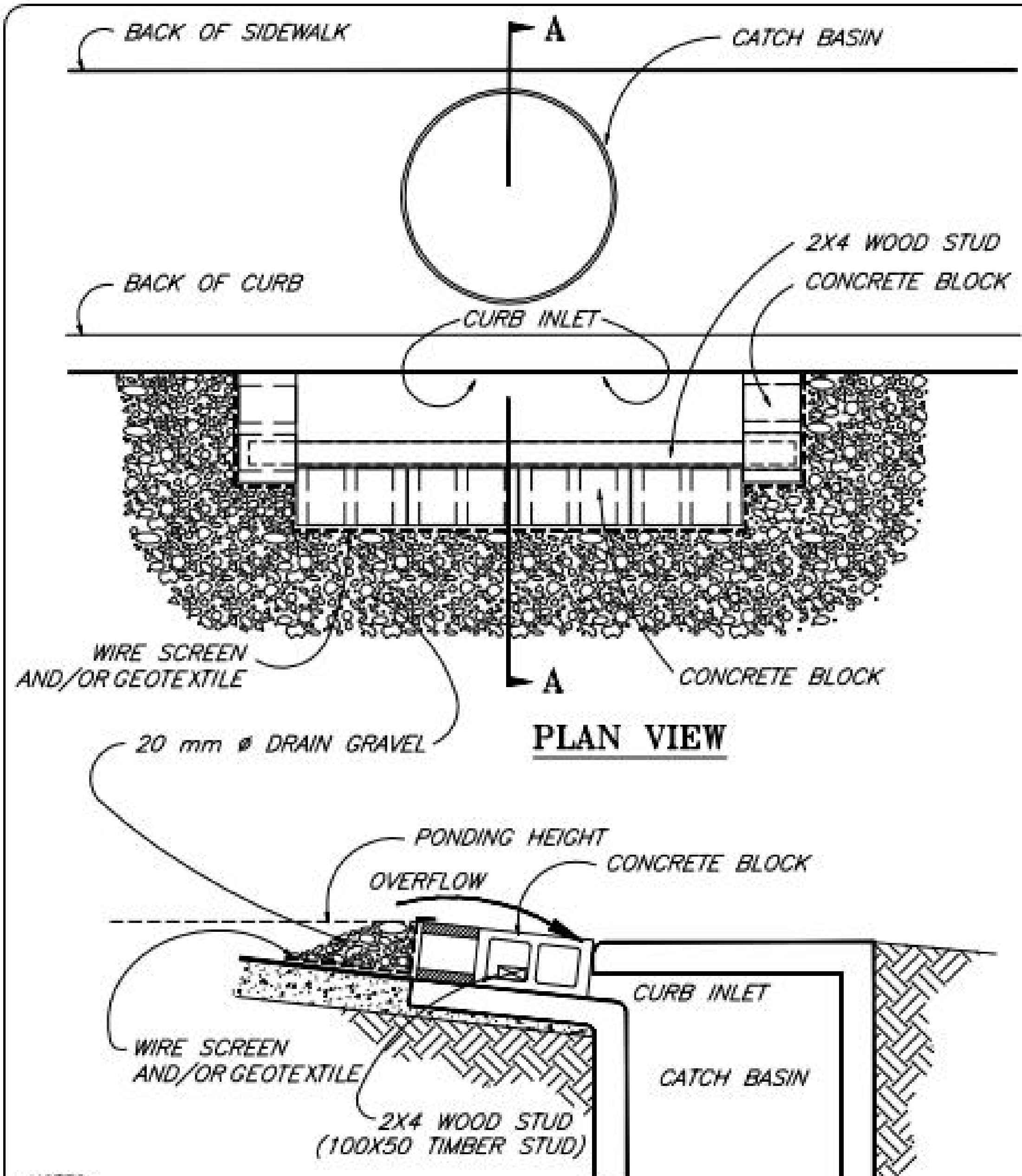
SECTION A – A

NOTES:

1. STORM DRAIN DROP INLET SEDIMENT BARRIERS ARE TO BE USED FOR SMALL, NEARLY LEVEL DRAINAGE AREAS. (LESS THAN 5%).
2. EXCAVATE A BASIN OF SUFFICIENT SIZE ADJACENT TO THE STORM DRAIN DROP INLET.
3. THE TOP OF THE STRUCTURE (PONDING HEIGHT) MUST BE WELL BELOW THE GROUND ELEVATION DOWNSLOPE TO PREVENT RUNOFF FROM BYPASSING THE INLET. A TEMPORARY DYKE MAY BE NECESSARY ON THE DOWNSLOPE SIDE OF THE STRUCTURE.
4. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

STORM DRAIN DROP INLET SEDIMENT BARRIER
(BLOCK AND GRAVEL – OPTION 1)

FILE: BCSEDBAR

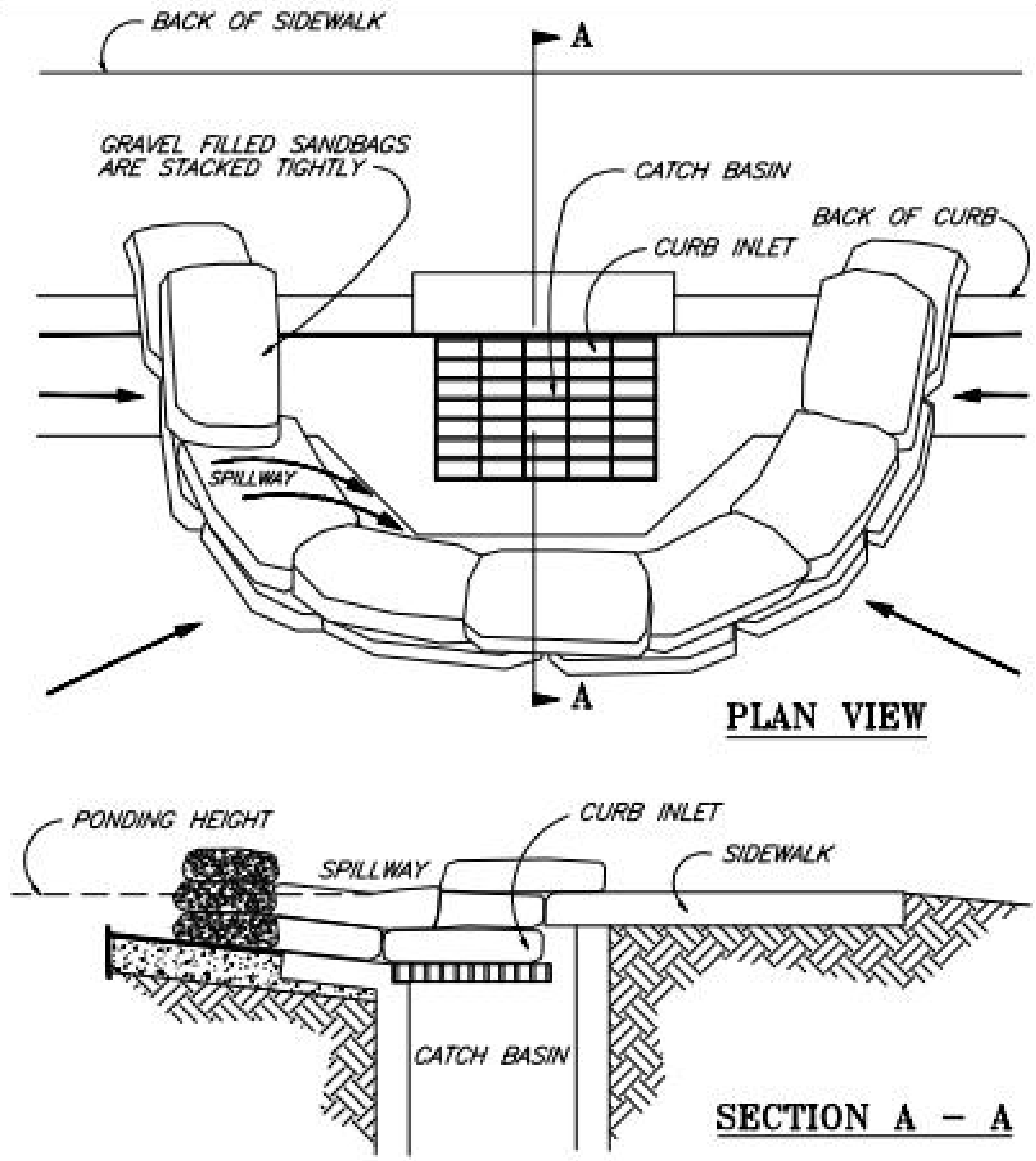


NOTES:

1. USE BLOCK AND GRAVEL TYPE SEDIMENT BARRIER WHEN CURB INLET IS LOCATED IN GENTLY SLOPING STREET SEGMENT, WHERE WATER CAN POND AND ALLOW SEDIMENT TO SEPARATE FROM RUNOFF.
2. BARRIER SHALL ALLOW FOR OVERFLOW FROM SEVERE STORM EVENT.
3. INSPECT BARRIERS AND REMOVE SEDIMENT AFTER EACH STORM EVENT. SEDIMENT AND GRAVEL MUST BE REMOVED FROM THE TRAVELED WAY IMMEDIATELY.
4. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

STORM DRAIN CURB INLET SEDIMENT BARRIER
(BLOCK AND GRAVEL – OPTION 2)

FILE: BLOCKCURB

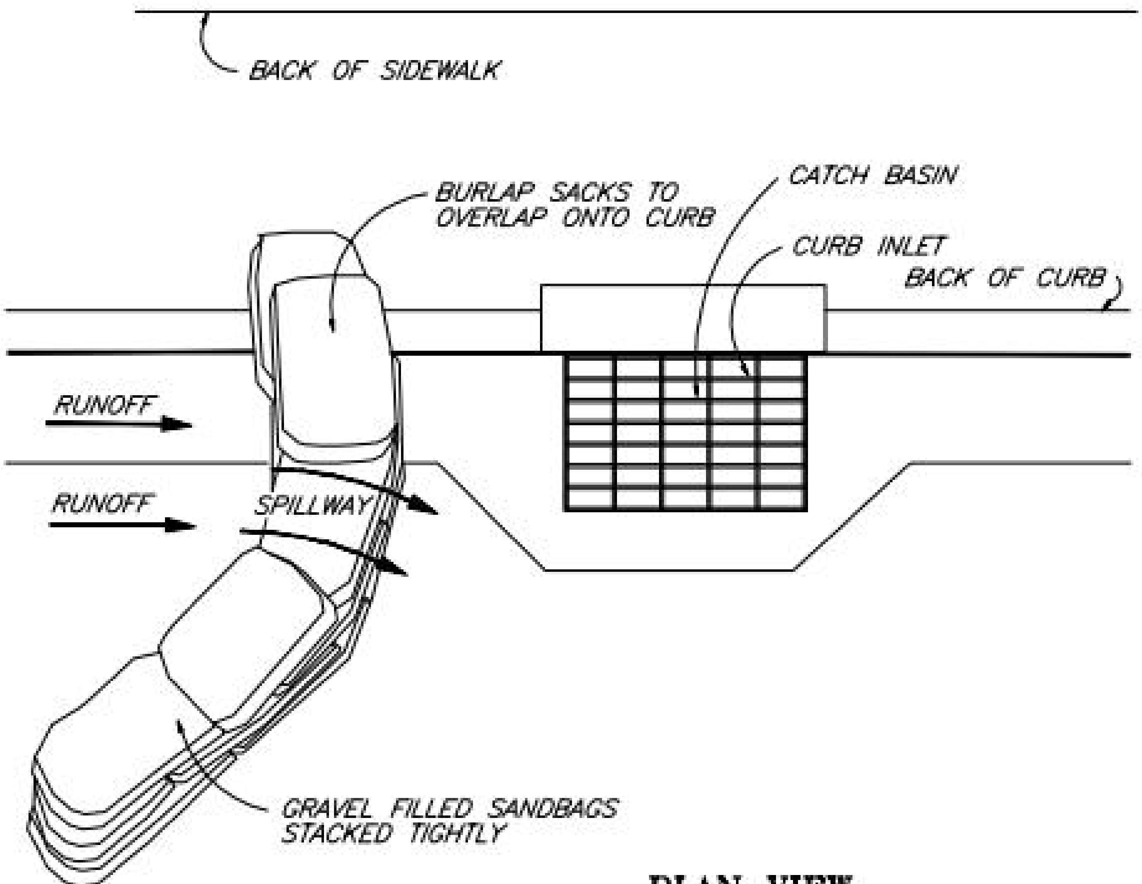


NOTES:

1. PLACE CURB TYPE SEDIMENT BARRIERS ON GENTLY SLOPING STREET SEGMENTS WHERE WATER CAN POND AND ALLOW SEDIMENT TO SETTLE OUT.
2. SANDBAGS, OF EITHER BURLAP OR WOVEN GEOTEXTILE FABRIC, ARE FILLED WITH GRAVEL, LAYERED AND PACKED TIGHTLY.
3. LEAVE ONE SANDBAG GAP IN THE TOP ROW TO PROVIDE A SPILLWAY FOR OVERFLOW.
4. INSPECT BARRIERS AND REMOVE SEDIMENT AFTER EACH STORM EVENT. SEDIMENT AND GRAVEL MUST BE REMOVED FROM THE TRAVELED WAY IMMEDIATELY.
5. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

STORM DRAIN CURB INLET SEDIMENT BARRIER
(SANDBAGS – OPTION 1)

FILE: SANDCURB



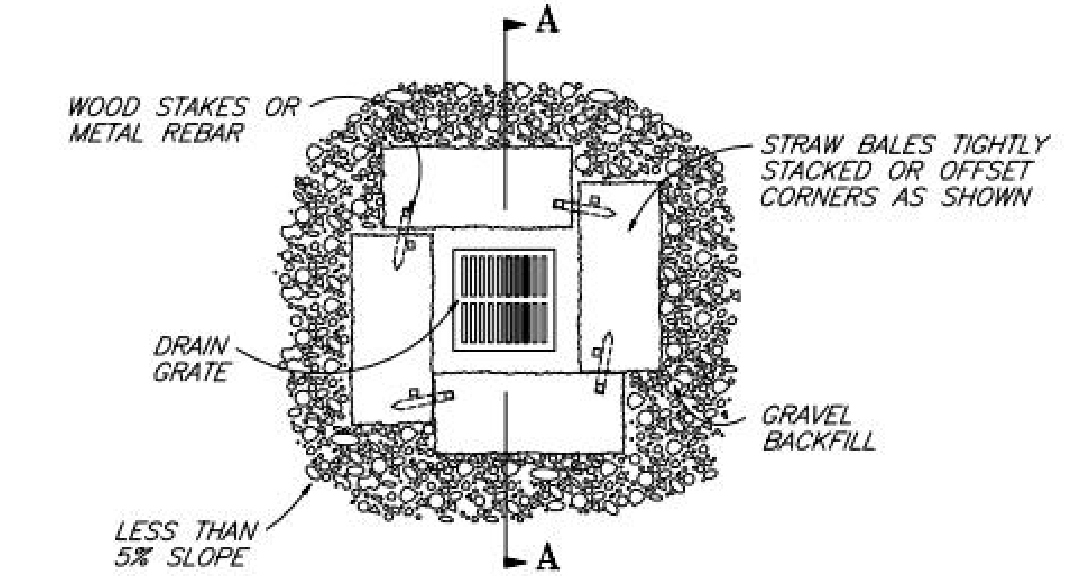
PLAN VIEW

NOTES:

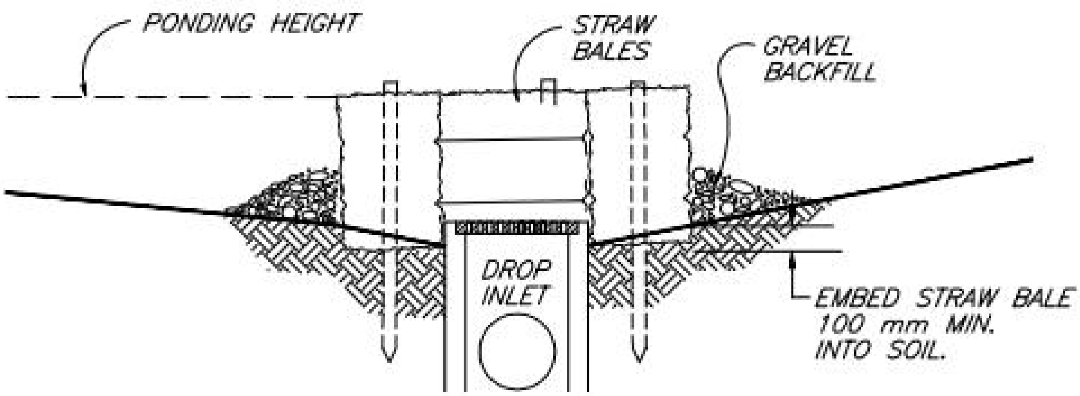
1. PLACE CURB TYPE SEDIMENT BARRIERS ON GENTLY SLOPING STREET SEGMENTS, WHERE WATER CAN POND AND ALLOW SEDIMENT TO SETTLE OUT.
2. SANDBAGS OF EITHER BURLAP OR WOVEN 'GEOTEXTILE' FABRIC, ARE FILLED WITH GRAVEL, LAYERED AND PACKED TIGHTLY.
3. LEAVE A ONE SANDBAG GAP IN THE TOP ROW TO PROVIDE A SPILLWAY FOR OVERFLOW.
4. INSPECT BARRIERS AND REMOVE SEDIMENT AFTER EACH STORM EVENT. SEDIMENT AND GRAVEL MUST BE REMOVED FROM THE TRAVELED WAY IMMEDIATELY.
5. DESIGN CENTRE SPILLWAY LOWER THAN OUTSIDE EDGE TO MINIMIZE FLOW OUTFLANGING.
6. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

STORM DRAIN INLET CURB AND GUTTER SEDIMENT BARRIER
(SANDBAGS – OPTION 2)

FILE: CURBGTTR



PLAN VIEW



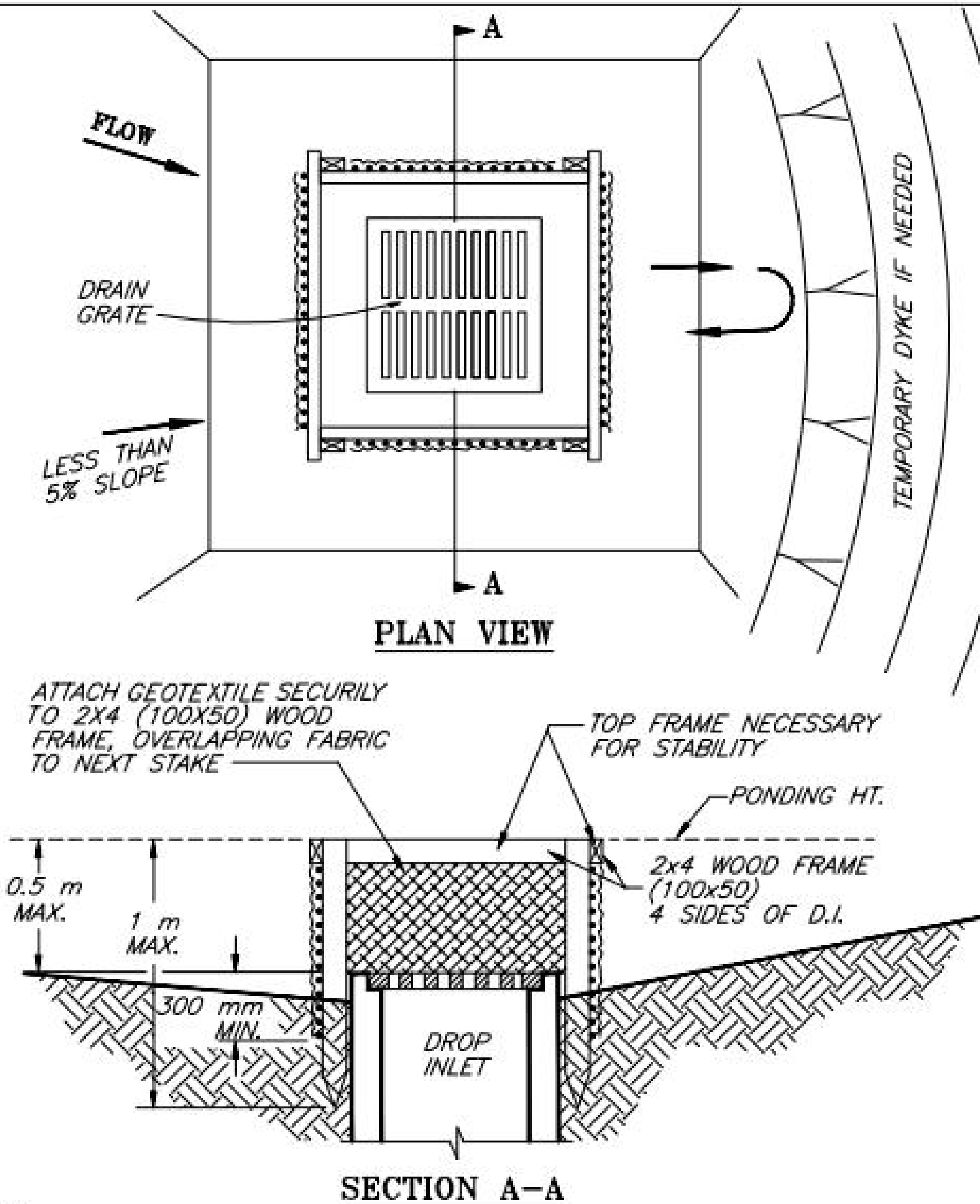
SECTION A–A

NOTES:

1. DROP INLET SEDIMENT BARRIERS ARE TO BE USED FOR SMALL, NEARLY LEVEL DRAINAGE AREAS. (LESS THAN 5%)
2. EMBED THE BALES 100 mm INTO THE SOIL AND OFFSET CORNERS OR PLACE BALES WITH ENDS TIGHTLY ABUTING. GRAVEL BACKFILL WILL PREVENT EROSION OR FLOW AROUND THE BALES.
3. THE TOP OF THE STRUCTURE (PONDING HEIGHT) MUST BE WELL BELOW THE GROUND ELEVATION DOWNSLOPE TO PREVENT RUNOFF FROM BYPASSING THE INLET. EXCAVATION OF A BASIN ADJACENT TO THE DROP INLET OR A TEMPORARY DIKE ON THE DOWNSLOPE OF THE STRUCTURE MAY BE NECESSARY.
4. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

STORM DRAIN DROP INLET SEDIMENT BARRIER
(STRAW BALE / GRAVEL – OPTION)

FILE: STRWGRVB



NOTES:

1. DROP INLET SEDIMENT BARRIERS ARE TO BE USED FOR SMALL, NEARLY LEVEL DRAINAGE AREAS. (LESS THAN 5%)
2. USE 2"X4" (100X50mm) WOOD OR EQUIVALENT METAL STAKES, 1 m MINIMUM LENGTH.
3. INSTALL 2"X4" (100X50mm) WOOD TOP FRAME TO INSURE STABILITY.
4. THE TOP OF THE FRAME (PONDING HEIGHT) MUST BE WELL BELOW THE GROUND ELEVATION DOWNSLOPE TO PREVENT RUNOFF FROM BY-PASSING THE INLET. A TEMPORARY DYKE MAY BE NECESSARY ON THE DOWNSLOPE SIDE OF THE STRUCTURE.
5. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

FILE: SILTFDIB

NOT TO SCALE

STORM DRAIN DROP INLET SEDIMENT BARRIER
(SILT FENCE – OPTION)

Rock Check Dam Erosion Control	B.M.P. #5

Description and Purpose

- Small check dam constructed of rock pieces placed across steep (3-8% grade) channel
- Decrease flow velocities to reduce erosion caused by storm runoff
- Detain sediment laden runoff to slow water and allow sediment to settle out

Applications

- Primarily used as an erosion control method.
- Temporary or permanent measure
- Suitable in areas where rock is readily available
- Reduces long steep grade to intervals of gentle grades between successive structures
- Reduces flow velocities to decrease erosion potential caused by runoff
- Sediment laden runoff is detained behind structure allowing sediment to settle out
- May be used in channels that drain 4 hectares (ha) (10 acres (ac)) or less
- May be used in steep (3-8% grade) channels where storm water runoff velocity is less than 1.5 m/s (5 fps)

Advantages

- Cheaper than using riprap armouring or gabion structures in a ditch
- Easy to construct

Limitations

- Not appropriate for high flow velocity >1.5 m/sec; (use gabion structures for flow velocity >1.5 m/sec)
- Not appropriate for channels draining areas larger than 4 ha (10 ac)
- Expensive if rock has to be end-hauled to site
- Susceptible to failure if water undermines or outflanks structure

Construction

- Excavate a trench key-in a minimum of 0.15 m in depth at the rock check dam location
- Place non-woven geotextile fabric over footprint area of rock check dam

Rock Check Dam Erosion Control	B.M.P. #5

- Construct structure by machine or hand
- Structure should extend from one side of the ditch or cha nnel to the other and the outer ends are not higher than the adjacent ground surface
- Structure should be constructed so that centre of the check dam is depressed to form an outlet at the ce ntre which is a m inimum of 0.30 m lower than the outer edges
- Height of structures should be less than 0.8 m in height to avoid impounding large volumes of runoff
- Downstream slope of the check dam should be 5H:1V (minimum)
- Upstream slope of the check dam should be 4H:1V (minimum)

Construction Considerations

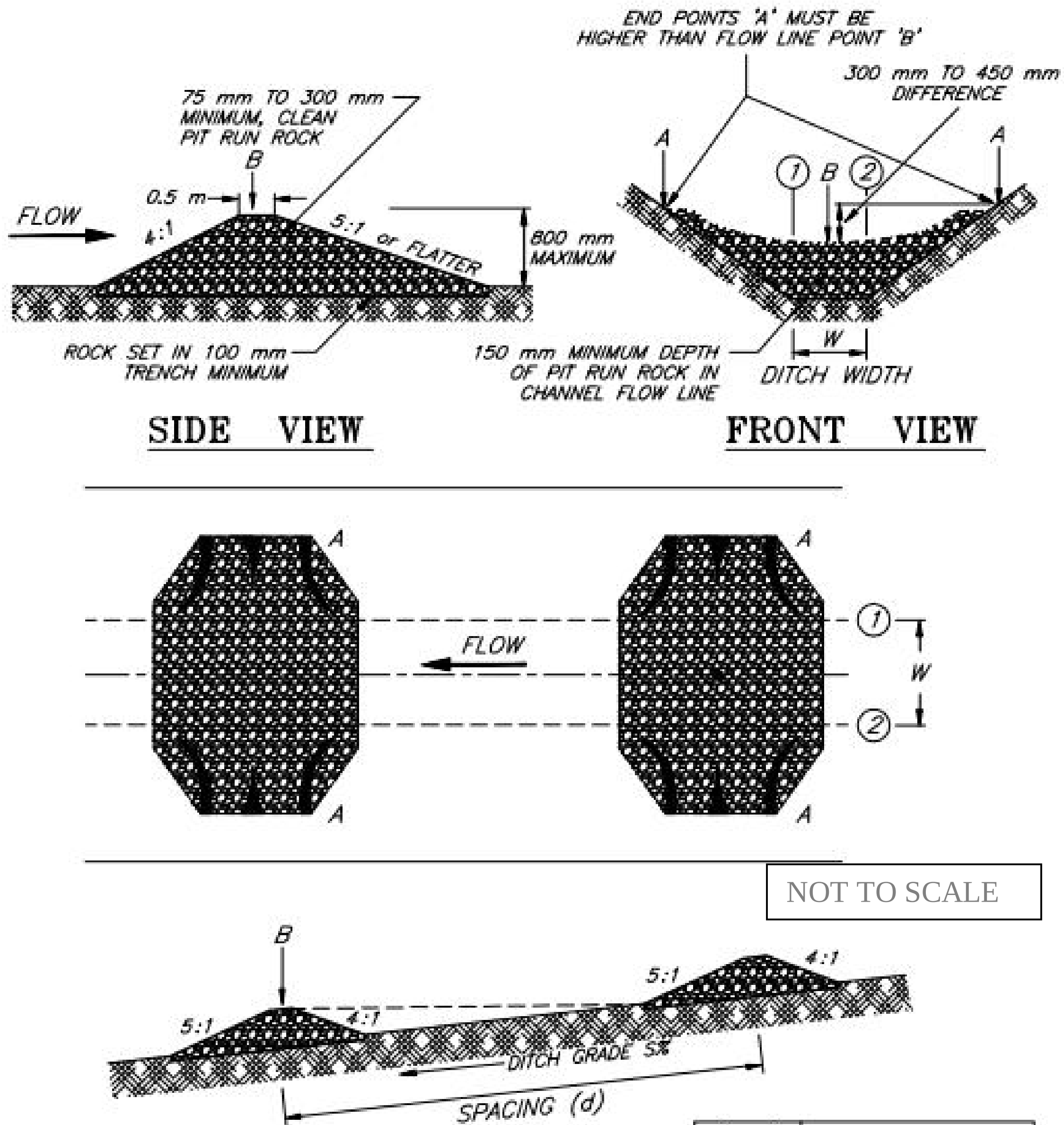
- Should be designed with roadside design clear zone requirements in mind.
- Height and spacing between structures should be designed to reduce steep channel slope to intervals of gentler gradient
- Rock check structures should be const ructed of free dr aining aggregate or broken rock
- Aggregate used should have a m ean diameter (D_{50}) of between 75 mm and 150 mm and must be large enough to remain in place during high velocity flow situations. Maximum rock diameter should not exceed 150 mm if the structure is to be used as a sediment trap.
- If rock check structures are to be placed in channels with significant high flows, they must be properly designed for stone size and structure spacings

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Remove sediment build up before it reaches one half the check structure height. Store sediment in a stable location with drainage
- Erosion repairs should be made immediately to prevent failure of the structure
- Replace dislodged aggregate immediately with heavier aggregate or gabion structures

Similar Measures

- Synthetic Permeable (Ditch) Barriers



D_{50} of ROCK (mm)	MAXIMUM FLOW DEPTH OVER ROCK (mm)
75	50
150	100

SUGGESTED ROCK DIAMETER AND OVERFLOW DEPTHS

NOTES:

1. SUITABLE FOR FLOW VELOCITY ≤ 1.5 m/s.
2. SUITABLE FOR DRAINAGE AREA ≤ 4 ha.
3. SUITABLE FOR GRADES FROM 5% TO 8%.
4. SPACING (d) AND ROCK SIZE (D_{50}) TO BE DETERMINED BY ENGINEER BASED ON HYDRAULIC CONDITIONS.
5. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

NOT TO SCALE

ROCK CHECK DAM

Synthetic Permeable Barrier Erosion Control	B.M.P. #6

Description and Purpose

- Double panel, low profile, uni-body porous synthetic barriers used to dissipate flow energy and reduce velocity
- Barriers of patented design constructed of lightweight and durable synthetic materials
- May be used to create a grade break to reduce flow energy and velocities allowing some sediment to settle out at the upstream barrier panel of the barrier structure
- Can be used to dissipate flow energy and trap sediment during the period of revegetation; should be removed after successful re-establishment of vegetation

Applications

- Primarily used as an erosion control measure. Trapping of sediment is a secondary effect of slowing the water velocity.
- Temporary structure
- May be placed across trapezoidal (flat bottom) ditch to dissipate flow energy and reduce flow velocities
- Can be used to supplement as grade breaks along ditch section between permanent drop structures along steep ditch grades
- May be used as midslope grade breaks along contours of midslope or at toe of disturbed slopes
- Usually used as grade breaks along ditch (3 to 7% grade) in conjunction with erosion control matting or non-woven geotextile as soil covering mattings; may be used in conjunction with permanent gabion structure (i.e., gabion) at steep grade (+6%) areas

Advantages

- Prefabricated
- Reusable/moveable
- More appropriate for installing at transition areas where there is changing channel gradients to dissipate flow energy, thus minimizing erosion potential
- Provide portable flow control for construction sites, ditches, channels, roads, slopes
- The double panel porous barrier may allow significant energy loss as the flow of water undergoes change from moderate flow to low flow from the upstream panel to the downstream panel with sheet flow resulting downstream and roughly parallel

to the stream bed. Less turbulence and erosion energy may be created in comparison to cascading, over-topping flow fr om drop structures (i.e., gabions, check structures, straw bales)

- Barriers constructed of UV resistant material may be left in place for final channel stabilization as UV degradation is low
- Biodegradable synthetic option available
- Observed to enhance settling of silt material and may function as a sediment barrier with the formation of an earth berm behind the upstream barrier panel area

Limitations

- Not suitable for high flow velocities
- More appropriate for use as a grade break and may be installed between permanent drop structures
- Partially effective in retaining some sediment and reducing flow velocities
- Less sturdy as drop structures in resisting high flow impact
- Not to be designed as drop structures
- Must be hand installed
- Become brittle in cold weather and may be easily damaged by maintenance activities (snow plowing) or by the public
- At the time of deactivation of the structure, metallic anchor pins, if not biodegradable, will require removal Exposure of metallic anchor pin above ground may be a nuisance, may be a human hazard or cause damage to maintenance equipment
- The use of biodegradable (wood) anchor pins is advisable

Construction

- Install as per manufacturers recommended installation instructions when available
- Normally installed in conjunction with erosion control matting in ditches and channels
- Prepare soil surface
- Install basal layer of erosion mat or geotextile fabric; key-in basal mat/fabric at upslope end
- Place and anchor barrier panels to basal soils with adequate pin anchors

Synthetic Permeable Barrier Erosion Control	B.M.P. #6

Construction Considerations

- Maintain direct contact between base of barrier and soil with placement of bottom matting/fabric in direct contact with ground surface
- Ensure the ends of barrier extendto outer edges of channel and to a sufficient height to provide freeboard for channel flow

Inspection and Maintenance

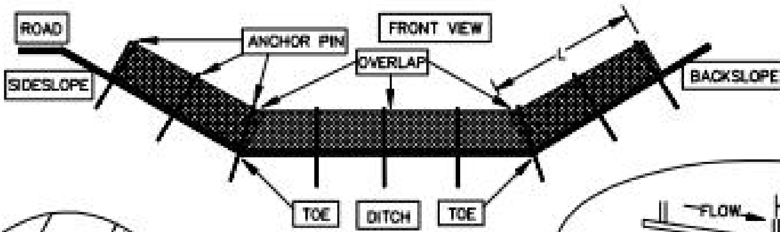
- Inspection frequency should be in accordance with the PESC and TESC Plans
- Remove sediment build-up before it reaches one-half the check structure height
- Do not damage barrier panel during maintenance and removal of sediment
- Partial or non-removal of sediment build-up will create a non-permeable barrier and a low elevation drop structure which will force water flow over top of the barrier. The option of non-removal of sediment may be open to converting the sediment build-up into a "vegetated earth mini-drop structure" along the ditch with the non-removal of the synthetic permeable barrier in-place. This will require topsoil and seeding (or intensive mulch seeding) to promote vegetation growth
- If erosion is noted at the toe or upslope edges of the structure, hand regrading or suitable repairs should be made immediately to prevent failure of the structure
- Remove and deactivate 1 year after vegetation is established

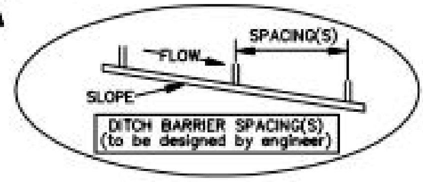
Similar Measures

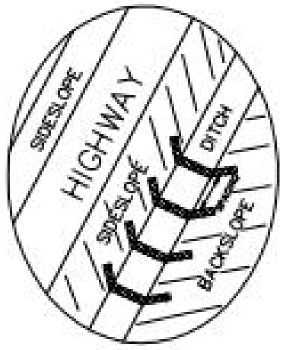
- Sediment fences or straw bales partially equivalent in retaining sediment

Design Considerations

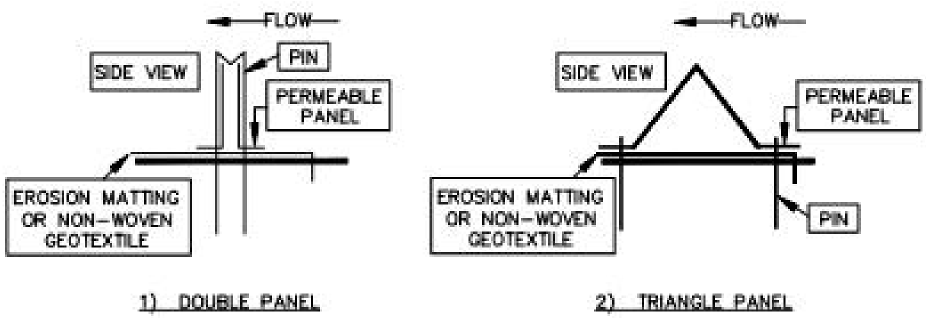
- Install synthetic permeable barrier along ditch interval between permanent drop structures (i.e., gabions)
- Can be economical alternative and supplemental to (i) total hard armouring of complete channel length, or (ii) high frequency of gabion installation required for high flow applications in steep ditch grade







MINIMUM INSTALLATION LENGTH UP SLOPES	
SLOPE	LENGTH: L (m)
2:1	0.55
2.5:1	1.1
3:1	1.1
3.5:1	1.1
4:1	1.1
5:1	1.3
6:1	1.5



SYNTHETIC PERMEABLE DITCH BARRIER
N.T.S.

NOTES:

1. *FOR USE MAINLY AS A GRADE BREAK STRUCTURE FUNCTIONING AS A FLOW ENERGY DISSIPATOR AND VELOCITY RETARDER.*
2. *FOR SECONDARY USE AS SEDIMENT BARRIER.*
3. *REQUIRES NON-WOVEN GEOTEXTILE FABRIC OR BIODEGRADABLE (COCONUT FIBRE PREFERABLE) EROSION BLANKET MAT AT BASE AND KEY-IN TO SOIL AT UPSTREAM END.*
4. *MAY BE INSTALLED AS GRADE BREAK AT GRADE TRANSITION AREAS TO CREATE DISSIPATION OF FLOW ENERGY AND A MORE LAMINAR FLOW REGIME DOWNSTREAM OF STRUCTURE.*
5. *THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.*

SYNTHETIC PERMEABLE BARRIERS

Straw Bale Sediment Barrier Sediment Control	B.M.P. #7

Description and Purpose

- A barrier of clean straw bales primarily used as a perimeter sediment control measure
- May be used to intercept and detain sediment laden runoff allowing a portion of the sediment load to settle out

Applications

- Temporary measure
- Suitable for flow velocities of 0.3 m/s or less
- Usually placed 1 m to 2 m out from the toe of disturbed slopes
- Size of drainage area should be no greater than 0.1 ha per 30 m length of straw bale sediment barrier
- Maximum flow path length upstream of barrier should be less than 30 m
- Maximum slope gradient above the barrier should be no greater than 2H:1V
- May be used in conjunction with filter fabric as external wrap to encapsulate the bales

Advantages

- Straw bales are biodegradable. Clean straw minimizes the amount of weed/invasive plant seed and minimizes attraction to livestock and wildlife.
- Only requires one row of straw bales
- Easier to install than other barriers and economical if straw bales are readily available

Limitations

- Not appropriate for flow velocities greater than 0.3 m/s
- Susceptible to undermining and erosion damage if not properly keyed into substrate soil or if joints are not completely filled with straw
- Require extensive maintenance following high velocity flows associated with storm events
- Not as robust as some continuous perimeter control structures
- Availability of clean weed-free straw will be limited in most parts of the Territory. Clean straw minimizes the amount of weed/invasive plant seed and attraction to

wildlife and livestock. Do not use hay, as it may contain unwanted seed material and may attract wildlife and livestock.

- Short service life
- Must be installed by hand and must be keyed in (embedded) and staked securely into substrate
- Not to be used on asphalt or concrete covered surfaces
- Maximum straw bale barrier height of one bale or 0.5 m maximum height

Construction

- Straw bale barrier should be located a minimum distance 1.8 m away from the toe of the slope to provide adequate detention and sedimentation area as well as room for maintenance equipment
- Excavate a trench approximately 0.10 m deep with a width of one straw bale at the straw bale barrier location
- Place straw bales in excavated trench along contour, perpendicular to flow direction
  - Ensure twine or wire is not in contact with the soil
  - Ensure straw bale is in continuous contact with base of trench
  - Ends of barrier should be angled upslope to form enclosure to contain runoff
- Fill all joints with loose straw
- Drive two 50 mm by 50 mm wooden stakes 1.2 m long through each straw bale, ensuring each stake is embedded a minimum of 0.15 m into soil
- Backfill and compact the upstream and downstream edges of the structure to secure the straw bales into the subgrade
- Construct a splash pad using non-woven geotextile and angular rock on the downslope side of the check structure to protect the bed from erosion

Construction Considerations

- Maximum lengths of barriers should be 40 m, including ‘J-hook’ or ‘smile’ (similar to sediment fence in BMP #1) configuration to minimize risk of failure
- Barrier should be placed far enough away from toe of slope to provide adequate detention and sedimentation area (minimum of 1.8 m away from toe of slope is recommended) and room for maintenance equipment
- Ends of barriers should be angled upslope (in a ‘J-hook’ or ‘smile’ configuration) to form a pocket to collect runoff

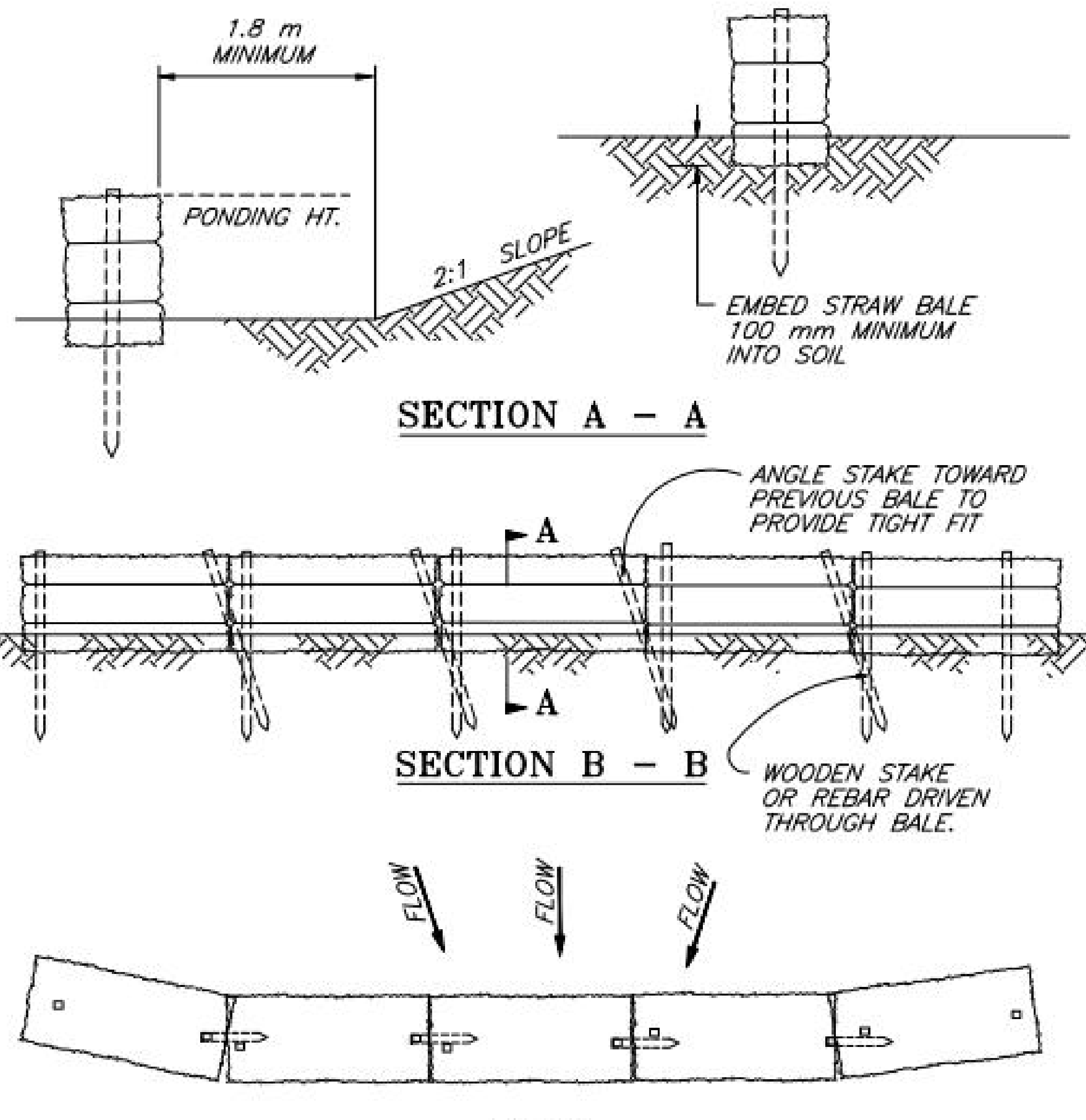
- Straw bales should be:
  - Machine-made, firm/tight bales
  - Weed-free cereal crop straw such as wheat, oats, rye, or barley
  - Tightly compacted and bound with two rows of wire or synthetic string and shall show no signs of weathering
  - No more than one year old

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Remove sediment build up before it reaches one half the check barrier height
- Immediately repair visible erosion damage and modify the barrier to prevent failure of the structure
- Watch for undermining, flanking of the structure (water going around) or erosion at overflow point of structure
- Replace damaged, decayed or dislodged straw bales immediately

Similar Measures

- Sediment fences
- Continuous Perimeter Control Structures
- Berm Interceptors



PLAN

NOTES:

1. THE STRAW BALES SHALL BE PLACED ON SLOPE CONTOUR.
2. BALES TO BE PLACED IN A ROW WITH THE ENDS TIGHTLY ABUTTING.
3. KEY IN BALES TO PREVENT EROSION OR FLOW UNDER BALES.
4. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

STRAW BALE BARRIER

FILE: STRWDIKE

Rolled Erosion Control Products (RECP) a) Channel Installation b) Slope Installation c) Straw or Coconut Fiber Rolls Erosion Control	B.M.P. #8

Description and Purpose

- Biodegradable or synthetic fabricated soil coverings used for temporary protection of disturbed soils on slopes and drainages until vegetation can be established
- Natural fibrous organic material (sod) stripped from the site may be utilized to protect soils from erosion if carefully removed and stored. This material may require staking or staked netting to hold it in place
- Categories of rolled erosion control products (RECP) can be:
  - Erosion control blankets (ECB) (generally biodegradable and temporary)
  - Turf reinforcement mats (TRM)
  - Composite turf reinforcement mats (C-TRM)
- RECP may be manufactured of organic material, synthetic material, or as a composite of organic and synthetic materials. There are many different products available with varying qualities, durability and lifespan (e.g. Curlex – wood product; expands to conform to the surface; filters; and is lighter in color to reduce heat).
- RECPs protect disturbed soils from raindrop impact and surface runoff erosion, increase water infiltration into soil, retain soil moisture and decrease evaporation loss
- Protect seeds from raindrop impact, runoff, and birds/animals
- Stabilize soil temperature and increase soil moisture to promote seed germination and enhance vegetation growth

Applications

- Temporary or permanent erosion control measure
- May be used to protect disturbed, exposed soils for cut or fill slopes at gradients of 2.5H:1V or steeper
- May be used on slopes where erosion potential is high
- May be used on slopes where vegetation is likely to be slow to develop
- May be used to protect disturbed exposed soils in ditches and channels (with high flow velocities) by providing additional protective cover while allowing successful high density vegetative growth to become established

Rolled Erosion Control Products (RECP) a) Channel Installation b) Slope Installation c) Straw Rolls Erosion Control	B.M.P. #8

Advantages

- Erosion protection is higher, more uniform, and longer lasting than sprayed-on products (e.g., mulches)
- Wide range of commercially available temporary (biodegradable) or permanent products

Limitations

- Poor performance of RECP may result from the following:
  - Low density vegetation growth (beneath RECP) due to non-favourable weather and growth conditions (i.e., soil type, moisture, storm events at critical times). The effectiveness of RECP, especially along channels, is very dependent on success of vegetation growth on site. It is important that the designer assess the effectiveness of RECP in accordance with site, soil, terrain and vegetation growth conditions
  - Heaving (lifting) of RECP and the erosion of underlying soils (undermining) can occur under rapid snow melt conditions when melt water gets underneath the RECP or when high flow velocity is created in a narrow channel. This situation can occur along steep channels interlaced with drop structures where the RECP is installed between the check structures. Undermining can occur along un-anchored edges of RECP at upper edges of ditch when snow melt or overland flow occurs at tops of ditch and gets beneath the RECP. This is especially critical when underlying soil is easily erodible (e.g., fine-grained non-cohesive silty soils). It is important to trench-in and anchor the edges of the RECP installations and install anchor pins (staples) at sufficient density intervals (refer to BMP #8 Figures)
  - Ice build-up from groundwater seepage sources can uplift and dislocate the RECP which may cause flow to pass beneath the RECP to erode the substrate soils. Winter ice accumulation may be related to the groundwater regime frozen soils (permafrost or ground ice). Investigative design on subsurface drainage by a geotechnical engineer may be required in these areas.
- Can be labour intensive to install
- Must be installed on unfrozen flat ground
- Temporary blankets may be used for erosion control and require removal before implementation of the permanent measures
- Rolled erosion control products (RECP) are not suitable for rocky sites

- Proper surface preparation is required to ensure direct contact between blanket and soil
- Polyethylene sheeting (poly) can be used on sensitive slopes with precautions:
  - Poly sheeting RECP product can be easily damaged, ripped or cut, is non-biodegradable, and proper disposal is required
  - Poly sheeting product results in 100% runoff, thus increasing erosion potential in downslope areas receiving the increased flow volumes
  - Poly sheeting may increase flow velocity and should be used in conjunction with check dam structures on long slopes
  - Poly sheeting should be limited to a temporary covering for sensitive soil stockpiles or small critical unstable slope areas

Construction (Slopes)

The following is a general installation method for RECP on slopes:

- Prepare soil surface to make smooth and place topsoil and seed
- Surface must be smooth and free of large rocks, debris, or other deleterious materials. This is a critical step to get the RECP to stay in contact with the soils at all times
- RECP is to be securely anchored at top of slope in a minimum 0.15 m by 0.15 m trench for the entire width of the blanket

  The blanket should be rolled out downslope and anchors (pegs) should be placed along central portion of blanket spaced at 4 anchors per m^2 minimum (0.5 m spacing) for slopes steeper than 2H:1V and 1/m^2 (1 m spacing) for slopes flatter than 2H:1V

  - (1) Where the blanket roll is not long enough to cover the entire length of the slope, a minimum 0.15 m by 0.15 m anchor trench should be excavated at the location of the lap, and the downslope segment of the blanket anchored in the trench, similar to the method used for the top of the slope, or
  - (2) When blankets must be spliced down the slope, place blanket end over end (shingle style with approximately 0.10 m overlap). Staple through overlapped area at 0.3 m intervals.
  - The upslope portion of blanket should overlap the downslope portion of blanket, shingle style, at least 0.15 m with staple anchors placed a maximum 0.3 m apart
  - Adjacent rolls of blanket should overlap a minimum 0.1 m

- Anchors along overlap between adjacent rolls should be placed 0.5 m apart

Construction (Channels)

- A RECP should be installed in accordance with the manufacturer's directions where available

The following is a general installation method for channels:

- Prepare the surface and place topsoil and seed
  - Surface must be smooth and free of large r ocks, debris, or other de leterious materials
- Begin by excavating a minimum 0.15 m deep and 0.15 m wide trench at the upstream end of channel and place end of RECP into the trench
  - Use a double row of staggered anchors ('U' shaped pegs) approximately 0.1 m apart (i.e., 0.2 m linear spacing) to secure RECP to soil in the base of trench
  - Backfill and compact soil over RECP in trench
- Roll the centre RECP in direction of water flow on base of channel
- Place further rolls of RECP, starting with the upstream RECP over top of the downslope section (shingle style).A minimum 0.15 m overlap of the upper roll over the top of the downslope section is required.
  - Use a double row of staggered anchors approximately 0.1 m apart to secure the RECP to soil
  - Use an anchor channel (excavated trench as above) for the second row of RECP where high flows may be anticipated, ensuring good overlap with upslope RECP section
- Full length (side) edge of RECP at top of sideslopes must be anchored in a minimum 0.15 m deep and 0.15 m wide trench
  - Use a double row of staggered staple anchors a maximum of 0.1 m apart (i.e., 0.2 m linear spacing) to secure RECP to soil in base of trench
  - Backfill and compact soil over RECP in anchor trench
- Overlap RECP on sideslopes (shingle style down channel) and a minimum of 0.1 m over the centre RECP and secure the RECP to soi l with anchors spaced a maximum of 0.2 m apart

- In high flow channels, an anchor trench across the width of the channel is recommended at a maximum spacing of 10 m to anchor the ends of the RECP to the underlying soil
  - Use a double row of staggered anchors (‘U’-shaped pegs) a maximum of 0.1 m apart (0.2 m linear spacing) to secure the RECP to the soil in the base of the trench
  - Backfill and compact soil over the RECP in the anchor trench
- Anchor terminal ends of the RECP in a minimum 0.15 m deep and 0.15 m wide anchor trench
  - Use a double row of staggered anchors a maximum of 0.1 m apart (i.e., 0.2 m linear spacing) to secure the RECP to the soil in the base of anchor trench
  - Backfill and compact soil over the RECP in anchor trench

Construction Considerations

- Slopes should be topsoiled and seeded prior to placing RECP
- Ensure blanket is in direct contact with the soil by properly grading soil, removing rocks or deleterious materials, prior to placing blanket. This is critical to the success of the installation.
- In channels, RECPs should extend above the anticipated high flow height, with a minimum 0.5 m of free board (extra room)
- For turf reinforcement mat (TRM), RECP should be placed immediately after topsoiling
- RECP should be anchored by using wire staples, metal geotextile stake pins, or triangular wooden stakes
  - All anchors should be a minimum of 0.15 to 0.2 m in length
  - For loose or saturated soils, use longer anchors
- RECPs must be placed to run with the direction of flow, without stretching the fabric and maintaining direct contact with underlying soil
- It is essential to understand product specifications and follow manufacturer’s instructions on installation methods. These are available from suppliers, and on the Internet. The BMP #8 Figures offer guidance.

Product Quality Assurance/Quality Control (QA/QC) Certification

RECPs should be certified by the supplier/manufacturer to ensure product performance and compliance with specified property requirements. A certificate for QA/QC testing of manufactured products is required. The performance and QA/QC testing should be carried out by reputable laboratories to ensure a commonly acceptable QA/QC standard. Dependent on product type and intended performance, the product information certificate should be provided by the product supplier/manufacturer to include the following: Manufacturer's Certificate on:

- Performance specification
  - Permissible Tractive Resistance (include testing methods and vegetative growth conditions)
  - Permissible Flow Velocity (if available)
  - Longevity (for biodegradable or non-biodegradable products)
- Minimum Average Roll Values (MARVs) along with specified testing methods for
  - Physical properties
    - Mass per unit area
    - Thickness
    - Tensile strength
    - UV Resistance
  - Other physical properties (for non-woven below Erosion Mat (if specified)
    - Grab tensile strength
    - Grab elongation
    - Puncture strength
    - Trapezoidal tear
    - UV Resistance

Inspection and Maintenance

- Areas covered with RECPs should be inspected regularly and repaired as required and in accordance with the PESC and TESC Plans. After periods of heavy rainfall or storm events check for RECP for separation or damage
- Any damaged or poorly performing areas should be repaired immediately. Regrading of the slope by hand methods may be required in the event of erosion.

- Inspection and maintenance should continue until dense vegetation is established
- Seeded areas should be monitored and areas with low vegetation density should be reseeded
- After approximately one year, a top dressing of fertilizer may be applied to improve vegetation cover and assist degradation of temporary blankets
- Some RECPs contain and embedded seed mix which may be suitable for use. Discuss the seed contained in the product to ensure compliance with GNWT requirements for seeding and invasive species.

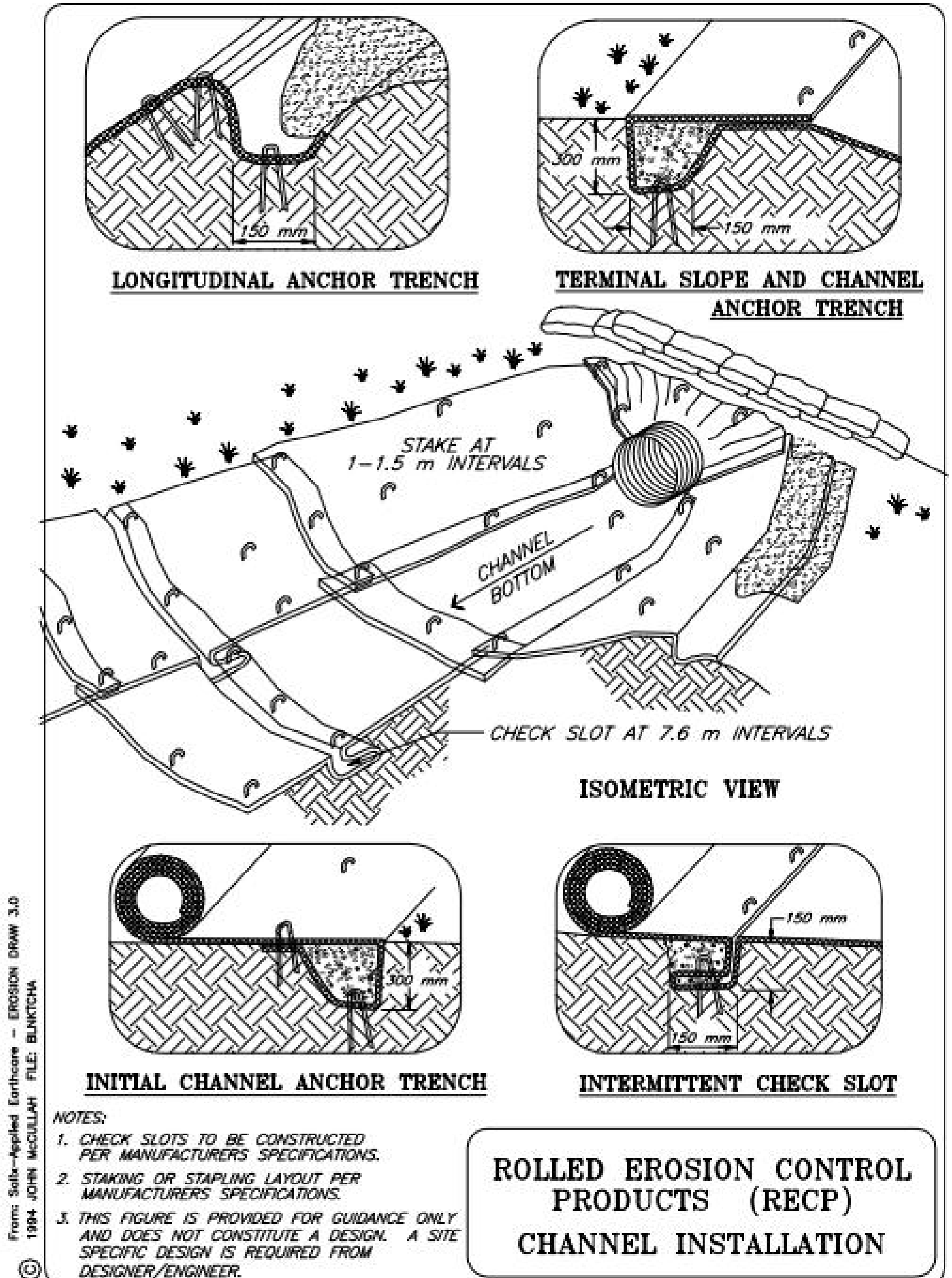
Similar Measures

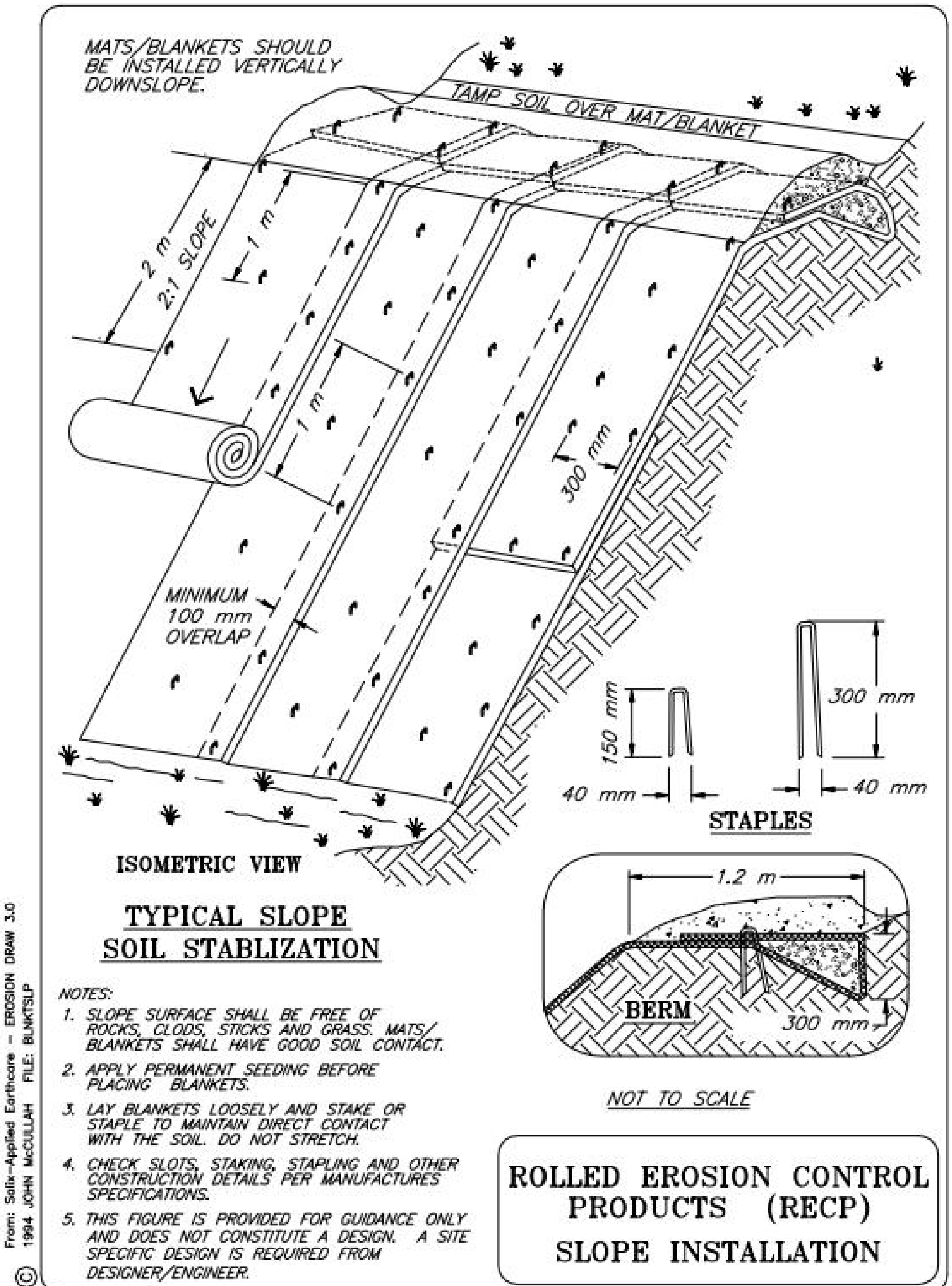
- Re-spreading of natural fibrous organic material (Sodding)
- Mulching (for slopes only)
- Riprap (primarily in channels)
- Gabion mattresses (primarily in channels)

Design Considerations

- Assess hydraulic (water) flow conditions and tractive stress on channel
- In areas which are anticipated to have slow vegetation return (northern areas with short growing seasons and permafrost zones), consideration should be given to covering the site with a layer of dense fibrous organic material, where available
- Assess local soil, weather and growth conditions for revegetation (within 3 to 12 months of the project) to determine if the use of RECP as a protective measure is suitable. If the revegetation conditions are assessed as favourable, the use of RECP can be considered

Discuss the suitability of the RECP product for use on the site with your supplier. Suppliers are key information sources and can provide detailed recommendations suitable to the specific location or site conditions.


150 mm
LONGITUDINAL ANCHOR TRENCH
300 mm
150 mm
TERMINAL SLOPE AND CHANNEL ANCHOR TRENCH
STAKE AT 1–1.5 m INTERVALS
CHANNEL BOTTOM
CHECK SLOT AT 7.6 m INTERVALS
ISOMETRIC VIEW
300 mm
INITIAL CHANNEL ANCHOR TRENCH
150 mm
150 mm
INTERMITTENT CHECK SLOT
NOTES:
1. CHECK SLOTS TO BE CONSTRUCTED PER MANUFACTURERS SPECIFICATIONS.
2. STAKING OR STAPLING LAYOUT PER MANUFACTURERS SPECIFICATIONS.
3. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.
ROLLED EROSION CONTROL PRODUCTS (RECP)
CHANNEL INSTALLATION
From: Salix-Applied Earthcare – EROSION DRAW 3.0
© 1994 JOHN McCULLAH FILE: BLNKTCHA


MATS/BLANKETS SHOULD BE INSTALLED VERTICALLY DOWNSLOPE.
TAMP SOIL OVER MAT/BLANKET
2 m
2:1 SLOPE
1 m
1 m
300 mm
MINIMUM 100 mm OVERLAP
150 mm
300 mm
40 mm
40 mm
STAPLES
ISOMETRIC VIEW
1.2 m
BERM
300 mm
TYPICAL SLOPE SOIL STABLIZATION
NOTES:
1. SLOPE SURFACE SHALL BE FREE OF ROCKS, CLODS, STICKS AND GRASS. MATS/BLANKETS SHALL HAVE GOOD SOIL CONTACT.
2. APPLY PERMANENT SEEDING BEFORE PLACING BLANKETS.
3. LAY BLANKETS LOOSELY AND STAKE OR STAPLE TO MAINTAIN DIRECT CONTACT WITH THE SOIL. DO NOT STRETCH.
4. CHECK SLOTS, STAKING, STAPLING AND OTHER CONSTRUCTION DETAILS PER MANUFACTURES SPECIFICATIONS.
5. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.
NOT TO SCALE
ROLLED EROSION CONTROL PRODUCTS (RECP)
SLOPE INSTALLATION
From: Salix-Applied Earthcare - EROSION DRAW 3.0
© 1994 JOHN McCULLAH FILE: BLNKTSLP

Riprap Armouring a) Slope Protection b) Channel Protection Erosion Control	B.M.P. #9 (a & b)

Description and Purpose

- Large, machine or hand-placed angular rock or boulders placed along ditchlines, stream channel and banks (e.g. bridge abutments) or on slopes to protect underlying soils from erosion due to flowing water
- The rock for riprap should be pieces with angular edges of a rock -type and size which will not erode or weather in air or water. The rock should not generate acidic drainage or metal contamination which may need to be confirmed by lab testing.
- Can be used for lined downdrains which pass ditchline or stormwater flows to the base of a slope to prevent erosion of the slope
- Used as a velocity diffuser for outlets of culverts, sediment pond inlets/outlets and protective barrier for splash pad on permanent check dam structures in ditchlines.

Applications

- Permanent measure
- May be used on channel banks and slopes with flow velocities ranging from 2 m/s to 5 m/s (dependent on rock size and thickness); appropriate for slopes that do not exceed 2H:1V
- Riprap may be applied as a lining on the drainage channel from the base to the anticipated flow height (mean annual peak flow) plus freeboard
  - Other forms of soft armouring (RECP blankets with seeding) can be used to promote vegetation and to protect soils within the channel or on the portion of channel slopes above the riprap
- Rip Rap should be used in conjunction with a non-woven geotextile underlay or a graded rock which prevents intrusion of fines from the basal soil or erosion beneath the rock structure. Fabric underlay is not recommended for use within the stream channel as it does not permit vegetative growth and can become a hazard if it becomes dislodged. .
- For fluctuating high flow channels, the riprap should be underlain by a layer of granular filter material for long-term performance under cyclic drawdown conditions with/without an extra layer of non-woven geotextile as underlay

Advantages

- Easy to install and repair
- Very durable, long lasting, and virtually maintenance free
- Flexible

Riprap Armouring a) Slope Protection b) Channel Protection Erosion Control	B.M.P. #9 (a & b)

Limitations

- Expensive form of channel lining and stabilization
- Requires heavy equipment and transport of broken rock or coarse aggregate to site
- May not be feasible in areas where suitable rock is not available
- Riprap may have to be placed by hand
- Normally 2 to 3 times riprap thickness is required in comparison with gabion mattress thickness for equivalent protection performance under identical hydraulic conditions
- Use of gabion materials are preferred at flow rates greater than 3 m/s due to larger nominal size of riprap and thickness required for erosion protection during flow velocities of this magnitude
- Can be classified as uniform or graded. Uniform riprap would contain stones which are of a single size range. Graded riprap would contain a mixture of stones ranging from small to large. Graded riprap forms a flexible self-healing cover and may be best for stream channels

Construction

- Grade the slope or channel to final design grade
- Place filter (underlay) layer on prepared slope
  - Filter layer can consist of non-woven geotextile underlay and/or well graded granular material dependent on hydraulic conditions
  - Filter fabric must stay in direct contact with underlying soils to prevent undermining of the structure
- Place riprap layer
- Riprap should consist of a graded mixture of sound, durable, angular stone with at least 50% of the riprap material being larger than 200 mm in diameter. The size range for rock material depends on the flow conditions and may require design by a qualified professional

Riprap Armouring a) Slope Protection b) Channel Protection Erosion Control	B.M.P. #9 (a & b)

- Riprap should be sized according to the following gradation and mass:

		Riprap Class			
		1M	**1**	**2**	**3**
Nominal Mass **Nominal Diameter**	**kg** **mm**	**7** **175**	**40** **300**	**200** **500**	**700** **800**
None heavier than:	kg or mm	40 300	130 450	700 800	1800 1100
No less than 20% or more than 50% heavier than:	kg or mm	10 200	70 350	300 600	1100 900
No less than 50% or more than 80% heavier than:	kg or mm	7 175	40 300	200 500	700 800
100% heavier than:	kg or mm	3 125	10 200	40 300	200 500

Percentages quoted are by mass.
Sizes quoted are equivalent spherical diameters, and are for guidance only.

Source: AT Bridge Spec. 2010

- Non-woven geotextile fabric underlay below riprap should meet the following specifications and physical properties or as specified by the designing qualified professional:

Non-Woven Geotextile Filter Fabric
Specifications and Physical Properties

	Class 1M, 1 and 2	**Class 3**
Grab Strength	650 N	875 N
Elongation (Failure)	50%	50%
Puncture Strength	275 N	550 N
Burst Strength	2.1 MPa	2.7 MPa
Trapezoidal Tear	250 N	350 N
Minimum Fabric Overlap to be 300 mm		

Source: AT Bridge Spec. 2010

Construction Considerations

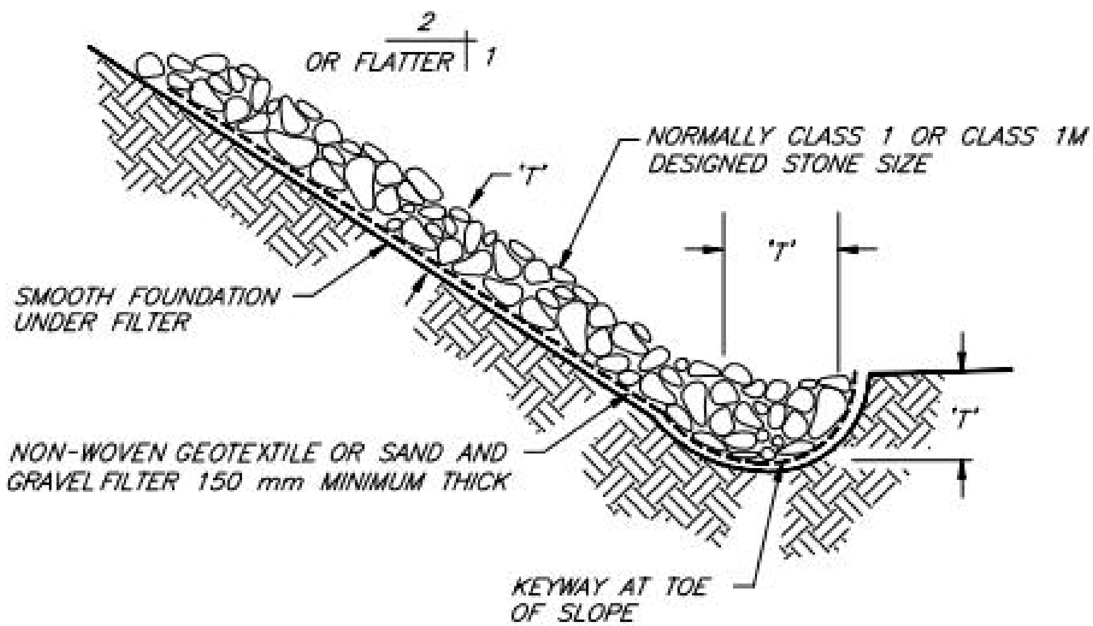
- Riprap should be placed in a uniform thickness across the channe l so as not to constrict channel width
- Blasted rock is preferred (if available)
- Riprap layer should be 1.5 to 2 times the thickness of the largest rocks used, 1.5 to 3 times the thickness of the D_{50} material, and not less than 300 mm in thickness

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Periodic inspections to check fo r erosion of protective material (undermining) or movement of riprap should be conducted at a minimum of once per year following freshet

Similar Measures

- Rolled erosion control products (RECP) which are well vegetated (not for use at very high flow and high velocity areas)
- Gabion mats/mattresses



TYPICAL SECTION

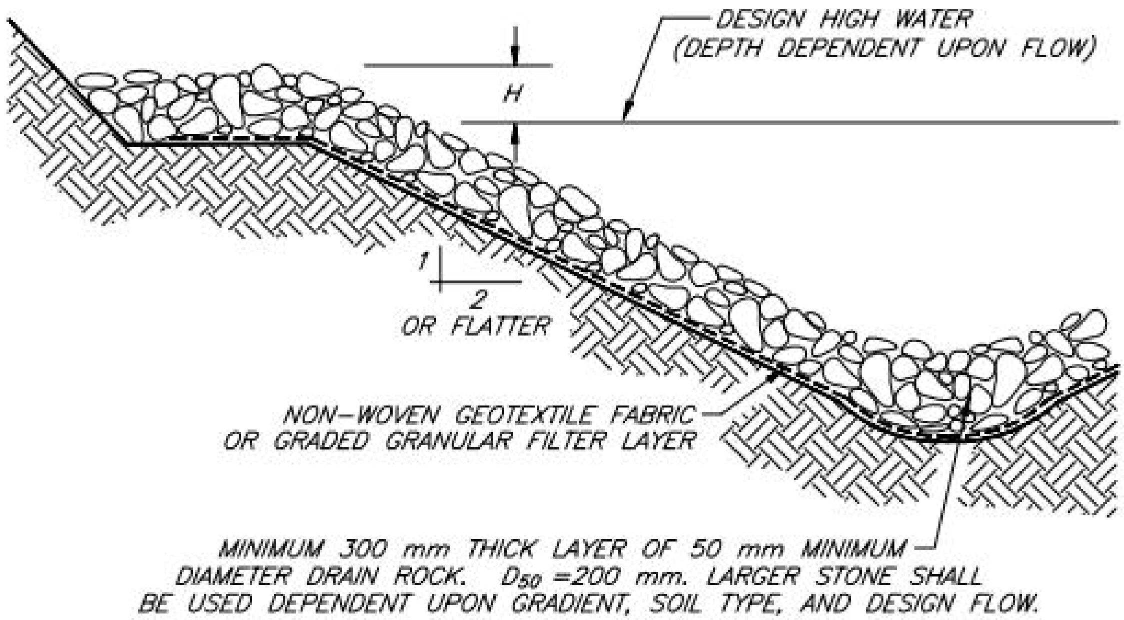
NOTE:

1. 'T' = THICKNESS: THICKNESS SHALL BE DETERMINED BY THE ENGINEER.
   MINIMUM THICKNESS = 300 mm. (i.e. 1.5x D_{50}) FOR D_{50} = 200 mm.
2. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

RIPRAP ARMOURING FOR SLOPE

FILE: RIPRAP

DESIGN HEIGHT (H), WIDTH AND STONE SIZE SHALL BE DETERMINED BY THE ENGINEER



TYPICAL SECTION

NOTES:

1. RIPRAP GRADATION AND THICKNESS SHALL BE DETERMINED BY THE ENGINEER IN ACCORDANCE WITH HYDRAULIC CONDITIONS.
2. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

RIPRAP ARMOURING FOR CHANNEL

FILE: RCKCHNEL

Cellular Confinement System Erosion Control	B.M.P. #10

Description and Purpose

- Manufactured 3-dimensional, plastic matting with open cells which may be filled with topsoil or aggregate
- 3-dimensional structure stabilizes cut or fill slopes
- Cells confine topsoil or aggregate and protect the rooting zone while permitting surface drainage

Applications

- Permanent measure
- May be used with granular fill on cut or fill slopes up to a 1H:1V slope
- May be used with granular fill on slopes and in ditches where flow velocities are 3 m/s or less
- May be used as a flexible channel lining with aggregate fill used in cells
- 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
- May be used in locations where rock is not available for rip rap armouring for some applications
- Use of native rock or granular fill materials reduces costs; local granular fill is preferred

Limitations

- Expensive
- May become brittle and easily damaged in freezing conditions
- Installation can be labour intensive
- Not to be used on slopes steeper than 1H:1V
- Slopes of 1H:1V can be difficult or hazardous to work on

Construction

- Cellular Confinement System mats should be installed in accordance with the manufacturer's directions when available
- The following is a general installation method
  - Slope should be graded to design elevations and final grade

- Rocks or other deleterious debris should be removed from mat location to provide a smooth surface
- Cellular confinement mats (mats) should be installed so that the top of the mat is flush with surrounding soil, extending 0.6 to 1.2 m beyond crest of slope.
- Every second cell along crest of slope should be anchored securely into the soil using 'J' pins or other suitable anchoring device
- The mat should be rolled out downslope
- Where the roll is not long enough to cover the entire length of the slope, the downslope section of mat should be butt-jointed to the upslope section and secured using staples, hog rings, or other suitable fasteners
- Adjacent rolls of mat should be butt-jointed and secured using staples, hog rings, or other suitable fasteners
- Anchors are placed at 1 m intervals down the slope
  - Additional anchors may be required to ensure the mat is in direct contact with soil
  - Additional anchors may be required along edges of mat
- Backfilling should start at the crest of the slope and proceed downslope
  - For topsoil, over-fill cells approximately 25 to 50 mm and lightly compact so that top of topsoil is flush with matting
  - For granular fill, overfill cells approximately 25 mm and tamp compact so that top of fill is flush with matting
- Seeding and/or an organic layer should be applied after fill placement

Construction Considerations

- Properly grading the soil surface by removing rocks or deleterious materials and grading to provide a smooth surface prior to installing the matting is required to ensure the mat stays in direct contact with the soil. This is critical to the stability and effectiveness of the structure.
- Mats should be placed running with the direction of flow or from upslope to downslope
- Use only a single layer of mats
- Prepare the site so that the top of the matting ends up flush with the adjacent terrain
- Infill from top of slope ensuring no large piles (<1m height) of fill are placed on the mat which may cause downward movement of the mat.

Inspection and Maintenance

- The area covered with mats should be inspected regularly in accordance with the PESC and TESC Plans. Inspections should be conducted after heavy rain or snow melt events to check for damage or loss of material
  - Any damaged areas should be repaired immediately
  - Areas with material loss should have material replaced and seed reapplied where vegetation is required
- Inspections should continue until soils have stabilized or vegetation is established
  - Areas where vegetation fails to grow should be reseeded immediately
- If matting is broken or damaged, washout of the mat and underlying soils may occur. Should the mat be undermined (material washed out from under the mat) the area should be re-graded and the mat repaired or replaced

Similar Measures

- Rolled erosion control products (RECP)
- Riprap armouring

Energy Dissipators a) for Culvert Outlets b) for Troughs at Bridge Headslopes Erosion Control	B.M.P. #11

Description

a) Hard armour (riprap, gravel, concrete) placed at pipe outlets, in channels, and downstream of check structures to reduce velocity and dissipate energy of concentrated flows (BMP 17a)

b) Standard Drain Trough Terminal Protection Structure[1] generally used at bridge headslopes (BMP 17b)

- Minimizes erosion at outlet location by dissipating flow energy

Applications

- Permanent measure
- 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 gentle 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, or other barriers to prevent erosion caused by overtopping of structure
- May be used at the inlet/outlet of a sediment pond or outlet of a pumping station hose.

Advantages

- Reduces flow energy to protect soils from erosion within a relatively small area

Limitations

- May be expensive if construction materials (riprap, gravel, or concrete) are not readily available
- Small rocks or stones can be dislodged during high flows. Suitably sized rock must be used.
- Grouted (cement) riprap may breakup due to hydrostatic pressure, frost heave, or settlement
- May be labour intensive to prepare and construct
- High flow velocities may require paved outlet structures, stilling basins, plunge pools, drop structures, baffles, or concrete splash pads. High flow velocities will

[1] Alberta Transportation: Specifications for Bridge Construction 2010: Section 9 for details.

require structures designed by qualified professional (QP). Energy dissipators constructed of riprap alone may not be adequate for high flow velocities

Construction

- Construct QP designed structures as per the designer's instruction.
- For non-QP installations:
  - o Grade the area to final design grades and elevations
  - o Sub-excavate the energy dissipator location to thickness of energy dissipator
  - o Place filtration bedding material on base of excavation
    - – Bedding material can be comprised of non-woven geotextile, or well graded sand and gravel, depending on flow velocity or engineering design. Bedding material acts as separating filter between the subgrade and the riprap energy dissipator material
  - o Place energy dissipator material (riprap, gravel, concrete) over bedding material
    - – Top of energy dissipator should be flush with surrounding grade

Construction Considerations

- Length of energy dissipator (L_a) at outlets shall be of sufficient length to dissipate energy. The following rule should be followed for sizing:
  - – L_a = 4.5 x D (where D is the diameter of the pipe or channel at the outlet)
- Width of energy dissipator (W_a) at outlets shall be of sufficient width to contain flow and initial splash
  - – W_a = 4 x D
- Thickness of energy dissipator (d_a) material at outlets shall be of sufficient size and thickness to reduce flow velocity
  - – d_a = 1.5 x maximum rock diameter (with a minimum thickness of 0.30 m)
- Energy dissipator (splash pad, apron) shall be set at a zero (0%) grade and be in alignment with the direction of flow from the outlet
- Bedding (filtration) layer can comprise of either non-woven geotextile (refer to suppliers or engineers for information on suitable thickness) or a minimum of 0.15 m well graded sand and gravel layer
- Energy dissipator should be constructed of well-graded riprap
  - – Minimum D_{50} = 150 mm. Preferable D_{50} = 300 mm

- Minimum thickness = a) 1.5 x D_{50} or b) 0.30 m to 0.45 m thickness (a or b whichever is greater)

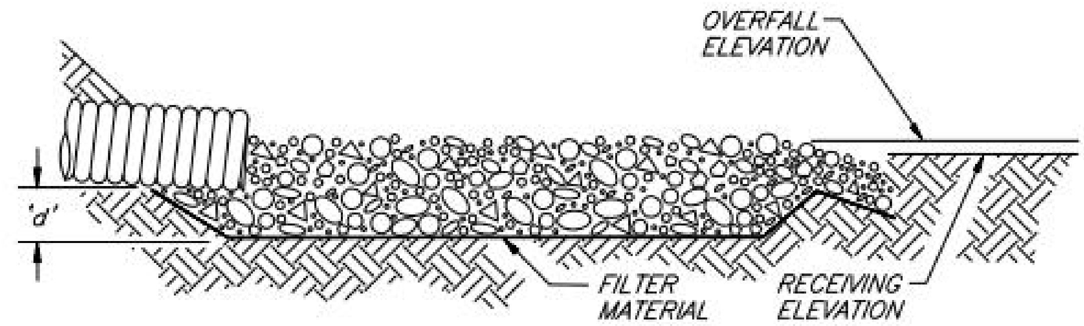
- Energy dissipator shall be designed to accommodate a 10-year peak runoff or the design discharge of the upstream channel, pipe, drain, or culvert, whichever is greater

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Inspections should be conducted once weekly, following heavy rain or snowmelt events during construction and following heavy rainfall or snowmelt events post-construction at a minimum. Any damage to the structure (undermining or washout) should be repaired immediately

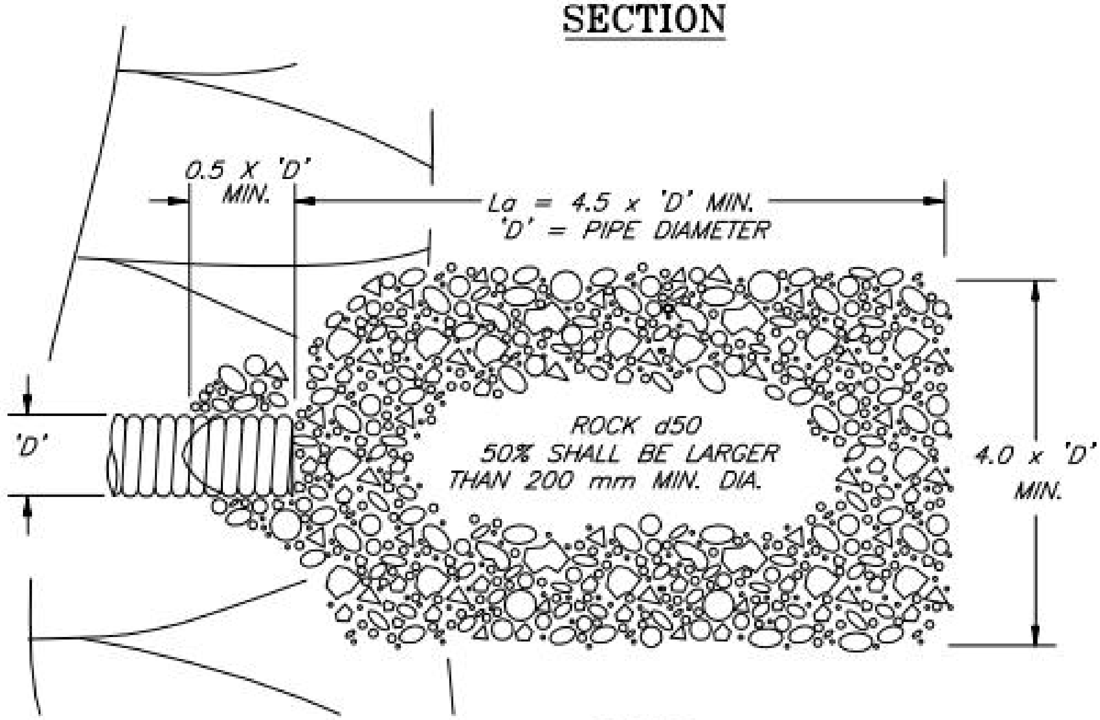
Similar Measures

- Gabion mattresses



B) MINIMUM THICKNESS = 300 mm. (i.e. 1.5x D_{50}) FOR D_{50} = 200 mm.

SECTION



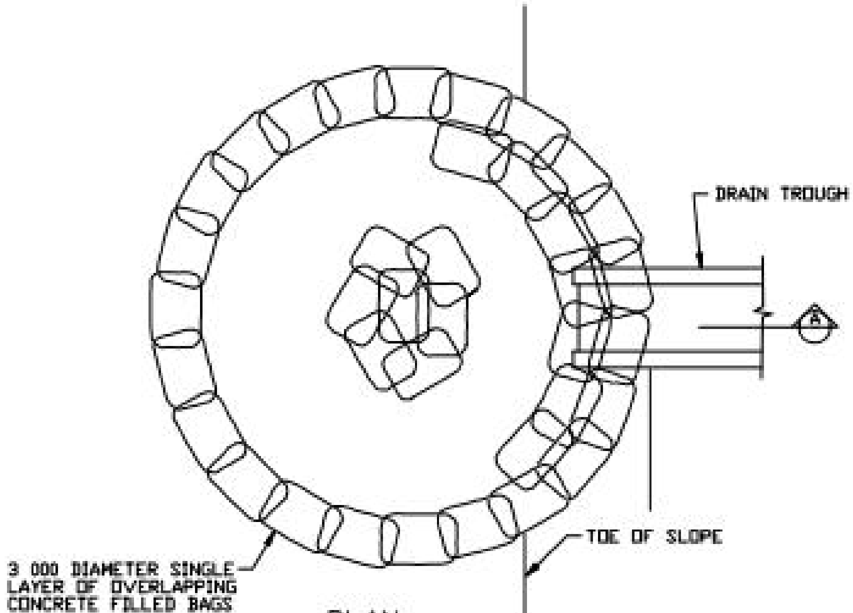
PLAN

NOTES:

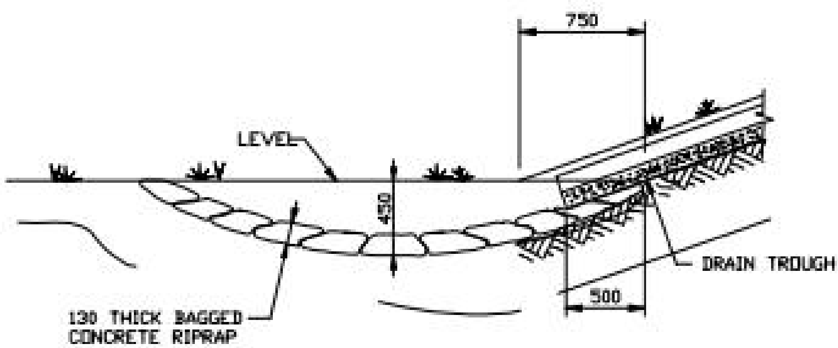
1. 'La' = LENGTH OF APRON. DISTANCE 'La' SHALL BE OF SUFFICIENT LENGTH TO DISSIPATE ENERGY.
2. APRON SHALL BE SET AT A ZERO GRADE AND ALIGNED STRAIGHT.
3. FILTER MATERIAL SHALL BE FILTER FABRIC OR 150 mm THICK MINIMUM GRADED GRAVEL LAYER.
4. FOR PIPE DIAMETER > 600 mm, DESIGN BY ENGINEER IS REQUIRED.
5. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

ENERGY DISSIPATOR FOR CULVERT OUTLET

FILE: ENRGYDIS



PLAN



A SECTION

GENERAL NOTES

- DIMENSIONS ARE GIVEN IN mm. DETAILS ARE NOT TO SCALE.
- PLACING OF BAGGED CONCRETE RIPRAP SHALL START AT THE BOTTOM CENTRE OF THE DISHED AREA AND SHALL PROCEED IN A CONTINUOUS SPIRAL FASHION OUTWARD UNTIL THE ENTIRE DISH IS COVERED. EACH CONCRETE FILLED BAG SHALL LAP OVER THE EDGES OF THE PREVIOUSLY PLACED BAGS.

  SOURCE: ALBERTA TRANSPORTATION SPECIFICATIONS FOR BRIDGE CONSTRUCTION
  DRAWING: S-1410-91

- THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

ENERGY DISSIPATOR

FOR SEMI-CIRCULAR TROUGH DRAIN TERMINAL PROTECTION FOR BRIDGE HEADSLOPE

Sediment Traps and Basins a) Riser Outlet Option b) Permeable Rock Berm Outlet Option Sediment Control	B.M.P. #12

Description and Purpose

- A low height dam or enclosure for impoundment of sediment-laden storm water to promote settling of smaller (silt) size particles
- Used to trap sediment-laden run off and promote settling of sediment prior releasing to enter downslope watercourses
- Constructed by excavating a pond or constructing berms above the original ground surface
- Sediment traps and basins can be divided on size of pond impoundment enclosure
  - – Basin (Type I) for pond area $\geq$500 m²
  - – Trap (Type II) for pond area $\leq$500 m²

Applications

- Temporary or Permanent measure
- Used at terminal (end) or selected points for containing sediment laden water to promote the sedimentation of silts and larger sized soil particles prior to release downstream or downslope
- Used as a final (last chance) sediment control measure at the perimeter of a construction sites where sediment-laden runoff may enter watercourses, storm drains, or other sensitive areas
- Used where there is a need to control and contain a significant amount of sediment from stormwater due to site disturbance
- Sediment basins (Type I) used for disturbed drainage areas greater than 2.0 ha
- Sediment traps (Type II) used for disturbed drainage areas of 2.0 ha or less
- Where practical, contributing drainage areas should be subdivided into smaller areas and multiple sediment impoundment controls installed. Too much flow into the sediment pond will result in ineffective settling due to overloading of the structure.

Advantages

- High capacity of runoff containment where an efficient and effective means of promoting sedimentation is necessary along perimeters of construction sites where high risk sensitive environmental areas and watercourses may be impacted
- Accumulated sediment deposits can be cleaned out easily

- Can be deactivated easily by breaching the enclosure dike when empty to grade for project completion

Limitations

- Require design by a qualified person(QP)
- Permanent traps and basins should be avoided in areas of permafrost as ponding water increases permafrost melt. Temporary traps and basins should be removed as soon as they are no longer required (in-place no more than one summer season)
- Sediment traps and basins do not remove 100% of the sediment; net efficiency for removal of sediment may be around 50%, dependent on the trap or basin design and nature of surface soil
- Anticipated service life of 3 years or less due to possible clogging of outlets in the long-term
- Sedimentation traps and basins with a riser outlet should have a spillway with adequate erosion protection to permit overflow in the event that the riser pipe outlet clogs during a storm event
- For drainage areas greater than 40 ha, multiple basins may be required
- Efficiency of the sediment pond is very dependent on surface area, duration of water detention, and the suspended particulate size. Sediment ponds require large surface areas and long detention periods to permit settling of fine materials. Erosion protection measures are necessary and sediment controls will be needed to reduce the sediment load in the water entering the pond
- Fences and signage may be required to reduce danger to the public and wildlife
- Ponds must be monitored and the removal of sediment build up (maintenance) is required. The removed material must be placed in a stable suitable area where it is not subjected to water erosion.

Construction

- The consequences of failure for any water retaining structure (pond) will determine the level of effort in the design and construction phases. A qualified professional (e.g. engineer) should be consulted to design water-retaining structures
  - o The construction guidelines presented herein are minimum requirements and does not override the QP design criteria. All footprint area for a pond berm should be stripped of vegetation, topsoil, and roots to expose mineral subgrade soils

- o Fill material used for the berm should be clean mineral soil with sufficient moisture to allow proper compaction
- o Fill material should be placed in lifts not exceeding 150 mm in compacted thickness and should be compacted to a minimum of 95% Standard Proctor maximum dry Density (SPD)
- o The main outlet structure should be installed at farthest possible point from inlet
  - ▪ Outlet should be placed on firm, smooth ground and should be backfilled and compacted to 95% SPD
  - ▪ Proper inlet and outlet protection should be installed to protect from erosion
  - ▪ Outlet pipe should consist of corrugated steel pipe to protect against pinching and blockage unless otherwise recommended by the QP
- o The embankment should be topsoiled & seeded or protected with rolled erosion control product (RECP), gravel or riprap immediately after construction
- o Construct an emergency spillway to accommodate flows not carried by the principle outlet
  - ▪ Emergency spillway should consist of an open channel (earth or vegetated) over native undisturbed soil (not fill) where possible
  - ▪ If spillway is elevated, the spillway and the outlet location should be protected with riprap
  - ▪ Spillway crest should be at least 0.15 m below the berm level

Construction Considerations

- ▪ Preferable to strip to mineral soil only along the footprint area required for dike construction; within the pond floor (centre) area it may be preferred to clear by cutting stumps low but leaving the organic layers intact to minimize erosion and promote sedimentation. For maintenance purposes, a non-woven geotextile fabric should be placed over the organics and used as a liner for the pond area if the pond area is to be returned to pre-disturbance conditions. This should be outlined in the PESC Plan designs
- ▪ Can be constructed by excavating, constructing berms (embankments), or a combination of the two methods
- ▪ Baffles or deflection berms should be provided to increase retention time of flow from inlet to outlet

Sediment Traps and Basins a) Riser Outlet Option b) Permeable Rock Berm Outlet Option Sediment Control	B.M.P. #12

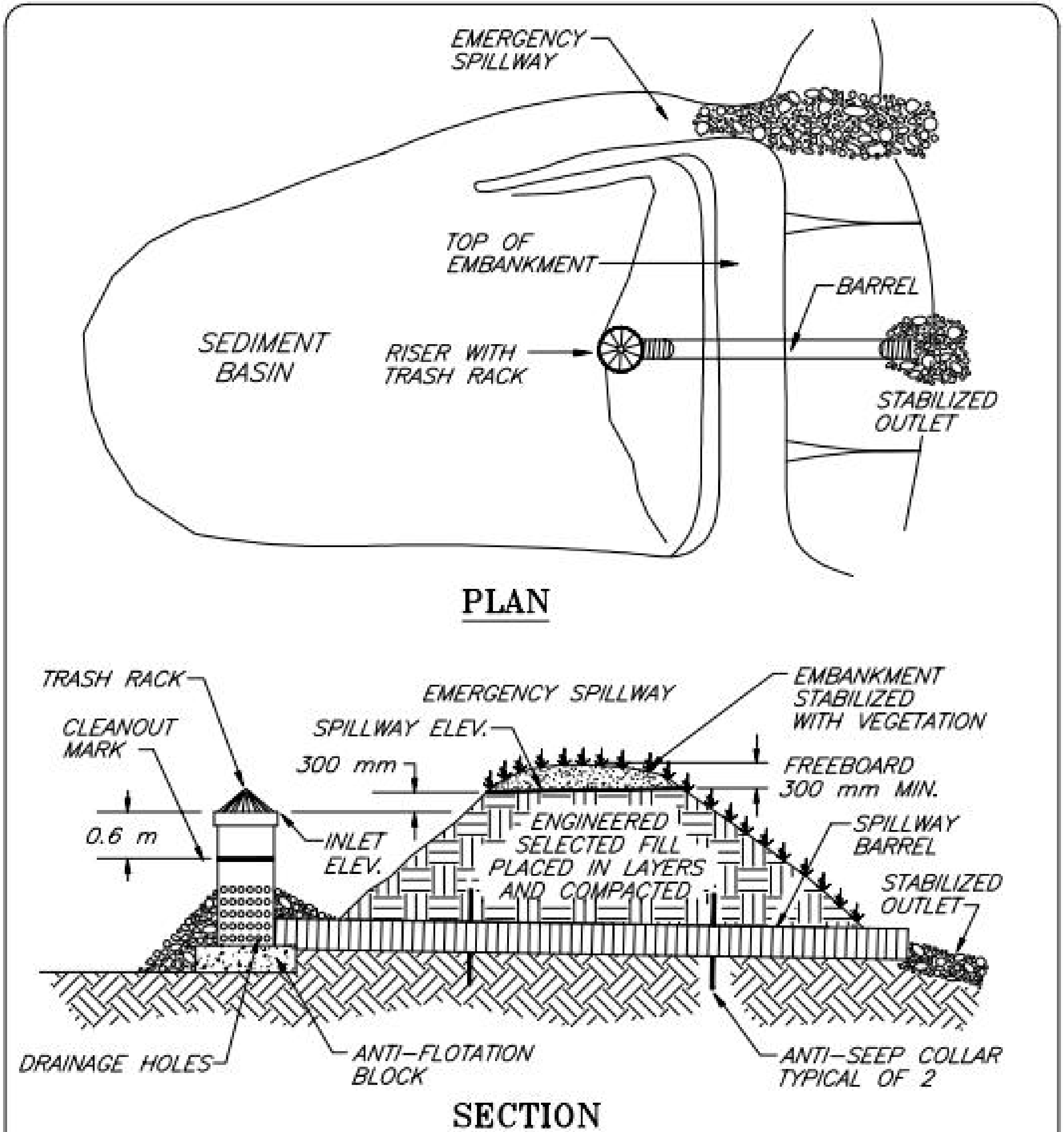
- Construct sediment ponds and basins where necessary to prevent sediment from leaving the site perimeter or entering environmentally sensitive areas. Ponds should be constructed prior to the wet season and main construction activities
  - o Sediment pond bottom should be flat or gently sloping towards outlet
  - o Berm slopes should not be steeper than 2H:1V and should be compacted
  - o Ponds should be located where:
    - Low berms can be constructed across a swale or low natural terrain
    - Ponds must be accessible to conduct maintenance work, including sediment removal
    - Ponds should be away from permafrost soil areas, where feasible

Inspection and Maintenance

- Regular inspection is required to identify seepage, structural soundness of berm, damage to the outlet or obstruction and the amount of sediment accumulation
- Inspection frequency should be in accordance with the PESC and TESC Plans
- Sediment should be removed upon reaching 1/2 height of the containment berm or within 0.4 m of crest of embankment
- Sediment traps may be deactivated or removed after vegetation has been established in previously disturbed upstream areas

Design Considerations

- The design can consist of (a) a riser outlet option or (b) a permeable rock berm outlet option. (The permeable rock berm outlet option is preferable for highway construction)
- Minimum particle size for riprap rock shall be 200 mm
- If the design of a riser outlet is utilized
  - – Main outlet pipe shall be fabricated from corrugated steel pipe conforming to CSA Standard CAN 5-G401-M81 or the latest revision thereof
  - – Outlet pipe shall consist of a horizontal pipe welded to a similar vertical riser at a 45 degree mitre joint
- Close to the base of the riser pipe, a 100 mm diameter hole shall be fabricated and a mesh with 12 mm square openings tack welded over the hole as a screen
  - – A similar hole shall be provided along the riser pipe immediately above the elevation of the maximum sediment build-up (usually 0.4 m below crest of berm)

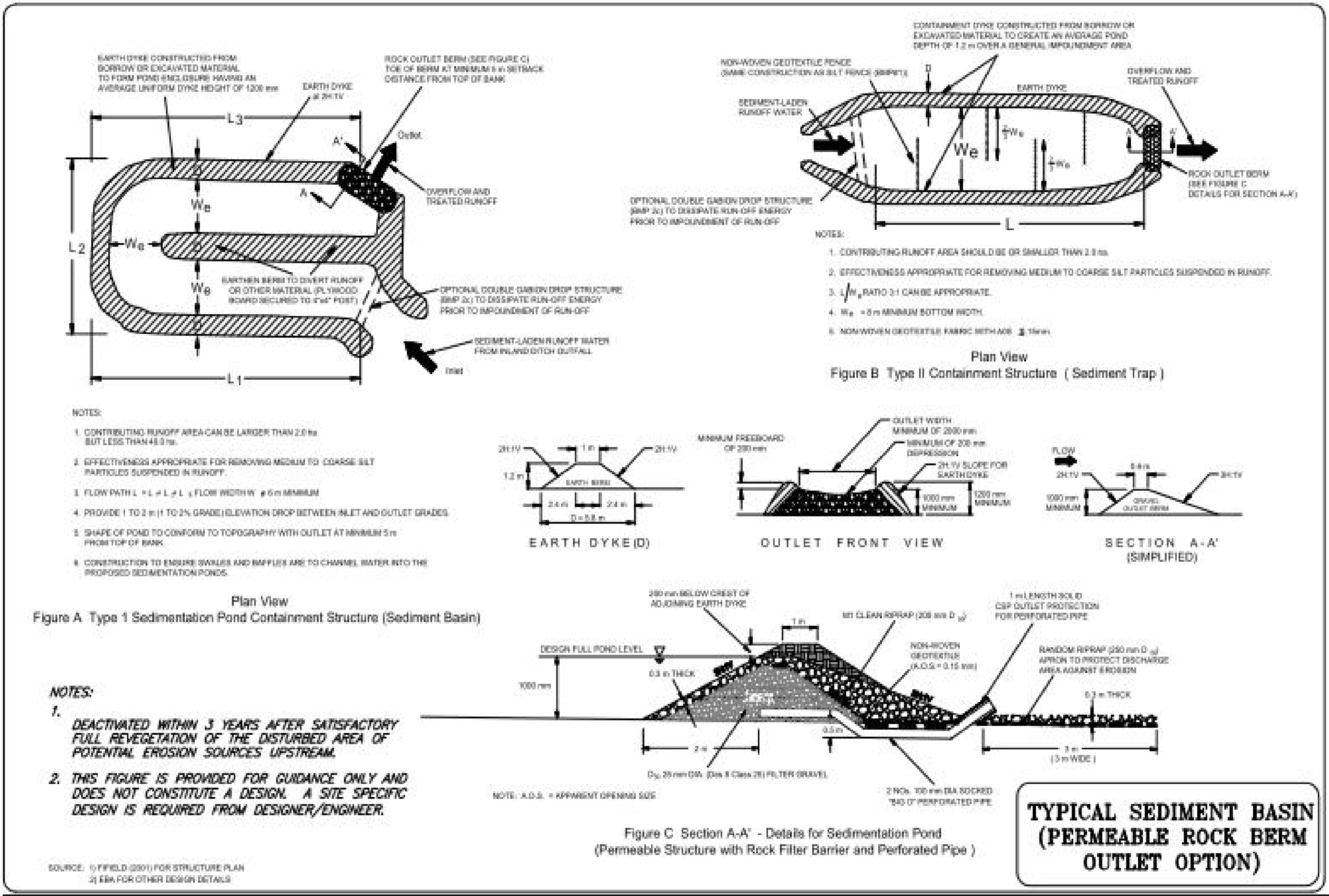


NOTES:

1. THE TEMPORARY SEDIMENT BASIN, DESIGNED BY A QUALIFIED PROFESSIONAL, IS REQUIRED FOR DISTURBED AREAS GREATER THAN 2.02 HECTARES (5 ACRES) WITH A DRAINAGE AREA LESS THAN 40.4 HECTARES (100 ACRES).
2. THE SEDIMENT BASIN MAY BE REMOVED WITHIN 3 YEARS.
3. HEIGHT OF ENGINEERED SELECTED FILL EQUAL TO 1 m.
4. FOR CONFIGURATION AND FLOW CHAMBER DESIGN (i.e. LENGTH(L) & WIDTH(W_e) OF BASIN), REFER TO BMP 18b.
5. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

TYPICAL SEDIMENT BASIN (RISER OUTLET OPTION)

FILE: SEDBASIN



EARTH DYKE CONSTRUCTED FROM BORROW OR EXCAVATED MATERIAL TO FORM POND ENCLOSURE HAVING AN AVERAGE UNIFORM DYKE HEIGHT OF 1200 mm
EARTH DYKE
ROCK OUTLET BERM (SEE FIGURE C) TOE OF BERM AT MINIMUM 5 m SETBACK DISTANCE FROM TOP OF BANK
Outlet
OVERFLOW AND TREATED RUNOFF
OPTIONAL DOUBLE GABION DROP STRUCTURE (BMP 2c) TO DISSIPATE RUN-OFF ENERGY PRIOR TO IMPOUNDMENT OF RUN-OFF
SEDIMENT-LADEN RUNOFF WATER FROM INLAND DITCH OUTFALL
Inlet
NOTES:
1. CONTRIBUTING RUNOFF AREA CAN BE LARGER THAN 2.0 ha BUT LESS THAN 40.0 ha.
2. EFFECTIVENESS APPROPRIATE FOR REMOVING MEDIUM TO COARSE SILT PARTICLES SUSPENDED IN RUNOFF.
4. PROVIDE 1 TO 2 m (1 TO 2% GRADE) ELEVATION DROP BETWEEN INLET AND OUTLET GRADES.
5. SHAPE OF POND TO CONFORM TO TOPOGRAPHY WITH OUTLET AT MINIMUM 5 m FROM TOP OF BANK.
6. CONSTRUCTION TO ENSURE SWALES AND BAFFLES ARE TO CHANNEL WATER INTO THE PROPOSED SEDIMENTATION PONDS.
Plan View
Figure A Type 1 Sedimentation Pond Containment Structure (Sediment Basin)
NON-WOVEN GEOTEXTILE FENCE
SEDIMENT-LADEN RUNOFF WATER
EARTH DYKE
OVERFLOW AND TREATED RUNOFF
ROCK OUTLET BERM (SEE FIGURE C DETAILS FOR SECTION A-A')
NOTES:
1. CONTRIBUTING RUNOFF AREA SHOULD BE OR SMALLER THAN 2.0 ha.
2. EFFECTIVENESS APPROPRIATE FOR REMOVING MEDIUM TO COARSE SILT PARTICLES SUSPENDED IN RUNOFF.
3. L/W RATIO 3:1 CAN BE APPROPRIATE.
4. MINIMUM BOTTOM WIDTH.
Plan View
Figure B Type II Containment Structure (Sediment Trap)
EARTH DYKE (D)
OUTLET FRONT VIEW
SECTION A-A' (SIMPLIFIED)
FLOW
DESIGN FULL POND LEVEL
NOTE: A.O.S. = APPARENT OPENING SIZE
Figure C Section A-A' - Details for Sedimentation Pond (Permeable Structure with Rock Filter Barrier and Perforated Pipe)
NOTES:
1. DEACTIVATED WITHIN 3 YEARS AFTER SATISFACTORY FULL REVEGETATION OF THE DISTURBED AREA OF POTENTIAL EROSION SOURCES UPSTREAM.
2. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.
SOURCE: 1) FIFIELD (2001) FOR STRUCTURE PLAN
2) EBA FOR OTHER DESIGN DETAILS
TYPICAL SEDIMENT BASIN (PERMEABLE ROCK BERM OUTLET OPTION)

Slope Drains (Pipe) a) Slope Drain b) Overside Drain Erosion Control	B.M.P. #13

Description and Purpose

- Heavy duty, UV resistant, corrugated, flexible, non-perforated "Big O" pipe (HDPE) that carries water from top to bottom of fill or cut slope to prevent concentrated water flowing downslope and eroding the face of the slope

Applications

- Temporary or Permanent measure
- Used where there is a high potential for water to flow over the face of the slope causing erosion, especially at areas where runoff converges resulting in concentrated runoff flows (e.g. outlet of ditches) onto cut or fill slopes
- Used in conjunction with some form of water containment or diversion structures, such as ditches, diversion channels, berms, or barriers, to convey water from the top to the base of the slope

Limitations

- Pipes must be sized correctly to accommodate anticipated flow volumes. This will require a qualified professional (QP) to estimate discharge
- Water can erode around the pipe inlet if inlet protection is not properly constructed
- Erosion can occur at base of the structure if outlet protection such as an energy dissipator is not constructed
- Slope drains must be anchored securely to face of slope
- Pipes may become blocked with ice

Construction

- Construct diversion or intercept channel, ditch block, barrier, or other inflow apron structure at crest of slope to channel flow toward the slope drain inlet
- Install slope drain through inlet berm or barrier with a minimum of 0.5 m of soil cover above top of drain pipe to secure the inlet
  - Install riprap or other protection measure at inlet for scour protection
- Install energy dissipator (such as riprap, gravel, concrete pad) at downslope outlet end of slope drain
  - Outlet must not discharge directly onto unprotected soil or organic material or into a water body (stream, pond)

- Secure the pipe from movement using steel anchor stakes, concrete collars, hold-down grommets, or other approved anchor method
  - Space anchors on each side of drain pipe at maximum 3 m intervals along entire length of drain pipe
  - Anchor stakes should have a minimum of 1 m embedded

Construction Considerations (For guidance only)

- Use coiled drain pipe for low flows only - temporary
- If constructing a temporary inflow apron at crest of slope out of sandbags, only fill each sandbag ¾ full, this will allow sandbag to be flexible enough to mould around drain pipe and remain in continuous contact with the ground. Sandbags degrade quickly and should not be used alone as a permanent installation. Rip Rap underlain with non-woven fabric is recommended for permanent inlet installations.
- Several slope drains may be required if upslope drainage areas are large or runoff volumes are too large for one drain pipe

Size of Slope Drain	
Maximum Drainage Area (ha)	**Pipe Diameter (mm) (minimum)**
0.2	300
0.6	450
1.0	530
1.4	600
2.0	760

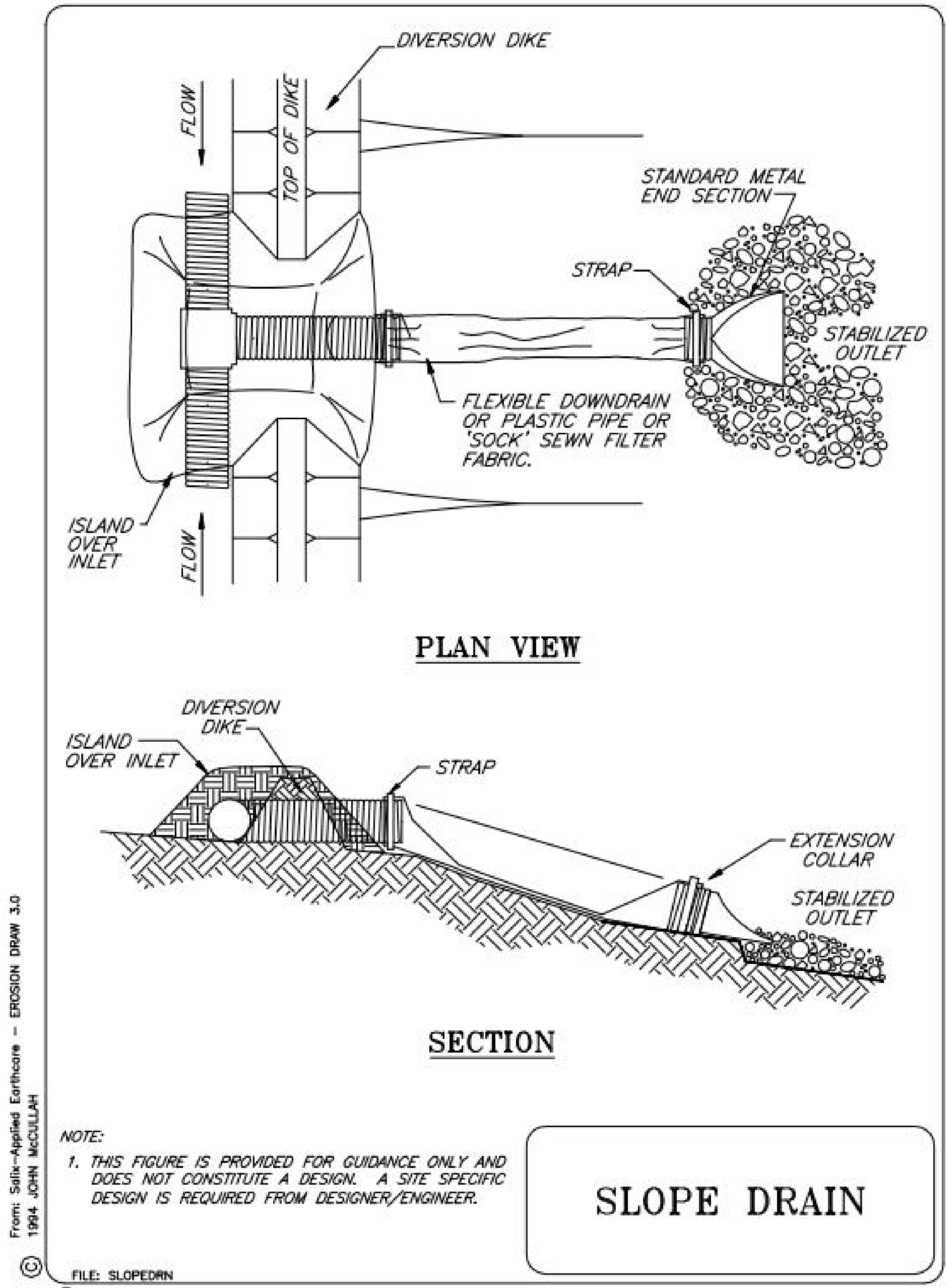
Inspection and Maintenance

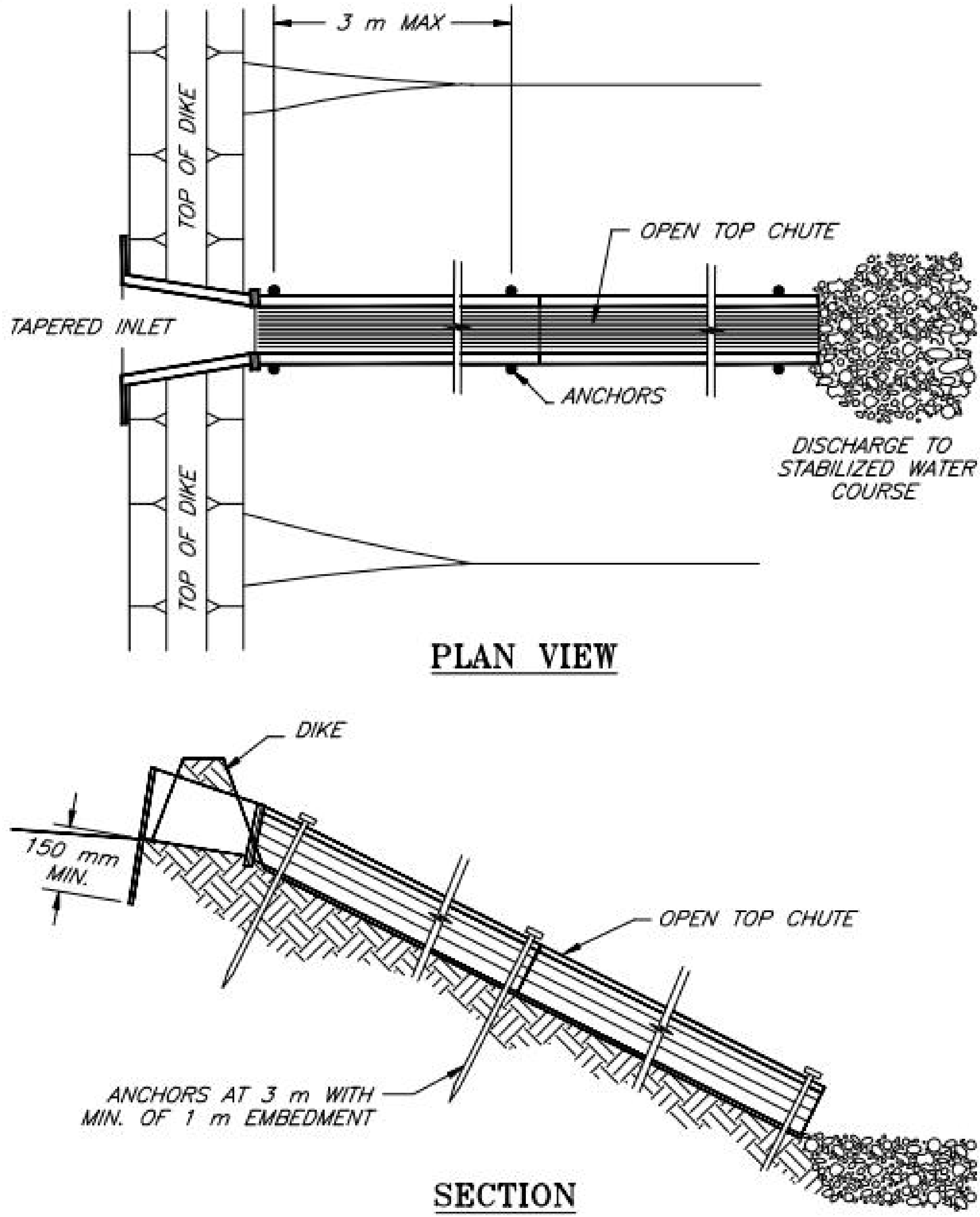
- Inspection frequency should be in accordance with the PESC and TESC Plans
- Repair any damaged section of pipe immediately. HDPE pipes are subject to damage from: equipment, ice, UV, animals, falling objects, or settling while frozen and brittle
- If evidence exists of pipe movement, install additional anchor stakes to secure and anchor at zones of movement
- Remove sediment and organics from upslope inflow apron area after each major storm event. Transport of material into the pipe will occur which may cause the drainpipe to become plugged which could result in overtopping of inflow apron structure and sheet flow over slope face

- Monitor the drain for blockage due to icing conditions. If blockage due to icing is identified as a potential concern, a secondary elevated pipe may be installed as backup measure. Adequate controlled drainage is necessary to minimize erosion and maintain slope stability
- Monitor drains for leakage causing piping (water creep along the outside of pipe) and undermining. Repair as necessary

Similar Measures

- Rock lined channel
- Permanent Pipe (slope drains)
  - Corrugated steel pipe (CSP) downdrain
  - Half-round corrugated steel (1/2 CSP) downslope drain for low flow areas such as bridge headslopes


DIVERSION DIKE
FLOW
TOP OF DIKE
STANDARD METAL END SECTION
STRAP
STABILIZED OUTLET
FLEXIBLE DOWNDRAIN OR PLASTIC PIPE OR 'SOCK' SEWN FILTER FABRIC.
ISLAND OVER INLET
FLOW
PLAN VIEW
DIVERSION DIKE
ISLAND OVER INLET
STRAP
EXTENSION COLLAR
STABILIZED OUTLET
SECTION
NOTE:
1. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.
SLOPE DRAIN
FILE: SLOPEDRN
From: Salix-Applied Earthcare – EROSION DRAW 3.0
© 1994 JOHN McCULLAH



NOTE:

1. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

OVERSIDE DRAIN

FILE: OSDRAIN

Diversion Ditch (Intercept Ditch) Erosion Control	B.M.P. #14

Description and Purpose

- Channels or swales constructed along the crest of slopes to intercept and prevent overland flows from entering areas with bare soil slopes. This diversion will convey runoff away from the slope or construction area and minimize erosion and downslope sediment delivery from overland sheet flow
- Can be used to direct runoff to slope drains (or downdrains) which carry water from higher to lower slope elevations

Applications

- Permanent or temporary measure
- Effective method of intercepting overland flows to avoid flow over exposed slopes and resulting erosion, especially on cut slopes in highly erodible soils (sand and silt)
- Can be used in conjunction with an existing slope drain which was installed down a steep slope
- May be lined with vegetation, riprap, erosion control blankets, or some other erosion protection measure in order to divert clean water, protect the ditchline base from erosion, and to protect highly sensitive and high risk environmental areas downslope
- Can be used in conjunction with erosion or sediment control measures, such as check dam structures, diversion into vegetated areas, or permeable synthetic barriers as part of permanent channel design to protect highly sensitive and high risk environmental areas

Limitations

- Ditch may require design by qualified personnel if flow velocities and/or volumes are large, or if the ditch crosses areas with soil stability conditions
- Ditch may require lining with riprap, RECP or non-woven geotextile fabric to minimize soil erosion from the concentrated flow
- Ditch must be graded to maintain adequate depth, and positive drainage to avoid ponding and breaching of channel sides, which may lead to overtopping of the channel and result in downslope erosion
- Removal of sediment build-up and other ditch maintenance works may be difficult due to limited access in some areas (crest of slopes)
- Ditch may require removal or infilling for reclamation activities on the work site

Diversion Ditch (Intercept Ditch) Erosion Control	B.M.P. #14

Construction

- Excavate the diversion ditch a minimum setback distance of 2 m from the crest of the slope. The ditch ex cavation material can be used to prepare a berm on the downslope side but this must not load the top of slope or add soil to the slope. This may require design by a geotechnical engineer
  - Place and compact excavated soil to form a berm between the crest of slope and the diversion ditch to provide adequate depth (up to 1 m) for the ditch
    - The potential for failure and the consequence of a failure of this berm will determine the level of compaction effort required
  - Sideslopes of the ditch should not be steeper than 2H:1V (depending upon material type)
  - Depth of ditch (from base of ditch to top of berm) should be a maximum of 1 m in depth; width of ditch should be 1 m maximum. If a l arger ditch is required, then alternate drainage control measures should be explored
  - Ditch grade should be a minimum of 1% to promote positive drainage and prevent ponding and saturation of soils

Construction Considerations

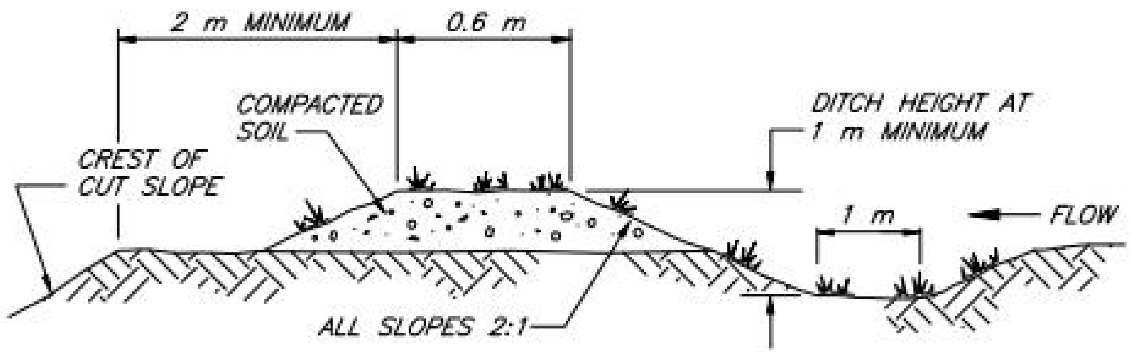
- Channel should be graded towards nearest natural draw or drainage pipe

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Repair any damage or erosion to the ditch base or berm immediately

Similar Measures

- Berms
- Barriers



TYPICAL DIVERSION DITCH

NOTES:

1. THE DITCH BEHIND THE DYKE SHALL HAVE POSITIVE GRADE TO A STABILIZED OUTLET.
2. THE DYKE SHALL BE ADEQUATELY COMPACTED TO PREVENT FAILURE.
3. FOR SENSITIVE HIGH RISK AREAS, THE DITCH SHALL BE STABILIZED WITH TEMPORARY OR PERMANENT SEEDING OR RIPRAP.
4. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

DIVERSION (INTERCEPT) DITCH

FILE: TEMPDIKE

Seeding Erosion Control	B.M.P. #15

Description and Purpose

- The planting or placing of seed mixes into soils for revegetation of a disturbed site before or after a layer of topsoil is spread over the slope
- Promotes faster revegetation of the area and increased erosion protection through development of a root and leaf structures from plant growth
- Established vegetation reduces available space for the growth of invasive species.

Applications

- Permanent measure
- Permanent seeding may be applied to exposed bare mineral soil areas which have been graded to final contours
- Permanent seeding may be applied to landscape corridors, cut slopes and road shoulders by broadcasting, furrowing or spraying on. A protective mulch & tackifier may be recommended dependant on the site conditions.
- Seeding should be applied and protected by RECP in channels where there may be erosion of soil and seed
- The establishment of vegetation by seeding methods in some areas may not be feasible due to climatic conditions or may be very slow in recovery. Seek advice from seed suppliers with northern expertise when selecting seed or other appropriate vegetation specific to the site
- Fertilizers should be avoided unless recommended specifically for the site by the seed supplier, as fertilizer tends to promote top growth over root growth. Root growth is extremely important for plant survival in the northern climates
- The seed mix should be approved by the GNWT-DOT and not include palatable grass or plant species, in order to avoid attracting larger wildlife or domestic animals. This will minimize vehicle-animal collisions. The vegetation may provide some minor habitat for wildlife after vegetation establishment
- Seed growth can be enhanced with a protective layer of topsoil, mulch or rolled erosion control product (RECP) to improve germination and growth environment

Advantages

- Enhances terrestrial and aquatic habitat with vegetation growth re-establishment and reduction of surface erosion
- Aesthetically pleasing with established vegetation cover
- Grows stronger with time as root structure develops

- Generates vegetation which enhances infiltration of runoff and transpiration of groundwater
- Seeding with a suitable mixture of grasses and herbaceous legumes in disturbed areas is an inexpensive method of stabilizing the soil, particularly if the area is flat to gently sloping and has suitable soils
- Cost of seeding disturbed areas is relatively low and its effectiveness on a long-term basis is relatively high

Limitations

- Invasive species should be avoided when choosing seed mixtures. Information about species to avoid can be located on the GNWT-ENR website
- Uncut dry grass may present a fire hazard
- Seeding of long steep slopes may be difficult without using measures such as RECP's or hydroseeding-hydromulching-tackifier methods
- Seasonal windows on planting are very short may not coincide favourably with the construction schedule
- Areas that have not been covered with seed and topsoil or a layer of organic material are susceptible to erosion until vegetation is established. Use of topsoil and mulch can supply necessary nutrients, moisture control and reduce rain drop erosion potential during germination and until vegetation is established
- Additional erosion control measures, such as RECPs, may be required for steep slopes and channels
- Reseeding may be required in areas of limited plant growth
- Time to establish root structure may be unacceptable for some high risk areas; rolled erosion control products or spreading of reserved organic fibrous mat should be considered for these areas

Construction

- Preserving fibrous mats (sod) during stripping operations may be beneficial as these mats may contain native seed. Avoid areas with invasive species when stockpiling sod.
- The site should be prepared prior to seeding. Most seed of northern species require mineral soil contact to root successfully
- Surface should be graded to design grades and then have topsoil added
- Seedbed should be 10-40 mm deep, with the top 10 mm consisting of topsoil which is free of large chunky material or stones

- Seed should be applied immediately after seedbed preparation using broadcast seed spreaders, cyclone (broadcast) spreaders, or hydroseeding to ensure uniformity of application
- Seedbed may be harrowed, raked, or chain-dragged to ensure proper seed-soil contact based on the conditions of the site
- Fertilization for plant development in northern climates is not recommended as fertilizer tends to promote top growth rather than root growth in the plants. Root growth is critical to plant survival in northern climates. Time released fertilizer, if recommended by the seed supplier, should be applied unless the site drains immediately to streams or water bodies

Construction Considerations

- Seeding rate for all mixes should be 20 kg/ha minimum or adjusted to the local rate as determined through previous project experience
- Fall rye may be added to each mix, with approval from the GNWT-DOT, to provide early growth and protection from soil erosion. Fall rye seeding rate is 5 kg/ha
- Selection of proper vegetation seed mix depends on soil conditions, climate, topography, land use, and site location
- Planting of seeds by hydroseeding and mulching techniques should be considered for slopes steeper than 3H:1V where seedbed preparation is difficult, or where application of seed, mulch, and fertilizer in one continuous operation is desirable
- Grass sod may be installed for faster results around community developments in southern locations within the NWT, however it is very costly and may be limited by ground conditions and supply. If mulch is placed as a germination medium for seeds, the mulch layer may be further protected with a biodegradable matting (jute burlap) to prevent mulch from being washed or blown away

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Freshly seeded areas should be inspected frequently to ensure growth is progressing, erosion is controlled and invasive species have not colonized the site
- Additional stormwater control measures should be considered for areas damaged by runoff erosion
- Re-seeding may be required after initial seeding to get suitable density of plants
- Cutting or mowing thin grasses will encourage the establishment and spread of the grass roots

Seeding Erosion Control	B.M.P. #15

Similar Measures

- Hydraulic seeding (hydroseeding) and mulching

Design Considerations

- Seed application rate of 20 kg/ha may be used; if fall rye is to be added, it should have an application rate of 5 kg/ha
- Bacterial inoculants should be used when seeding with legumes. This is normally applied to the seed in accordance with the supplier's recommendations before it is shipped. Fertilizer use should be limited to slow release (2 year) types and shall be carefully controlled as too much nitrogen may increase nutrient loading to receiving streams and fertilizer can promote top growth instead of root growth.
- Seeding can occur during any period when germination can be successful and plants have sufficient time to become established before the end of the growing season. Seeding should occur in spring or in fall for optimum results. Seeding conducted in the fall or on up to 0.15 m of snow will overwinter and germinate the following spring. Seeding periods will vary dependant on specific seed type and mix ratio which is developed for the site. Seed mixes, application rates, and application schedule should follow the seed suppliers recommendation for best results
- Mulch is recommended when broadcast seeding. For specific needs of local growth environment, specific design and advice from local seed supplier may be required

The GNWT Department of Transportation has adopted the following general seed mixes for use on transportation projects in the Northwest Territories. Seed mix success is dependent on the site location, soil types and ground conditions, and the care taken in application.

Government of the Northwest Territories - Department of Transportation
Grass Seed Mixtures for use on Transportation Projects

The following seed mixes are provided as a guideline by the GNWT–DOT for *"Seeding".* A qualified person must perform the vegeta tion assessment and the soil testing for fertilizer (if required) as part of the design work.

The following seed mixes are very genera l and are standard mixes and each region of the NWT would vary. A knowledgeable seed supplier should be contact ed for site specific seed mix recommendations. Seeding application rates are 20kg/ha unless otherwise specified.

Seed Mix 1 - Native Seed Mix: General Reclamation

General Reclamation Mix		% by Dry Weight
Common Name	**Latin Name**	
Slender Wheat Grass	*Agropyron trachycaulum*	25%
Violet Wheatgrass	*Agropyron violaceum*	25%
Tufted Hairgrass	*Deschampsia cespitosa*	20%
Alpine Bluegrass	*Poa alpina*	20%
Tickle Grass	*Agrostis scabra*	5%
Fowl Bluegrass	*Poa palustris*	5%

(Arctic Alpine Seed Ltd – www.aaseed.com - Custom Mix for General Reclamation, 2012)

Seed Mix 2 – Custom Native Reclamation Mix (Kakisa)

Custom Native Reclamation Mix (Kakisa)		
Common Name	**Latin Name**	**% by Dry Weight**
AEC Hillcrest Awned Slender Wheatgrass	*Agropyron trachycaulum*	42%
Violet Wheatgrass	*Agropyron violaceum*	29%
Rocky Mountain Fescue	*Festuca saximontana*	17%
Boreal Creeping Red Fescue	*Festuca Rubra var. rubra*	7%
Alpine Bluegrass	*Poa alpina*	5%

(Arctic Rim Distributors – Brett Young: Custom Native Reclamation Mix #LEL-BLND-07-001351, 2008)

Seed Mix 3 – Silt-Clay Cut Slopes

Silt-Clay Cut Slope Mix		% by Dry Weight
Common Name	**Latin Name**	
Violet Wheatgrass	Agropyron violaceum	50%
Sheep Fescue	*Festuca ovina*	40%
Northern Fescue	*Festuca saximontana*	10%

(Arctic Alpine Seed Ltd - www.aaseed.com - Silt-Clay Cut Slope Mix, 2012)

Seed Mix 4 – Sand or Gravel Cut Slopes

Sand or Gravel Cut Slope Mix		% by Dry Weight
Common Name	**Latin Name**	
Violet Wheatgrass	*Agropyron violaceum*	50%
Northern Fescue	*Festuca saximontana*	25%
Tufted Hairgrass	*Deschampsia cespitosa*	25%

(Arctic Alpine Seed Ltd – www.aaseed.com - Sand or Gravel Cut Slope Mix, 2012)

Seed Mix 5 – Sandy Soil Mix

Sandy Soil Mix		% by Dry Weight
Common Name	**Latin Name**	
Violet Wheatgrass	*Agropyron violaceum*	50%
Northern Fescue	*Festuca saximontana*	30%
Sheep Fescue	*Festuca ovina*	20%

(Arctic Alpine Seed Ltd – www.aaseed.com - Sandy Soil Mix, 2012)

Seed Mix 6 – Saline Soil Mix

Saline Soil Mix		% by Dry Weight
Common Name	**Latin Name**	
Violet Wheatgrass	*Agropyron violaceum*	40%
Northern Fescue	*Festuca saximontana*	20%
Alkaligrass	*Puccinellia nuttalliana*	10%

(Arctic Alpine Seed Ltd – www.aaseed.com - Saline Soil Mix, 2012)

Seed Mix 7– Sub Alpine Environments

Sub Alpine Environments Mix		% by Dry Weight
Common Name	**Latin Name**	
Violet Wheatgrass	*Agropyron violaceum*	50%
Tufted Hairgrass	*Deschampsia cespitosa*	25%
Northern Fescue	*Festuca saximontana*	20%
Tickle Grass	*Agrostis scabra*	5%

(Arctic Alpine Seed Ltd – www.aaseed.com - Sub Alpine Environments, 2012)

Seed Mix 8 –Alpine Environments

Alpine Environments Mix		% by Dry Weight
Common Name	**Latin Name**	
Alpine Bluegrass	*Poa alpina*	40%
Violet Wheatgrass	*Agropyron violaceum*	20%
Northern Fescue	*Festuca saximontana*	20%
Tickle Grass	*Agrostis scabra*	10%
Tufted Hairgrass	*Deschampsia cespitosa*	10%

(Arctic Alpine Seed Ltd – www.aaseed.com – Alpine Environments, 2012)

Mulching Erosion Control	B.M.P. #16

Description and Purpose

- Application of organic material or other biodegradable material as a protection layer to the soil surface (i) to minimize raindrop/runoff erosion, (ii) to conserve a desirable soil moisture property and promote seed germination and plant growth, and/or (iii) to protect permafrost from melting.
- Mulches conserve soil moisture, reduce raindrop impact, reduce runoff velocities and surface erosion, control weeds, assist to establish plant cover, provide insulative qualities re: permafrost, and protect seeds from birds and animals.

Applications

- Temporary to semi-permanent measure
- Can be used as an organic cover or growth medium for seeds where topsoil is not readily available
- Can be used to provide temporary and semi-permanent erosion control
- May be used with or without seeding in areas that are rough graded or final graded
- May be applied in conjunction with seeding to promote plant growth
- Made of organic mulches (such as straw, peat, wood chips, compost)
- Thick fibrous organic materials removed during the stripping process may be re-applied and utilized as an insulating layer to minimize permafrost melting and to protect soils from erosion due to water and wind.

Advantages

- Relatively inexpensive method of promoting plant growth and soil protection
- Natural material may be readily available if stockpiled during stripping operations.
- Vegetation or sod mats may be salvaged, stored and transplanted for use instead of or in conjunction with seeding where available
- May provide insulation for permafrost or areas with ground ice

Limitations

- Application of mulch may be difficult on steep slopes
- May require spray-on method to apply mulch with tackifier to provide adhesion to steep slopes
- Collection of vegetation for mulch material may not be available locally
- Requires storage area for materials

Installation

- Prepare soil surface by removing large rocks or other deleterious materials
- Apply topsoil and seed, if required, if topsoil is readily available
- Apply mulch as per supplier's recommendations
- Certain mulches may require additional anchoring to minimize loss of mulch due to wind or water erosion

Construction Considerations

- Consult with and install mulches as per supplier's recommendations
- Organic Mulches
  - Straw
    - Refers to stalks or stems of small grain (primarily wheat) after drying and threshing
    - Straw should be free of weed seeds
    - Loose straw is very suscept ible to removal by blowing wind and water runoff and should be anchored either with tackifier or a netting/burlap. When properly secured to surface, straw is highly suitable for promoting good grass cover quickly
  - Raw Wood Fibre
    - Mixture of cellulose fibres; a minimum of 4 mm in length extracted from wood
    - Wood fibres usually require a soil binder (tackifier) and should not be us ed as erosion control during late fall seeding unless it is used in conjunction with another suitable mulch. It is prone to removal by blowing wind or water runoff
    - Wood fibre is primarily used in hydroseeding-hydromulching-tackifier operations where it is applied as part of a slurry (a mix of fiber, seed, fertiflizer and tackifier with water); it is well suited for tacking straw mulch on steep slopes
  - Peat
    - Comprises partly decomposed mosses and organic matter under conditions of excessive moisture
    - Usually available in dried and compressed bundles
    - May be available as stockpiled material from stripping operations
    - Should be free of coarse material
    - Useful soil conditioner to improve organic content of soil promoting plant growth

- Highly susceptible to removal by blowing wind and water runoff if dry and loosely spread on top of soil

– Wood Chips

- By-products of timber processing or wood c hipping comprised of small, thin pieces of wood
- Decompose slowly
- Suitable for placing around individual plants (shrubs and trees) and for areas that will not be closely mowed
- Highly resistant to removal by blowing wind and water runoff

– Bark Chips (Shredded Bark)

- Limited by availability of wood sources
- By-products of timber processing or wood c hipping comprised of small, thin pieces of tree bark
- Suitable for areas that will not be closely mowed
- Have good moisture retention properties and are resistant to removal by blowing wind and water runoff

– Compost

- Comprised of organic residues and straw that have undergone biological decomposition until stable
- Should be well shredded, free from coarse material, and not wet
- Has good moisture retention properties and is suitable as a soil conditioner promoting plant growth
- Relatively resistant to removal by blowing wind and water runoff if not dried out completely

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Areas damaged by erosion should be protected, if necessary, and reapplied with mulch immediately.
- Additional stormwater control measures should be installed for areas of erosion damage by runoff

Mulching Sediment Control and Erosion Control	B.M.P. #16

Similar Measures

- Topsoiling
- Hydraulic seeding and mulching (hydroseeding, hydromulching)
- Rolled erosion control products (RECP)

Hydroseeding Erosion Control	B.M.P. #17a

Description and Purpose

- Hydroseeding is the spraying-on of a slurry to a slope to provide a layer of seed and growth medium
- The slurry consists of a combination of seed, mulch, tackifier, and possibly fertilizer with a colouring agent and water which are mixed together in a tank. The seed and fertilizer choice will be individually determined for the site specific conditions
- When sprayed on the soil, the slurry forms a continuous seed blanket and protects the soil from wind and water erosion and raindrop impact by binding (or adhering) the seeds in place
- The hydroseeded layer reduces soil moisture evaporation, and decreases soil surface crusting due to evaporation or drying of soil
- Enables revegetation of steep or long slopes where revegetation by any other method would be very difficult or unsafe; re-seeding and special mix design may be required. Slopes with bedrock outcrop or large gravel are not generally favourable for hydroseeding

Applications

- Temporary or Permanent measure
- Slurry is held in suspension through constant agitation and is sprayed onto disturbed areas by hose using high pressure pumps mounted on trucks. Coloring of the slurry is used to determine coverage and density
- Can be used for spray-on seeding covering large areas efficiently after placement of topsoil or organic material
- Can be used to provide temporary and permanent surface erosion control prior to establishment of permanent native vegetation
- May be used to provide soil stabilization for seeding disturbed soil areas
- Can be used with higher efficiency and cover large areas with advantages over conventional methods (broadcast seeders)
- Can be used in areas where little topsoil is available

Limitations

- Site must be accessible to hydroseeding equipment
  - Tanks and pumps mounted on trucks which use roads or flat areas
  - Maximum hose and spray range of approximately 30 m to 50m

- May require subsequent spraying to reseed bare spots or cover areas with low growth
- Requires significant amount of a local water source

Construction

- Prepare soil surface by removing large rocks or other deleterious materials
- Apply topsoil or organic materials if available
- Apply hydroseed-mulch as per supplier's recommendations

Construction Considerations

- Seed
  - Seed selection should be made in accordance with Government of the Northwest Territories (GNWT) approved seed mixes for ecological zones
  - GNWT – Department of Transportation has approved seed mixes, specific to supplier recommendations, for transportation construction projects depending on site location (see BMP #22 Seeding)
  - Seed mixes have been developed based on historic performance results on other northern Canadian sites

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Areas damaged by runoff may need to be repaired and/or protected from further erosion before hydroseeding
- Site may need to be reseeded to achieve required densities

Similar Measures

- Seeding
- Mulching
- Rolled Erosion Control Products (RECP)

Hydromulching Erosion Control	B.M.P. #17b

Description and Purpose

- The spraying-on of a slurry to a slope to provide a layer of growing medium
- Seed must be in contact with mineral soils to take root. Th is consideration is especially important for successful revegetation in northern areas.
- The slurry consists of seed, m ulch and may contain time released fertilizer, and water which are mixed together in a tank. Tackifiers (natural or synthetic material used to stick fibers together (e.g. cornstarch)) may be added dependent upon site conditions and location
- The slurry reduces soil moisture evaporation, reduces raindrop erosion and decreases soil surface crusting due to evaporation or drying of soil

Applications

- Temporary or Permanent measure
- Can be used in areas where little topsoil is available
- Used where soil amendments (fertilizer or fibers) may be required
- Usually used in conjunction with hydroseeding

Advantages

- Relatively efficient spraying method of promoting plant growth as well as applying erosion protection
- Allows spray-on seed application on steep slopes where conventional re-vegetation methods are very difficult
- Minimizes effort required to re-vegetate disturbed areas as hydromulching usually only requires one spray-on application in comparison with hand seeding methods
- Relatively efficient operation for high coverage rates
- Provides protection from wind erosion when tackifiers are added

Limitations

- Site must be accessible by hydromulching equipment
  - Usually mounted on trucks
  - Maximum hose range of approximately 30 m to 50 m
  - Requires significant supply of local water

Construction

- Prepare soil surface by removing large rocks or other deleterious materials
- Apply topsoil if available
- Spray on hydromulch as per supplier's recommendations

Construction Considerations

- Hydraulic Mulches
  - Cellulose
    - Comprised of recycled paper from newspapers, magazines, or other paper sources
    - Rapid method for applying seed, fertilizer, mulch, and water in almost any disturbed area
    - Usually installed without tackifier in slurry
    - Short fibre lengths and lack of tackifier limits water erosion control effectiveness and does little to control moisture content and temperature within the soil
    - Residual inks within the recycled paper may leach into soil, potential problem on environmentally sensitive areas
    - Longevity significantly shorter than for wood fibre mulches or bonded fibre matrices (BFM)
    - Cheaper than wood fibre mulches and bonded fibre matrices (BFM)
  - Wood Fibre
    - Comprised of whole wood chips
    - Industry standard, provides quick and uniform method and medium for re-vegetating large areas quickly and economically
    - Longer fibre lengths than for cellulose mulches
    - Longer lasting and has better wet-dry characteristics than cellulose mulches
    - Provides limited erosion control even when sprayed on with tackifiers
    - Provides limited control of soil moisture content and temperature when applied at higher rates
    - Less expensive than BFM, however, less effective than BFM
    - More expensive than cellulose mulches, however, more effective than cellulose mulches

- Bonded Fibre Matrices (BFM)
  - Slurry comprised of either cellulose mulch, wood fibre mulch, or a combination of the two
  - Mulches are bound together using chemical bond, mechanical bond, or a combination of the two
  - All fibres and binding agents are premixed by manufacturer, ensuring uniformity and consistency throughout the application
  - Well suited for sites with existing desirable vegetation and where worker safety and minimal ground disturbance are desired
  - Degree of protection similar to that obtained from rolled erosion control products (RECP)
  - Quicker installation/application than for RECP
  - Chemically bonded BFM may require a ‘set-up’ or curing/drying period
    - Application must be limited to periods where there is no threat of rain during curing period
    - Mechanically bonded BFM have no curing time and are effective immediately after application
  - Application on dry soils is not recommended
  - More expensive than cellulose and wood fibre mulches
  - More effective than cellulose or wood fibre mulches

- Tackifiers
  - May include chemical or other substances mixed with water
  - Natural component tackifiers (cornstarch based) are available

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Areas damaged by runoff may need to be repaired and/or protected from further erosion.

Similar Measures

- Seeding
- Mulching
- Rolled Erosion Control Products (RECP)

Topsoiling Erosion Control	B.M.P. #18

Description and Purpose

- The covering of exposed mineral soils with soils of high organic content to minimize raindrop erosion potential
- May be used to provide some thermal insulation for underlying permafrost
- Provides a medium for vegetation to grow

Applications

- Usually a Permanent measure
- May be used to provide bedding medium for seed germination and a cover and nutrients to exposed nutrient poor soil that is not suitable for vegetation growth. Seed within northern climates requires mineral soil contact to root efficiently. This should be considered during application of topsoil and seed may need to be applied first in some areas
- May be used on slopes with a maximum gradient of 2H:1V
- Normally topsoil is placed prior to seeding, mulching, hydroseeding-hydromulching, and installing rolled erosion control products (RECP), or planting of trees/shrubs

Advantages

- Placing topsoil provides organic medium for vegetation, and promotes root structure growth
- Topsoil organic content provides nutrients to promote plant growth
- Absorbs raindrop energy to reduce erosion
- May provide some thermal insulation for permafrost

Limitations

- Not appropriate for slopes steeper than 2H:1V
- Placing and grading topsoil can be time consuming and expensive
- Long steep slopes may not be accessible for topsoil spreading
- Dry topsoil may be eroded by blowing wind, sheet flow or concentrated flows
- Topsoil may not be readily available in some areas

Construction

- Prepare ground surface to final grade by removing large rocks or other deleterious materials

- Apply topsoil with a bulldozer or light track equipment to design thickness
- Track walk upslope or downslope (do not overcompact topsoil by heavy equipment; only track walk one pass) to provide a contour of roughness of topsoil to further minimize erosion

Construction Considerations

- Topsoil should be free of weeds which may inhibit re-vegetation of desirable plants (i.e., grass and native species)
- Subgrade should be roughened (by track walking up/down the slope prior to topsoiling) to promote adherence of topsoil to subgrade. Topsoil should be moistened regularly prior to vegetation establishment during periods of hot dry weather to minimize wind erosion
  - Hydroseeding-hydromulching with tackifier application will minimize wind erosion of topsoil

Design Considerations

- Perform pre and post disturbance survey
- Consider use of a soil amendments (fiber and fertilizer additives) in areas with little topsoil or topsoil with poor growth nutrients
- Perform a pre-construction topsoil assessment to determine topsoil thickness hence design thickness

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Areas damaged by erosion (rilling or gulleying) should be regraded and topsoiled immediately. Erosion controls should be added such as sediment fencing, wattles and/or RECPs

Similar Measures

- Hydroseeding-Hydromulching
- Mulching
- Rolled Erosion Control Products (RECP)

Soil and Root Mat Transplanting (Sodding) Erosion Control	B.M.P. #19

Description and Purpose

- Use of mats of retained sod or organic material with roots to cover and stabilize disturbed areas of bare mineral or organic soil.
- Sod and root mats are retained natural topsoil or organic layers with the original roots and rhizomes from deciduous brush and herbaceous plants.
- May be considered in regions where natural soil and root mats are substantial and free of invasive species.
- Rapidly establishes a vegetative cover in environmentally sensitive areas where complete cover of the disturbed mineral soil surface is essential and conventional or hydroseeding and mulching may not be effective for erosion protection in high risk areas.
- Acts as a vegetation buffer for filtering sediment from runoff.
- May be used as a protective layer for permafrost areas

Applications

- Permanent measure.
- May be used to protect soil surface from water and wind erosion or thawing.
- Best used for low gradient areas that require immediate protection, or at locations where aesthetic appearance is a priority.

Advantages

- Immediate protection for sensitive areas from water and wind erosion.
- Aesthetically pleasing.
- May provide protective insulating material for permafrost or ground icing areas.

Limitations

- Expensive due to time required for removing, storing and replacing the soil and root mat.
- Labour and equipment intensive to remove and replace.
- Soil and root mat may not be readily available.
- Soil and root mat cannot be stored on-site for long periods of time.
- Stored material may need sufficient space, to be protected from invasive seed and may require watering to maintain moisture content

Soil and Root Mat Transplanting (Sodding) Erosion Control	B.M.P. #19

Construction

- During stripping operations of roads and right-of-ways, cut out soil and root mat sections horizontally by hand or with machine bucket. Retain the soil and root mats as squares or strips. Reserve these in shaded, moist locations where cool, moist conditions will be maintained. May be laid on geogrid or jute blanket to allow retrieval, replacement into new area and continued root growth.
- Prepare the surface by removing large rocks or other deleterious materials and lightly scarifying the surface.
- Replace soil and root mats onto the surface to be rehabilitated.
  - Lay reserved soil and root mats on the prepared surface with long axis parallel to direction of slope (up/down). Butt-joint ends and sides of adjacent strips tightly together to reduce water loss.
  - Anchor each soil and root mat to ensure continuous contact between topsoil and underside of sod strip using stakes(wooden stakes are cheap and are natural)
  - Secure each soil and root mat with a wood stake or metal pin anchor embedded a minimum of 0.15 m into underlying mineral soil and spaced a maximum distance of 0.6 m apart.
- Adjacent rows of soil and root mat strips should have staggered joints.

Construction Considerations

- Soil and root mats may be placed on frozen ground.
- Underlying surface should be cool and wet prior to placing soil and root mat strips.
- Successful installation requires the use of freshly cut, moist and undamaged soil and root mat. Mats should be stored for as short a time as possible before replacing onto the new surface.
- Mats should be watered after installation to encourage plant root development.

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans.
  - Areas damaged by erosion (rilling or gulleying) should be regraded and root mat installed immediately, where mat is available.
- Additional erosion control measures should be considered for eroded areas.
- Small bare spots may need to have small mats reapplied.

Soil and Root Mat Transplanting (Sodding) Erosion Control	B.M.P. #19

Similar Measures

- Mulching
- Hydroseeding
- Hydromulching
- Rolled Erosion Control Products (RECP)

Live Staking Streambank Stabilization Technique	B.M.P. #20a

Description and Purpose

- Consists of installing woody plant cuttings (trees and shrubs) before leafing out, to develop a root matrix within the soil, increasing subsurface soil strength and stabilizing slopes with deeper root systems than grasses
- Reduces erosion potential of slopes and channel banks by providing leaf cover to minimize raindrop erosion and by binding the soil by root growth

Applications

- Permanent measure
- May be used on slopes stable enough to support vegetation; however, there is a low success rate for steep slopes and channel banks with gradients greater than 1H:1V
- May be used on slopes and channel banks with adequate sunlight, moisture, and wind protection to support vegetation
- May be used as bio-technical erosion control (bioengineering) for stabilization in cases where there has been historical shallow slope instability, and soil movement on eroded slopes and gullies
- May be used along channels to provide higher channel roughness to reduce flow velocity and in permanent sedimentation ponds to provide longer cycling time and higher sedimentation during impoundment

Advantages

- Promotes development of organic mat
- Dense leaves and large diameter plant stalks increase slope or channel roughness and reduces flow velocities thus decreasing erosion potential
- May use and promote local species
- Traps sediment and stabilizes soil
- Aesthetically pleasing once developed
- Grows stronger with time as branching occurs and root structure develops
- Has deeper root penetration than grass providing a greater depth of stabilization
- Manual planting may be attempted on steep slopes that are sensitive to machinery disturbance or represent an area of high erosion potential

Live Staking Streambank Stabilization Technique	B.M.P. #20a

Limitations

- Can be labour intensive to install
- Some level of uncertainty as success of plant growth dependent on various unpredictable site parameters (i.e., moisture, soil, terrain, weather, seeding and growing conditions, etc.)
- Re-vegetated areas are susceptible to erosion until vegetation develops. Live staking should be used in conjunction with hydroseeding and/or hydromulching or application of topsoil and seed and/or root mats
- Plants may be damaged by wildlife (mild browsing may promote increase root growth and branching)
- Potential for low success rate
- Few precedents as this measure is generally not used on GNWT-DOT construction projects

Construction

- Used on cut or fill slopes in ditches/channels
- Normally comprised of willow or poplar stakes, cut before leafing out, inserted into the ground; other indigenous plants may be acceptable
- Individual dormant willow or poplar stakes should be cut to a minimum length of 0.5 m and minimal diameter of 0.02 m using pruning shears
  - Cuts should be made at a 45° angle a minimum of 0.05 m (5 cm) below a leaf bud on the bottom and at 90° angle (flat) on the top
  - All side shoots should be trimmed to within 0.05 m of the main stem
- Install live stakes in a 1 m by 1 m or smaller grid Make a pilot hole a minimum of two-thirds of the stake length to insert live stake into
  - Use iron bar (e.g. rebar) or other tool to make pilot hole
- Insert live stake into pilot hole and lightly tamp the soil around live stake to provide soil contact with the stake for successful root growth
- A minimum of three leaf buds should remain above grade and should facing in the upright direction

Construction Considerations

- Successful installation requires the use of freshly cut branches or stakes, gathered while dormant

- Storage time of cut branches/stakes on site prior to installation should be kept to as short a time period as possible
- Stakes should be soaked 4 - 10 days prior to planting

▪ Successful growth is dependent on soil contact, moisture and rainfall conditions

▪ Consultation with an agrologist, greenhouse growers, and other local expertise can be beneficial in selecting and procuring appropriate species for planting

Inspection and Maintenance

▪ Inspection frequency should be in accordance with the PESC and TESC Plans

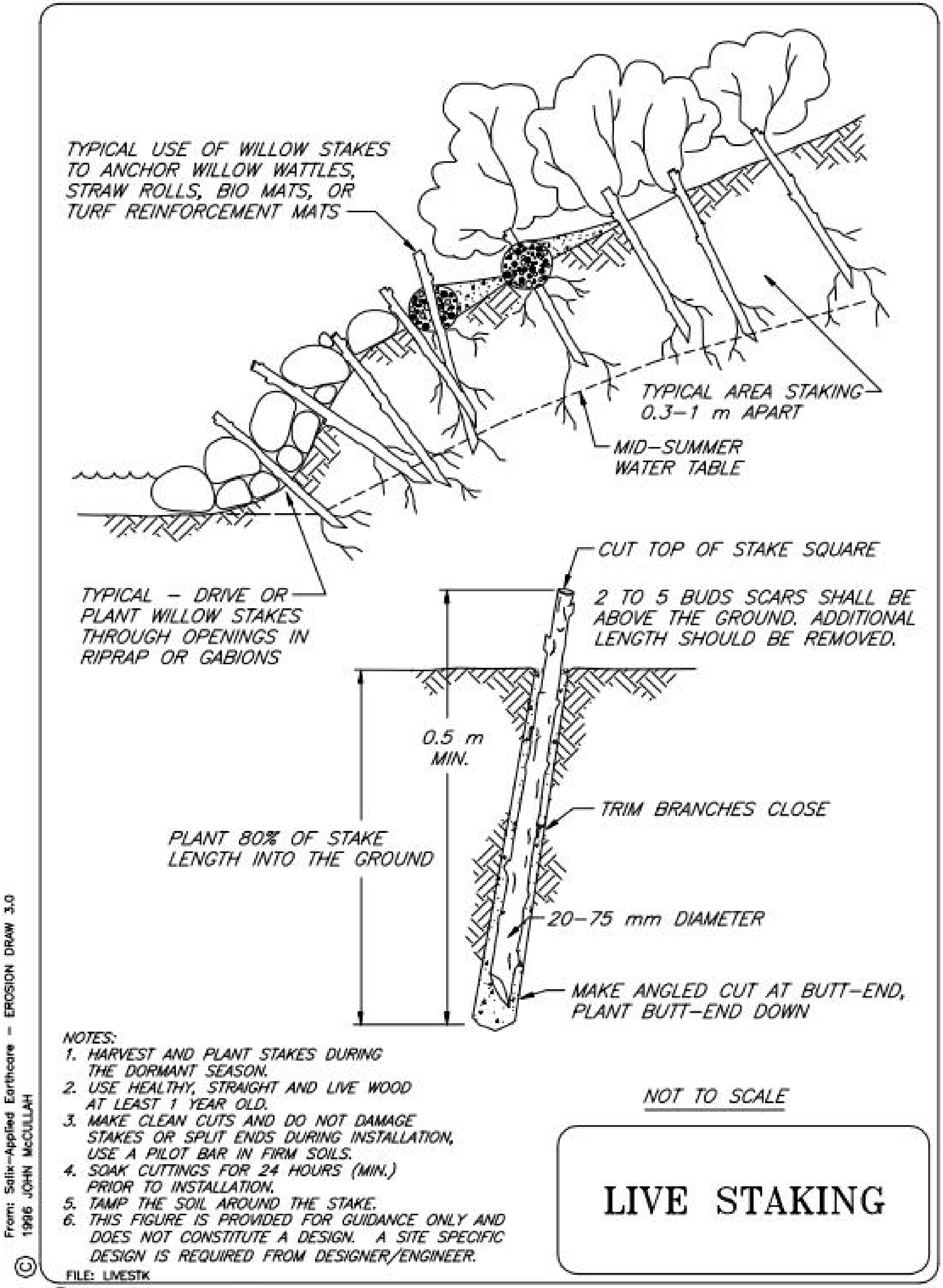
- Areas damaged by washout or erosion rilling should be replanted immediately

▪ Additional stormwater control measures should be considered for severe ril ling areas damaged by runoff

▪ Watering plants may be required for the initial one to two months after planting

Similar Measures

▪ Seeding
▪ Mulching
▪ Soil and Root Mat Replacement (Sodding)
▪ Hydroseeding
▪ Hydromulching
▪ Rolled erosion control products (RECP)
▪ Brush layering


TYPICAL USE OF WILLOW STAKES TO ANCHOR WILLOW WATTLES, STRAW ROLLS, BIO MATS, OR TURF REINFORCEMENT MATS
TYPICAL AREA STAKING 0.3–1 m APART
MID–SUMMER WATER TABLE
TYPICAL – DRIVE OR PLANT WILLOW STAKES THROUGH OPENINGS IN RIPRAP OR GABIONS
CUT TOP OF STAKE SQUARE
2 TO 5 BUDS SCARS SHALL BE ABOVE THE GROUND. ADDITIONAL LENGTH SHOULD BE REMOVED.
0.5 m MIN.
TRIM BRANCHES CLOSE
PLANT 80% OF STAKE LENGTH INTO THE GROUND
20–75 mm DIAMETER
MAKE ANGLED CUT AT BUTT–END, PLANT BUTT–END DOWN
NOTES:
1. HARVEST AND PLANT STAKES DURING THE DORMANT SEASON.
2. USE HEALTHY, STRAIGHT AND LIVE WOOD AT LEAST 1 YEAR OLD.
3. MAKE CLEAN CUTS AND DO NOT DAMAGE STAKES OR SPLIT ENDS DURING INSTALLATION, USE A PILOT BAR IN FIRM SOILS.
4. SOAK CUTTINGS FOR 24 HOURS (MIN.) PRIOR TO INSTALLATION.
5. TAMP THE SOIL AROUND THE STAKE.
6. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.
NOT TO SCALE
LIVE STAKING
FILE: LIVESTK
From: Salix–Applied Earthcare – EROSION DRAW 3.0
© 1996 JOHN McCULLAH

Brush Layering Streambank Stabilization Techniques	B.M.P. #20b

Description and Purpose

- Consists of installing woody plant cuttings (trees and shrubs) while dormant to develop a root matrix within the soil, increasing subsurface soil strength and stabilizing slopes with deeper root systems than grasses
- Reduces erosion potential of slopes once established

Applications

- Permanent measure
- May be used on slopes stable enough to support vegetation; however, there is a low success rate for steep slopes with gradients greater than 1H:2V
- May be used on slopes with adequate sunlight, moisture, soils and wind protection to support vegetation
- May be used as bio-technical erosion control (bioengineering) for stabilization of historical shallow slope instability soil movements or eroded slopes and gullies
- May be used to reduce flow velocity and in sedimentation ponds to provide higher duration of impoundment to promote sedimentation
- Particularly appropriate for embankments that encroach upon riparian areas or floodways
- Slopes that need additional geotechnical and erosion reinforcement are good candidates for brush layering
- Steeper slopes require the use of inert reinforcements such as geotextiles (ECBs, TRMs, coir netting), wire (twisted or welded gabion wire) or geogrids
- If either steady, long term seepage or temporary bank return flows after flood events are a problem, the brush layers act as a horizontal drainage layer or conduits that relieve internal pore water pressure

Advantages

- Promotes development of root mat and accumulation of organic material
- Dense leaves and large diameter plant stalks increase bank roughness and reduce flow velocities on the slope thus decreasing erosion potential
- Traps sediment and stabilizes soil
- Aesthetically pleasing once established
- Grows stronger with time as root structure develops

- Usually has deeper root penetration than grass and provides greater depth of stabilization
- Manual planting may be attempted on steep slopes that are sensitive to machinery disturbance or represent an area of high erosion potential
- Of all vegetative biotechnical techniques, brush layering has the greatest capacity for becoming successfully established, even in severe sites
- The use of synthetic geotextiles or geogrids provides long-term durability and greater security, especially if woody and herbaceous vegetation is established
- Can be used with other toe protection such as, rootwads, coir rolls, and log toes (willow or other logs embedded along waterline). Combining live brush layering with log toes is an effective and relatively low cost technique for re-vegetating and stabilizing streambanks
- Provide immediate soil stability and habitat
- Brush layers and the pioneer vegetation that develops from them allow the establishment of a stable soil-root complex
- Both living and non-living brush layers along streambanks enhance fish habitat, while slowing velocities and erosion along the bank during natural and flood period flows
- Provides a flexible strengthening system to fill slopes. A bank can sag or distort without pulling apart the brush layers
- Acts as horizontal drains and favourably modify the soil water flow regime

Limitations

- Can be labour intensive to install
- Require large source area of suitable plant material, where removal of logs, branches or root wads will not damage the source stand
- Some level of uncertainty as to the success of plant growth is dependent on various unknown site parameters (i.e., moisture, soil, terrain, weather, seeding conditions, etc.)
- Plants may be damaged by wildlife
- Potential for low success rate
- Few precedents as this measure in the NWT as it is generally not used on the GNWT-DOT construction projects
- Brush layers are vulnerable to failure before rooting occurs, and they are not effective at counteracting failure along very deep-seated failure planes

Construction

- First construct any lower bank or in- stream stabilizing measures such as a rock or log toe structure
- Excavate the first horizontal bench, sloping back into the slope at about 10% grade
- Install any drainage required along the back of each bench
- Place branches that are at least 1.8 m long on the bench
- Branches should crisscross at random with regard to size and age
- Place 20 branches per linear meter on the bench, with the butts of the branches along the inside edge of the bench
- About 0.20 to 0.45 m of the growing tip should protrude beyond the face of the slope
- Cover and compact (add water if necessary) the brush layer with 0.15 m lifts of soil to reach the designed vertical spacing, typically 0.5 m to 1.2 m apart
- Slope the top of each fill bench back into the slope
- Construct another brush layer above as necessary
- When placed, the protruding tips of the cuttings are above the butts due to the back slope of the bench
- Proceed up the bank as desired
- The erosion and failure potential of the slope (i.e., drainage, soil type, rainfall, and length and steepness of the slope) determine spacing between the brush layers
- On long slopes, brush layer spacing should be closer at the bottom and spacing may increase near the top of the slope

Construction Considerations

- Successful installation requires the use of freshly cut branches or stakes
  - Storage time of cut branches/stakes on site prior to installation should be kept to as short a time period as possible
  - Branches/stakes should be soaked for 4 - 10 days prior to planting
- Successful growth dependant on soil moisture and rainfall conditions
- Consultation with agrologist, greenhouse growers, local expertise can be beneficial in selecting and procuring appropriate species for planting

- Should be installed during soil fill operations which result in the branches being inserted deeply into the slopes and thereby increasing the likelihood that the branches will encounter optimum soil and moisture conditions
- Live cuttings are most effective when implemented during the dormancy period (between leaf fall and bud break) of chosen plant species
- Live willow branches (or cuttings of other adventitiously-rooting (naturallyrooting) species) at least 1.8 m long, with a minimum diameter of 0.02 m
- Heavy equipment, such as a bucket loader and/or backhoe or excavator is usually employed for the construction of embankments
- Water should be available for achieving optimum soil moisture

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Inspect planted areas at least twice per year or after significant storm events (1:2 year storm and/or 40 mm rainfall in 24 hours) for growth and signs of erosion
  - Areas damaged by washout or erosion rilling should be replanted immediately
- Additional stormwater control measures should be considered for areas damaged by erosion
- Watering plants may be required for first one to two months after planting during a dry summer
- The live cuttings or branches near the stream waterline should establish successfully without irrigation requirements given the proximity to water
- Inspect the cuttings for adequate vegetative establishment (as evidenced by root and shoot production from the imbedded stems) and for signs of localized erosion such as rilling from runoff or sloughing from stream scour
- Brush layered streambanks should be inspected for localized slope movements or slumps
- Localized slope failures and/or areas of poor vegetative establishment can often be repaired by re-installing the brush layers in these zones
- The site should be examined for possible signs of erosion which outflanks the treated area (goes around or at either end), which must be addressed with additional protective measures should the flanking erosion threaten the integrity and effectiveness of the protective brush layer fill

- If frozen soil is used in constructing the soil lifts between brush layers, some settlement or slumping may occur when the soil thaws. This settlement may falsely signal a slope failure
- The most likely causes of failure are the following:
  - Inadequate reinforcement from the brush layer inclusions, i.e., too large a vertical spacing or lift thickness for the given soil and site conditions, slope height, slope angle, and soil shear strength properties
  - Inadequate tensile resistance (ability to withstand tearing) in the brush layers as a result of too small an average stem diameter and/or too few stems per unit width
  - Failure to properly consider seepage conditions and install adequate drainage measures, e.g., chimney drain, behind the brush layer fill can result in poor growth.
  - Lack of moisture applied during installation and initial plant growth, and inadequate attention to construction procedures and details, can also result in poor growth

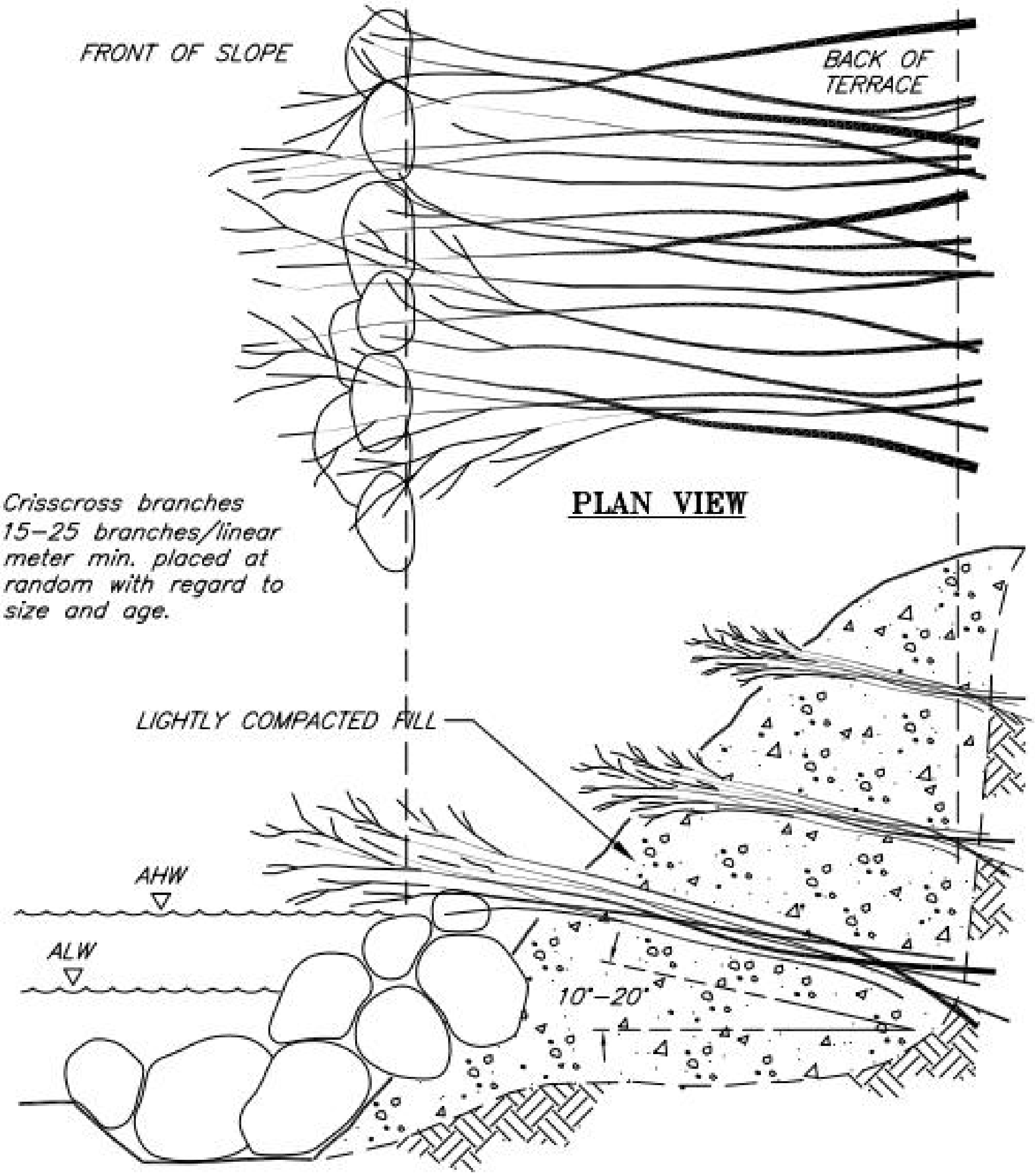
Design Considerations

- Live branches and brush cuttings, cut while dormant, are used to make brush layers
- Up to 30% of the brush may be non-rooting species that provide immediate strength to the soil mass, but will then rot away, providing organic material
- Plant material harvesting and installation should be performed during its dormant season (late fall to early spring) or in other seasons if soil moisture is available
- The ideal plant materials for brush layers are those that:
  - root easily
  - are long, straight and flexible
  - are in plentiful supply near the job site
- Willow makes ideal brush layer material, and some species of *Cornus* (Dogwood), and *Populus* (Poplar) also have very good rooting ability
- All cuttings should be soaked for a minimum of 4 - 10 days, whether they are stored or harvested and immediately installed
- Brush layer reinforced fills must have adequate internal stability. This means that the tensile inclusions, i.e., the brush layers, should have a sufficient unit tensile resistance and/or be placed in sufficient numbers to resist breaking in tension

- The inclusions must also be sufficiently long and provide enough stem "friction" to resist failure by pullout
- Allowable velocity for brush layering is 3.7 m/s and allowable shear stress is 19 to 300 N/m^2 or less depending on how long the brush layers have had to establish
- Schiechtl & Stern (1996) suggest an allowable shear stress of 140 N/m^2

Similar Measures

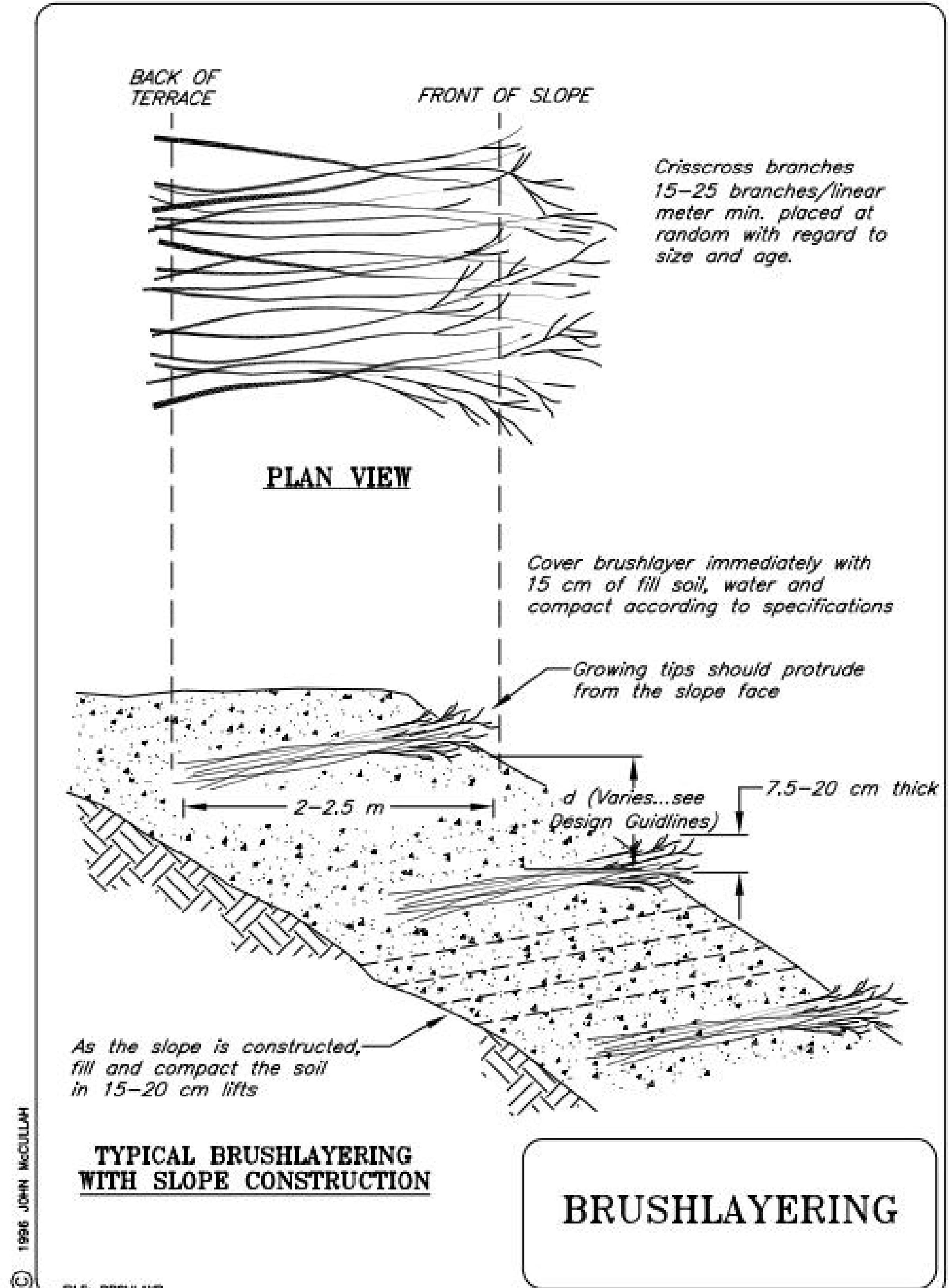
- Seeding
- Mulching
- Hydroseeding
- Hydromulching
- Rolled Erosion Control Products (RECP)
- Live Staking

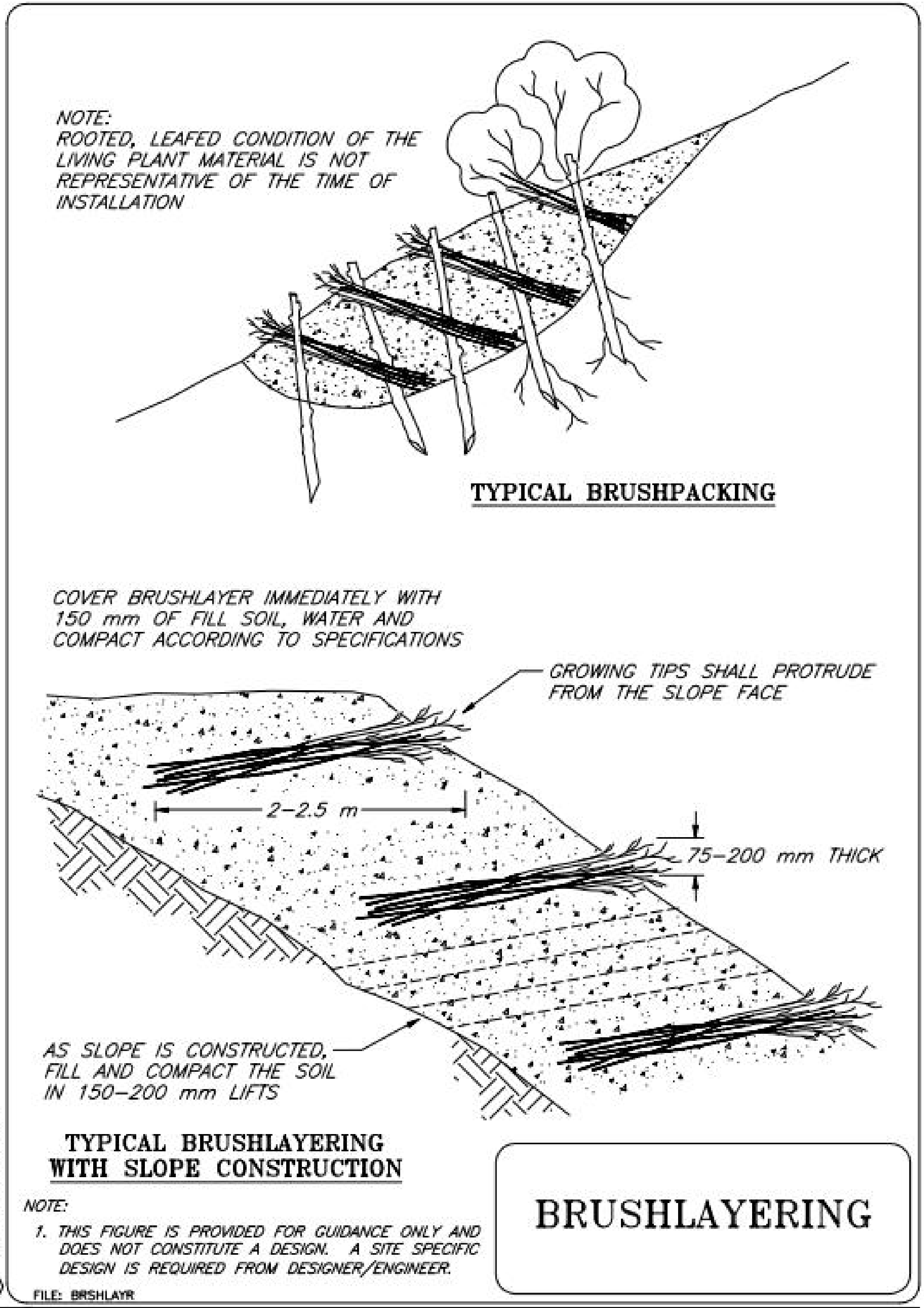


NOTES:
1. Tilt branches down into the slope 10°–20° min.
2. Brushlayering may be constructed with non–compacted or compacted backfill without damage to the brush layer.
3. Branches irrespective of length, should protrude 20–45 cm beyond the face of the slope.

BRUSHLAYERING WITH ROCK TOE PROTECTION

FILE: BRLAY–RT


BACK OF TERRACE
FRONT OF SLOPE
Crisscross branches 15–25 branches/linear meter min. placed at random with regard to size and age.
PLAN VIEW
Cover brushlayer immediately with 15 cm of fill soil, water and compact according to specifications
Growing tips should protrude from the slope face
2–2.5 m
d (Varies...see Design Guidlines)
7.5–20 cm thick
As the slope is constructed, fill and compact the soil in 15–20 cm lifts
TYPICAL BRUSHLAYERING WITH SLOPE CONSTRUCTION
© 1996 JOHN McCULLAH
FILE: BRSHLAYR
BRUSHLAYERING


NOTE:
ROOTED, LEAFED CONDITION OF THE LIVING PLANT MATERIAL IS NOT REPRESENTATIVE OF THE TIME OF INSTALLATION
TYPICAL BRUSHPACKING
COVER BRUSHLAYER IMMEDIATELY WITH 150 mm OF FILL SOIL, WATER AND COMPACT ACCORDING TO SPECIFICATIONS
GROWING TIPS SHALL PROTRUDE FROM THE SLOPE FACE
2–2.5 m
75–200 mm THICK
AS SLOPE IS CONSTRUCTED, FILL AND COMPACT THE SOIL IN 150–200 mm LIFTS
TYPICAL BRUSHLAYERING WITH SLOPE CONSTRUCTION
NOTE:
1. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.
FILE: BRSHLAYR
BRUSHLAYERING

Riparian Zone Preservation Sediment Control and Erosion Control	B.M.P. #21

Description and Purpose

- Protection of existing plants and trees adjacent to all natural water bodies (riparian zones) adjacent to and downslope of construction areas
- Existing vegetation acts as an effect ive vegetative buffer strip as an erosion and sediment control measure

Applications

- Permanent measure
- Existing established vegetation acts as an effective sediment control and erosion control buffer strip to slow runoff flows and allow sediment deposition and the organic matter provides filtration
- May be used along site boundaries to minimize sediment transport off of construction sites despite lack of adjacent watercourses

Advantages

- Existing dense vegetation is more effective than any man-made structures or other methods for erosion or sediment control, however, other forms of sediment and erosion control may be required on construction sites in addition to preserved vegetation zones
- Any vegetation removal along steep valley slopes with highly erodible soil will be detrimental and will contribute to long-term sediment yield; it is important to minimize stripping and strip only the necessary areas within the construction footprint. Preservation of the riparian zone is important to stability (erosion) and sediment control along river valley slopes and along the edges of waterbodies

Limitations

- Preservation of riparian zones may interfere with construction efficiency and access
- Careful planning is required to work around preserved riparian zones
- Too much sediment laden water introduced into one area may cause damage to the vegetation through erosion or through deposits of sediment causing smothering

Construction

- It is highly important to preserve an established vegetative buffer as freshly planted vegetation generally requires substantial growth periods before they are as effective as established riparian vegetation

- Wherever possible, retain as much existing vegetation as possible between construction areas and sensitive zones (wetlands, marshes, streams, floodplains, permafrost areas, etc.) to entrap sediment and to minimize sediment transport off of the construction site into the sensitive zones
- Define and delineate those riparian zones to be preserved in the Environmental Management Plan (EM Plan) prior to commencement of construction
- Clearly mark (e.g., easily seen by equipment operators) those riparian zones to be preserved in the field (with construction fencing, survey flagging, spray paint or other highly visible measures) so all construction personnel can immediately identify those areas to be preserved

Construction Considerations

- Riparian zone reserves must be clearly marked prior to start of construction work to minimize trespassing and to ensure the integrity of the reserved riparian zone is maintained
- Do not allow equipment to enter areas not necessary for construction purposes
- Based on site-specific situations, established buffer zones of adequate width may be used to protect these areas

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Maintain fences or other marking for protecting reserved riparian zones from trespass by equipment or other operations (e.g., hand falling operations)

Crushed Rock Buttress on Cut Slope in Permafrost Erosion Control	B.M.P. #22

Description and Purpose

- This BMP utilizes concepts, suggested designs and construction recommendations from Vinson and McHattie (2009) which should be consulted.

Applications

- In ground ice-rich soil conditions, highway cut slopes should be minimized through road alignment design and grade adaptations.
- Where cuts in ground ice-rich soil will not naturally stabilize through build-up of toe debris, a buttress of crushed rock or coarse aggregate may be placed against the cut slope.
- A buttress may be considered for road cut slopes exceeding 3 m high if engineering, drainage, slope stability, thermal protection and other requirements are met.
- The buttress may be 2.5 m or greater in thickness to facilitate construction by machinery and provide the necessary thermal protection.

Advantages

- The cut slope can be rapidly prepared and buttressed to provide support and ensure continued thermal insulation.
- Local rock and aggregate materials can be used, if crushing facilities are available.
- When ground ice melting occurs, the wetted soils will be held by the buttress and drainage can occur, to increase overall soil stability.

Limitations

- Obtaining sufficient crushed rock or coarse aggregate for the buttress may be difficult in permafrost areas.
- The buttress will require maintenance and replacement of failed buttress material.

Construction

- The design of a crushed rock buttress for cut slopes in ground ice-rich permafrost should be completed by a geotechnical engineer familiar with permafrost conditions.
- As continued thermal protection of the ground ice-rich permafrost is required during summer construction season, all personnel, machinery, geotextile, crushed rock

and other items must be available at site, to allow rapid construction and re-instatement of thermal protection. All construction procedures should be determined and discussed in advance with construction personnel.

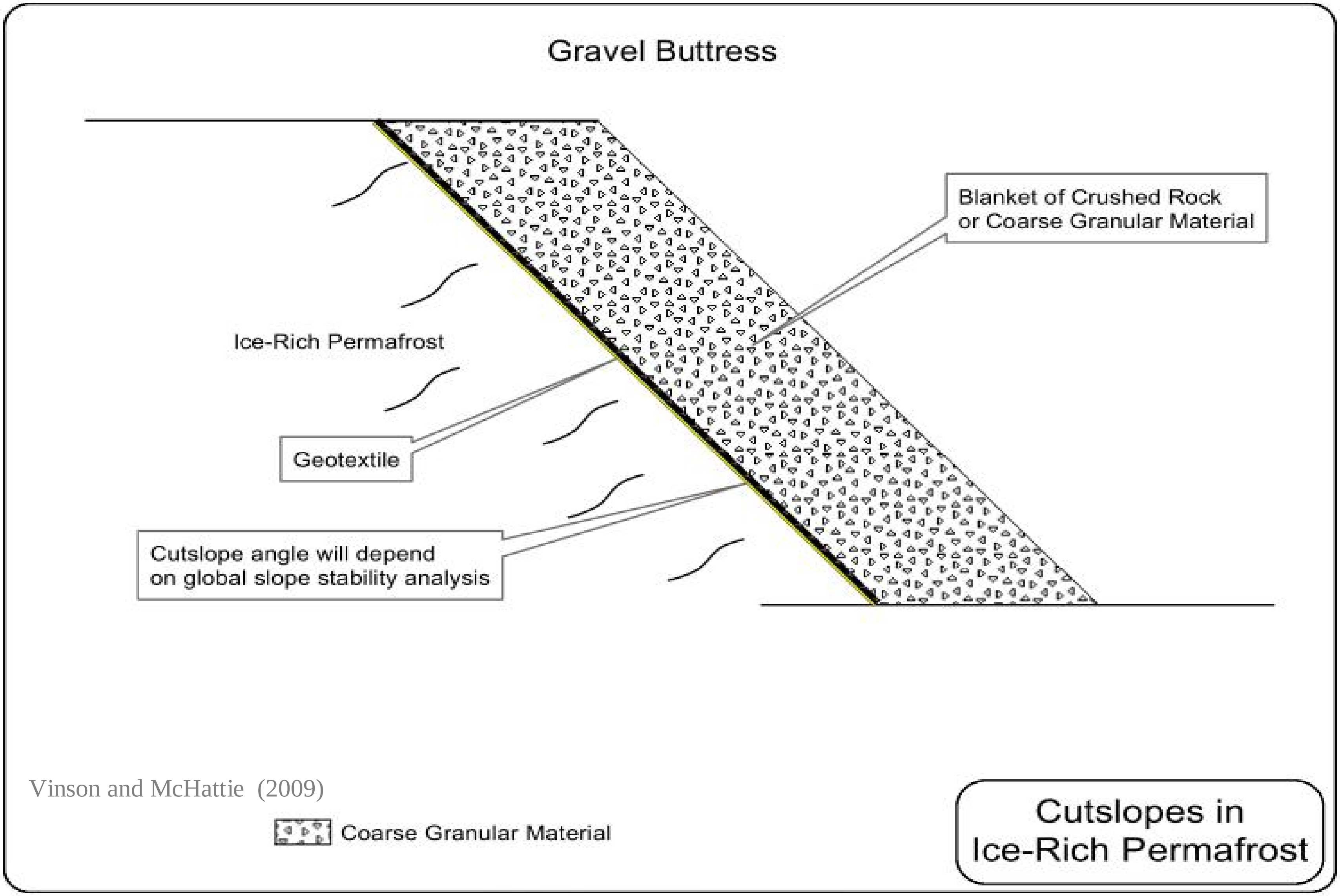
- The crushed rock should be of light colour to minimize sunlight adsorption and heating which would be detrimental to permafrost preservation.
- The cut slope should be prepared with the strategy of minimizing the volume and extent of disturbance.
- Any stripped organic or topsoil material should be retained and stockpiled for use in covering exposed sub soil in the cut slope area.
- The cut slope should not be greater than 1H:2V slope and must be designed according to global slope stability requirements and thermal preservation considerations.
- Geotextile sheeting should be placed tight over the cut slope and staked or pinned, to allow installation of the crushed rock buttress and prevent intrusion of fines into the free draining crushed rock material.
- If the natural angle of repose is greater than the buttress angle, then the crushed rock material may not require mechanical compaction and will naturally consolidate in place.

Construction Considerations

- If cold air transfer is required into the rock buttress, the crushed rock material gradation and pore space characteristics should be designed and specified for construction.
- Ramps may be required for construction machinery access at the buttress site.
- Site conditions and availability of equipment will determine if standard design features and construction techniques can be used for the buttress.

Inspection and Maintenance

- The buttress and cut slope will require periodic inspection after snow melt and major rain storms.
- Where crushed rock has been lost from the buttress due to ground ice melting, it should be replaced with similar material.


Gravel Buttress
Blanket of Crushed Rock
or Coarse Granular Material
Ice-Rich Permafrost
Geotextile
Cutslope angle will depend
on global slope stability analysis
Vinson and McHattie (2009)
Coarse Granular Material
Cutslopes in
Ice-Rich Permafrost

Controlled Ablation (Melt) of Cut Slope, Containment Ditch and Separation Berm Erosion Control	B.M.P. #23

Description and Purpose

- This BMP utilizes concepts and suggested designs from Vinson and McHattie (2009) which should be consulted.
- It is preferable to design highway alignments in permafrost terrain to minimize extensive cut slopes which disturb dispersed or massive ground ice in surface soils.
- If extensive cuts into soils with ground ice will be required, and the environmental impacts from melt, slope regression and creation of fluidized soils are too large, then changing the highway location and alignment should be considered.
- Where minimal cuts into soils with ground ice are required, consideration should be given to minor relocation of the highway alignment to eliminate cuts completely.

Applications

- The controlled ablation of cut slope BMP is recommended if the cut slope height exceeds 3 m and significant ground ice in fine-grained sediment is present behind the cut slope.

Advantages

- Where no other highway configuration is possible to avoid permafrost with high ground ice, this BMP allows controlled ablation of the ground ice and stabilization of the cut slope over the long term.
- The separation berm can be constructed of local materials if available.

Limitations

- Construction of the separation berm requires consideration and use of an overflow drainage feature (armoured notch) for extreme rain events or high runoff from snowmelt. Other drainage systems, such as standpipes, may be considered.
- Light coloured crushed rock or aggregate will be required for the separation berm to limit thermal degradation of permafrost.
- The retrogressive soil failure at the cut slope will require time to come to a slope gradient in equilibrium with water, soil and thermal conditions.

Controlled Ablation (Melt) of Cut Slope, Containment Ditch and Separation Berm Erosion Control	B.M.P. #23

Construction

- The design of a controlled ablation (melt) of cut slope with containment ditch and separation berm in ice-rich permafrost should be completed by a geotechnical engineer familiar with permafrost conditions.
- As thermal protection of the ice-rich permafrost is required during the summer construction season, all personnel, machinery, geotextile, crushed rock, coarse aggregate and other items must be available at site, to allow rapid construction and re-instatement of thermal protection. All construction procedures should be determined and discussed in advance with construction personnel.
- Hand clear the brush and trees in the area beyond the cut slope stake limit to allow controlled ablation of the ground ice in the slope. No machinery must be allowed on the area to be cleared. The cleared area width should be about 1.5 times the cut slope height. If a 3 m cut slope is planned, the hand clearing should extend about 4.5 m back from the cut slope edge. Trees over 0.1 m diameter and brush taller than 1.5 m should be cleared off, and the organic mat and topsoil are preserved intact. Cut tree stumps close to the ground. If the organic mat is thin or expected to break apart when the cut slope retreats back, light-coloured geotextile netting should be installed on the surface and pinned or staked to keep the organic mat together as a sheet and not broken apart.
- Prepare a cut slope as steep as possible to reduce the area of soil disturbance and impact to the natural insulation from surface organic deposits. The slope may be cut up to 1H:4V (nearly vertical) if the geotechnical engineer has determined this.
- Any stripped organic or topsoil material should be retained and stockpiled for use in covering exposed sub-soil in the cut slope area.
- The crushed rock for the separation berm should be of light colour to minimize sunlight adsorption and heating which would be detrimental to permafrost preservation.
- Construct a wide ditch at the cut slope base to capture and drain sloughed soil material. The ditch should be built to allow cleanout of accumulated material, if necessary. If no separation berm is constructed, the ditch should be a minimum of 2.5 m wide. If a separation berm is included, the ditch should be a minimum of 4.5 m wide.

- Construct a separation berm of crushed rock or coarse aggregate to act as a lateral containment feature which will allow drainage of wet, failed soils. The berm should be about 1 m high and about 2 to 3 m wide at the base.
- Sloughed and flowed soil will build up against the berm, to prevent highway ditch blockage and begin to stabilize the slope toe.
- In order that the separation berm has no intrusion of fines from the failed soils, a layer of geotextile should be placed below the berm and wrapped up the top of the berm on the cut slope side, and later covered with further crushed rock or coarse aggregate to protect the geotextile.
- Construct a ditch outside the separation berm and beside the highway for road surface runoff.
- As the ground ice ablates and the wet soil accumulates behind the berm, the organic mat will subside and drape over and shade the cut slope and provide some thermal insulation.
- The sloughed and flowed soil from melt should be retained by the berm and not removed as it serves to buttress the subsiding cut slope.
- The separation berm should be maintained as required, to hold back the soil and allow drainage. No soil should overtop the berm and drainage should be maintained through the berm.
- Additional site drainage requirements may arise which should be referred to the geotechnical engineer. No ponded water should be allowed to accumulate in the ditch which will cause permafrost degradation below.
- Dry seeding of the cut slope and accumulated sloughed sediment using native species may be attempted when the surface is stable.
- The cut slope, separation berm and ditch should be designed so that only minimal maintenance is required. The cut slope and accumulated sediment should be inspected after large rain events.

Construction Considerations

- The gravel buttress technique can be used instead of the controlled ablation technique for cut slopes up to 3 m high.
- Where cut slopes in fine-grained soils with high ground ice content will not self-stabilize through build-up of toe deposits, the insulated thermal blanket technique may be considered.

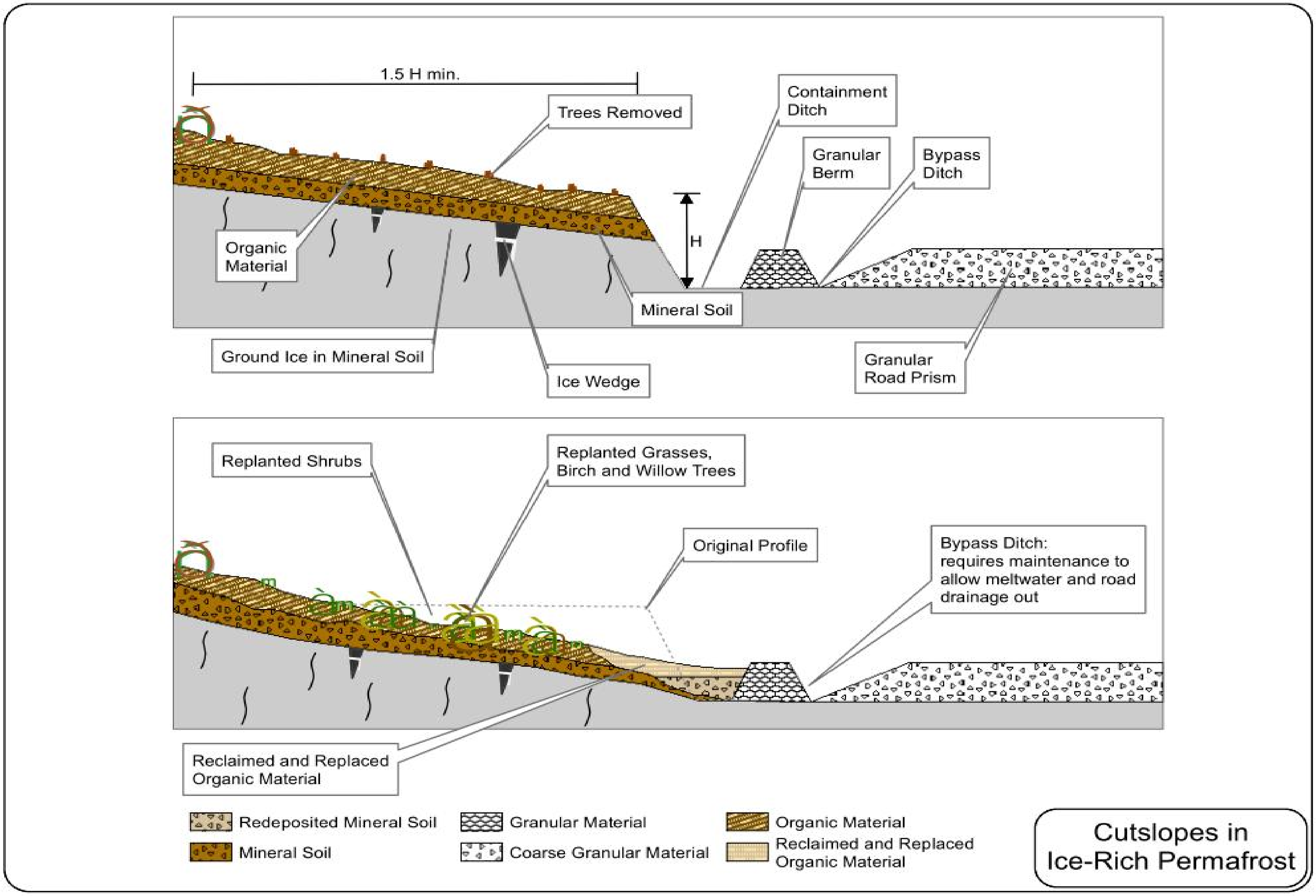
- Where slope height and crushed rock availability make the gravel buttress technique too impractical, the insulated thermal blanket technique may be considered.

Inspection and Maintenance

- The cut slope, the accumulated sediment and the organic mat cover should be inspected after large rain events.
- The organic mat cover should be preserved as a complete layer over the cut slope for thermal protection. If the cover becomes fragmented, additional organic material can be added to complete the organic mat cover.

Design Considerations

- The controlled ablation technique should be designed by a geotechnical engineer familiar with permafrost conditions.


1.5 H min.
Trees Removed
Containment Ditch
Granular Berm
Bypass Ditch
H
Organic Material
Mineral Soil
Ground Ice in Mineral Soil
Ice Wedge
Granular Road Prism
Replanted Shrubs
Replanted Grasses, Birch and Willow Trees
Original Profile
Bypass Ditch: requires maintenance to allow meltwater and road drainage out
Reclaimed and Replaced Organic Material
Redeposited Mineral Soil
Mineral Soil
Granular Material
Coarse Granular Material
Organic Material
Reclaimed and Replaced Organic Material
Cutslopes in Ice-Rich Permafrost

Insulated Thermal Blanket on Cut Slope in Ice-Rich Permafrost Erosion Control	B.M.P. #24

Description and Purpose

- This BMP utilizes concepts, suggested designs and construction recommendations from Vinson and McHattie (2009), which should be consulted.
- Where cut slopes must be prepared for highway construction where the sub-soil has extensive ground ice, an insulated thermal blanket can be installed to assist with preservation of the ground ice through thermal insulation, support of the cut slope, and water drainage.

Applications

- Insulated thermal blanket technique may be used on cut slopes in fine-grained soils with ground ice that will not self-stabilize when disturbed.
- The method can be implemented where gravel buttresses are impractical.

Advantages

- The thermal blanket material can be obtained locally.
- The cut slope may regress back from ground ice melt over time but the blanket material will shift and conform to the underlying slope surface, providing support and thermal protection.
- For cut slopes with ground ice in permafrost areas, the cut slope can be prepared at a steep gradient, preserving the natural vegetation and organic deposit cover, and a thermal blanket can be placed over the cut slope to reduce ground ice melting and allow water drainage out.

Limitations

- Melting of ground ice is usually progressive, resulting in loss of soil strength and volume, and may cause retrogressive slope failure behind the blanket.
- Climate change with slow increase in average air temperatures is causing general increase of ground temperatures, melt of permafrost, especially along the belt of discontinuous permafrost where the permafrost is thin, at shallow depth and at a temperature not far below freezing.

Insulated Thermal Blanket on Cut Slope in Ice-Rich Permafrost Erosion Control	B.M.P. #24

Construction

- The design of an insulated thermal blanket on cut slopes in ice-rich permafrost should be completed by a geotechnical engineer familiar with permafrost conditions.
- As thermal protection of the ice-rich permafrost is required during the summer construction season, all personnel, machinery, geotextile, crushed rock, insulating material, reserved organic materials, and other items must be available at site, to allow rapid construction and re-instatement of thermal protection. All construction procedures should be determined and discussed in advance with construction staff.
- Prepare the cut s lope with the steepest gradient possible for stability, so that a minimum amount of subsoil with ground ice is exposed.
- Remove and retain al l surface topsoil and organic material for later use as the top insulating layer.
- Install a layer of non-woven geotextile against the cut surface, to prevent intrusion of fines into the thermal blanket material. This geotextile may be pinned or s taked down or secured above and draped over the cut surface and the bl anket material placed.
- Have the insulated thermal blanket material on hand and place this against the slope, creating a layer about 1 m thick perpendicular to the face and thinning slightly upwards.
- The thermal blanket material should be crushed rock or large size aggregate obtained locally.
- The crushed rock or aggregate may be placed with minimum compaction only if the natural friction angle is larger than the finished slope, (i.e. the material will self-support).
- For a finished slope angle of 1.5H:1V, the angle of repose for the material must be greater than 35 degrees (coarse durable angular rock pieces w ill often maintain a natural slope angle of 45 degrees).
- A non –rigid, permeable synthetic insulating layer may be placed over the lower layer at this stage (the choice of insulating layer material will depend on cost, availability and degree of thermal insulation required). The manufacturer’s instructions and recommendations on installation and maintenance should be followed.
- The reserved organic material should be placed on the slope in a layer at least 0.6 m thick, with a geogrid or natural erosion control net placed over top with pins or stakes to ensure it covers and retains the organic material.

- Vegetation should be established on the topsoil or organics by dry broadcast seeding or planting of rooted native plant stock. A vegetation cover will help ensure sunlight is absorbed or reflected before it warms the soil.

Construction Considerations

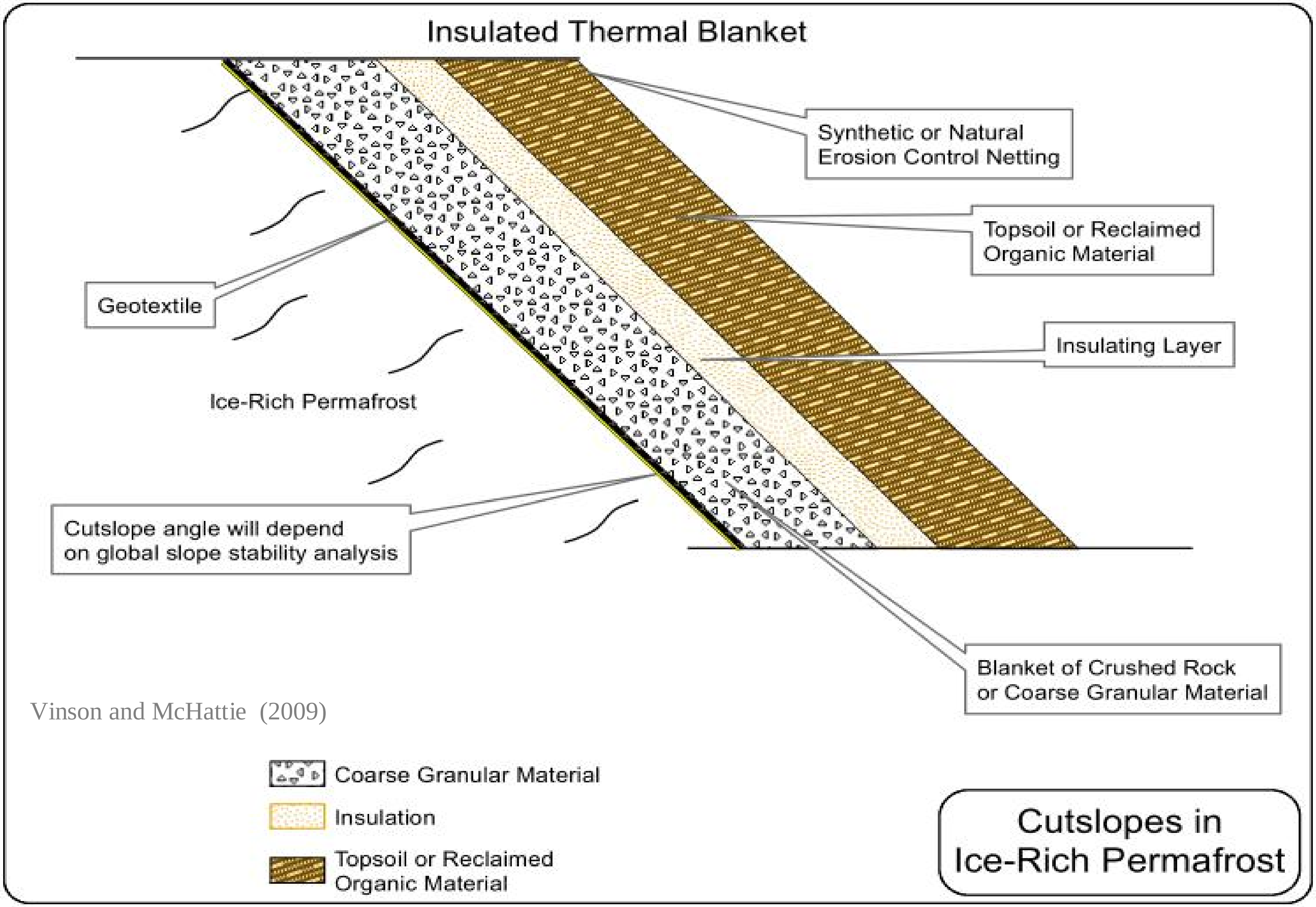
- The thermal blanket material should be light coloured rock to avoid absorbing sunlight and heating and so causing ground ice melt.

Inspection and Maintenance

- The insulated blankets should be inspected after snowmelt and after major rain storm events.
- These insulated cut slopes should be inspected at regular intervals and areas with sunken thermal blanket from ground ice loss should be in-filled with further blanket material.

Design Considerations

- The insulated thermal blanket technique should be designed by a geotechnical engineer with experience in permafrost terrain.



Insulated Thermal Blanket
Synthetic or Natural Erosion Control Netting
Topsoil or Reclaimed Organic Material
Geotextile
Insulating Layer
Ice-Rich Permafrost
Cutslope angle will depend on global slope stability analysis
Blanket of Crushed Rock or Coarse Granular Material
Vinson and McHattie (2009)
Coarse Granular Material
Insulation
Topsoil or Reclaimed Organic Material
Cutslopes in Ice-Rich Permafrost

Scheduling Sediment Control and Erosion Control	B.M.P. #25

Description and Purpose

- Schedule the sequence and timing of construction activities in order to:
  - o Efficiently maximize the amount of erosion protection installed (such as topsoiling and seeding) as soon as a portion of grade construction is completed, and
  - o Limit the por tion of land disturbance from c onstruction compatible with the efficient and achievable rate of erosion control measures constructed Incorporate erosion and sedimentation control concerns during the sched uling phase which w ill minimize the amount and duration of bare soi l exposure to erosion elements and ensure erosion and sedimentation control measures are implemented at an appropriate time
- An operational schedule may be designed during planning stages by the contractor and altered during actual construction to suit variable conditions as these are encountered

Applications

- Temporary measure

Advantages

- Ensures erosion and sedimentation control issues are identified during the planning stage by the contractor
- Promotes timely implementation of erosion and sediment control practices
- Planning for activities to be completed during dry seasons to reduce erosion due to rainfall and sediment transport due to excessive overland flows (avoid flooding periods)
- Planning may avoid fish and wildlife sensitive periods (spawning and nesting)
- Planning to ensure timely mobilization of equipment and labour
- Plan to have all needed ESC materials on hand when required
- May be used to minimize bare soil exposure and erosion hazards
- Promotes efficient utilization of equipment where needed for erosion and sedimentation control on construction projects
- Promotes the installation of permanent erosion control measures (such as topsoiling and seeding) immediately after completion of each phase to get vegetation establishment underway

- Avoids the cost of costly remobilization if equipment is moved off site and is then required for implementing an erosion control measure.
- Finishes the project as it progresses rather than leaving all of the finish work until the end. Promotes good will, allows erosion and sediment controls to be removed and reduces liability while the labour is on site to do the work. No re-deployment required.
- Promotes good housekeeping

Limitations

- May not have been accounted for in the bidding and contract finalization or planning stages

Implementation

- Incorporate a schedule for erosion control and protection structures as part of the overall construction plan
- Determine sequencing and timetable for the start and end of each item, such as clearing, grubbing, stripping, etc., as part of the construction schedule
- Incorporate installation of appropriate erosion and/or sediment control measures in the construction schedule
- Allow sufficient time before construction operations and seasonal rainfall periods to install erosion and/or sediment control measures
- Whenever possible, schedule work to minimize the extent of site disturbance (soil exposure) at any one time
- Incorporate staged topsoiling and revegetation of graded slopes as work progresses
  - Don’t leave all topsoiling and revegetation until the very end of the project
  - Remove un-necessary ESC controls as and when they are no longer needed

Inspection and Maintenance

- Routinely verify that construction activities and the installation of erosion and sediment control measures are progressing in accordance with the approved schedule
  - If progress deviates from schedule, take corrective action
  - An ESC Plan is a living document and is expected to be updated as required.
- When changes to the project schedule are unavoidable, alter the schedule as soon as practical to maintain control of erosion

- If previously unidentified erosion issues occur, install control measures to correct the problem and, if significant, add to the inspection plan and amend the Erosion and Sediment Control Plan.

Stabilized Worksite Entrances Sediment Control	B.M.P. #26

Description and Purpose

- Comprised of a gravel pad located at site access points (entrances and exits) that are used to reduce the amount of sediment carried off construction sites by vehicles
- Used within communities to protect stormwater infrastructure, protect city streets and paved highway or linear sections
- Collects sediment from vehicle washing and retains sediment on construction site
- Should include a water supply to wash off excess soil from vehicles prior to exiting the constructions site

Applications

- Temporary measure
- For use anywhere vehicles enter or exit a construction site and control of sediment is required (paved surfaces, near storm drains)

Advantages

- Retains sediment on construction site
- Reduces deposition of sediments on public roads which may be carried by runoff into natural watercourses or lakes or stormwater infrastructure
- Reduces tracking of sediment down roadways and deposit into stormdrain infrastructure
- Reduces creation of dust

Limitations

- Measures should be installed to collect the sediment-laden runoff from the gravel pads and keep it on site
- Installation of gravel pads may be limited by space constraints

<u>Tire wash facilities may be restricted by lack of suitable water source</u>
Implementation

- Install gravel pad at planned entrances and exits to worksite
  - Gravel pad (minimum of 15 m in length) should be of sufficient length to accommodate longest anticipated vehicle entering or exiting the site
  - Width of pad should be sufficient to accommodate the widest anticipated vehicle entering or exiting the site (minimum of 3.6 m in width)

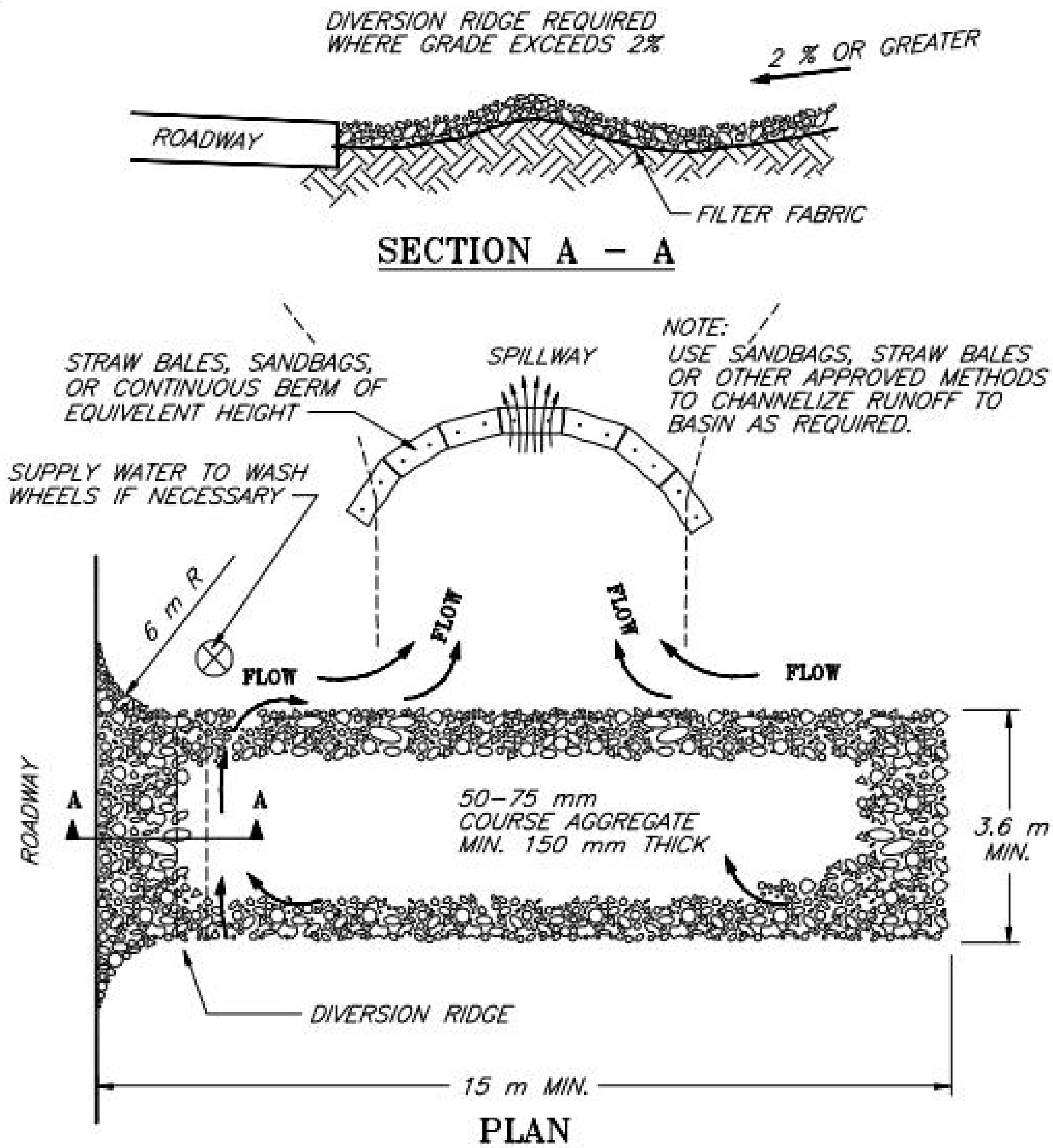
  - Thickness of gravel pad should be a minimum of 0.3 m thick (0.3 m thickness is preferred for linear projects) and should comprise 50 to 150 mm diameter coarse aggregate placed on top of woven geotextile filter fabric
- Install temporary sediment control measures (such as straw bale barriers) to collect the washed off sediment from the gravel pad

Construction Considerations

- Should be constructed at all access points to construction sites
  - If impractical to construct at all access points, limit vehicle access to stabilized worksite entrances only
- Entrances located with steep grades or at curves on public roads should be avoided
- Woven geotextile filter fabric should be used as underlay be low gravel pad as a strength requirement and to stop gravel from being impacted into fine soils below
- Install an elevated ridge adjacent to roadway if gradient of the gravel pad is steeper than 2%, sloped towards the roadway

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Granular material should be regraded when required
  - Material may need to be added to fill large voids to maintain a minimum pad thickness of 0.3 m
- Inspect and clean out downslope sediment control measures as required, (at least once per week) and after periods of significant rainfall
- Material incidentally deposited onto public roads should be removed as soon as the problem is identified



NOTES:

1. THE ENTRANCE SHALL BE MAINTAINED IN A CONDITION THAT WILL PREVENT TRACKING OR FLOWING OF SEDIMENT ONTO PUBLIC RIGHT–OF–WAYS. THIS MAY REQUIRE TOP DRESSING, REPAIR AND/OR CLEANOUT OF ANY MEASURES USED TO TRAP SEDIMENT.
2. WHEN NECESSARY, WHEELS SHALL BE CLEANED PRIOR TO ENTRANCE ONTO PUBLIC RIGHT–OF–WAY.
3. WHEN WASHING IS REQUIRED, IT SHALL BE DONE ON AN AREA STABLIZED WITH CRUSHED STONE THAT DRAINS INTO AN APPROVED SEDIMENT TRAP OR SEDIMENT BASIN.
4. FOR HIGHWAY CONSTRUCTION, 300mm THICKNESS OF GRAVEL IS PREFERRED.
5. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

TEMPORARY GRAVEL CONSTRUCTION ENTRANCE/EXIT

FILE: ENTRANCE

Slope Texturing (a-c) Erosion Control	B.M.P. #27 (a - c)

Description and Purpose

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

a) Surface Roughening

b) Grooved or Serrated Slope

c) Benched Slope

Applications

- Temporary and Permanent measure
- May be used to roughen the exposed soils on the slope surface, opposite to the direction of water flow, to minimize erosion. May trap a small amount of sediment as a secondary benefit
- May be used on fresh cut or fill slopes (8 m length or longer; practical travel reach of a bulldozer) with gradients of generally 3H:1V or steeper (2H:1V as general steepness limit) constructed in cohesive soils
- May be used on slope subgrade that will not be immediately topsoiled, vegetated or otherwise stabilized
- May be applied to topsoiled slope to provide track serration to further reduce erosion potential and promote water infiltration. May also capture seed which is moved by wind or water
- May be used in graded areas with smooth and hard surfaces to avoid and intercept sheet flow
- As part of slope design, benching (terracing) may be used to effect a reduction in erosion hazard where a long slope length needs to be shortened into smaller section lengths with mid-benches; normally a 3 m wide bench can be appropriate
  - Benching is usually a permanent slope design feature and should only be designed by a qualified geotechnical engineer
  - Benching of a long slope section to divide it into short sections can reduce erosion hazard in the range of 30 to 50% (e.g., sediment yield for 15 m high 3H:1V slope with mid-bench)

Slope Texturing (a-c) Erosion Control	B.M.P. #27 (a - c)

Advantages

- Reduces erosion potential of a slope by breaking up steep slope sections
- Texturing will create small ridges to increase surface roughness to reduce overland flow velocities and erosion energy
- Texturing will create minor spaces to entrap a portion of the coa rse sediment and reduce amount of sediment transported downslope
- Texturing of slopes will benefit development of vegetation through retaining of water, fines and seeds
- Texturing of slopes aids in performance of topsoiling, addition of mulches and hydroseeding by reducing soil creep and losses due to overland flows
- Texturing with track-walking up/downslope may effect a 50% reduction of sediment yield compared with an untracked slope

Limitations

- Surface roughening and tracking may increase slope grading costs
- Surface roughening and tracking may cause sloughing in certain soil types (i.e., sandy silt) and in seepage areas. Geotechnical advice is recommended
- Texturing by tracking provides limited sediment and erosion control and should be used in conjunction with other measures and prior to topsoiling to reduce creep on steeper slopes
  - Should be used in conjunction with other erosion and sediment control measures (i.e., offtake ditches, topsoiling and seeding) to limit the sheet flow downslope

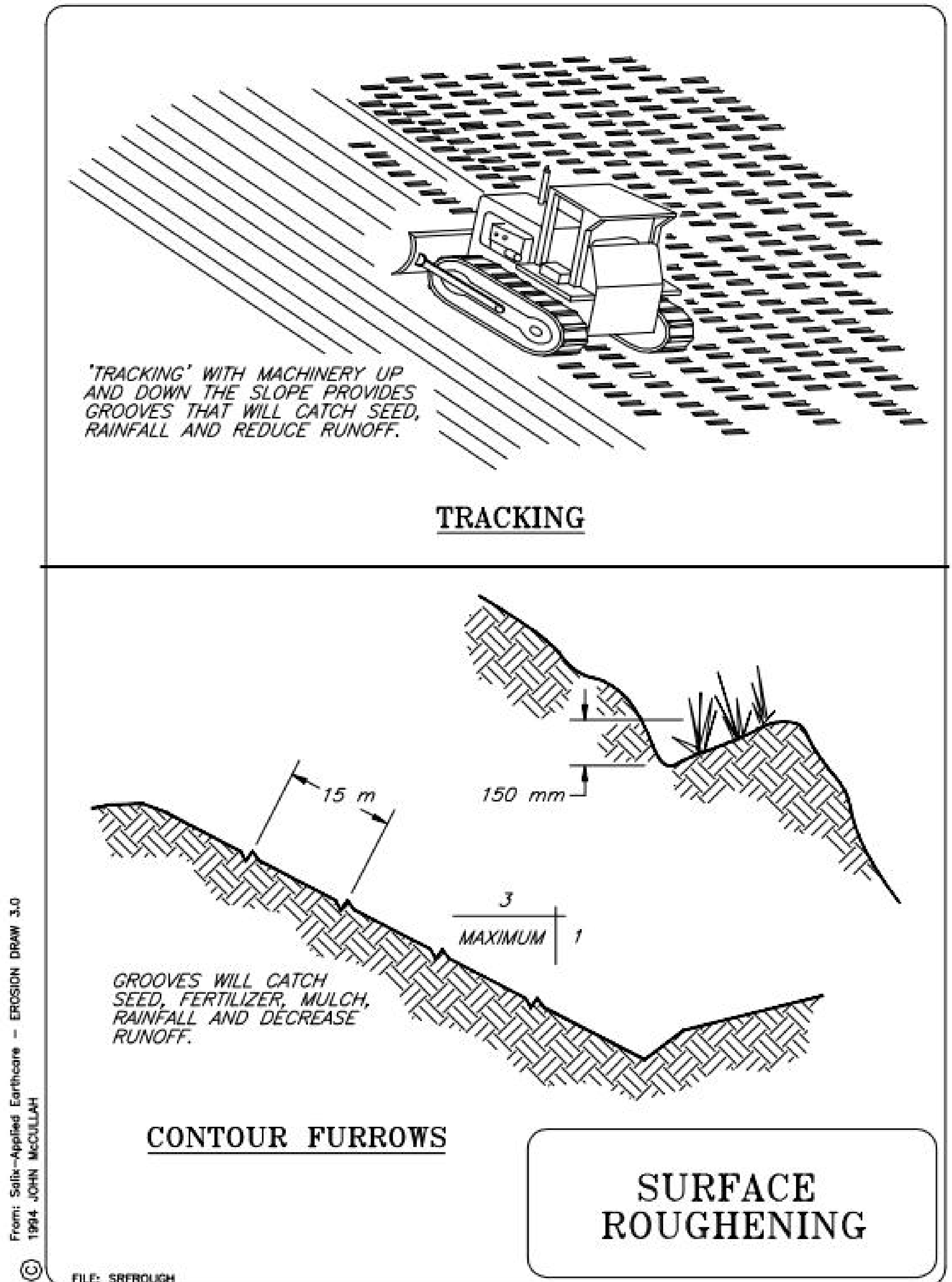
Construction

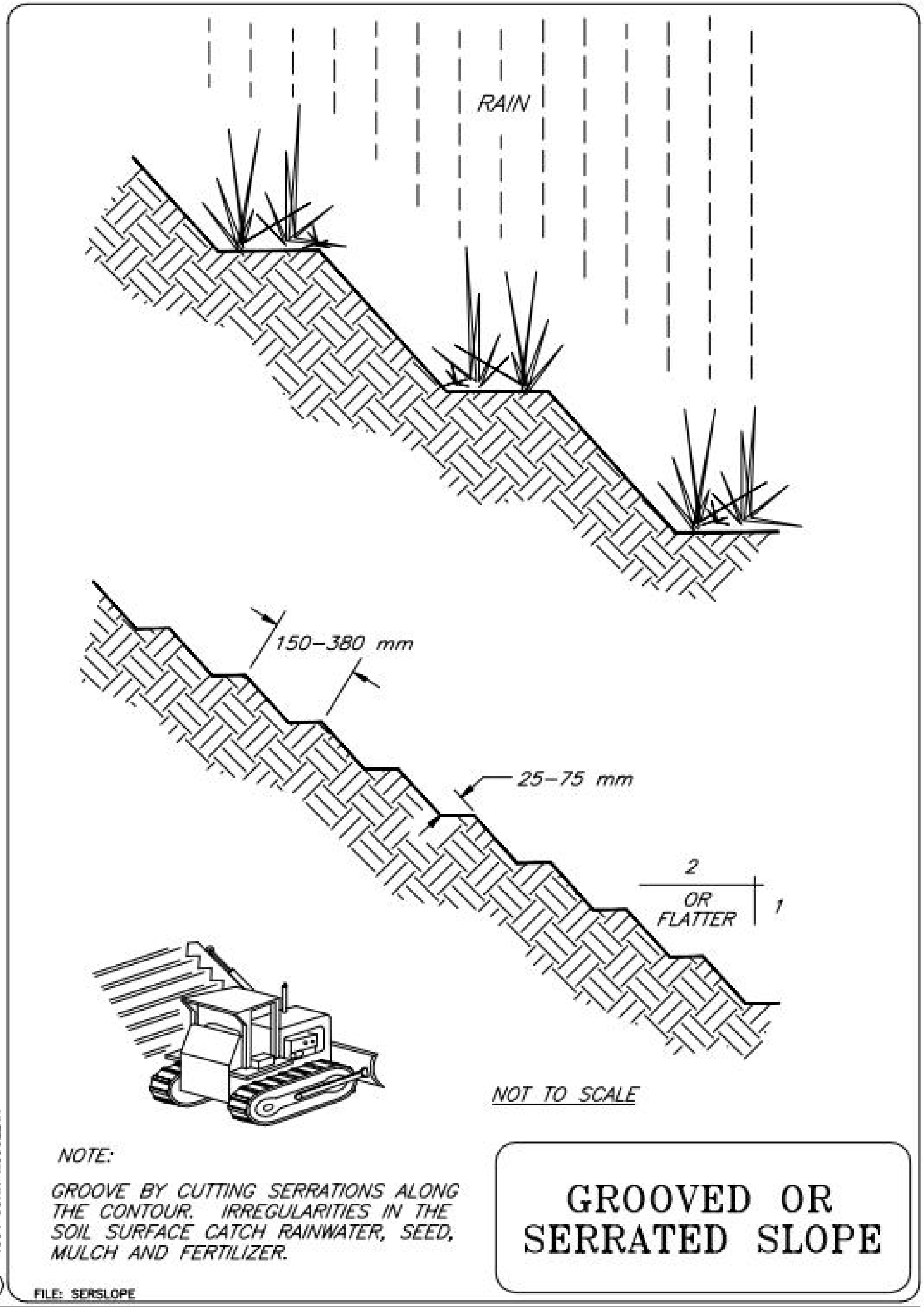
- Surface Roughening
  - Leave soil in rough grade condition, do not smooth graded slopes
  - Uneven surface of the soil will aid in decreasing runoff velocities, will trap sediment, and will increase infiltration of water
- Surface Tracking
  - Use tracked construction equipment to move up and down the slope, leaving depressions opposite (horizontal) to the slope direction; limit passes to prevent over compaction of the surface soils
  - Depressions in the soil will aid in decreasing runoff velocities, trap sediment, and increase infiltration of water

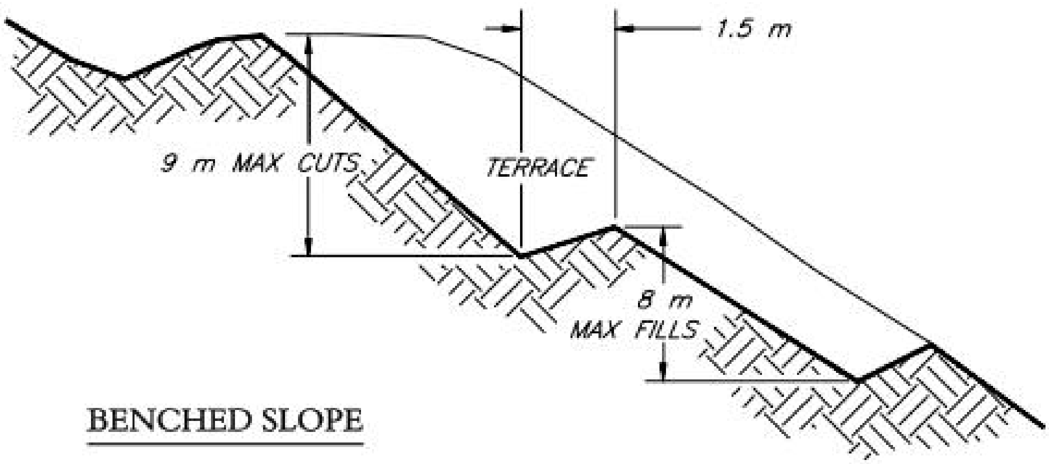
- Grooving
  - Excavate shallow furrows across the width of the slope, opposite to the direction of the slope
  - If used, contour grooves should be approximately 0.1 to 0.2 m in depth
  - Grooves can be made by using equipment or by hand
- Benching
  - Construct narrow, flatter sections of soil on the slope, perpendicular to the direction of the slope
  - Benches should be designed by a qualified geotechnical engineer

Construction Considerations

- During tracking operations, care must be taken to minimize disturbance to the soil where the equipment turns or changes direction
- Minimize the number of tracking passes to 1 or 2 times to avoid overcompaction, which can negatively impact the vegetation growth
- It is practical to track roughen a slope length of greater than 8 m for efficient up/down slope operation of a small bulldozer. It is important to minimize the loosening of soil caused by turning movement of the bulldozer at the end of each pass. As the erosion potential is lower for slopes of low vertical height (<3 m height and 3H:1V slope), the tracking of low slopes is not required and not practical for a bulldozer tracking operation.


'TRACKING' WITH MACHINERY UP AND DOWN THE SLOPE PROVIDES GROOVES THAT WILL CATCH SEED, RAINFALL AND REDUCE RUNOFF.
TRACKING
150 mm
15 m
3
MAXIMUM
1
GROOVES WILL CATCH SEED, FERTILIZER, MULCH, RAINFALL AND DECREASE RUNOFF.
CONTOUR FURROWS
SURFACE ROUGHENING
FILE: SRFROUGH
From: Salix-Applied Earthcare - EROSION DRAW 3.0
© 1994 JOHN McCULLAH


RAIN
150–380 mm
25–75 mm
2
OR
FLATTER
1
NOT TO SCALE
NOTE:
GROOVE BY CUTTING SERRATIONS ALONG THE CONTOUR. IRREGULARITIES IN THE SOIL SURFACE CATCH RAINWATER, SEED, MULCH AND FERTILIZER.
GROOVED OR SERRATED SLOPE
FILE: SERSLOPE



BENCHED SLOPE

NOT TO SCALE

FILE: STPSLOPE

BENCHED SLOPE

Compost Blanket Erosion Control	B.M.P. #28

Description and Purpose

- Compost is the product resulting from the controlled biological decomposition of organic material, occurring under aerobic conditions
- Compost has been sanitized through the generation of heat and biologically stabilized to the point that it is appropriate for its particular application
- Active composting is typically characterized by a high temperature phase that sanitizes the product and allows a high rate of decomposition
- It is followed by a lower temperature phase that allows the product to stabilize while still decomposing at a slower rate
- Compost should possess no objectionable odours, chemical characteristics (high biological oxygen demand) or substances toxic to plants
- Compost contains plant nutrients but is typically not characterized as a fertilizer
- May derive from agricultural, forestry, food or industrial residues, bio-solids, leaf and yard trimmings, manure, or tree wood

Applications

- Compost blankets are commonly used for permanent erosion control (does not require removal)
- The technique is appropriate for slopes up to 2H:1V grade and on level surfaces
- Only used in areas that have low sheet flow drainage patterns (not for areas that receive concentrated flows)
- Compost used on GNWT-DOT projects must meet Canadian Council of Ministers of the Environment (CCME) Guidelines for Compost Quality (trace elements, maturity/stability, pathogens), which are adopted by the Government of the Northwest Territories – Department of Transportation.

Advantages

- Relatively cheap method of promoting plant growth and slope protection if available in the area
- Reasonably cost effective if material availability allows compost to be made on or near the site

Limitations

- May require approval from the GNWT Environment and Natural Resources
- May not be readily available therefore may be expensive

- Application of compost may be difficult on steep slopes
- May require spray-on method to apply compost to steep slopes
- Requires specialized blower truck, hose and attachments for blanket installation

Installation

- Slightly roughen (scarify) slopes and remove large clods, rocks, stumps, roots larger than 50 mm in diameter and debris on slopes where vegetation is to be established
- Apply compost at the rates as follows:

Annual Rainfall/Flow Rate	Total Precipitation	Application Rate for Vegetated Compost Surface	Application Rate for Unvegetated Compost Surface
Low	25 mm – 635 mm	12.5 mm – 19 mm	25 mm – 37 mm
Medium	635 mm – 1270 mm	19 mm – 25 mm	37 mm – 50 mm
High	>1270 mm	25 mm – 50 mm	50 mm – 100 mm

- Compost shall be uniformly applied using an approved spreader, (e.g., bulldozer, discharge spreaders)
- A pneumatic blower unit propels the compost directly at the soil surface, thereby preventing water from moving between the soil-compost interface
- Seeding can be incorporated during the compost application

Construction Considerations

- Use higher blanket application rates in area with high rates of precipitation and rainfall intensity, and snow melt
- Tackifier may be used in conjunction with a compost blanket, especially in regions with spring melt, and sites with severe grades and long slopes
- In areas subjected to wind erosion, a coarser compost product or higher blanket application rate is preferred
- Use lower blanket application rate in areas with lower precipitation rates and rainfall intensities

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Areas damaged by erosion (washout or rilling) should be regraded, if necessary, and re-covered with compost immediately. Action should also be taken to mitigate the cause of the erosion

Similar Measures

- Rolled Erosion Control Products (RECP)
- Hydroseeding
- Hydromulching

Rolls a) Coir Roll b) Fibre Roll Streambank Stabilization Techniques and Erosion Control	B.M.P. #29

Description and Purpose

- Coir rolls are long cylindrical tubes that are composed of interwoven coconut fibres which are bound together with durable coir netting. Coir rolls are particularly applicable for wetland, streambank, and shoreline projects. Coir rolls are most commonly available in 0.3 m diameters and 6 m lengths. These rolls can be linked together to form longer tubes, and are often used in combination with other biotechnical techniques, such as brush layering or live siltation methods or branch staking. Coir logs encourage siltation and wetland/floodplain maintenance
- Fibre rolls are installed along slope contours as a grade break to reduce erosion potential by reducing overland flow velocities
- Straw rolls consist of bundled straw (or natural fibre) wrapped in photo-degradable open-weave plastic or natural fiber netting staked into the soil along slope contours as a grade break to reduce erosion potential
- Live stakes or branches can be installed to anchor the fibre rolls to provide deep rooted vegetation with potential favourable moisture retention provided by fibre roll
- Fibre rolls may capture sediment, organic matter, and seeds carried by runoff

Applications

- The tough, long-lasting coconut fibres make coir rolls appropriate for wetland, streambank, and shoreline applications. Coir rolls work well when immediate erosion control is needed. Brush layers work well with coir roll applications, adding further stabilization with a live root system , while also providing excellent habitat features. The coir roll provides a base for the brush layer cuttings to be laid upon at an appropriate angle which benefits the growth of cuttings. The cuttings provide further protection from breaking waves and high flows
- Fibre rolls may be used on slopes stable enough to support vegetation (steep, confined slopes and channel banks with gradients greater than 1H:1V may have low success potential)
- Fibre rolls may be used on long slopes as a grade break to shorten the length of slope between other slope retention features
- Fibre rolls may be used as grade breaks, where slopes transition from flatter to steeper gradients

Advantages

- The coir material is natural and long lasting (5 to 7 years), and has high tensile strength

Rolls a) Coir Roll b) Fibre Roll Streambank Stabilization Techniques and Erosion Control	B.M.P. #29

- The coir rolls and fibre rolls accumulate sediment while the plant roots develop. Eventually the coir material biodegrades and the cohesive strength of the root systems and flexible nature of the roots become the primary stabilizing element
- The coir roll/brush layering combination provides immediate shoreline and streambank protection, with additional benefits of riparian enhancement when the cuttings become established
- Coir rolls address ecological concerns by encouraging vegetation and small wildlife habitat, and are an alternative to stone revetments or other structural measures
- The high tensile strength coconut fibres, the fibre netting and the wooden stakes used to anchor the material make up the initial structural components of the system, while plant root and to p growth increase the strength and water velocity reduction and sediment capture effects of the structure
- Fibre rolls can be used on slopes too steep for sediment fences or straw bale sediment barriers
- In time, the plastic netting will degrade due to the sunlight an d straw will degrade and be incorporated into the soil. Natural fiber netting (Bionet™) is also available
- The primary purpose of fibre rolls is erosion control, however fibre rolls do provide a small amount of sediment control as a secondary benefit.

Limitations

- This technique should be implemented during the dormancy period of the cut tings used for brush layering and staking
- Coir rolls are relatively expensive
- Fibre rolls are designed for low sheet flow velocities
- Fibre rolls are designed for short slopes with a maximum gradient of 1H:1V
- Fibre rolls may be labour intensive to install
- Straw rolls have a shorter life span due to natural degradation
  - Usually only functional for two seasons
  - Susceptible to undermining and failure if not properly keyed into the soil
- Labour intensive maintenance may be required to ensure rolls are in continuous contact with the soil, especially when used on steep slopes or sandy soils

Construction

- Determine the annual maximum water elevation
- Mark the water level on a stake driven into the substrate, 0.3 or 0.6 m offshore. Installing the materials and plants at the correct elevation is the most important aspect to assure success of the installation. Determine, on site, where the installation will begin and end
- Determine soil level by laying a straight cutting on the coir roll with approximately 20% of the cutting sticking out past the roll, and with the basal ends dipping down into the soil
- Begin installation at the downstream end (if using in a streambank project)
- Prepare the site for installation of coir rolls by removing any large rocks, obstructions or material that may prevent the coir from making direct and firm contact with the soil. Coir rolls must be level, installed along a horizontal contour. Place coir rolls parallel to the stream bank or shoreline. It is very important to key the ends of the coir rolls firmly into the shoreline or stream bank, so waves and flows will not scour behind the rolls and compromise the integrity of the structure
- Install the coir roll such that 0.05 m of th e roll ex tends above the annual water elevation
- Adjacent rolls shall be laced together, end-to-end, tightly and securely
- If using brush layer cuttings, prepare the soil bed behind the installed coir rolls for brush laying. It is important that the bud ends of the live cuttings angle up to some degree from the basa l ends. Lay cuttings in this fashion, slightly crisscrossed for additional strength
- Next, backfill over the cuttings with soil, covering the lower 80% of the branches. At this time, the soil can be levelled and prepared for a soil wrap for additional height and soil stability
- If simply covering the cuttings with soil, compact slightly and grade slope to appropriate angle. Use water to wash soil in between branch layers
- If using plant materials, such as container-grown, pre-rooted plant plugs or willow stakes, they should be planted into the coir rolls and through th e coir mats and netting
- To install plant plugs and willow stakes into the coir roll, use a planting iron or pilot bar into the roll and wedge it back and forth to create a hole for the plant. It is extremely important that the root system of the plant be placed below the water

table for certain species. All plants shall be checked to ensure that they have been firmly installed through the fibre material, into the soil

- Mulch and seed exposed areas with native species
- Prepare the slope face and remove large rocks or other deleterious materials
- Excavate small trenches a minimum of 0.15 m deep and 0.15 m wide across the width of the slope, perpendicular to the slope direction, starting at the toe of the slope and working upwards towards the crest of slope
- Space trenches a maximum of 3 to 8 m apart along the slope incline, with steeper slopes having trenches spaced closer together
- Place fibre rolls into the trenches, ensuring continuous contact between the fibre roll and the soil surface
- Butt-joint adjacent fibre roll segments tightly against one another and lace together
- Use a metal bar to make a pilot hole through middle of the fibre roll a minimum depth of 0.3 m into underlying soil
- Pilot holes should be spaced a maximum of 1 m apart
- Secure fibre roll to soil using wooden stake or other appropriate anchor. Live stakes may be used as alternate anchors
- Place soil excavated from the trench on the upslope side of fibre roll Seed the soil along the upslope and downslope sides of the fibre roll to promote vegetation growth
- Compact the soil upslope of the fibre roll to minimize undermining by runoff

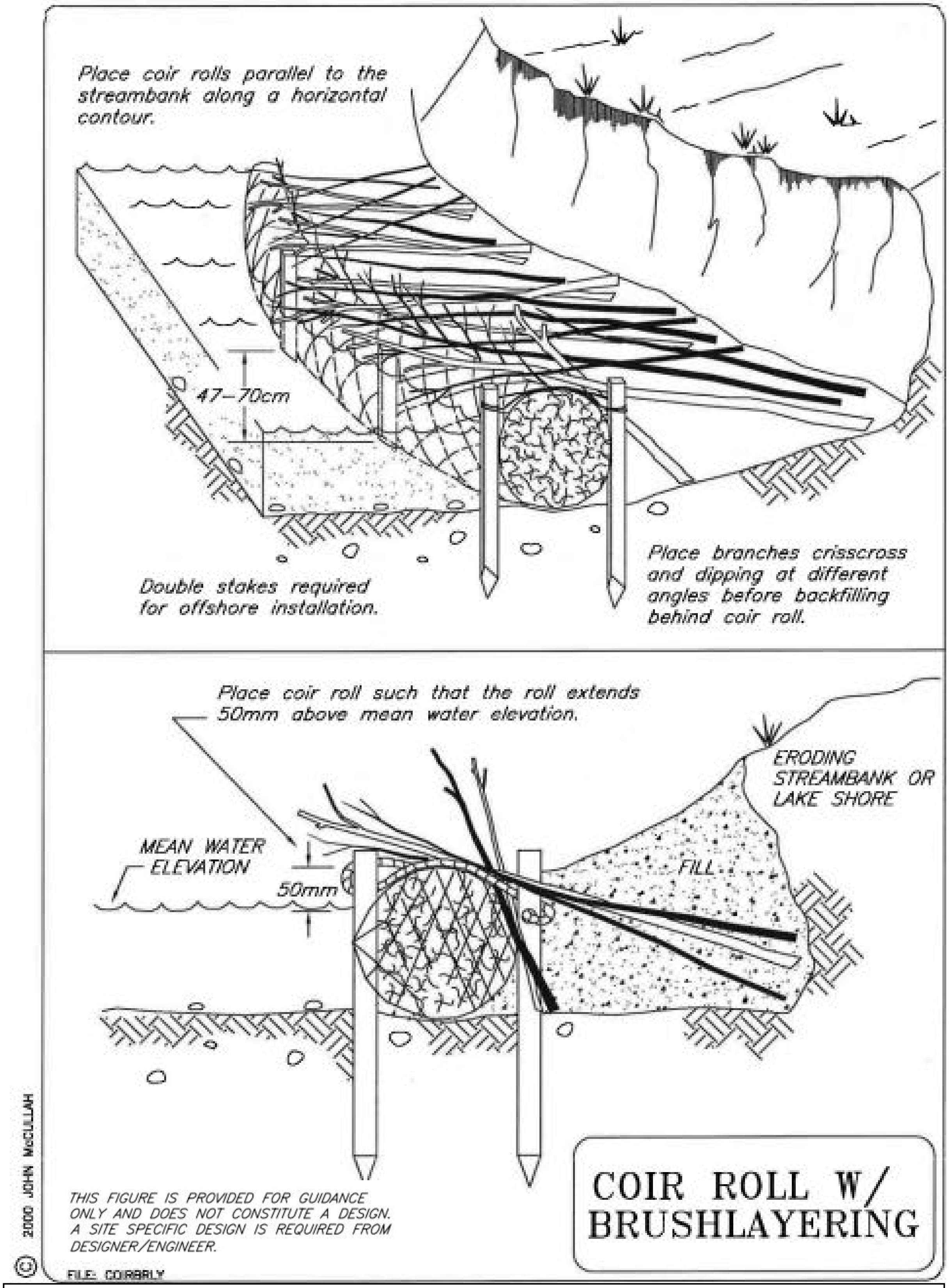
Construction Considerations

- All work site disturbance should be minimized. Protect any existing plants, when possible, and avoid additional disturbance that can lead to erosion and sedimentation
- Install additional erosion and sediment control measures such as temporary diversion dikes, sediment fences and continuous berms, as needed, before beginning work
- Coir rolls can be used in the stream as a sediment barrier, silt curtain, and/or coffer dam to control sediment while work is being done in the water
- Topsoil should be saved, if possible, and replaced once the subsoil has been removed or regraded. Soil shall be stored away from the water’s edge and it shall be moved to its final location and stabilized as quickly as possible

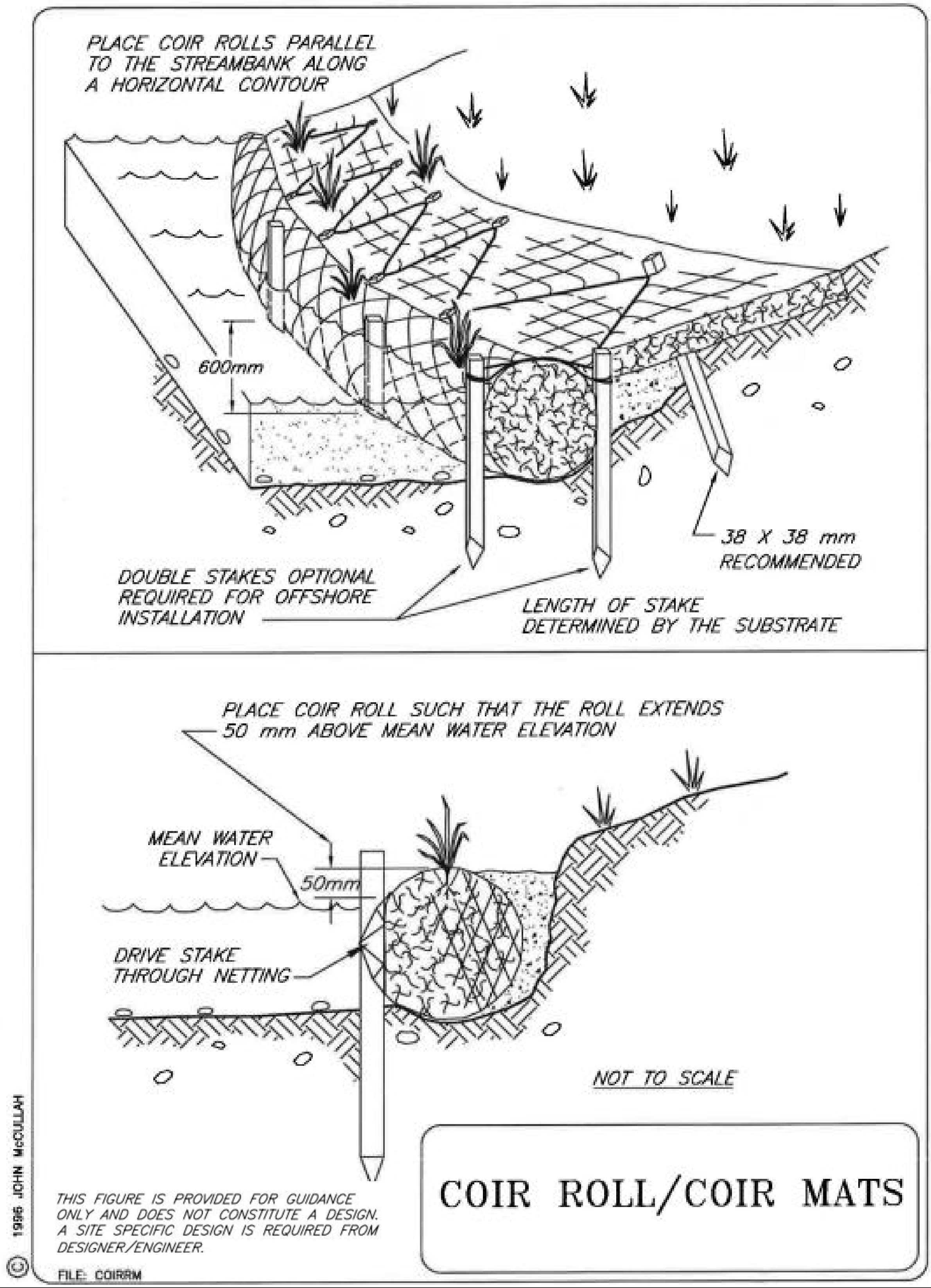
- For typical applications at the water's edge, coir rolls are held in place with a single row of stakes, spaced 0.3 m apart. Stakes may be driven through the netting on the outer edge of the roll. It is very difficult to drive stakes through the high-density rolls, however, a stake can be driven w ith the help of a pilot hole through the low density part of the coir rolls
- Lacing among the stakes is recommended for coir mats exposed to extreme conditions such as ice, waves, or flooding
- Coir rolls shall be placed along streambanks or shorelines at a height sufficient to protect the bank from flows or waves. Additional coir rolls may be placed above the lower rolls, in a tile-like fashion, to protect the upper shore or stream bank
- Use live stakes in place of wooden stakes for streambank coil rolls
- If the slope soil is loose and uncompacted, excavate a trench to a minimum depth of 2/3 of the diameter of the coir roll
- For steep slopes, additional anchors placed on the dow nslope side of the coir roll may be required

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Check plants to ensur e that they have bee n firmly installed into the soil below the fibre material
- Water plants, if necessary, during the establishment phase
- Check all materials periodically or after major storms to ensure they remain properly secured. Make necessary repairs promptly
- All temporary and permanent erosion control measures shall be maintained and repaired as needed to ensure continued performance of their intended use
- Areas damaged by washout (rilling or gulleying) should be repaired immediately
- Additional stormwater control measures should be considered for erosion (rilling or gulleying) areas damaged by runoff



Place coir rolls parallel to the streambank along a horizontal contour.
47–70cm
Double stakes required for offshore installation.
Place branches crisscross and dipping at different angles before backfilling behind coir roll.
Place coir roll such that the roll extends 50mm above mean water elevation.
ERODING STREAMBANK OR LAKE SHORE
MEAN WATER ELEVATION
50mm
FILL
THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.
COIR ROLL W/ BRUSHLAYERING
© 2000 JOHN McCULLAH
FILE: COIRBRLY


PLACE COIR ROLLS PARALLEL TO THE STREAMBANK ALONG A HORIZONTAL CONTOUR
600mm
38 X 38 mm RECOMMENDED
DOUBLE STAKES OPTIONAL REQUIRED FOR OFFSHORE INSTALLATION
LENGTH OF STAKE DETERMINED BY THE SUBSTRATE
PLACE COIR ROLL SUCH THAT THE ROLL EXTENDS 50 mm ABOVE MEAN WATER ELEVATION
MEAN WATER ELEVATION
50mm
DRIVE STAKE THROUGH NETTING
NOT TO SCALE
THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.
FILE: COIRRM
COIR ROLL/COIR MATS
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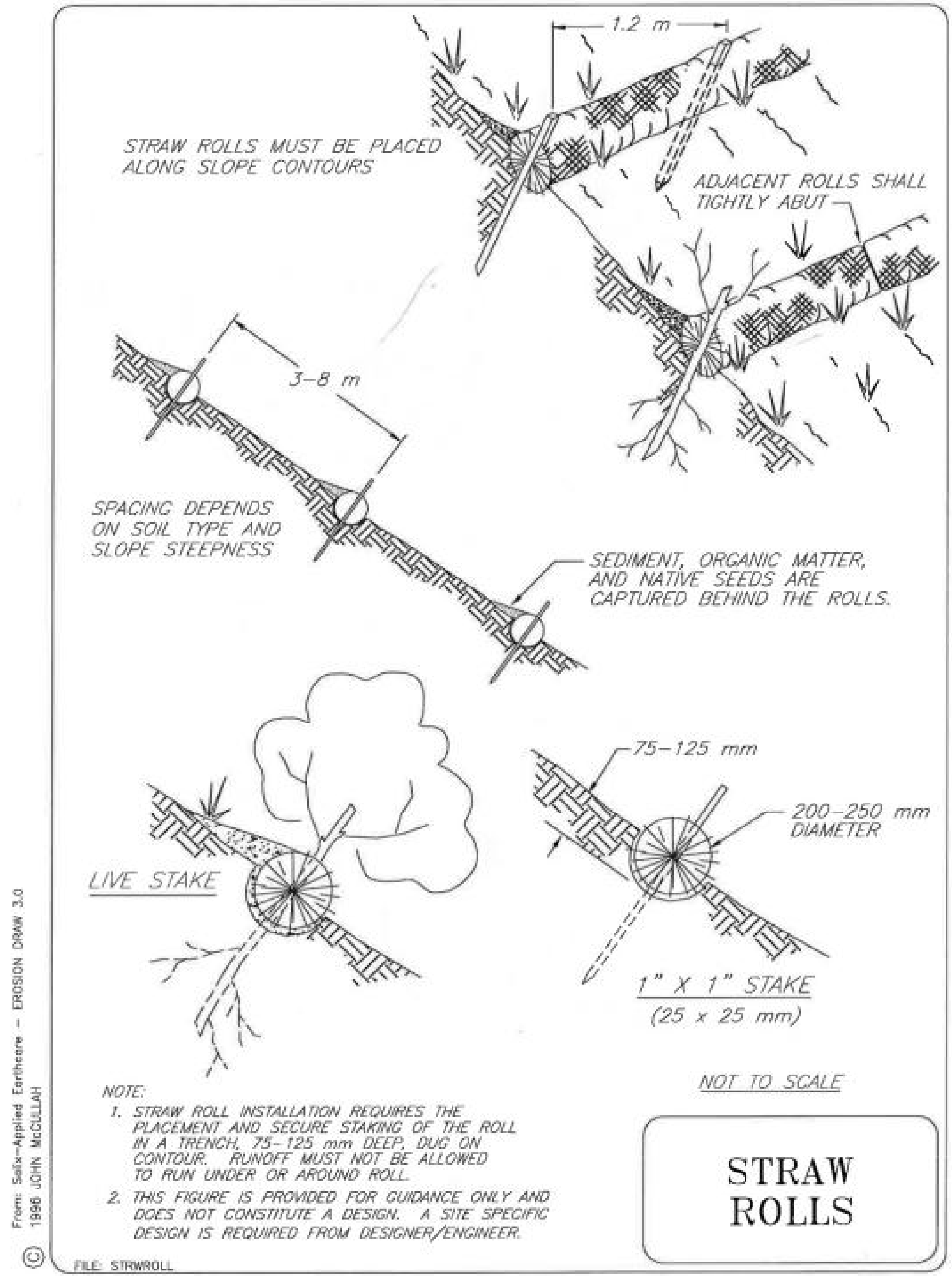

1.2 m
STRAW ROLLS MUST BE PLACED ALONG SLOPE CONTOURS
ADJACENT ROLLS SHALL TIGHTLY ABUT
3–8 m
SPACING DEPENDS ON SOIL TYPE AND SLOPE STEEPNESS
SEDIMENT, ORGANIC MATTER, AND NATIVE SEEDS ARE CAPTURED BEHIND THE ROLLS.
LIVE STAKE
75–125 mm
200–250 mm DIAMETER
1" X 1" STAKE
(25 x 25 mm)
NOT TO SCALE
NOTE:
1. STRAW ROLL INSTALLATION REQUIRES THE PLACEMENT AND SECURE STAKING OF THE ROLL IN A TRENCH, 75–125 mm DEEP, DUG ON CONTOUR. RUNOFF MUST NOT BE ALLOWED TO RUN UNDER OR AROUND ROLL.
2. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.
STRAW ROLLS
FILE: STRWROLL
From: Salix–Applied Earthcare – EROSION DRAW 3.0
© 1996 JOHN McCULLAH

Wattles (Live Fascine) Erosion Control	B.M.P. #30

Description and Purpose

- Wattles consist of a line of live branch bundles, staked into a soil trench along the slope contours, and covered by soil and seed
- Normally live staking can be installed to anchor the wattles to provide deeply rooted vegetation with potential favourable moisture retention provided by wattles
- Wattles are primarily an erosion control as they slow the velocity of water and stabilize the soils but they also capture small amounts of sediment, organic matter, and seeds carried by runoff

Applications

- Permanent measure (may naturally degrade but does not require removal)
- May be used on slopes stable enough to support vegetation (steep, confined, slopes and channel banks with gradients greater than 1H:1V may have low success potential)
- May be used on slopes and channel banks with adequate sunlight, moisture, soil and wind protection to support vegetation
- May be used as grade breaks, where slopes transition from flatter to steeper gradients
- May be used on shores of small lakes as a wave break to assist in revegetation and stabilization of banks
- Can be used in conjunction with live staking as biotechnical erosion control measure

Advantages

- Native vegetation (willow, alder, red-osier dogwood and poplar) may be used
- Technique used as grade break to lower sheet and rill erosion potential
- Can be used on slopes too steep for silt fences or straw bale sediment barriers

Limitations

- Designed for low velocity sheet flow
- Designed for short slopes with a maximum gradient of 1H:1V
- Are labour intensive to install
- Few precedents as this measure is generally not used on GNWT-DOT construction projects

- Susceptible to undermining and failure if not properly keyed into the soil

Construction

- Prepare slope face and remove large rocks or other deleterious materials
- Excavate small trenches a minimum of 0.15 meters (m) deep and 0.15 m wide across the width of the slope, perpendicular to slope direction, starting at the toe of the slope and working upwards towards crest of slope
- Space trenches a maximum of 3 m to 8 m apart along the slope incline, with steeper slopes having trenches spaced closer together
- Place branch bundles into trench ensuring continuous contact between bundles and soil surface
- Butt-joint adjacent bundles tightly against one another
- Use a metal bar (e.g. rebar) to make pilot hole through middle of the bundle a minimum depth of 0.3 m into underlying soil
- Pilot holes should be spaced a maximum of 1 m apart
- Secure bundle to soil using wooden stake or other appropriate anchor; live stake may be used as alternate anchor
- Place soil excavated from trench on upslope side of whole wattle and compact to minimize undermining of wattle by runoff
- Seed the soil along the upslope and downslope sides of the wattle to promote vegetation growth

Construction Considerations

- Use live branch stakes in place of wooden stakes
- If the slope soil is loose and uncompacted, excavate trench to a minimum depth of 2/3 of the diameter of the bundle
- For steep slopes, additional anchors placed on the downslope side of the whole wattle may be required

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Areas damaged by washout (rilling or gulleying) or slope failure should be repaired immediately

- Additional stormwater control measures should be considered for rilling areas damaged by runoff

Similar Measures

- Synthetic permeable barriers
- Straw or Fiber Rolls
- Coir Rolls

Brush Mattress Streambank Stabilization Techniques	B.M.P. #31

Description and Purpose

- Consists of a thick (0.15 to 0.3 m) blanket of live cuttings and soil fill placed on a streambank or lake shore designed to re-vegetate and armour the bank. It provides erosion protection and re-vegetation and is constructed using live willow branches or other species that root easily from cuttings. The dense layer of brush increases roughness, reduces velocities at the bank face, and protects the bank from scour, while trapping sediment and providing habitat directly along the waters' edge.

Applications

- Appropriate for eroding streambanks or slopes where immediate protection is needed from flooding stream flows or wave-induced erosion
- Willow is the most common plant material used because of its rooting ability
- Suitable for streams where willow is naturally occurring and where the soil and moisture conditions are favourable
- As the live branches are planted to a relatively shallow depth, as compared to brush layering, it is most successful on streams where the basal ends of the cuttings will be kept moist during most of the growing season, but flows do not exceed the tolerance of the structure

Advantages

- Provides a dense network of branches that quickly stabilize a slope or streambank
- As the live branches root and grow, not only do they provide cover, but the soil is reinforced with an underground matrix of spreading roots
- If used on streambanks, a brush mattress will trap sediments during high water and once established plant growth will enhance aquatic habitat
- If used on slopes, a brush mattress collects transported soil, providing germination sites for other plants
- Well suited for combined installation with many other streambank or slope stabilization techniques
- Often combined with Vegetated Riprap, Live Stakes, Live Fascines, Rootwad Revetment, Live Siltation and Coir Rolls
- Provides immediate surface protection against floods, greatly reducing water velocity at the soil surface
- Well-anchored mattress provides some resistance to scour
- Cuttings are usually available locally

- Relatively economical technique
- Captures sediment during floods, assisting in rebuilding of bank
- Produces riparian vegetation rapidly
- Enhances wildlife habitat value

Limitations

- Does not show high success on streams where basal ends cannot be kept wet for the duration of the growing season
- The live branches should be installed during the dormant season for woody vegetation (late fall to early spring)

Installation is labour intensive Construction

- Prepare the slope or streambank by clearing away large debris and grading the slope so the branches will lay flat on the bank
- If bank is not graded evenly, air pockets will form during backfilling, causing poor stem to soil contact, and ultimately resulting in poor sprouting
- Do not over compact the slope soils as it will inhibit rooting
- Excavate a horizontal trench, 0.2 to 0.3 m deep at the toe of the streambank
- Lay the cuttings flat against the graded slope, slightly crisscrossed, with the basal ends placed as deeply into the trench as possible, and just below any toe protection to be installed
- Continue to lay the cuttings along the face of the bank or slope until 80% groundcover is achieved
- The mattress will be about 0.06 to 0.3 m thick
- It will take 10 to 50 branches per metre of mattress
- Pound a grid of wooden stakes, 0.6 to 0.9 m long, into the mattress at 0.9 to 1.2 m centers
- Do not pound the stakes completely in, as this will be done after tying
- Longer stakes can be used in sandy soil and shorter stakes in heavy soils
- Secure the brush mattress by using cord, rope, or 10 to 12 gauge galvanized annealed wire, tied with clove hitches in a diamond pattern between each row of stakes
- After securing the mattress with cord or wire, drive the stakes in further to compress the mattress tightly against the slope

- Secure the toe of the mattress using a suitable technique such as Vegetated Riprap, Live Fascines, Rootwad Revetments or Coir Rolls
- Backfill around and in between the branches of the mattress by us ing material excavated from the trench, and additional soil if needed
- Work the soil in well around the branches
- Tamp soil by walking on it, and lightly water the soil with buckets or a hose to wash it down into the stems, and ensure good stem to soil contact
- It is necessary for the thicker, basal ends of the mattress to get good soil cover for rooting; at least 1/4 of the depth of the mattress is recommended
- Leaving some branches exposed above the soil will facilitate sprouting

Construction Considerations

- Brushy cuttings (stems having leaves and twigs) of tree and shrub species capable of propagating from cuttings, typically willow species
- 10 to 50 branches per metre of bank to be protected should be harvested
- The cuttings should be long (1.5 to 3 m), straight, brushy, 2 to 3 year old branches up to 0.04 m in diameter
- For optimum success, the fascines should be soaked for 4-10 days or installed on the same day they are harvested and prepared
- Wooden construction stakes and/or live stakes are used
- The length of stakes will vary based on soil conditions
- Biodegradable natural fibre or polypropylene rope is usually preferable to wire
- A sledgehammer will be needed for driving in the w ooden stakes, or a dead-bl ow mallet and pilot bar (rebar) for live stakes

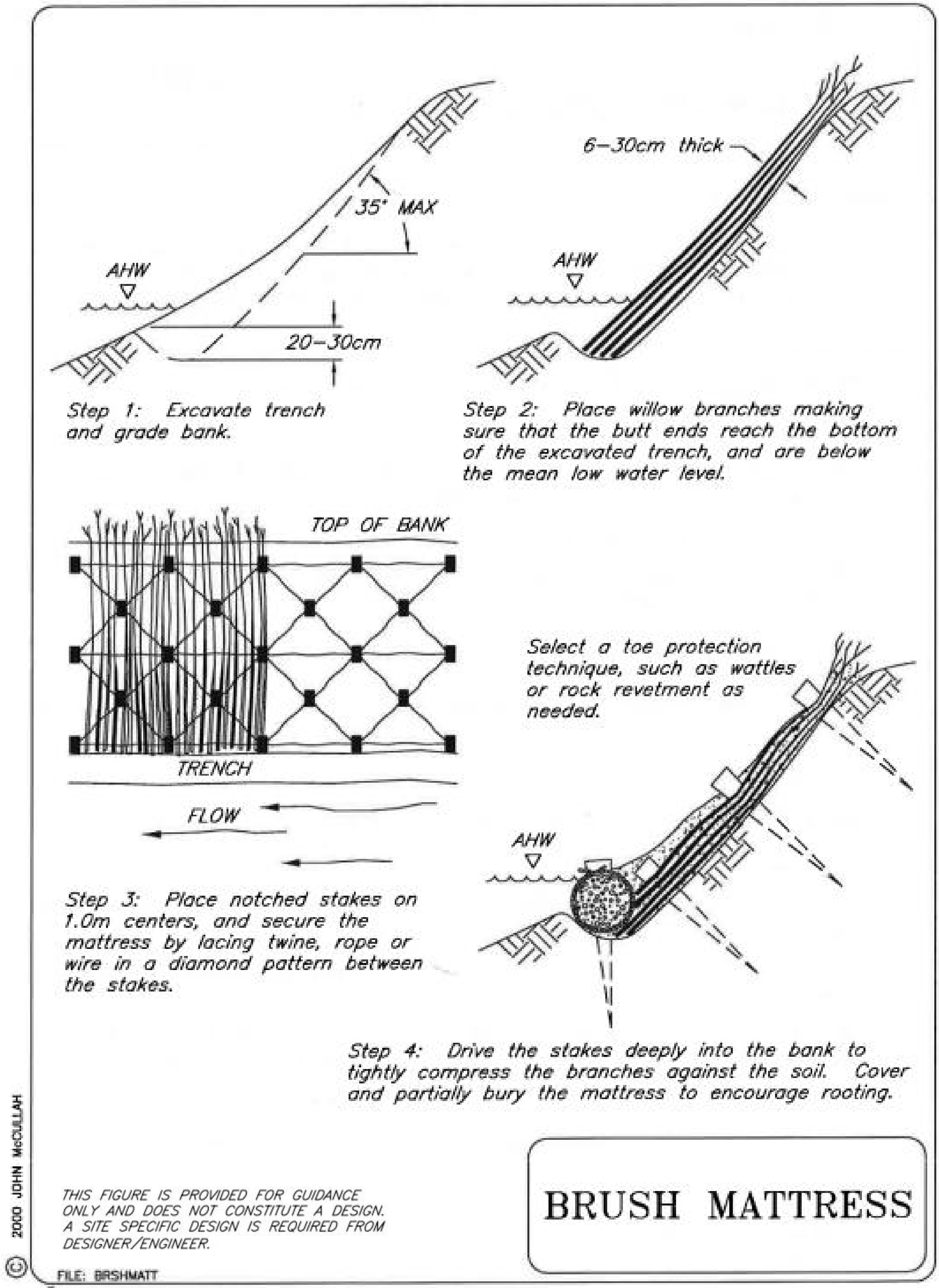
Inspection and Maintenance

- During the first growing and flood season, periodic maintenance is necessary to make sure the stakes and cord/wire are still securing the mattress to the streambank, and to verify that erosive flows are not getting behind the mattress
- Inspect for flanking or undermining of the revetment

Design Considerations

- The optimal bank slope for brush mattresses is 1V:2H, because stem to soil contact can be maximized at that angle; however, mattresses can successfully be installed at angles of 1V:1.25H or steeper, but sprouting will occur mostly at the basal ends

- In some cases, fill will be required to bring the bank to the desired grade
- If rock fill is used, at least 0.5 m of soil should be placed over the rock to ensure proper stem to soil contact for the cuttings
- It is important to protect the brush mattress against erosion outflanking and undermining
- Some type of toe protection is necessary, and depending upon the erosivity of the bank, keys or refusals may be necessary at upstream and downstream ends
- Rock toe protection is useful with brush mattresses
- If there is any overbank runoff occurring, flows should be diverted around the brush mattress and outleted in a stable area
- If piping is evident, a granular filter should be installed underneath the brush mattress
- The survival of cuttings that do not have their basal ends near the annual low water level is questionable in arid and semi-arid environments
- Studies have shown that brush mattresses have stabilized a bank in a test flume against velocities exceeding 7 m/s


6–30cm thick
35° MAX
AHW
20–30cm
Step 1: Excavate trench and grade bank.
Step 2: Place willow branches making sure that the butt ends reach the bottom of the excavated trench, and are below the mean low water level.
TOP OF BANK
TRENCH
FLOW
Step 3: Place notched stakes on 1.0m centers, and secure the mattress by lacing twine, rope or wire in a diamond pattern between the stakes.
Select a toe protection technique, such as wattles or rock revetment as needed.
Step 4: Drive the stakes deeply into the bank to tightly compress the branches against the soil. Cover and partially bury the mattress to encourage rooting.
THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.
BRUSH MATTRESS
© 2000 JOHN McCULLAH
FILE: BRSHMATT

Live Siltation Streambank Stabilization Techniques	B.M.P. #32

Description and Purpose

- A re-vegetation technique used to secure the toe of a stream bank, trap sediments, and create fish rearing habitat. It can be constructed as a living or a non-living brush system at the water's edge and will help to secure the toe of a streambank

Applications

- An appropriate practice along an outer stream bend with sufficient scour or toe protection

Advantages

- Can be constructed in combination with rock toes, Rootwad Revetments, Coir Rolls, Live Fascines, and Brush Mattresses
- A very effective and simple conservation method using local plant materials
- Valuable for providing immediate cover and fish habitat while other re-vegetation plantings become established
- The protruding branches provide roughness, slow velocities, and encourage deposition of sediment
- The depositional areas are then available for natural recruitment of native riparian vegetation

Limitations

- If using a living system, cuttings must be taken during the dormancy period

Construction

- Construct a V-shaped trench at the annual high water (AHW) level, with hand tools or a backhoe
- Excavate a trench so that it parallels the toe of the streambank and is approximately 0.6 m deep
- Lay a thick layer of willow branches in the trench so that 1/3 of the length of the branches is above the trench and the branches angle out toward the stream
- Place a minimum of 40 willow branches per metre in the trench
- Backfill over the branches with a gravel/soil mix and secure the top surface with large washed gravel, bundles/coir logs, or carefully placed rocks

- Both the upstream and downstream ends of the live siltation construction need to transition smoothly into a stable streambank to reduce the potential for the system to wash out
- More than one row of live siltation can be installed
- A living and growing siltation system typically is installed at the annual high water (AHW) elevation
- A non-living system can be constructed below AHW during low water levels
- If it is impossible to dig a trench, the branches can be secured in place with logs, armour rock, bundles made from wattles, or coir logs

Construction Considerations

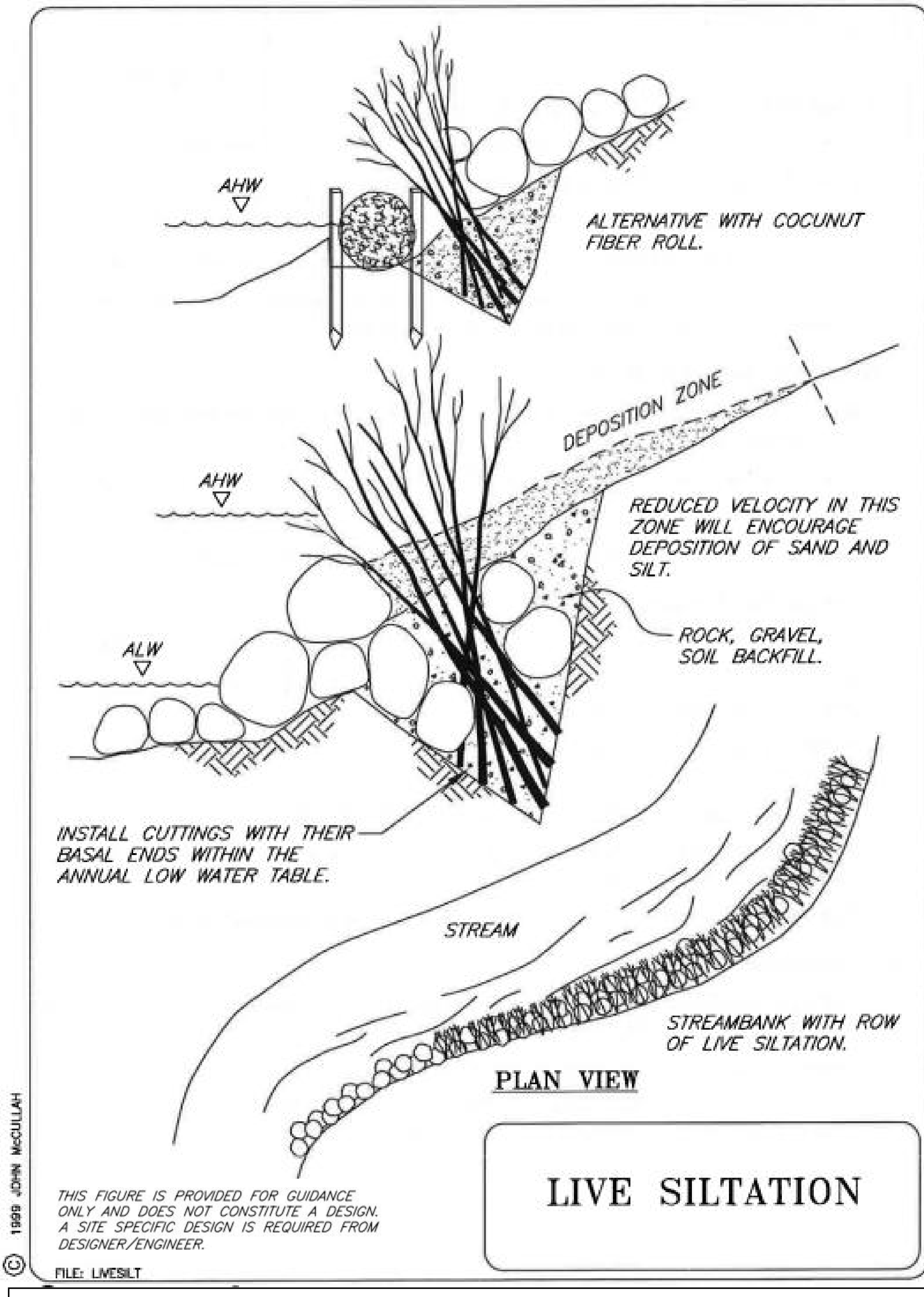
- Natural stone, willow wattles, logs and/or root wad revetments are needed for toe and scour protection
- The live siltation will require live branches of shrub willows 1 to 1.5 m in length
- Branches should be dormant, and need to have the side branches still attached
- Any woody plant material, such as alder, can also be installed for a non-living system

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- During the first year, the installation should be checked for failures after all 1-year return interval and higher flows, and repaired as necessary
- During summer months of the first year, ensure that cuttings are not becoming dehydrated by watering as necessary
- Cuttings will not promote siltation if not located at the water's edge
- If located further up the bank, cuttings may dry out, and will only trap sediments and slow velocities during high flows
- Cuttings may not grow well if not handled properly prior to installation

Design Considerations

- Cuttings should be placed adjacent to the water's edge to ensure effective sediment trapping and velocity reduction at the toe of slope
- At least 40 branches per metre should be installed
- This technique may be used for velociti es up to 2 m/s, but velocities should be at least 0.25 m/s for the system to function properly


AHW
ALTERNATIVE WITH COCUNUT FIBER ROLL.
DEPOSITION ZONE
AHW
REDUCED VELOCITY IN THIS ZONE WILL ENCOURAGE DEPOSITION OF SAND AND SILT.
ALW
ROCK, GRAVEL, SOIL BACKFILL.
INSTALL CUTTINGS WITH THEIR BASAL ENDS WITHIN THE ANNUAL LOW WATER TABLE.
STREAM
STREAMBANK WITH ROW OF LIVE SILTATION.
PLAN VIEW
LIVE SILTATION
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FILE: LIVESILT

Willow Posts and Poles Streambank Stabilization Techniques	B.M.P. #33

Description and Purpose

- Willow trees and shrubs may be propagated by planting cuttings
- Although smaller (< 0.04 m) diameter cuttings (stakes) grow more vigorously than older, larger materials (posts and poles), larger materials provide mechanical bank protection during the period of plant establishment
- Dense arrays of posts or poles reduce velocities near the bank or bed surface, and long posts or poles reinforce banks against mass instabilities occurring in shallow failure planes
- Willow posts and poles can be used in most areas in need of re-vegetation
- Those most conducive to this practice are midbank areas on banks with a 1V:2H slope or shallower
- Although posts and poles can be planted in the toe and upper bank areas, vigorous growth is rare, due to drowning of posts and desiccation of the poles

Applications

- Willow species are lead pioneers in riparian zones Once established, willow provide cover and create conditions conducive to colonization by other native species that comprise the riparian community
- Functional riparian zones provide habitats for a wide range of aquatic and terrestrial plants and animals, generally improve bank stability, mediate water quality, and improve visual resources

Advantages

- Willow posts and poles are excellent additions to any technique that requires excavation, particularly when the depth and location of the excavation intercepts soils conducive to willow growth
- Willow posts and poles may be inserted into aggregate/broken rock or soil backfill and thus become incorporated with the structure as they root
- They can also be incorporated into many techniques during construction (e.g., Vegetated Riprap**,** Vegetated Gabions)**,** and can be planted in the keyways of many structures
- When placed along a channel with perennial flow, willows generally will not survive when planted at the toe, but may serve as short-term protection for plantings at higher elevations

- If permanent protection is needed, structural measures like stone toes are recommended
- Willow posts and poles are inexpensive to acquire, install, and maintain
- Willow posts and poles provide long-term protection
- The mature willows provide canopy cover for the stream which also lowers stream temperatures, and creates more favourable conditions for the aquatic and terrestrial fauna
- Aquatic and terrestrial habitat is provided and/or improved through willow posts and poles
- Willows act as a pioneer species, and allow other plant species to later colonize the area during and after the willows become established

Limitations

- Approval for tree harvesting may be required from the GNWT Environment and Natural Resources
- Willows generally do not grow into the stream or above the top of bank
- Willow posts and poles have higher survival rates when planted during their dormant season, so planning should be adjusted accordingly
- Optimum stabilization is not achieved until the willows become established, typically at least one season after installation, although they provide some reinforcement immediately following installation
- Machinery access may be limited

Construction

- Willow poles and posts should be planted deeply (1 to 2 m) in holes created by a backhoe with a “stinger” attachment or with an auger.

Construction Considerations

- Willow poles, approximately 0.05 to 0.15 m in diameter, and 1.8 to 3 m in length should be utilized
- Optimum hole digging equipment is a backhoe (with "Waterjet Stinger", normal Stinger or auger attachment)
- An excavator with bucket can also be used

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans

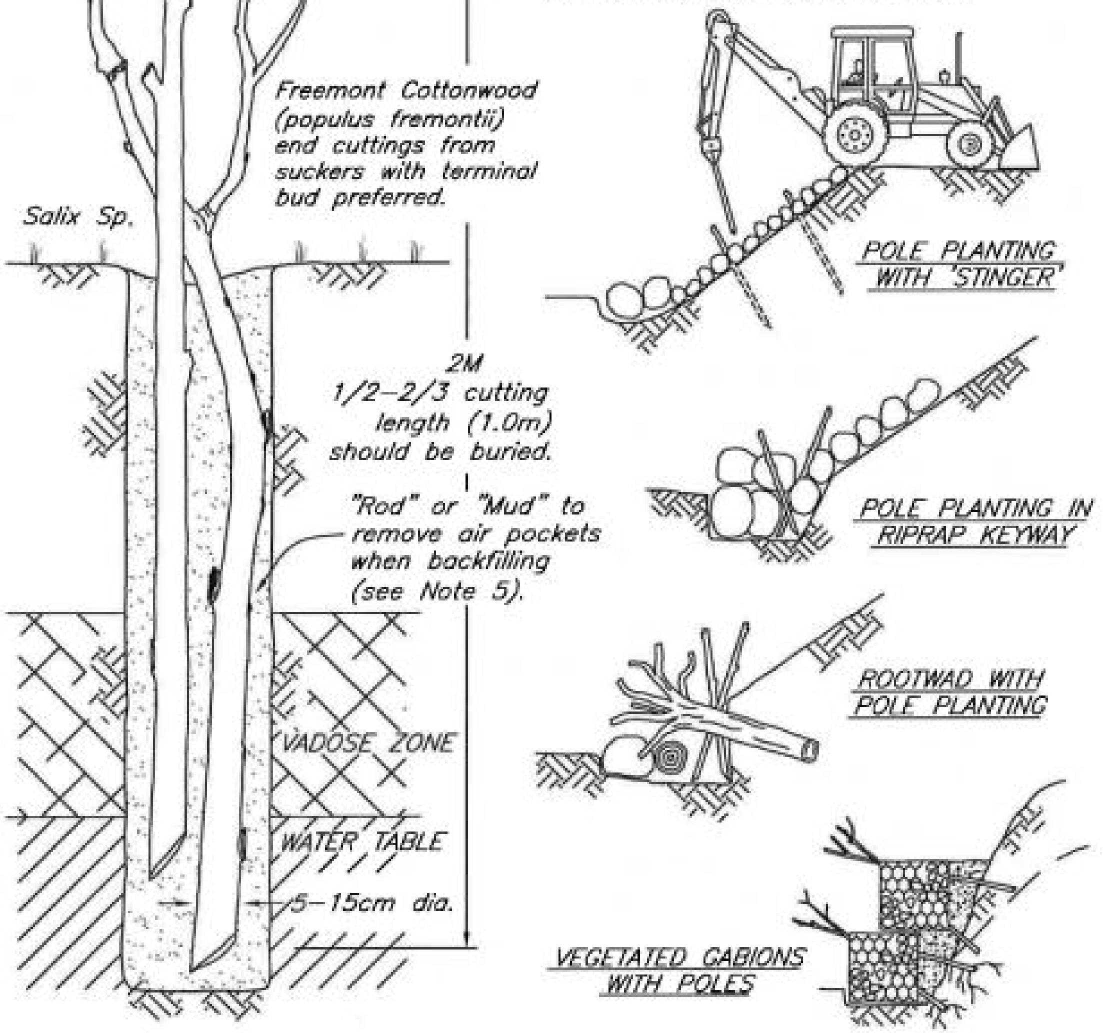
- Willow posts should be inspected for vigor, dehydration, and animal browsing problems
- Desiccation (severe drying) and browsing are the two biggest reasons for failure
- Often, willow post installations need to be fenced for a year or so, especially in agricultural areas, to allow the willows to get established
- Willows that are not planted deeply enough, have too much of their stem exposed, or do not have good stem to soil contact can dry out and die before getting established

Design Considerations

- Willow cuttings should be planted while dormant, and care should be taken to prevent desiccation or dormancy break of cuttings between harvest and planting
- Poles and posts should be deeply planted (1 to 2 m) in holes created using a hydraulic hoe with an auger or metal "stinger" attachment , or an excavator bucket
- Poles should be planted to such a depth that desiccation does not occur during summer (for sites with water tables lower than the stream) and poles are not undermined by local scour during high flows
- Augered holes offer the advantage that soils added back to the hole, adjacent to the planted stem, are not compacted
- Good contact between the plant stem and soils is essential, so holes that do not collapse must be refilled with compacted soil to prevent desiccation of the plants due to air pockets
- High stream flows that occur shortly after planting can ensure collapse of the holes and filling of air pockets
- Only a small portion of the pole should remain above the surface of the ground – about 80% of the cutting should be buried, to prevent desiccation and ensure good stem to soil contact
- Willow success is governed by soil texture and moisture regime, and damage from browsing
- Planting willow posts deeply enough to maintain contact with groundwater table throughout the growing season is important to survival

CONSTRUCTION TECHNIQUES

Plant poles deeply during construction of biotechnical streambank work.



NOTES:

1. Pole cuttings of willow or cottonwood are longer and have a larger diameter than branch cuttings or live stakes.
2. Larger diameter cuttings have a greater supply of stored energy (stored photosynthesis) than smaller diameter cuttings.
3. Pole cuttings are better suited for highly erodible areas and sites with fluctuating water levels.
4. The pole cuttings should extend through the vadose zone and into the permanent water table. At least 1/2 to 2/3 of the pole should be below the ground, at least 1.0m, and long enough to emerge above adjacent vegetation.
5. "Muddying" – filling the hole with water and then soil to make a mud slurry can remove air pockets.

WILLOW POSTS & POLES

POLEPLNT

Rock Vanes Streambank Stabilization Techniques	B.M.P. #34

Description and Purpose

- Vanes are individual transverse (structure have two parallel sides) structures angled into the flow in order to reduce local bank erosion by redirecting flow from the near bank to the center of the channel
- The instream tips of the structures are typically low enough to be overtopped by all flows and crests slope upward to reach bankfull stage elevation at the bank
- Structures angled upstream redirect overtopping flows away from the protected bank
- Vanes are installed to provide toe protection and improve lateral stability by redirecting flow away from eroding banks, while providing greater environmental benefits than a stone blanket or revetment
- Vanes can increase scour at the tips, in the backwater area, and at the vane edge or shoreline, and increase the diversity of stream depth, velocity and substrate
- When properly positioned, a vane deflects flow away from the bank and induces deposition upstream and downstream of the structure
- This redirection of flow reduces velocity and shear stress along the bank while creating a secondary circulation cell that transfers the energy toward the middle of the channel
- Rock vanes, protruding 1/3 of the bankfull width into the channel and oriented at an upstream angle between 20° and 30°, move the thalweg an average of 20% of the bankfull width away from the eroding bank. Therefore, vanes, whether made of rock and/or logs, redirect water away from streambanks into the center of the channel
- This serves to decrease shear stress on banks, as well as creating aquatic habitat in the scour pools formed by the redirected flow
- By increasing shear stress in the center of the channel, the vanes create a stable width/depth ratio, maintain channel capacity and maintain sediment transport capacity and competence
- J-hook vanes can also be paired and positioned in a channel reach to initiate meander development or migration

Rock Vanes Streambank Stabilization Techniques	B.M.P. #34

Applications

- Vanes are to be designed by a qualified person
- Vanes are installed on the outside of stream bends where high velocity and shear stress is causing accelerated bank erosion
- Can often be used at sites where riprap revetments are traditionally applied but greater environmental benefits are desired
- Vanes and other redirective, discontinuous practices should only be applied with direction from a river engineer at project sites where infrastructure is immediately adjacent to the protected bank
- Can be combined with other structures such as longitudinal stone toe or toe or vegetated riprap if continuous protection from channel erosion is necessary
- Vanes have been successfully installed in rivers and streams with bankfull widths ranging from 9 m to 150 m, with gradients between 0.05 to 0.0003, and in a variety of bed materials
- The ability of vanes to redirect flows and shift local scour and stream power to the center of the channel makes the technique particularly effective where bridge infrastructure is threatened by scour or flanking
- Vanes can be used where it is necessary to preserve as much of the existing bank vegetation as possible, and where aquatic habitat and substrate complexity is an important consideration
- Unlike riprap revetment, which requires reshaping of the bank for installation, vanes require bank disturbance only where keys are placed. This provides opportunities for using vanes in combination with soil biotechnical erosion control techniques

Advantages

- Since rock vanes can successfully reduce near-bank velocities and shear stress, bank erosion is reduced and on-bank vegetation establishment is greatly improved
- Vanes are often combined with other biotechnical soil stabilization measures for bank areas between the vanes
- Vegetated ground cover techniques such as Turf Reinforcement Mats, Erosion Control Blankets, Live Stakes, Live Brush Mattress, and Vegetation Alone are appropriate candidates for combined measures
- Rock vanes are sometimes used in conjunction with continuous and resistive armouring measures, such as Cobble or Gravel Armour, Vegetated Riprap or Longitudinal Stone Toe, when additional protection between the vanes is required

- Live Brush Layering, Willow Poles, and Live Siltation are extremely effective when implemented at the bank during excavation of the keyways
- Posts and Poles can be used to create overhanging cover for pools up- or downstream from rock vanes
- Intermittent structures such as rock vanes provide aquatic habitats superior to continuous resistant structures like Riprap and Longitudinal Stone Toe
- Controlled scour at the vane tip, the creation of pool/riffle bed complexity, and increased deposition at the upstream end are the major environmental benefits of vanes
- Vanes provide some fish rearing and benthic habitat, create or maintain pool and riffle habitat, provide cover and areas for adult fish, and create low velocity refuges for fish
- Rock vane installation can often be accomplished from the top of the bank, and does not require bank regrading, which minimizes the impacts to existing vegetation and reduces the amount of site disturbance needed for installation
- The redirection of impinging flows away from the bank and the sedimentation on the upstream side of the rock vane creates areas where vegetation can effectively re-establish. Thus, areas of previous active bank erosion become depositional, vegetate, and subsequently become permanently stable
- Vanes can be used to reduce local streambank erosion, improve lateral stability, and modify flow direction and local scour, while simultaneously gaining environmental benefits
- The technique is appropriate under a range of flow conditions and bed materials and can be used in series to redirect flows around bends
- Vane installation does not require extensive bank reshaping, and most heavy equipment work can be done from the top of the bank, further reducing site disturbance
- Vanes require less rock and heavy equipment than riprap for a similar length of protected bank
- When used to protect bridge infrastructure, vanes placed upstream of abutments force the thalweg toward the center of the channel

Limitations

- Unintended impacts can result from improper vane design, placement and construction. **Design should be conducted by a qualified person.**

- **Complex sites or sites near existing infrastructure (bridges, pipeline crossings) should be designed by a river engineer**.
- The rock vanes should be used at a location where frequent monitoring can occur, in case of vane failure or unintended erosion from high flows. Rock vanes may not work consistently where active channel bed erosion, deposition and transport of bedload occurs.
- Approval for in-stream works may be required by the Department of Fisheries and Oceans Canada (DFO) and/or the GNWT Environment and Natural Resources
- If the vane is not properly keyed into the bank, it is likely to fail, creating new localized erosion problems
- Improper vane angle and crest elevation can redirect flow in unintended directions, triggering downstream or cross-channel erosion

Construction

- Construction will require excavation of a key a minimum of 3 m into the bank, and up to the height of bankfull elevation
- If the bank is higher than bankfull, a bench at bankfull elevation can be built to key in the vane
- The keyways should be constructed by digging a trench, placing rock and installing vegetation, and backfilling
- If vegetative techniques are used, such as Willow Post and Poles or Live Siltation, the chances of successful establishment can be increased by "watering in" the cuttings
- Self launching rock can be placed on the existing substrate, however, if footer rocks are necessary, then excavation of the trench into the channel bed for the footer rocks will be required
- The depth of the trench varies depending on bed material
- For a gravel or cobble bed stream, a depth of twice the diameter of the average vane rock is recommended for the footer trench
- The footer rocks should be placed with a gap between the stones equal to 1/3 their diameter which allows them to interlock as the vane adjusts and equilibrates
- In sandy bed material, or where excessive scour is predicted, the trench depth should be four times the diameter of the average vane rock and the gaps between the rocks should be eliminated
- It may be feasible to place a filter fabric geotextile under the footer stones on sand-bed streams

Construction Considerations

- Vanes are generally constructed with graded rock; however, successful vanes have also been constructed from single logs and log cribs with stone fill
- An excavator or backhoe is usually needed to construct the keyways and place the vane rocks

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- The vane should be inspected regularly
- Maintenance staff should determine:
  - Is the vane intact?
  - Are flows being redirected where expected?
  - Is there any unintended scour?
  - Is there deposition on the upstream side of the vane?
  - Has the vane (or vane series) created or increased erosion or lateral instability downstream of the structure?
- If the vane is not properly keyed into the bank, it is likely to fail, creating new localized erosion problems
- Improper vane angle and height can redirect flow to unintended places, creating further bank erosion downstream of the structures

Design Considerations

- Regardless of project goals, the key design and construction elements of vanes are stream discharge, and vane length, angle, crest elevation, slope, rock size, the placement of appropriate footer rocks, and vane spacing if using the structures in series
- **Designs should be created by a river engineer**
- ***Hydraulic Considerations**:*
  - The primary hydraulic design consideration for vanes is the water surface elevation of bankfull stage
  - Cross vanes are independent of design high-water and freeboard and vegetation establishment is the most common bank protection from bankfull stage to top of bank.

- ***Length***:
  - The vane should extend 1/4 to1/3 the bankfull width of the channel
  - However, this maximum applies to small streams; the larger the channel, the shorter the vane should be relative to the channel width.
- ***Angle:***
  - Optimum results are obtained when the vane is oriented upstream at an angle with the protected bank between 20° and 30°. A 20° angle requires a longer vane, but protects a greater length of bank
  - When orienting vanes for the specific goal of protecting bridge infrastructure, i.e., directing flow through and reducing scour at bridge abutments, a 30° angle is generally more effective at reducing scour at the abutment and moving maximum scour depth toward the center of the channel than the 20° angle
- ***Height***:
  - The crest elevation of the bank end of the vane should be equal to the bankfull or AHW stage elevation
  - The key into the bank is also designed to bankfull elevation
  - The vanes must be keyed into the bank at least 3 m
  - If the bank is higher than bankfull, build a bench at bankfull elevation to key in the vane
- ***Crest Slope***:
  - Vanes are designed to be overtopped at the tip by all but the lowest flows and should pitch from the bank to the tip of the vane with a 3 to 7% slope
  - Steeper vanes act more like spurs or barbs and have different effects on scour and velocity
- ***Rock Gradation and Shape***:
  - When possible, vanes should be constructed with graded (self-launching) stone. Self-launching stone will automatically stabilize the toe of the structure in any scour holes that form
  - Where additional scour is anticipated, more stone may be added to widen the rock vane crest
  - In this way, stone may be sacrificed without modifying the crest elevation

- Weirs and vanes which are placed on sand beds devoid of gravel may subside as sand is washed from beneath the stone. This problem may be addressed by placing filter fabric or a filter layer of finer stone underneath the stone spur
- In very sandy-bottomed streams, it is advantageous to build vanes using "shot rock" or well-graded stone that includes fines, as they prevent ‘through-flow’ of sand, and subsequent scour

▪ ***Rock Size:***

- The size of the rock will depend upon the stream size and shear stress
- See comments below under "Hydraulic Loading" on rock sizing.

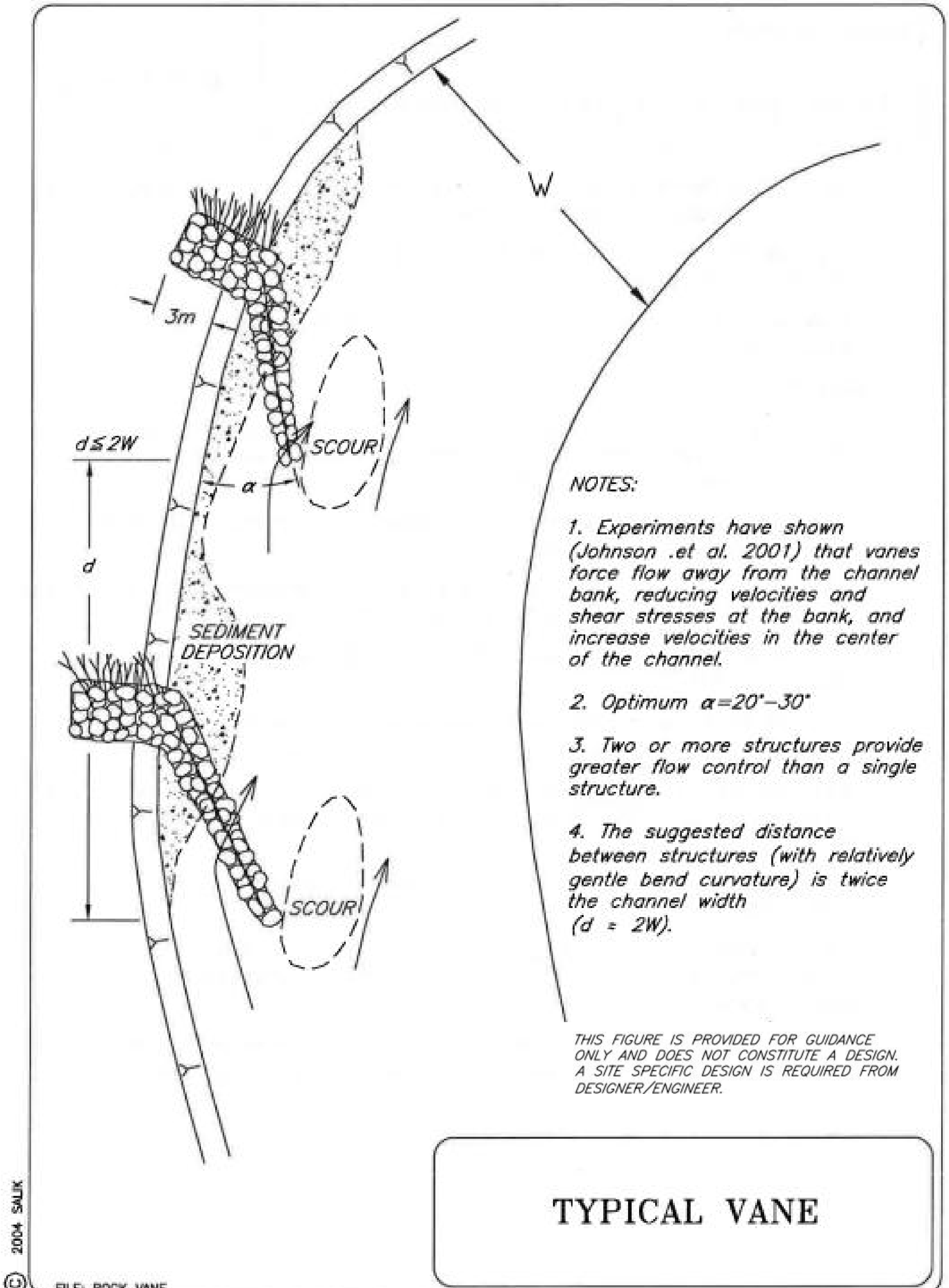
▪ ***When to use footers***:

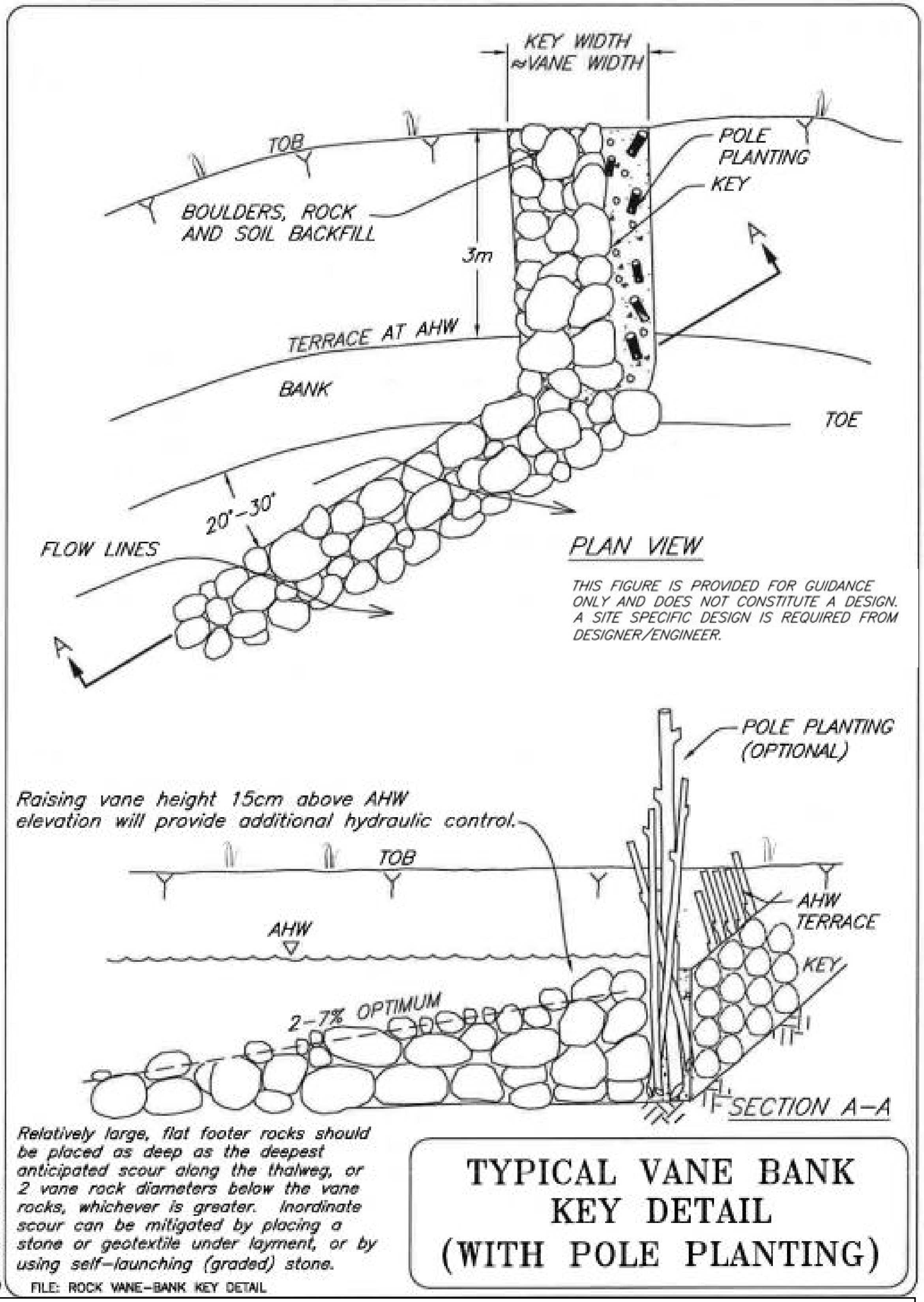
- The footer rocks should be heavier, longer, and flatter than the average vane rocks
- As a rule of thumb, the weight of the heaviest footer rock is comparable to the heaviest rock used for riprap for the design flow
- In sandy streams, an extra layer of footer rocks may be necessary to compensate for the additional scour
- Even in small sand bed streams, 2 m of scour next to a structure like this is not uncommon

▪ ***Spacing***:

- The distance from the convergence point of impinging flows along the eroding bank (or upstream corner of a bridge abutment) to the upstream tip of the vane should be twice the channel width
- When using vanes in series, the spacing between the upstream tips of the vanes should also be twice the channel width
- When using vanes in a series along an outer bend, the upstream vane should be located at the point where impinging flows are first causing erosion
- The second vane is to be located at the point on the bank that will be impacted by the redirected flows
- This method of spacing requires that the design be based on the flow angles, flow depth and flow direction from the anticipated design storm stage
- As a general rule, small to moderate rivers, less than 20 m wide and where the vane projects approximately 1/3 the width, require spacing that is approximately twice the channel width

- Permissible shear and velocity for rock vanes is related to the size of rock used in construction
- Other factors, such as the angularity of the stone, the thickness of the layers of stone, and the angle at which the faces of the stone structure are constructed also come into play
- The Maynord (1995) equation gives a D_{50} stone size for an angular stone riprap revetment of 0.875 m if the near-bank vertically-averaged velocity is 3.5 m/s, and flow depth = 1 m, and stone is placed on a bank slope of 1V:1.5H. Use of riprap larger than this is unusual


W
3m
d≤2W
d
α
SCOUR
SEDIMENT
DEPOSITION
SCOUR
NOTES:
1. Experiments have shown (Johnson .et al. 2001) that vanes force flow away from the channel bank, reducing velocities and shear stresses at the bank, and increase velocities in the center of the channel.
2. Optimum α=20°–30°
3. Two or more structures provide greater flow control than a single structure.
4. The suggested distance between structures (with relatively gentle bend curvature) is twice the channel width (d = 2W).
THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.
TYPICAL VANE
© 2004 SALIK
FILE: ROCK VANE


KEY WIDTH
≈VANE WIDTH
TOB
POLE
PLANTING
KEY
BOULDERS, ROCK
AND SOIL BACKFILL
3m
A
TERRACE AT AHW
BANK
TOE
20°–30°
FLOW LINES
PLAN VIEW
THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.
A
POLE PLANTING
(OPTIONAL)
Raising vane height 15cm above AHW elevation will provide additional hydraulic control.
TOB
AHW
AHW
TERRACE
KEY
2–7% OPTIMUM
SECTION A–A
Relatively large, flat footer rocks should be placed as deep as the deepest anticipated scour along the thalweg, or 2 vane rock diameters below the vane rocks, whichever is greater. Inordinate scour can be mitigated by placing a stone or geotextile under layment, or by using self–launching (graded) stone.
TYPICAL VANE BANK
KEY DETAIL
(WITH POLE PLANTING)
© 2004 SALIK
FILE: ROCK VANE–BANK KEY DETAIL

Longitudinal Stone Toe Streambank Stabilization Techniques	B.M.P. #35

Description and Purpose

- **Should be designed and monitored by a qualified person.**
- A longitudinal stone toe is continuous bank protection (revetment) consisting of a stone dike placed longitudinally at, or slightly streamward of the toe of an eroding bank
- The stone toe is triangular in cross-section
- Success of this method depends upon the ability of rock pieces to self-adjust or "launch" into any scour holes formed on the stream side of the revetment
- The stone toe does not need to follow the bank toe exactly, but should be designed and placed to form an improved or "smoothed" alignment through the stream bend. The "smoothed" longitudinal alignment results in improved flow (less turbulence) near the toe of the eroding bank
- It is especially effective in streams where most erosion is due to relatively small but frequent events
- It protects the toe so that slope failure of a steep bank landward of the stone toe will produce a stable angle
- Such a bank is often rapidly colonized by natural vegetation

Applications

- Longitudinal stone toe can be applied in some situations where the bankline needs to be built back out into the stream, where the existing stream channel needs to be realigned, where the outer bank alignment makes abrupt changes (scallops, coves, or elbows), or where the stream is not otherwise smoothly aligned

Advantages

- A variety of techniques can be used with Longitudinal Stone Toe
- Willow posts and poles may be incorporated into key sections and used to re-vegetate the middle and upper bank above stone toe
- Longitudinal stone toe has proven cost-effective in protecting lower banks and creating conditions leading to stabilization and re-vegetation of steep, caving banks
- Live Siltation, Live Brush Layering, Live Brush Mattresses, Live Staking, Live Fascines, Turf Reinforcement Mats, Erosion Control Blankets, Geocellular Containment Systems, Vegetated Articulated Concrete Blocks, Vegetated Riprap, Soil and Grass Covered Riprap, and Vegetated Gabion Mattress may all be used to provide rapid re-vegetation and additional protection on middle and upper banks

- Cobble or Gravel Armour, Vanes with J Hooks, Cross Vanes, Boulder Clusters, and Newbury Rock Riffles may be used to enhance benthic and water column habitats
- Longitudinal Stone Toe with Spurs is a variation on this technique
- It has documented environmental benefits, especially for aquatic habitat
- Stone interstices provide cover and habitat for smaller fish and other organisms, and rocky surfaces provide stable substrate for benthic invertebrates. However, fish habitat provided by Longitudinal Stone Toe has been found generally inferior to that provided by intermittent, redirective measures like Spur Dikes, Rock Vanes, or Bendway Weirs
- Vegetative cover can become established, even growing through the crevices between rocks, and can provide canopy and a source of woody debris
- Bank grading, reshaping, or sloping is usually not needed (existing bank and overbank vegetation need not be disturbed or cleared), nor is a filter cloth or gravel filter needed
- If the stone is placed from the water side, existing bank vegetation need not be disturbed. This necessitates putting an excavator in the stream, however.
- It is very cost-effective and is relatively easy to construct
- It is simple to design and specify
- It is easily combined with other bank stability techniques that provide superior habitat compared to pure riprap

Limitations

- Requires agency approval
- Only provides toe protection and does not protect mid- and upper bank areas
- Some erosion of these areas should be anticipated during long-duration, high energy flows, or until the areas become otherwise protected
- Longitudinal stone toe is not suitable for reaches where rapid bed degradation (lowering) is likely, or where scour depths adjacent to the toe will be greater than the height of the toe

Construction

- **Should be designed and monitored by a qualified person.** Complex stream conditions may require a river engineer to design the structure.
- Longitudinal stone toe should be constructed in an upstream to downstream sequence
- Construction requires heavy equipment for excavation of the keys (tie-backs) and efficient hauling and placement of stone
- Can be constructed from within the stream, from roadways constructed along the lower section of the streambank itself, or from the top
- The preferred method is from the point bar side of the stream (especially possible with ephemeral or intermittent streams), as this causes the least disturbance of existing bank vegetation
- The least preferred is from the top of the bank, as it disturbs or destroys more bank vegetation and the machine operator's vision is limited
- Usually, the keyways are excavated first and rock is placed into the key by excavator bucket with thumb
- The rock is then formed into tie-backs (if needed) and finally the stone toe is constructed along a "smoothed" alignment, preferably with a uniform radius of curvature throughout the bend
- In a multi-radius bend, smooth transitions between dissimilar radii are preferred

Construction Considerations

- Stone for the structure should be well graded and properly sized and of rock types which will not weather or degrade or create acid drainage or release metals
- The Maynord (1995) equation gives a D_{50} stone size for an angular stone riprap revetment of 0.875 m if the near-bank vertically averaged velocity is 3.5 m/s, and flow depth = 1 m, and stone is placed on a bank slope of 1V:1.5H

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans
- Stone toe structures rarely require maintenance
- Maintenance and monitoring requirements should be linked to consequences of failure
- Features that should be monitored are similar to those for all stone structures:

– Loss of stone due to subsidence, scour of underlying sediments, ravelling or excessive launching of rock into new low areas on the channel bed

– Extreme scour or bed lowering on the stream side of the toe can cause the entire mass of stone to launch, creating an opening or gap in the longitudinal structure

– If this situation is anticipated or encountered, the problem can be remedied by adding more rock for additional width

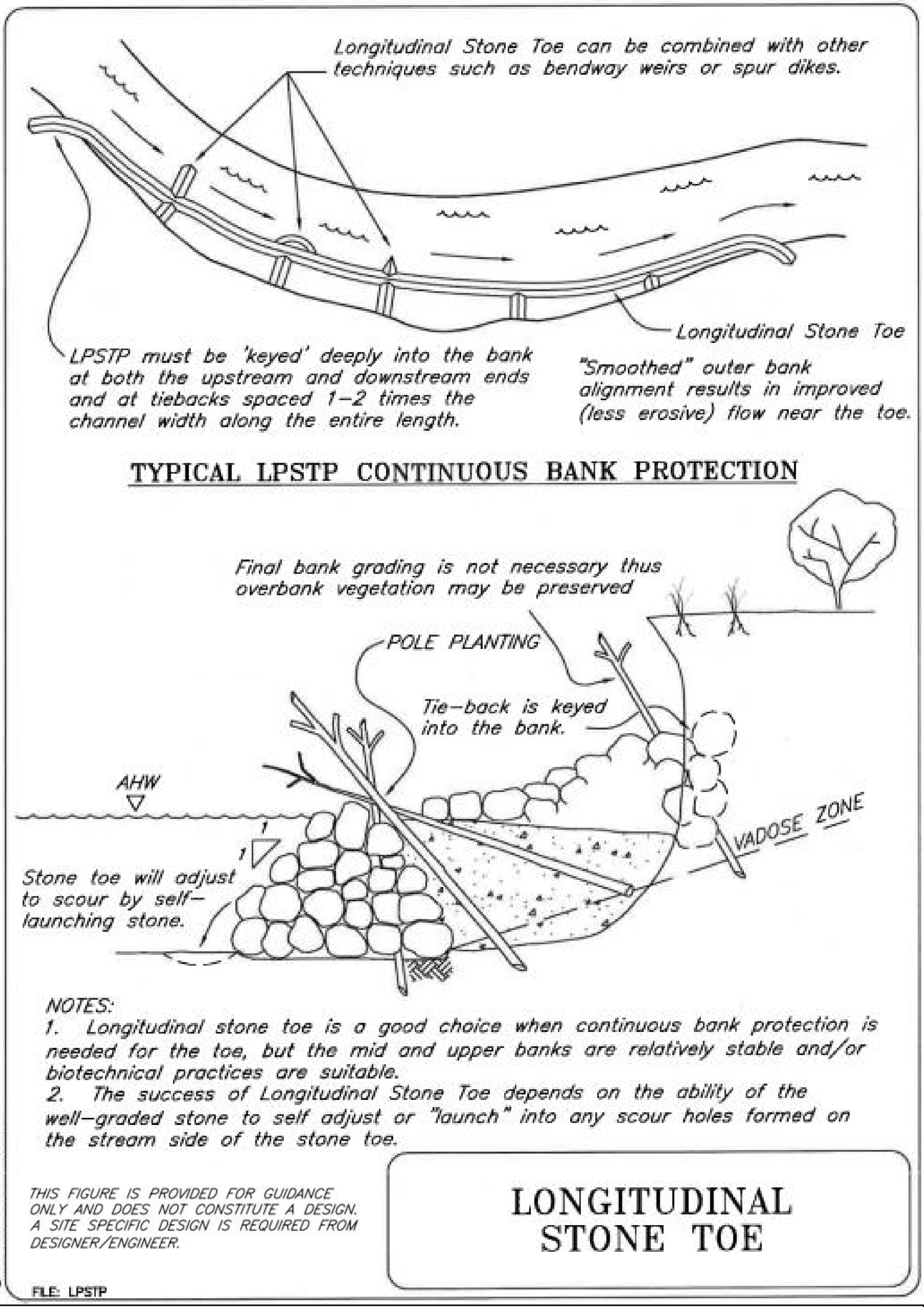
– Longitudinal stone toe may be flanked during extremely high flows if the key trenches are incorrectly built or if the tiebacks are spaced too widely or are constructed with inadequate amounts of stone

– These terminal key trenches at the upstream and downstream ends should be excavated into the bank at an angle of approximately 30° with the primary flow direction and of sufficient length that flows will not be able to get around them during the design storm

Design Considerations

- **Should be designed by a qualified person.** Complex channel conditions will require a river engineer to design the longitudinal stone toe
- Longitudinal stone toe can be specified by weight per unit length or to a specific crest elevation
- A specific crest elevation may be specified when the bed of the stream is uneven or deep scour holes are evident
- Longitudinal fill stone toe or weighted riprap toe are similar to stone toe except that the cross-section may be rectangular rather than triangular or peaked
- The dimensions for the weighted riprap toe are based on projected scour depth and a minimum "thickness", which corresponds to stone toe height of 2.5 to 4 times the maximum stone diameter - about 1 to 1.5 m
- Longitudinal stone toe side slopes should be equal to the angle of repose
- Typically stone toe applied at a rate of 3 metric tons of stone per lineal metre of protected bank will have a height of approximately 1 m
- Stone toe constructed with 6 metric tons/m stands approximately 1.5 m high, whereas 1.5 metric tons/m is approximately 0.6 m high
- Longitudinal stone toe must be keyed deeply into the bank at both the upstream and downstream ends and at regular intervals along its entire length

- On small streams, 25 to 30 m spacing between keys (tie-backs) is typical, while on larger streams and smaller rivers, one or two multiples of the channel width can be used as a spacing guide
- Excavation of trenches for keys provides a good opportunity for deep planting willow posts or poles
- The toe itself does not need to be keyed into the streambed because of its ability to "self-launch"
- However, in areas where the bed of the stream is uneven or deep scour holes are evident, the crest of the structure should be constructed to a specific elevation
- The key trenches at the upstream and downstream ends should be excavated into the bank at an angle of approximately 30°, with the primary flow direction and of sufficient length that flows will not be able to get around them during the design storm
- A gentle angle is important for the end keyways, often referred to as "refusals", because it allows for smooth flow transitions coming into and flowing out of the treated reach
- Tiebacks or "refusals" oriented at 90° to the bank have resulted in many failures at the downstream end of the structure, due to flow expansion at that point
- Permissible shear and velocity for longitudinal stone toe is related to the size of rock used in construction
- Other factors, such as the angularity of the stone, the thickness of the layers of stone, and the angle at which the faces of the stone structure are constructed also come into play


Longitudinal Stone Toe can be combined with other techniques such as bendway weirs or spur dikes.
Longitudinal Stone Toe
LPSTP must be 'keyed' deeply into the bank at both the upstream and downstream ends and at tiebacks spaced 1–2 times the channel width along the entire length.
"Smoothed" outer bank alignment results in improved (less erosive) flow near the toe.
TYPICAL LPSTP CONTINUOUS BANK PROTECTION
Final bank grading is not necessary thus overbank vegetation may be preserved
POLE PLANTING
Tie–back is keyed into the bank.
AHW
1
1
VADOSE ZONE
Stone toe will adjust to scour by self–launching stone.
NOTES:
1. Longitudinal stone toe is a good choice when continuous bank protection is needed for the toe, but the mid and upper banks are relatively stable and/or biotechnical practices are suitable.
2. The success of Longitudinal Stone Toe depends on the ability of the well–graded stone to self adjust or "launch" into any scour holes formed on the stream side of the stone toe.
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LONGITUDINAL STONE TOE
© 2000 JOHN McCULLAH
FILE: LPSTP

Vegetated Mechanically Stabilized Earth (VMSE) Streambank Stabilization Techniques	B.M.P. #36

Description and Purpose

- Vegetated Mechanically Stabilized Earth (VMSE) technique consists of live cut branches (brush layers) interspersed between lifts of soil wrapped in fabric, (e.g., coir, synthetic geotextiles or geogrids)
- The live brush is placed in a criss-cross or overlapping pattern between each wrapped soil lift (similar to conventional brush layering)
- The fabric wrapping provides the primary reinforcement for the slope. The live cut stems root, providing stability to the bank or slope through the root ing structure Other vegetative treatment may consist of using a coarse netting for the soil wraps and establishing a herbaceous or grass cover by hydroseeding or by coverage with soil and root mats
- Fabric provides the primary reinforcement and mechanical stabilization, permitting much steeper slopes to be constructed than would be possible with live brush layers alone

Applications

- This technique provides an alternative to vertical retaining structures, (e.g., timber pile walls), and to techniques that require slope stripping and grading, which may result in heavy erosion potential. The use of synthetic geotextiles or geogrids provides greater long-term durability and security
- The fabric or geotextile wrap also provides additional protection to upper sections of the structure that may be subject to periodic scour or tractive stresses
- Brush layers act as a drainage layer that relieves internal pore water pressure, and favourably modifies the groundwater flow regime within the slope to minimize slope stability problems

Advantages

- The presence of vegetation softens the visual appearance of conventional mechanically stabilized earth structures and provides potential habitat for riparian wildlife
- Overhanging branches of the live brush layers provide shade for fish and a substrate for insects and other organisms that the fish feed upon
- Branches also drop leaves and twigs into the stream adding to food sources for various organisms

- Fabric wraps or geosynthetic tensile inclusions provide reinforcement and mechanical stabilization, and permit steeper slopes to be constructed than would be possible with live brush layers alone
- Brush layering treatment by itself is normally restricted to slopes no steeper than 1V:2H. VMSE can be constructed with a slope as steep as 1V:0.5H
- The vegetation shields the fabric against damaging UV radiation, and provides visual and riparian habitat benefits
- In addition, when live brush layers are used, they provide secondary reinforcement, both from the stems themselves, and from rooting along their embedded lengths
- The brush layers act as horizontal drains that favourably modify the groundwater regime in the vicinity of the slope face, thereby improving stability against mass slope failure

Limitations

- A VMSE structure can be constructed during the dormancy period to ensure good vegetative propagation and establishment
- Live cuttings may be harvested during dormancy, and placed in temporary cold storage until they are ready for use during the normal growing season. Cold storage can greatly increase the cost
- Materials procurement can be more demanding and installation more complex, because of the blending of two distinct methods, (e.g., conventional MSE and live brush layering) into a single approach
- Costs can be higher than brush layering alone, because of the expense of the geotextile and additional labour costs
- VMSE streambank structures should be constructed during periods of low water to reduce erosion and ensure a stable foundation for the structure.

Construction

- A VMSE installation begins at the base of the slope and proceeds upwards
- The structure should be supported on a rock toe or base and be inclined at an angle of 10 to 20° to minimize lateral earth forces
- The following guidelines and procedures apply:
  - Excavate a trench to a level below the anticipated depth of scour, and backfill it with rock to provide a secure base for the structure

- The top surface of the rock should be inclined toward the bank at the desired angle and kept level to establish the desired base for the structure
- Construct an earthen structure reinforced with either geotextile fabric, geogrid, or coir fabric and layered with live cuttings on the rock base
- Layers are made with fill material on the geogrid or fabric which is compacted in 7.5 cm lifts to a nominal thickness ranging from 30 to 76 cm
- Thinner lifts should be used at the base of the structure, where shear stresses are higher
- Temporary batter boards may be required at the front face to confine the select fill during the installation process and to form an even face
- When geogrids are used, burlap strips at least 1.2 m wide can be inserted between the earthen fill and the geogrids at the front face to contain the fines and prevent initial ravelling of the fill through the apertures in the geogrid
- The geogrid or fabric sheeting should be allowed to drape down or protrude beyond the front edge of each underlying lift of earthen fill to create at least a 0.9 m overlap when it is pulled up and over the next lift
- The exposed sections of geogrid or fabric layers are pulled up and over the faces of the fill layers and staked in place
- The geogrids should be pulled as uniformly as possible before staking to develop initial tension in the geogrid or fabric. A tractor or winch pulling on a long bar with hooks or nails along its length works well for this purpose
- The tensioned geogrid overlap sections should be secured in place using wood construction stakes spaced every 0.9 m
- Layers of live cut branches are then placed criss-crossed atop the underlying wrapped soil lift
- 2.5 to 5 cm of topsoil should be mixed in with the cut branches to permit soil contact with the stems
- Up to three layers of live, cut branches interspersed with 2.5 to 5 cm of topsoil can be placed in this manner
- The process is repeated with succeeding layers of earth fill, live brush and geogrids (or fabric) until the specified height or elevation is reachedThe recommended earthen lift thickness between geogrid (or fabric) layers depends on various soil and site variables, properties of the reinforcements, and desired safety factor

- The maximum vertical spacing and embedded length of successive geogrid or reinforcement layers are determined from the specified safety factor, slope angle, soil shear strength, allowable unit tensile strength, and interface friction properties of the reinforcement layer

Construction Considerations (Materials and Equipment)

- The technique can also be used in conj unction with other techniques, particularly resistive techniques, designed primarily to protect the bank toe (Vegetated Riprap and Rootwad Revetments) and redirective techniques (Bendway Weirs, Spur Dikes, and Rock Vanes)
- If excessive seepage exits the bank, then a vertical drainage course can be interposed between the bank and the VMSE structure
- Approval of agencies may be required for harvesting of local species
- Select long branches of native tree species that are capable of vegetative propagation. Willows are the most commonly used plant material, because they generally root well from cuttings.
- Alder, poplar and red osier dogwood *(Cornus)* can also be used effectively, particularly when mixed in with willow
- The length of the branches will vary depending upon the desired depth of reinforcement, but they should be long enough to reach the back of an earthen buttress placed against a streambank while protruding slightly beyond the face
- The diameter of the live cuttings will also vary depending on their length, but typically should range from 20 to 50 mm at their basal ends.

Inspection and Maintenance

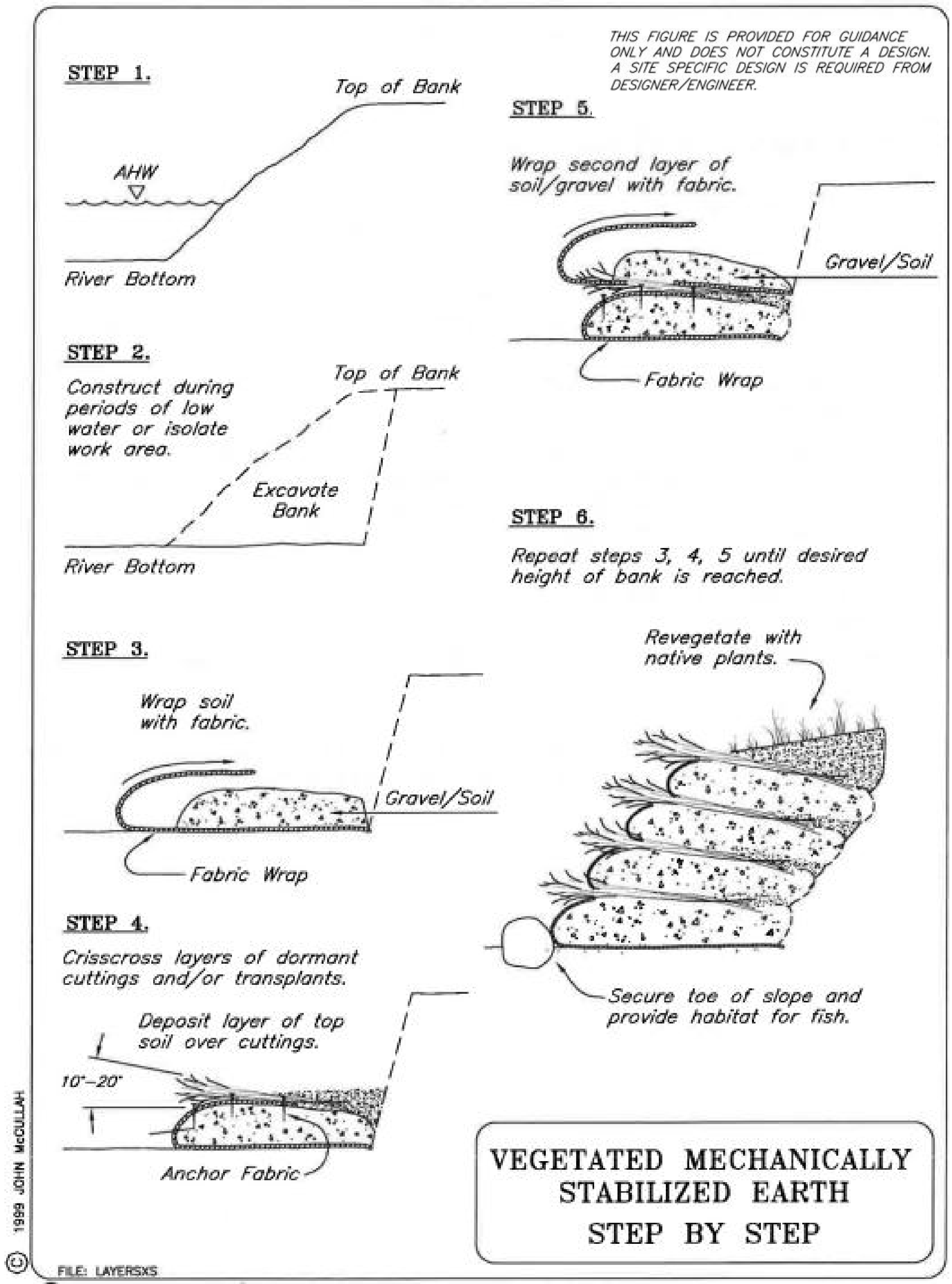
- Inspection frequency should be in accordance with the PESC and TESC Plans
- Maintenance requirements for a VMSE installed along a streambank includes monitoring after large storm events for undermining or other damage or as determined necessary for the specific site
- The vegetation should establish successfully without costly irrigation Monitoring should consist of inspecting the geogrids (or fabric) for signs of breakage or tearing from scour damage or possibly from excessive tensile stresses due to higher than expected lateral earth pressures
- Signs of uncontrolled seepage, such as weeping or wet spots in the structure, should also be noted

- The site should be examined for possible signs of flanking erosion, which must be addressed with added protective measures so that the erosion does not threaten the integrity and effectiveness of the VMSE structure
- Common modes of failure:
  - Inadequate primary reinforcement from the geotextile material, improper vertical spacing or lift thickness, deficiencies in selected fabric or geotextile, too short an embedment length, etc., for the given soil and site conditions (e.g., slope height, slope angle, and soil shear strength properties)
  - Failure to identify seepage conditions or install adequate drainage measures

Design Considerations

- Critical factors such as scour depth must be determined for each particular project and be incorporated into the project design. A geotechnical or river engineer may be required to provide designs
- Inclusions with various shapes and properties can be used to reinforce and buttress earthen slopes. These inclusions may include embedded metal strips, geogrids fabricated from polymeric nets, and natural or synthetic geotextiles fabrics or various other products made for this purpose
- Shear stresses that develop in the soil matrix are transferred into tensile resistance in the imbedded inclusions via friction along the soil-inclusion interface
- MSE retaining structures must satisfy external stability requirements, (e.g., have adequate resistance to sliding, overturning, and bearing capacity failure)
- The tensile inclusions or reinforcements in these structures must have a sufficient unit tensile resistance and/or be placed in sufficient numbers to resist breaking The inclusions must also be sufficiently long and "frictional" enough to resist failure by pullout
- Synthetic geogrids fabricated from high-tensile polymeric materials are widely used in reinforced earth embankments and retaining walls. Geogrids tend to have superior pullout resistance compared to geotextile or fabric sheets. Geogrids can be used in a wrap-around fashion to provide both backfill reinforcement or as containment for the front face
- Live cuttings act as tensile inclusions and help to stabilize a slope, embankment, or structural fill and grow in strength as they become established
- Key considerations in the design of geogrid or geotextile reinforced earthen slopes and embankment fills is the vertical spacing (d) and total length (L) of the reinforcing layers

- The total length (L) is comprised of the length or distance required to reach the expected failure surface in the backfill and an additional length, the effective or embedment length (L_E), extending beyond the failure surface required to prevent pullout



Government of the Northwest Territories – Transportation

Vegetated Riprap Streambank Stabilization Techniques	B.M.P. #37

Description and Purpose

- Vegetated Riprap combines the widely-accepted, resistant, and continuous rock armouring techniques with vegetative techniques. It consists of a layer of stone and/or boulder armouring that is vegetated, optimally during construction, using pole planting, brush layering and live staking techniques
- Continuous and resistant bank protection measures, such as riprap and longitudinal rock toes are primarily used to armour outer bends or areas impacted by flows
- The stream energy is resisted by the continuous protection, and is subsequently directed downward into the streambed
- The riprap will resist the hydraulic forces, while roots and branches increase geotechnical stability, reduce soil loss (or piping) from behind the structures, and increase pull-out resistance
- The roots, stems, and shoots will help anchor the rocks and resist ‘plucking’ and gouging by ice and debris

Applications

- Vegetated Riprap is appropriate where infrastructure is at risk, and where redirective and discontinuous bank protection measures have been deemed inappropriate
- Incorporating large or densely spaced trees may be beneficial along north-facing banks (trees will cast shade) and where cover is necessary to protect temperature sensitive fish rearing habitat

Advantages

- Correctly designed and installed, Vegetated Riprap offers an opportunity to obtain the immediate and long-term protection afforded by riprap and the habitat benefits inherent with the establishment of a healthy riparian buffer
- Above ground plant components will create habitat for both aquatic and terrestrial wildlife, provide shade (controlling stream temperature), and improve aesthetic opportunities
- When graded stone is used, riprap is self-adjusting with benefits including substrate consolidation, or be subject to movement or scour
- Vegetated Riprap can sustain minor damage and still continue to function adequately without further damage
- The rough surface of the riprap dissipates flow velocity and minimizes wave action more than a smooth revetment (e.g.; concrete blocks)

- Where rock is readily available the local materials are less expensive than many other "hard armouring" techniques
- The riprap provides some minor aquatic habitat
- Riprap is easily repaired by placing more rock where needed
- The fibrous roots of the planted vegetation reduces washout of fines, stabilizes the native soil, anchors armour stone to the bank, and increases the lift-off resistance
- Vegetation improves drainage of the slope by increasing soil permeability and by removing soil moisture through root uptake
- Vegetated Riprap has a more natural appearance, and aesthetically pleasing, which may be important in high-visibility areas
- Environmental permits are frequently easier to obtain if the project has biotechnical and habitat enhancement benefits incorporated into the design
- Environmental benefits offered by Vegetated Riprap, are derived from the planting of willows or other woody species in the installation
- Willow provides canopy cover to the stream, providing fish and other aquatic fauna shaded places to hide
- Supplies the water body with carbon-based debris, which is integral to many aquatic food webs. Birds that catch fish or aquatic insects will be attracted by the increased perching opportunities next to the stream
- Rock surface area is a substrate that is available for colonization by invertebrates
- The small spaces between the rocks also provide benthic habitat and hiding places for small fish and fry
- The brush layering methods reach out over the water, and provide shade and organic debris to the aquatic system

Limitations

- Vegetated Riprap may be inappropriate if flow capacity is an issue, as bank vegetation can reduce flow capacity, especially when in full leaf along a narrow channel
- In remote areas, large rock material may be difficult to obtain and transport, which may greatly increase costs
- Riprap may present a barrier to wildlife trying to access the stream

Construction

The vegetation obtained should be poles of easily-rooting native species (such as willow, cottonwood or red osier dogwood), with a minimum diameter of 40 mm, and be of sufficient length to extend below the groundwater table located below the riprap.

Vegetated Rip-Rap with Willow Bundles

- Grade the desired slope to provide a smooth base where the riprap will be placed
- Dig a toe trench for the keyway (if required) below where the riprap will be placed
- Place 10 to 15 cm (5 to 8 stems) of live branch bundles on the slope, with the butt ends placed at least 30 cm into the low water table
- Place the poles in the toe trench before the rock is placed, if standard riprap rock is being used
- Digging shallow trenches for the willows prior to placing them on the slope will decrease damage to the cuttings from the rocks, and may increase rooting success because more of the cuttings will be in contact with soil
- The bundles should be placed every 1.8 m along the bank, and be pointed straight up the slope
- Once the bundles are in position, place rock on top of it to the top of the slope
- The bundles should extend 0.3 m above the top of the rock
- If the bundles are too short, they may show decreased sprouting success

Vegetated Rip-Rap with Bent Poles

- Grade the slope to create a smooth base where the riprap will be placed
- Dig a toe trench for the keyway (if required) below where the riprap will be placed
- If non-woven geotextile is being used, lay the fabric down on the slope, all the way into the toe trench, and cut holes in the fabric about 0.6 to 0.9 m above the annual low water level
- Slip the butt ends of the willow poles through the fabric and slide them down until the bases are at least 0.15 m into the perennial water table, or at the bottom of the toe trench, whichever is deepest
- If using filter gravel, lay it down on the slope, and place a layer of willow poles on top of the gravel, with the bases of the cuttings at least 0.15 m into the perennial water table, or at the bottom of the toe trench, whichever is deepest
- Place the largest rocks in the toe trench
- Ensure that the rock pieces lock together tightly, as they are the foundation for the structure

- Place the next layer of boulders such that it tapers back slightly toward the streambank
- Bend several willow poles up, such that they are perpendicular to the slope, and tight against the first layer of rocks
- Now place the next layer of rocks behind these poles
- Placement will require an excavator with a thumb, as someone will have to hold the poles while the rocks are placed
- As the poles are released, they should be trimmed to 30 cm above the riprap
- This last step should be repeated until all the poles have been pulled up, and the entire slope has been covered

Vegetated Rip-Rap with Brush Layering and Pole Planting

There are two methods of constructing brush layered riprap; one involves building up a slope, and the other works with a pre-graded slope – neither method can be used with non-woven geotextile

Method 1 (building up a slope):

- Trim the bank slope back to somewhat less than the desired finished slope
- Dig a toe trench, if needed, and lay the key rocks into the trench. Pack soil behind these rocks, with filter gravel in between the soil and rocks
- Continue installing riprap 0.9 to 1.2 m up the bank
- Slope the soil back into the bank at a 45° angle, such that the bottom of the soil slope is in the vadose zone
- Place a layer of willow cuttings on top of the soil, with the butt ends extending into the low water table, and the tips of the branches sticking out 0.3 to 0.6 m
- Place the next layer of rock pieces on top of the initial rocks, but graded slightly back, and repeat the soil and brush layering process
- When finished, trim the ends of the willow branches back to 0.3 m
- Do not cut shorter than 0.3 m, as the plant will have difficulty sprouting

Method 2 (pre-graded slope):

- Trim the bank slope back to the desired finished grade, and dig a toe trench if self-launching stone is not being used
- Place the largest rocks in the key-way, and fill in behind with filter gravel and soil
- Continue installing riprap 0.9 to 1.2 m up the bank
- Place the bucket of an excavator just above the layer of rocks at a 45° angle

- Pull the bucket down, still at a 45° angle, until the water table is reached, or the stream is dry, to the elevation at the bottom of the key trench
- Pull up and back on the bucket; this will provide a slot in the bank into which willow poles can be placed
- Place willow poles (about 20 poles per linear m), ensuring that the butt ends are at the bottom of the trench
- Release the scoop of earth, and allow it to fall back in place on the slope
- Then place the next layer of rock on top of the branches, flush with the slope
- If graded stone is not being used, filter gravel should be placed behind the rocks
- Repeat the process, beginning again with pulling back a scoop of soil
- Continue this process to the top of the slope, or if preferred, use joint-planted riprap on the upper slope, where it is difficult to reach the perennial water table with the excavator bucket
- When finished, trim the ends of the branches back such that only 0.3 m extends beyond the revetment

Construction Considerations

- The technique can also be used in conjunction with other techniques, designed primarily to protect the bank toe such as directive techniques (Rock Vanes)
- While riprap is very effective at reducing bank erosion and providing relatively permanent bank protection, the environmental consequences may be less than desirable and should, therefore always be taken into account when selecting an environmentally-sensitive streambank stabilization treatment
- Scour counter-measures are sometimes required for continuous and resistant rock bank protection
- Another measure that may be employed is the use of graded, self-launching stone

<u>Filter Material</u>:

- Filter material is typically used to prevent piping of fine soils from below the riprap, if self-launching stone is not used
- There are two choices: non-woven geotextile fabric or graded filter gravel
- Non-woven geotextile fabrics are not recommended for use in Vegetated Riprap, as roots have difficulty penetrating the fabric
- If non-woven geotextile fabric is required, holes can be cut in the fabric where the vegetation is inserted
- Small slits in the fabric are especially appropriate with the bent pole method

- Filter gravel is the preferred filter media for Vegetated Riprap

Rock Size:

- There are two options for rock pieces – self-launching/self-filtering rock or standard riprap
- The advantage of self-launching/self-filtering rock is that the revetment will build its own toe, by self-launching, in any scour hole that forms
- The different sizes of rock together act as their own filter medium, so no geotextile fabric or filter gravel is needed
- This decreases cost, and also makes installation less labour-intensive for two of the three methods of installation
- Using self-launching stone is dependent on having a source of graded rock, which is not always available

Inspection and Maintenance

- Riprap should be visually inspected as outlined in the PESC and TESC Plans, with focus on transitions between undisturbed and treated areas
- Soil above and behind riprap may show collapse or sinking, or loss of rock may be observed
- Inspect riprap annually during low flows, to ensure continued stability of the toe of the structure
- Treat bank or replace rock as necessary

Design Considerations

- It often takes many years for riprap to become vegetated if vegetation is not integrated into its design and construction at the outset
- Flanking, overtopping or undermining of the riprap due to improperly installed or insufficient keyways are the biggest reasons for failure of riprap
- Improperly designed or installed filter material can cause undermining and failure of the installation
- Undersized stones can be carried away by strong currents, and sections of the riprap may settle due to poorly consolidated substrate

Vegetated Riprap with Willow Bundles

Is the simplest to install, but has a few drawbacks:

- This technique typically requires very long (3 to 7 m) poles and branches, as the cuttings should reach from 0.15 m below the low water table to 0.3 m above the top of the rock

- Only those cuttings that are in contact with the soil will take root, and therefore, the geotechnical benefits of the roots from those cuttings on the top of the bundle may not be realized

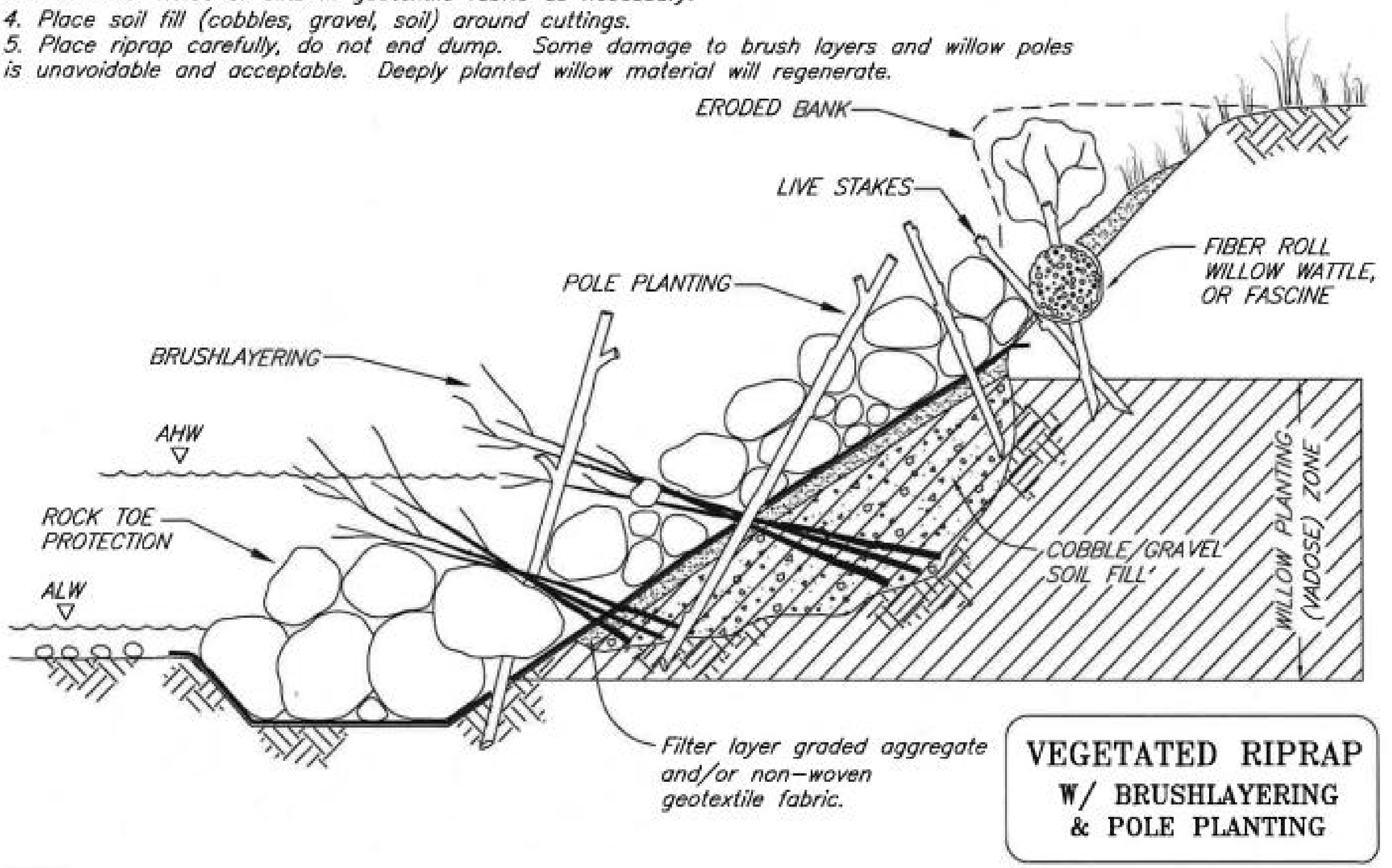
Vegetated Rip-Rap with Bent Poles

- Is slightly more complex to install
- A variety of different lengths of willow cuttings can be used, because they will protrude from the rock at different elevations
- The slope gradient can be 1V;1H, or forty-five degrees
- Root growth will develop along the entire length of each pole planted

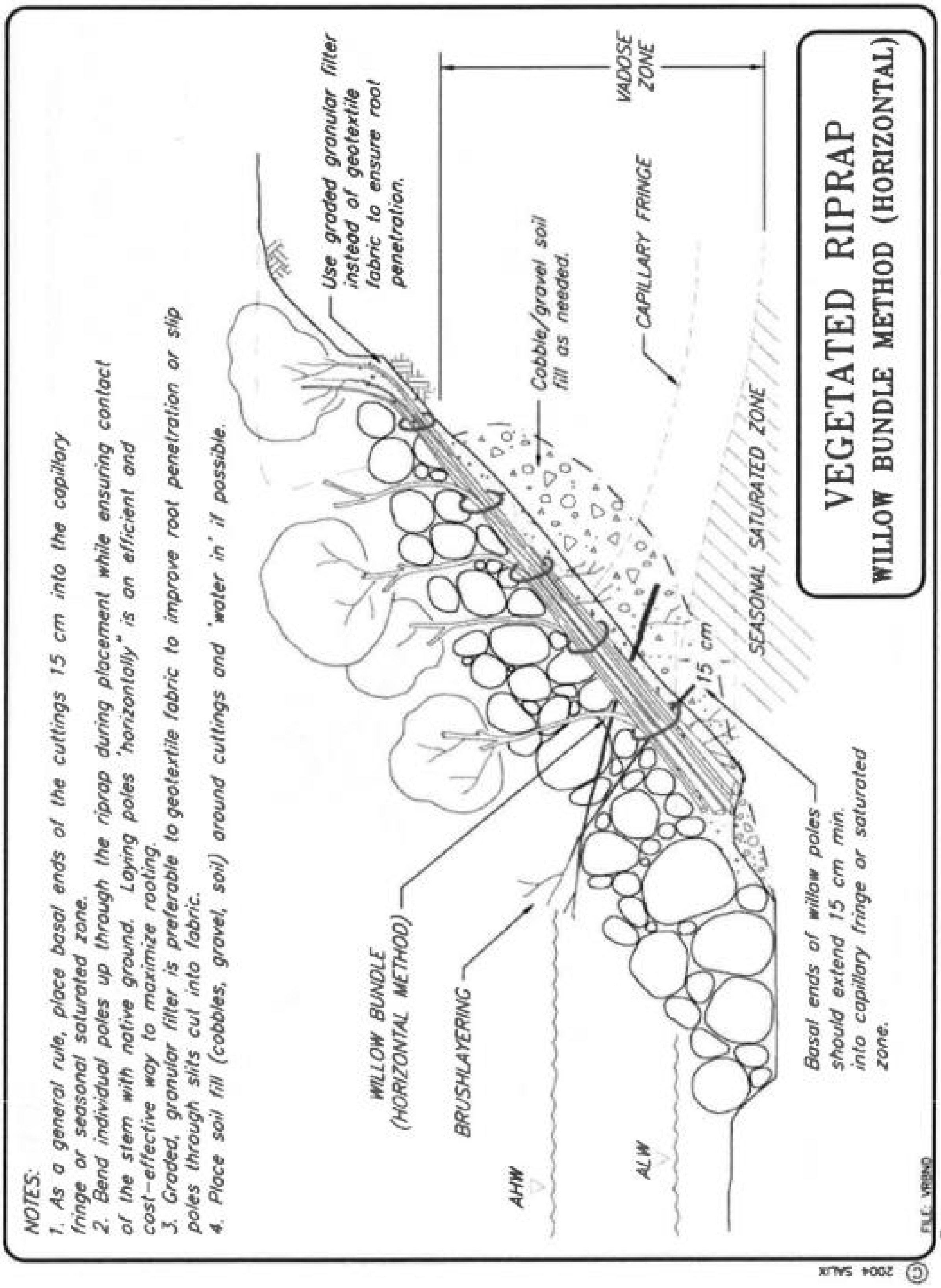
Vegetated Riprap with Brush Layering and Pole Planting

- Is the most complex type of vegetated riprap to install, but also provides the most immediate habitat benefits
- The technique for this installation is separated into 2 methods; one method includes installation when building a stream bank, while the other is for a well-established bank
- If immediate aquatic habitat benefits are desired, this technique should be used

NOTES:
1. Install willow pole planting and brushlayering during bank grading and riprap placement to ensure good contact with 'native ground' and/or soil fill.
2. Willow poles and brush layers shall extend down into expected soil moisture zones (vadose).
3. Cut small holes or slits in geotextile fabric as necessary.
4. Place soil fill (cobbles, gravel, soil) around cuttings.
5. Place riprap carefully, do not end dump. Some damage to brush layers and willow poles is unavoidable and acceptable. Deeply planted willow material will regenerate.

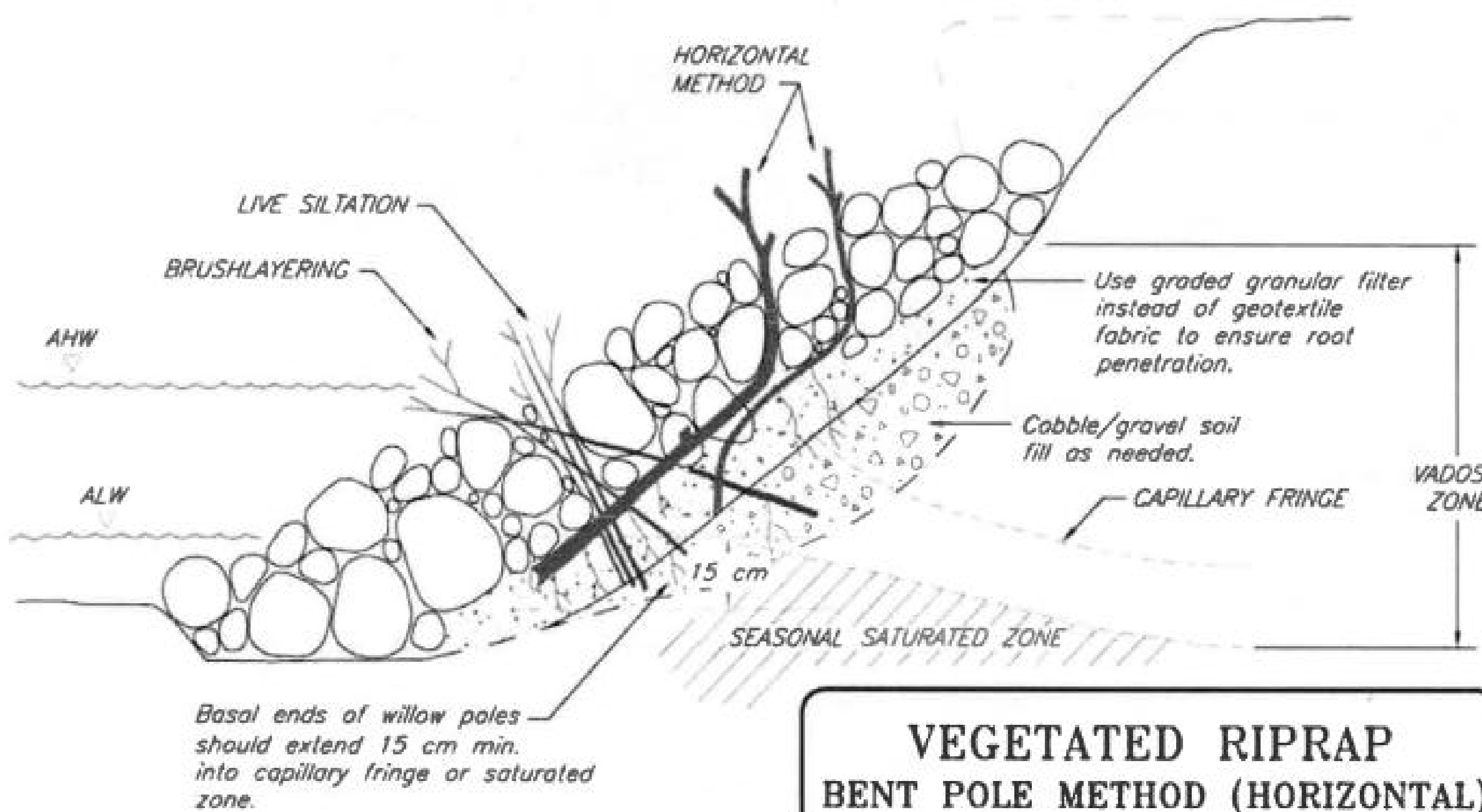


VGRIPRAP


NOTES:
1. As a general rule, place basal ends of the cuttings 15 cm into the capillary fringe or seasonal saturated zone.
2. Bend individual poles up through the riprap during placement while ensuring contact of the stem with native ground. Laying poles 'horizontally' is an efficient and cost-effective way to maximize rooting.
3. Graded, granular filter is preferable to geotextile fabric to improve root penetration or slip poles through slits cut into fabric.
4. Place soil fill (cobbles, gravel, soil) around cuttings and 'water in' if possible.
Use graded granular filter instead of geotextile fabric to ensure root penetration.
VADOSE ZONE
Cobble/gravel soil fill as needed.
CAPILLARY FRINGE
SEASONAL SATURATED ZONE
15 cm
WILLOW BUNDLE (HORIZONTAL METHOD)
BRUSHLAYERING
AHW
ALW
Basal ends of willow poles should extend 15 cm min. into capillary fringe or saturated zone.
VEGETATED RIPRAP
WILLOW BUNDLE METHOD (HORIZONTAL)
© 2004 SALIX

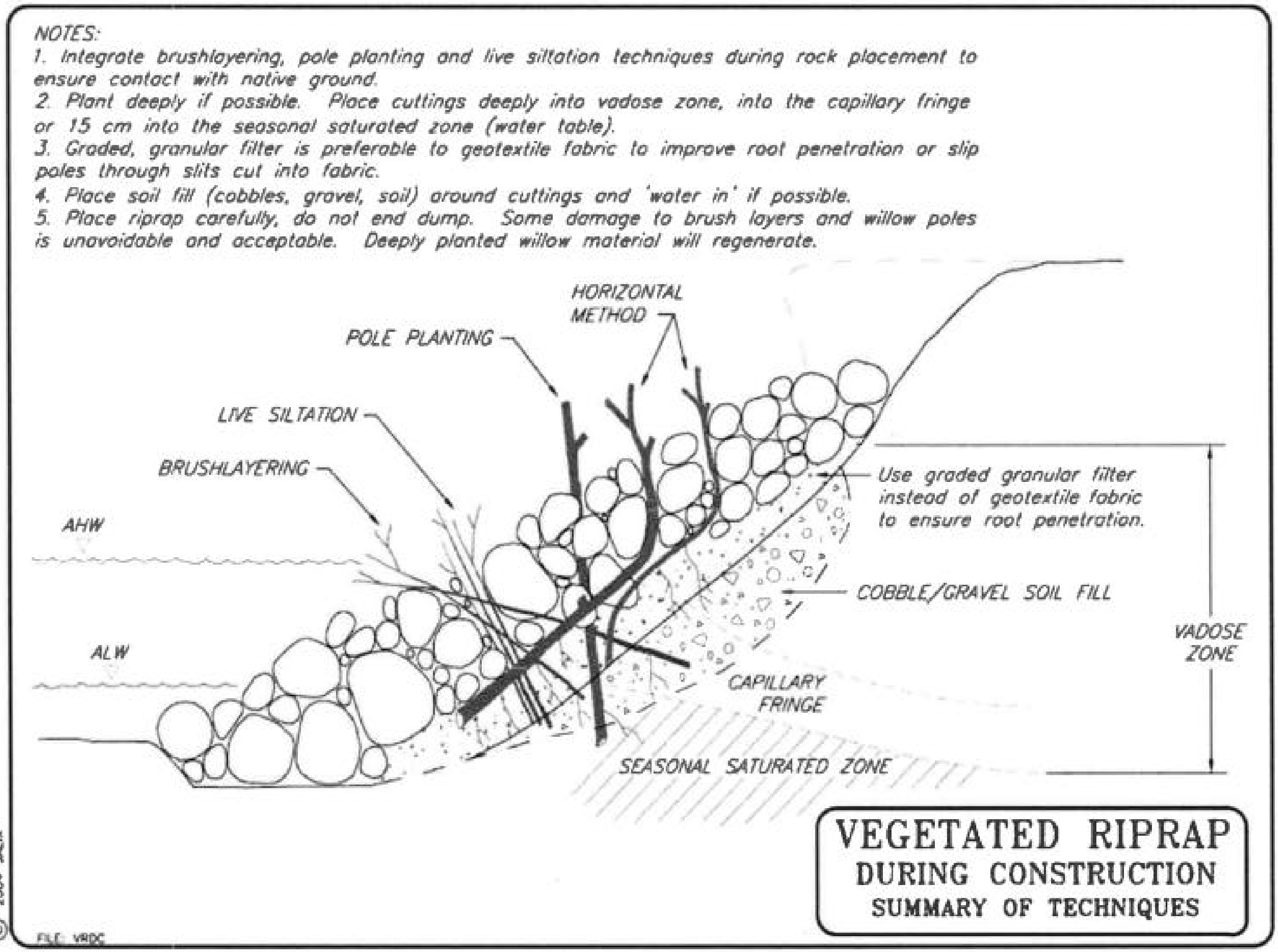
NOTES:

1. Integrate brushlayering, pole planting and live siltation techniques during rock placement to ensure contact with native ground. Laying poles 'horizontally' is an efficient and cost-effective way to maximize rooting.
2. As a general rule, place basal ends of the cuttings 15 cm into the capillary fringe or seasonal saturated zone.
3. Graded, granular filter is preferable to geotextile fabric to improve root penetration or slip poles through slits cut into fabric.
4. Place soil fill (cobbles, gravel, soil) around cuttings and 'water in' if possible.



VEGETATED RIPRAP
BENT POLE METHOD (HORIZONTAL)

FILE: VRBP


NOTES:
1. Integrate brushlayering, pole planting and live siltation techniques during rock placement to ensure contact with native ground.
2. Plant deeply if possible. Place cuttings deeply into vadose zone, into the capillary fringe or 15 cm into the seasonal saturated zone (water table).
3. Graded, granular filter is preferable to geotextile fabric to improve root penetration or slip poles through slits cut into fabric.
4. Place soil fill (cobbles, gravel, soil) around cuttings and 'water in' if possible.
5. Place riprap carefully, do not end dump. Some damage to brush layers and willow poles is unavoidable and acceptable. Deeply planted willow material will regenerate.
HORIZONTAL METHOD
POLE PLANTING
LIVE SILTATION
BRUSHLAYERING
AHW
ALW
Use graded granular filter instead of geotextile fabric to ensure root penetration.
COBBLE/GRAVEL SOIL FILL
VADOSE ZONE
CAPILLARY FRINGE
SEASONAL SATURATED ZONE
VEGETATED RIPRAP
DURING CONSTRUCTION
SUMMARY OF TECHNIQUES
© 2004 SALIX
FILE: VRDC

Temporary Stream Diversion Erosion Control	B.M.P. #38

Description and Purpose

- Diversion of a small watercourse into an artificial channel or pipe to re-enter the stream channel downstream to permit construction "in the dry" of a culvert, bridge or other instream works.
- Minimizes the erosion and sedimentation that results from construction within a watercourse.
- Isolates the construction site from watercourses.

Applications

- Temporary measure.
- Used at instream work sites (culvert installation or replacement or bridge crossings) to provide a dry work site.

Advantages

- Protects environmentally sensitive areas.
- Keeps clean water clean
- Conveys flow consistency better than a dam, impoundment and pumping.
- Not at risk of power failure or malfunction (e.g. pumps).
- May maintain fish passage
- Maintains continuous stream flow levels downstream.

Limitations

- Requires erosion protection.
- Risk of export of sediment downstream if not properly staged.
- Requires fish exclusion and fish salvage if working on a kn own or suspected fish-bearing stream. Permits may be required.
- In-stream work windows are regulated by agencies and must be adhered to.

Construction

- Install fish exclusion netting upstream and downstream of the site and perform fish salvage within the exclus ion area (A Fish Salvage permit may be required). A qualified person should conduct the fish salvage.
- A qualified person should oversee excavation of the diversion channel "in the dry". Do not excavate the upstream and downstream ends of the di version channel until

after the coffer dams and erosion protection is in place and fish salvage has been conducted.

- Place a Big-O pipe (flexible plastic corrugated pipe of suitable size) in the diversion channel, staying within the fish exclusion area.
- Construct small coffer dams to protect the inlet and outlet ends of the diversion structure using sandbags filled with clean sand and gravel material. The coffer dams will divert the water and allow the establishment of the inlet and outlet. Protect these areas with rolled erosion controlled products (geotextile fabric) or riprap in areas of high water velocity.
- Connect the downstream end of the diversion channel to the main watercourse, stabilize and armour the connection.
- Construct and stabilize the upstream connection to the main watercourse (within the water exclusion area made by the small coffer dam used to direct flow away from the work area).
- Divert flows from the main watercourse into the diversion using a coffer dam lined with polyethylene plastic (poly sheeting) or other suitable device.
- Allow the exclusion section of the main channel to drain. Once the site has drained, create a small sump hole downstream of the construction site (within the dry area) and pump any sediment laden water from the “dry” site to a suitable percolation area (well vegetated, protected from erosion) and monitor pump hose intake and outlet.
- Complete the culvert or bridge construction “in the dry”. Install all necessary armour and sediment control measures on the new structure and adjoining soils.
- When returning the stream to the natural channel, a qualified person should monitor the operation and sediment conditions.
- The return of flow to the original stream bed must be conducted very slowly so as not to overload the sump hole and pump, and avoid flushing sediment downstream. Pumping from the sump hole should continue until the water runs clean through the construction site. The flow is gradually increased until the water flows clear and no sediment is delivered downstream.
- Once the flow has been returned to the original channel, the diversion structure can be filled in and reclaimed, and the stream banks armoured to prevent erosion at the former diversion inlet and outlet.
- The fish exclusion netting can be removed once all in-stream works have been completed.

Temporary Stream Diversion Erosion Control	B.M.P. #38

Construction Considerations

- Fish must be salvaged from the work area in the main watercourse before any diversion or construction activities to prevent loss of fish.
- The diversion channel inlet and outlet are required to be within the fish exclusion zone or a second fish salvage is required to decommission the diversion.
- The diversion channel should be sized based on consultation with the regulatory agencies. Normal and potential storm flows for the duration of diversion use and risk to environmentally sensitive areas should be considered. For environmentally sensitive areas and long duration of construction, the diversion channel should be sized to convey a 1 in 10 year design flow.
- Lower design flows may be considered in areas of low environmental sensitivity or if the duration of construction is short (1-2 days).

Inspection and Maintenance

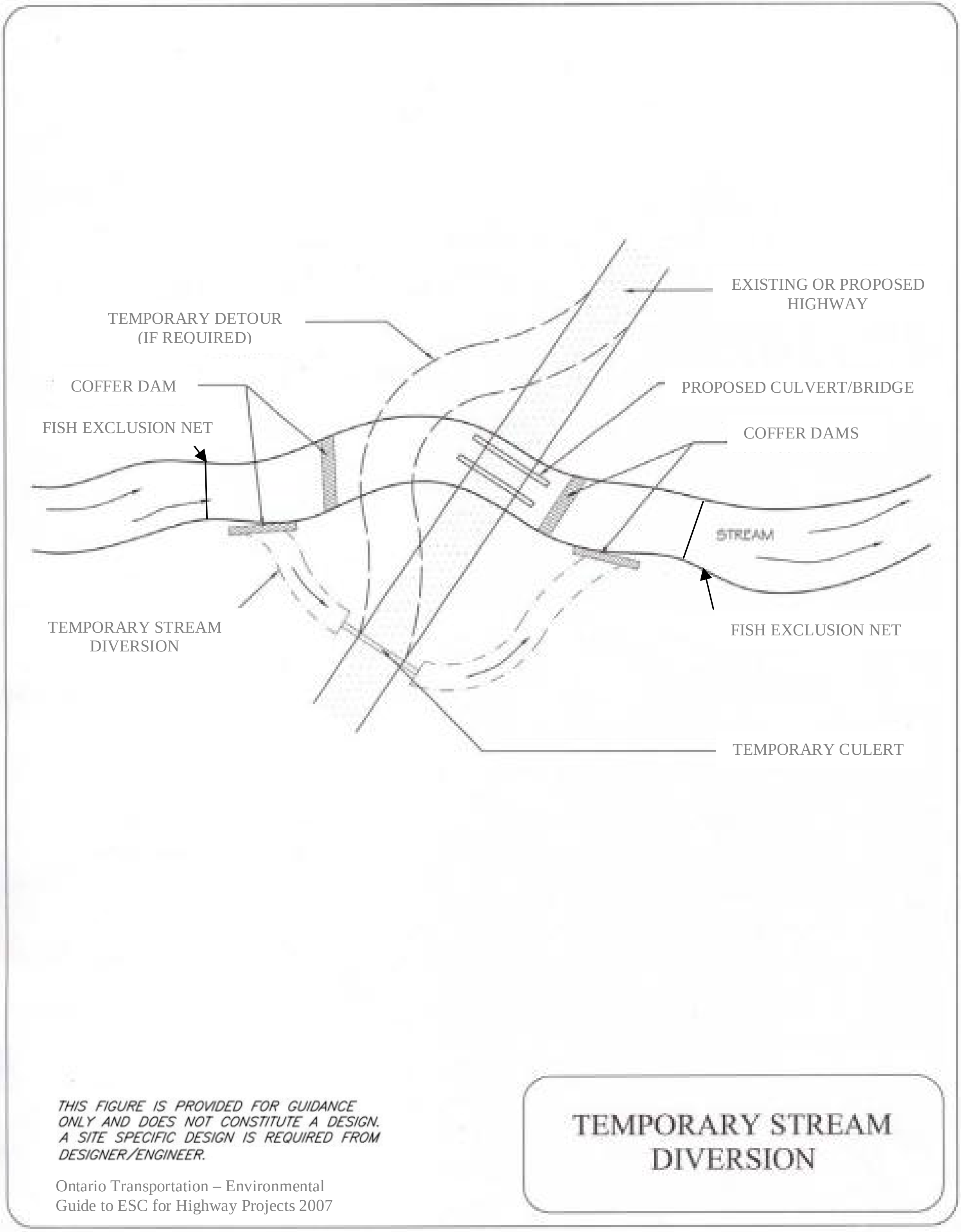
- Inspection frequency should be in accordance with the PESC and TESC Plans.
- The diversion channel should be inspected during and within 24 hours of a heavy rainstorm to identify areas of erosion. Eroded areas should be repaired and armoured promptly.

Similar Measures

- Diversion Ditch

Design Considerations

- A qualified person should be consulted and the stream diversion design and work plan approved.
- The slope of the diversion channel should be similar to that of the original stream bed where possible.


EXISTING OR PROPOSED HIGHWAY
TEMPORARY DETOUR (IF REQUIRED)
COFFER DAM
PROPOSED CULVERT/BRIDGE
FISH EXCLUSION NET
COFFER DAMS
STREAM
TEMPORARY STREAM DIVERSION
FISH EXCLUSION NET
TEMPORARY CULERT
THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.
Ontario Transportation – Environmental Guide to ESC for Highway Projects 2007
TEMPORARY STREAM DIVERSION

Coffer Dam (Small Streams) Sediment Control	B.M.P. #39

Description and Purpose

- It is the responsibility of project owners, consultants, and contractors to ensure that they are authorized by regulatory agencies to carry out instream works and are following the correct procedures.
- A coffer dam is a temporary diversion usually constructed of sandbags with clean aggregate and lined with polyethylene (poly) sheeting to divert shallow stream water around a work site or to enclose a work area in a watercourse and permit the exclusion of water from that portion.
- May be used to divert a watercourse into an artificial channel to permit construction "in the dry".
- Used to minimize erosion and sedimentation that can result from construction (culvert or bridge) within a watercourse.
- Isolates the construction site from the stream or waterbody.

Applications

- Temporary measure.
- Used at proposed culvert or bridge crossing construction sites or along watercourses or water bodies to provide a "dry" work site.
- Used at work areas that encroaches into a watercourse, lake, or wetland.

Advantages

- Protects environmentally sensitive areas.
- Permits work to be conducted "in the dry"
- Excludes water from the work site thereby reducing sedimentation within the stream.

Limitations

- Requires monitoring and maintenance.
- Risk of export of sediment downstream.
- Used in areas of shallow flow depth (less than 1.5 m).
- Pumping may be required to keep work area dewatered. Back-up pumping equipment may be needed.
- Height of the dam should provide protection for a 1 in 10 year event, if possible (height of dam to be less than 1.5 m).

- All debris and accumulated sediment inside the work area must be cleared away before removal of the coffer dam.
- Operations within the work area must be capable of withstanding flooding without risk to life and equipment damage.
- Requires authorization for instream works, fish exclusion and fish salvage on fish-bearing streams. Permits may be required.
- In-stream work windows are regulated by agencies and must be adhered to.

Construction

- Install fish exclusion netting upstream and downstream of the site and perform fish salvage (fish salvage permit may be required) within the exclusion area.
- Construct the coffer dam by stacking sandbags filled with clean washed material or other suitable product (cured cement blocks) and lining with poly sheeting within the fish exclusion area. (Sandbags filled 2/3 full will be more flexible and will form to the contours and can be placed tightly together to close gaps between bags).
- Construct and reinforce the upstream connection of the coffer dam to the stream bank. Continue to place sandbags across the stream on an angle or downstream to enclose/exclude the work area from the main watercourse or water body. Use caution so the displacement of the stream to the open side should not itself cause erosion or generate sediment.
- Can be used as a dam structure to divert the stream (See B.M.P. #38) to a temporary diversion channel or around small temporary work areas which only require a small section of a stream to be excluded.
- Once the “dry” site has drained, pump any sediment-laden water created by construction from the “dry” site to a suitable area (well vegetated, protected from erosion) and monitor intake and outlet for pumping.
- When removing the coffer dam structure and returning the stream or water body to natural conditions, a qualified person should monitor the operation. For small works, the sandbags may be removed slowly and pumping should continue until the water flows cleanly through the work area
- The fish exclusion netting can be removed once all in-stream works have been completed

Construction Considerations

- Fish must be salvaged by a qualified person from the work area to prevent loss of fish.
- Permits may be required for fish salvage

Inspection and Maintenance

- Inspection frequency should be in accordance with the PESC and TESC Plans.
- The weather forecast should be monitored to anticipate the occurrence of high flow events. Work operations should be adjusted to accumulate possible overtopping of the coffer dam.
- The coffer dam should be inspected during and within 24 hours of a heavy rainstorm, if possible, to identify areas of erosion or leakage. Eroded areas should be repaired promptly.

Design Considerations

- A qualified person should be consulted for i nstream works and the coffer dam design and work plan approved.

APPENDIX D
SAMPLE FORMS

- **INSPECTION AND MAINTENANCE FORM**
- **CHECKLIST FOR PERMANENT EROSION AND SEDIMENT CONTROL (PESC) PLAN DEVELOPMENT**
- **CHECKLIST FOR TEMPORARY EROSION AND SEDIMENT CONTROL (TESC) PLAN DEVELOPMENT**

*Forms may be modified or adjusted to meet site specific requirements.

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INSPECTION AND MAINTENANCE FORM

GNWT-DOT Contract Number: ______________________
Construction Site Location: ______________________
Heavy Equipment on Site: ______________________
Date: ____________ mm of rain in last week: ________
Date of Last Inspection: ____________ mm of rain in last 24 hours: ________

Contractors on Site: ____________
Construction Activities on Site: ____________
Current Weather: ____________
Weather Forecast: ____________

Type of Measure (BMP)	Location on Construction Site	Intended Function	Sediment Levels	General Condition	General Performance	Maintenance Required	Type of Maintenance Required	Site Manager Notified	Date Repairs to be Completed By
			0 – 1/4 - 1/2 – 3/4 Full not applicable	poor fair good	poor fair good	yes no		yes no	
			0 – 1/4 - 1/2 – 3/4 Full not applicable	poor fair good	poor fair good	yes no		yes no	
			0 – 1/4 - 1/2 – 3/4 Full not applicable	poor fair good	poor fair good	yes no		yes no	
			0 – 1/4 - 1/2 – 3/4 Full not applicable	poor fair good	poor fair good	yes no		yes no	
			0 – 1/4 - 1/2 – 3/4 Full not applicable	poor fair good	poor fair good	yes no		yes no	
			0 – 1/4 - 1/2 – 3/4 Full not applicable	poor fair good	poor fair good	yes no		yes no	
			0 – 1/4 - 1/2 – 3/4 Full not applicable	poor fair good	poor fair good	yes no		yes no	
			0 – 1/4 - 1/2 – 3/4 Full not applicable	poor fair good	poor fair good	yes no		yes no	

Notes:

Inspectors Signature: ____________ Inspectors Name: ____________

Copies to: GNWT-DOT Designated Inspector: ____________ Contractors Site Designate: ____________ ESC Plan Designer: ____________

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CHECKLIST FOR PERMANENT EROSION AND SEDIMENT CONTROL (PESC) PLAN DEVELOPMENT

The following checklist may be used to ensure that Permanent Erosion and Sediment Control Plans (PESC Plans) follow the method and structure outlined in the Guide. For small, low-risk transportation construction projects that only require the application of procedural BMPs, it may not be necessary to undertake detailed BMP design. Refer to Section 8 for guidance regarding the appropriate level of effort to be applied.

1.0 DATA COLLECTION

- ☐ Identify and initiate contact with other members of the ESC team:
    - ☐ Owner or owner's representative
    - ☐ Project designer
    - ☐ Contractor, and
    - ☐ Site inspector (if selected)
- ☐ Identify and initiate contact with applicable regulatory agencies
    - ☐ establish information needs
- ☐ Compile relevant site information, as applicable:
    - ☐ Construction drawings, design data and construction schedule
    - ☐ Geotechnical investigation reports
    - ☐ Aerial photography/imagery
    - ☐ Surficial geology maps
    - ☐ Vegetative cover maps
    - ☐ Regulatory requirements
    - ☐ Fisheries assessments
    - ☐ Wildlife requirements
- ☐ Site inspection by ESC Plan Designer:
    - ☐ Photographs to document existing site conditions
    - ☐ Review construction site and adjacent areas for:
        - ☐ Incoming water sources and pre-construction drainage patterns
        - ☐ Existing vegetation and potential retention areas
        - ☐ Soil types,
        - ☐ Site level topographic features
        - ☐ Riparian management zones
        - ☐ Wildlife features (nesting sites, travel corridors)
        - ☐ Sensitive sites and critical areas of concern
        - ☐ Other features (rock, permafrost, past soil failures, flooding)

2.0 SITE EROSION POTENTIAL AND EVALUATION

- ☐ Assess the site-specific erosion potential
- ☐ Assess the risk of erosion due to transportation construction activities
- ☐ Determine appropriate level of effort, performance goals and evaluation measures

3.0 EROSION AND SEDIMENT CONTROL PLAN DESIGN

3.1 PESC Plan

- ☐ Develop an erosion and sediment control plan that addresses the requirements of the permanent features for erosion protection, is effective, and can be coordinated with construction activities
  - ☐ Define the areas of concern for the project
  - ☐ Evaluate the construction site drainage:
    - ☐ Define drainage areas within the construction site
    - ☐ Define drainage patterns within each drainage area
    - ☐ Determine drainage channel alignments
    - ☐ Determine channel tributary areas and drainage channel characteristics
  - ☐ Based on drainage characteristics, specify Best Management Practices (BMPs)
  - ☐ Incorporate procedural BMPs to prevent erosion at its source
    - ☐ Promote good housekeeping measures to reduce the amount of erosion during construction
    - ☐ Consider minimizing exposed soils by scheduling just-in-time stripping activities, using existing drainage pathways, and identifying retention areas and installing signage around reserved or sensitive areas
    - ☐ Schedule activities during relatively dry conditions, installing permanent and temporary erosion and sediment control measures early, and revegetating exposed soils early
  - ☐ Incorporate appropriate erosion control BMPs
    - ☐ Divert upstream water around the construction site using a permanent structure (where applicable)
    - ☐ Incorporate and install permanent ditchlines, downdrains or channel realignments early in the construction schedule to promote keeping clean water clean
    - ☐ Apply revegetation techniques as soon as construction in each area is complete to promote germination and ground cover as quickly as possible
    - ☐ Consider factors such as flow, soil characteristics, presence/absence of permafrost, topography, climate, season, accessibility and cost when choosing erosion control measures

3.2 Report and Drawing Requirements

- [ ] Provide a project description
- [ ] Describe erosion and sediment control objectives
- [ ] Document existing site conditions
- [ ] Identify sensitive sites and critical areas of concern
- [ ] Describe preserved areas in the text and accurately map
- [ ] Include a section on erosion and sediment control accountability and administration
    - [ ] Provide a list of emergency and non-emergency contacts
    - [ ] Provide the contact's name, designation, employer's name, phone number
- [ ] Describe BMPs to be used
    - Gabions (BMP 2)
    - Rolled Erosion Control Products (BMP 8)
    - Rip Rap Armouring (BMP 9)
    - Cellular Confinement System (BMP 10)
    - Energy Dissipaters (BMP 11)
    - Sediment Traps and Basins (BMP 12)
    - Slope Drains (BMP 13)
    - Diversion Ditches (BMP 14)
    - Seeding (BMP 15)
    - Mulching (BMP 16)
    - Hydroseeding (BMP 17a)
    - Hydromulching (BMP 17b)
    - Topsoiling (BMP 18)
    - Soil and Root Mat Replacement (Sodding) (BMP 19)
    - Live Staking (BMP 20a)
    - Brush Layering (BMP 20b)
    - Riparian Zone Preservation (BMP 21)
    - Crushed Rock Buttress for Slopes (Permafrost) (BMP 22)
    - Controlled Ablation (Melt) of Cut Slope (Permafrost) (BMP 23)
    - Insulated Thermal Blanket on Cut Slope (Permafrost) (BMP 24)
    - Slope Texturing (BMP 27)
    - Compost Blanket (BMP 28)
    - Rolls – Fibre Coir or Wattles (BMP 29)
    - Wattles – Live Facine (BMP 30)
    - Brush Mattress (BMP 31)
    - Live Siltation (BMP 32)
    - Willow Post and Poles (BMP 33)
    - Rock Vanes (BMP 34)
    - Longtitudinal Stone Toe (BMP 35)
    - Vegetated Mechanically Stabilized Earth (VMSE) (BMP 36)
    - Vegetated Rip Rap (BMP 37)
    - Stream Diversion Channel (BMP 38)

- ☐ Include details by providing a description and mapping for installation locations and alignments
- ☐ Include an inspection plans for all permanent BMPs including a minimum schedule (e.g.: once per 7 days and following significant storm event during construction and annually and following significant events for post construction) and what the inspector is looking for specifically
- ☐ Include a maintenance plan for each BMP which describes installation requirements and when maintenance is required (e.g.: sediment fence – install with fabric embedded at base a minimum of 6 inches, sturdy, posts to the outside to area being controlled, - maintenance required when sediment reaches 50% height of fence, damage to fence evident (rips/tears), fence leaning under load)

☐ Provide a series of construction drawings illustrating and describing:

- ☐ Pre-construction drainage and site features,
- ☐ Construction grading and site modification, and
- ☐ Erosion and sediment control measures to be implemented during all phases of the project.

CHECKLIST FOR TEMPORARY EROSION AND SEDIMENT CONTROL (TESC) PLAN DEVELOPMENT

The following checklist may be used to ensure that Temporary Erosion and Sediment Control Plans (TESC) follow the method and structure outlined in the Guide. For small, low-risk transportation construction projects that only require the application of procedural BMPs, it may not be necessary to undertake detailed BMP design. Refer to Section 8 for guidance regarding the appropriate level of effort to be applied.

1.0 DATA COLLECTION

- ☐ Identify and initiate contact with other members of the ESC team:
  - ☐ Owner or owner's representative
  - ☐ Project designer
  - ☐ Contractor, and
  - ☐ Site inspector (if selected)
- ☐ Identify and initiate contact with applicable regulatory agencies
  - ☐ establish information needs
- ☐ Compile relevant site information, as applicable:
  - ☐ Construction drawings, design data and construction schedule
  - ☐ Geotechnical investigation reports
  - ☐ Aerial photography/imagery
  - ☐ Surficial geology maps
  - ☐ Vegetative cover maps
  - ☐ Regulatory requirements
  - ☐ Fisheries assessments
  - ☐ Wildlife requirements
- ☐ Site inspection by ESC Plan Designer:
  - ☐ Photographs to document existing site conditions
  - ☐ Review construction site and adjacent areas for:
    - ☐ Incoming water sources and pre-construction drainage patterns
    - ☐ Existing vegetation and potential retention areas
    - ☐ Soil types
    - ☐ Site level topographic features
    - ☐ Riparian management zones
    - ☐ Wildlife features (nesting sites, travel corridors)
    - ☐ Sensitive sites and critical areas of concern
    - ☐ Other features (rock, permafrost, past soil failures, flooding)

2.0 SITE EROSION POTENTIAL AND EVALUATION

- [ ] Assess the site-specific erosion potential
- [ ] Assess the risk of erosion due to transportation construction activities
- [ ] Determine appropriate level of effort, performance goals and evaluation measures

3.0 EROSION AND SEDIMENT CONTROL PLAN DESIGN

3.1 TESC Plan

- [ ] Develop an erosion and sediment control plan that addresses the requirements of the temporary features for erosion and sediment control protection, is effective, and can be coordinated with construction activities
  - [ ] Define the areas of concern for the project
  - [ ] Evaluate the construction site drainage:
    - [ ] Define drainage areas within the construction site
    - [ ] Define drainage patterns within each drainage area
    - [ ] Determine drainage channel alignments
    - [ ] Determine channel tributary areas and drainage channel characteristics
  - [ ] Based on drainage characteristics, specify Best Management Practices (BMPs)
  - [ ] Incorporate procedural BMPs to prevent erosion at its source
    - [ ] Promote good housekeeping measures to reduce the amount of erosion during construction
    - [ ] Consider minimizing exposed soils by scheduling just-in-time stripping activities, using existing drainage pathways, and identifying retention areas and installing signage around reserved or sensitive areas
    - [ ] Schedule activities during relatively dry conditions, installing permanent and temporary erosion and sediment control measures early, and revegetating exposed soils early
  - [ ] Incorporate appropriate erosion control BMPs
    - [ ] Divert upstream water around the construction site using a temporary structure (where applicable)
    - [ ] Incorporate and install permanent ditchlines, downdrains or channel realignments early in the construction schedule to promote keeping clean water clean
    - [ ] Apply revegetation techniques as soon as construction in each area is complete to promote germination and ground cover as quickly as possible
    - [ ] Consider factors such as flow, soil characteristics, presence/absence of permafrost, topography, climate, season, accessibility and cost when choosing erosion control measures

3.2 Report and Drawing Requirements

- ☐ Provide a project description
- ☐ Describe erosion and sediment control objectives
- ☐ Document existing site conditions
- ☐ Identify sensitive sites and critical areas of concern
- ☐ Describe preserved areas in the text and accurately map
- ☐ Include a section on erosion and sediment control accountability and administration
  - ☐ Provide a list of emergency and non-emergency contacts
  - ☐ Provide the contact's name, designation, employer's name, phone number
- ☐ Describe BMPs to be used
  - Sediment fence (BMP 1)
  - Berm Interceptor (BMP 3)
  - Storm Drain Inlet (BMP 4)
  - Rock Check (BMP 5)
  - Synthetic Permeable Barrier (BMP 6)
  - Straw Bale Barrier (BMP 7)
  - Rolled Erosion Control Product (RECP) (BMP 8)
  - Energy Dissipators (BMP 11)
  - Sediment Traps and Basins (BMP 12)
  - Slope Drains (BMP 13)
  - Diversion Ditches(BMP 14)
  - Mulching (BMP 16)
  - Scheduling (BMP25)
  - Stabilized Worksite Entrance (BMP 26)
  - Stream Diversion Channel (BMP 38)
  - Coffer Dams (BMP 39)
  - ☐ Include details by providing a description and mapping for installation locations and alignments
  - ☐ Include an inspection plans for all permanent BMPs including a minimum schedule (e.g.: once per 7 days and following significant storm event during construction and annually and following significant events for post construction) and what the inspector is looking for specifically
  - ☐ Include a maintenance plan for each BMP which describes installation requirements and when maintenance is required (e.g.: sediment fence – install with fabric embedded at base a minimum of 6 inches, sturdy, posts to the outside to area being controlled, - maintenance required when sediment reaches 50% height of fence, damage to fence evident (rips/tears), fence leaning under load).
- ☐ Provide a series of construction drawings illustrating and describing:
  - ☐ Pre-construction drainage and site features,
  - ☐ Construction grading and site modification, and
  - ☐ Erosion and sediment control measures to be implemented during all phases of the project.

APPENDIX E

ESTIMATING RUNOFF FROM SMALL WATERSHEDS

TABLES

E.1 Introduction

Drainage areas along highways are typically small (less than 20 ha) and can have long flow lengths. Highway catchments have relatively low imperviousness levels that generate lower runoff rates than similarly sized urban catchments. Runoff does, however, become concentrated along ditches and near outlet points, thus increasing erosion potential. Estimating peak runoff flow rate from small watersheds on a highway construction site is a key activity in the design of suitable erosion and sedimentation control measures. Using estimates of peak runoff flows, channels and control structures can be adequately sized to prevent overtopping and washout.

This chapter focuses on runoff calculation methods for highway construction sites in non-urban conditions. The estimation of runoff for urban highway construction sites is complicated by the effects of urbanization and development. As such, urban runoff flow rate estimation methods are not presented in this document.

The objective of utilizing flow estimates is to provide a stable and economical erosion protection design. It is of paramount importance that the erosion and sedimentation control strategy withstand the design runoff flow rates during the lifespan of the construction project. Generally, it is usually most cost-effective to utilize the existing drainage pattern as much as possible. In terms of design frequency, different road types have specific purposes and require different design standards. Table E.1 summarizes the general design levels for runoff capacity for several road service levels.

Table E.1: Return Frequencies for Roadway Drainage Design

Road Classification (RTAC 1976)	Return Period or Other Criteria for Storm Drainage System		
	Minor System	Major System	Stream Channels
Highway urban arterial	10 year	100 Year	10 year
Rural arterial collector	2 to 5 year	100 Year	2 to 5 year
Local	2 year	100 Year	2 year

Notes:

1. The flood frequencies for storm drainage systems may be modified to reflect local community requirements and adjacent land uses.
2. The minor system comprises the road gutters, inlets, storm sewers, and minor ditches. The major system is the route followed by runoff waters when the capacity of the minor system is exceeded and generally includes the roadway surface itself and major channels.

The amount of time involved in carrying out an economic analysis often cannot be justified when implementing small temporary or permanent erosion and sedimentation control measures. Guidelines are thus established by various jurisdictions for the choice of an appropriate event to be used in design based on experience. Erosion control work of a permanent nature should thus be designed for a runoff event that corresponds to a return period of at least once in 10 years (a 1:10 year event). Furthermore, provision should be made for safe overflow or bypass in more extreme events. Temporary erosion control work may be designed for a runoff event that corresponds to a return period of at least twice in 5 years (a 2:5 year event). Permanent vegetative or bio-technical erosion control measures that will replace any temporary measures should be capable of withstanding at least a 1:10 year runoff event.

Economic analyses are appropriate for large temporary or permanent structures. Costs associated with various structure sizes are estimated and are compared with the benefits to be derived, including the benefit of having a reduced probability of failure and reduced maintenance effort. The frequency of the event chosen for design is then based on an optimization of investment expenditure. However, major roadways required for emergency purposes will always be designed to withstand runoff events of 1:100 years. Therefore, erosion protection measures for these roadways should have a similar standard.

Designs should be based on professional judgement and should be performed by a qualified professional.

E.2 Approaches to Runoff Estimation

There are several different approaches to estimating peak runoff flow. The main categories for estimating peak runoff flow are listed as follows:

- Rational Method;
- Flood frequency analysis;
- Hydrologic modeling; and
- Empirical formulae.

Of these methods, only the Rational Method will be discussed in this document. The Rational Method provides reasonable peak runoff flow estimates for small watersheds. The use of this procedure assumes that precipitation events of a given frequency produce runoff events of similar frequency.

The individual or firm responsible for designing erosion and sedimentation control measures must use their judgement and experience in determining the most appropriate means for estimating runoff flow rates. Runoff will vary with presence or absence of permafrost, organic terrain and other site factors.

E.2.1 Rational Method

The Rational Method is widely used in determining peak runoff flows for small to medium sized catchments and can be applied to watersheds up to 25 km^2 (B.C. Ministry of Environment 1992). However, it is considered to be most applicable to basin sizes under 100 ha where storage and channel routing effects are small. It is understood that there is no specific design manual for use of the Rational Method in the Northwest Territories, but there are complete reference documents in several Canadian provinces and from the United States. Caution should be exercised where lake storage, water storage in the active layer, melting permafrost, and topographic attenuation effects are significant within a basin. This does not generally apply to roadway areas where grading is continuous. The procedure is simple and relies on a minimal amount of local data. The formula for the Rational Method is presented as follows:

$$Q = 0.00278\ C \times I \times A \qquad \text{(Equation E.1)}$$

Where: Q = peak flow (m^3/s)

C = runoff coefficient (dimensionless)

I = precipitation intensity (mm/hr)

A = effective drainage area (ha)

The simplicity of the equation has resulted in the method gaining widespread usage for more than 100 years. However, such simplicity was achieved by lumping the effects of a number of variables, namely soil conditions, surface vegetation cover, antecedent moisture, depression storage and land slope into a single input parameter referred to as the runoff coefficient “C”. Extreme care should therefore be taken in the choice of the coefficient if reasonable accuracy is to be obtained. The Rational Method has been determined, through comparisons, to typically overestimate flows so it is suitable for the design of erosion and sedimentation control measures. It is not applicable for bridge and major culvert designs.

The major limitation of the Rational Method is the output peak flow. While some other methods produce a runoff-time curve or hydrograph, the Rational Method produces only an estimate of the peak runoff. For erosion control works along roadways, this limitation is not significant, as all designs are done taking into consideration the peak discharge from an event having a particular design frequency. However, for larger sediment control structures, the peak flow into the sediment basin may be modified by the storage effect of the reservoir resulting in a peak outflow that will be smaller than the inflow. In such a case, routing the inflow hydrograph through the basin will produce an outflow hydrograph that will be more appropriate for design. Routing procedures are not simple and should be performed by a qualified engineer.

E.2.1.1 Key Assumptions

Inherent in the use of the Rational Method are a number of key assumptions. Understanding these assumptions will lead to a better appreciation of the results provided by this method. These assumptions are as follows:

1. The rainfall intensity is uniform over the watershed for the duration of the storm. However, rainfall events actually vary in both space and time. With very small catchments, the assumption may be true, but for larger catchments there will be a spatial variation in rainfall intensity and hence a tendency to overestimate runoff.
2. Maximum runoff occurs when the rainfall lasts as long as or longer than the time of concentration (t_c). The t_c is the time for runoff to travel from the hydrologically most distant point in the watershed to the outlet or point of interest. The assumption is that every point within the watershed is contributing to runoff to the point under consideration. With small watersheds, the assumption is likely to be true, but with

larger catchments, there may be a divergence from the assumption due to channel routing and storage effects.

3. The design precipitation event has the same frequency as the runoff event being estimated. In practice, this is not necessarily true, as identical storm events can produce highly variable runoff hydrographs over the same watershed when conditions such as antecedent moisture and thickness of active layer are different.
4. The effective drainage area should be used and it includes all areas that contribute runoff during major runoff events.

E.2.1.2 Runoff Coefficient

Table E.2 provides guidelines for evaluating the value of the runoff coefficient, C. In areas having more than one soil type or land use, the effective coefficient is obtained by evaluating a coefficient for each sub-area and computing a "weighted" average for the entire catchment based on area served.

E.2.1.3 Rainfall Intensity

The intensity and duration of rainfall events is currently collected at about seven stations within the Northwest Territories that record rainfall amounts. From the rainfall data, intensity – duration- frequency (IDF) curves have been derived. The locations of the recording stations are available through Environment Canada - Atmospheric Environment Service. Table 4-1 in the main manual lists the stations with available IDF curves as of 2012 – Yellowknife, Hay River, Fort Simpson, Norman Wells, Tungsten, Fort Reliance, and Inuvik.

Design intensity values for any selected duration and frequency can be read directly from the curves for the selected station. Locations in close proximity to any recording station can use the identical information from the IDF curves. However, as important as close proximity is, the selected station should also have a similar elevation and surrounding terrain, as mountain and valley effects greatly influence precipitation. Other sites may have to linearly interpolate data from two or more nearby sites.

The rainfall intensity to be used in the design of erosion and sedimentation control measures is taken from a nearby intensity-duration-frequency (IDF) curve, for the particular watershed. Available methods to determine t_c from an IDF curve include the Airport Method, SCS Upland Method and Branby-Williams Method.

Table E.2: Runoff Coefficients for Rational Method

LAND USE	C
MOUNTAIN	
Impermeable	1.00
Forested	0.90
STEEP SLOPE	
Impermeable	0.95
Forested	0.80
MODERATE SLOPE	
Impermeable	0.90
Forested	0.65
ROLLING TERRAIN	
Impermeable	0.85
Forested	0.65
PERMAFROST	
Continuous, near active layer detachment slides, High Arctic	0.6 to 0.9
HIGH ARCTIC (Lewkowicz and French 1982)	
Slopes with snowbanks	0.1 – 0.7
YELLOWKNIFE (Lewkowicz and French 1982)	
Bare Rock	0.82
Vegetated ridges	0.68- 0.72
Muskeg depressions	0.37-0.56
Compound Sites	0.5 – 0.77
AGRICULTURAL LAND, 0-30%	
BARREN PACKED SOIL	
Smooth	0.30-0.60
Rough	0.20-0.50
PASTURE	
Heavy soil	0.15-0.45
Sandy soil	0.05-0.25
Woodlands	0.05-0.25
BARREN SLOPES > 30%*	
Smooth, impervious	0.70-0.90
Rough	0.50-0.70

APPENDIX F

GUIDELINES FOR DESIGN OF OPEN CHANNELS

FIGURES

TABLES

F.1 Introduction

An open channel is any water conveyance route which allows a free passage of runoff, (e.g., the surface is exposed to the atmosphere and hence at atmospheric pressure). Closed pipes, when not at full capacity, act as open channels from a hydraulic perspective. Examples include ditches and other channels associated with roadway drainage, and culverts flowing less than full. Appropriate qualified professionals should be consulted in the determination of channel flow.

F.2 Type of Flow

Flow variations result from changes in runoff rate due to changes in rainfall intensity, snow melt rate, or groundwater seepage. Similarly, variations in flow depth occur along the length of the channel. Factors accounting for these variations are inflow from the sides and changes in channel characteristics such as roughness, cross-section and bed slope.

In attempting to simplify the approach to hydraulic problems, two states of flow are defined - unsteady and steady. Unsteady flow occurs whenever there is a variation in the quantity of water flowing along the channel.

Steady flow requires the flow rate to be constant with time. Therefore, most flows in the field are unsteady. However, many hydraulic calculations can be simplified by assuming a steady flow state. This steady flow is taken as the maximum flow that the facility can reasonably be expected to handle without incurring excessive costs. For roadway erosion control work, the peak discharge from a 1:10 year storm is typically used when permanent structures are designed. Temporary structures require less stringent conditions for which a 1:5 year storm or even a 1:2 year storm will suffice for the less important ones.

Steady flow is further subdivided into uniform and non-uniform flow modes. With uniform flow, the depth of water and the mean velocity are constant along every section of the channel possessing such a condition. The depth is referred as the normal depth, d_n, shown in Figure F.1.

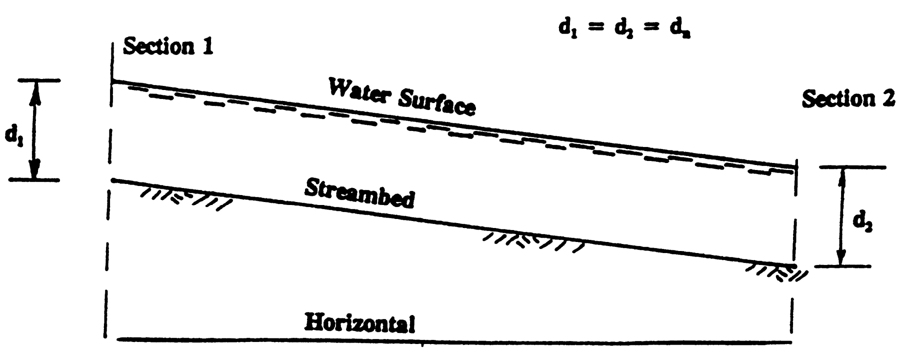


Figure F.1: Water Surface Profile of Channel with Uniform Flow

Uniform flow will occur when the following conditions are satisfied (otherwise the flow will be non-uniform).

- Channel cross-sectional area constant (including bottom width and sideslope angles);
- Bed slope constant;
- Channel roughness uniform; and
- Steady flow rate.

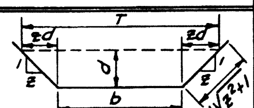
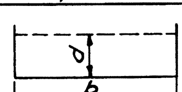
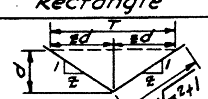
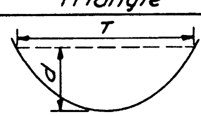
Even with the above conditions satisfied, there will still be non-uniform flow in the transition areas at the beginning and the end of the channel section.

While uniform flow conditions are rare, the simplification leads to channel sizes and flow depths that produce realistic design cross-sections and its use is therefore justified. Further, the error incurred as a result of the flow simplification is often small compared to errors built into estimating procedures for the other parameters required for design such as peak discharge rate and channel roughness. An appropriate freeboard allowance (for wave and wind effects) to road subgrade is typically added to peak channel flow elevations to further ensure flows remain in the channel under design conditions.

F.3 Geometric Properties of Channels

The solution of uniform flow problems and other hydraulic calculations require an input of various geometric properties of the conducting channel such as bottom width, sideslope angles, wetted perimeter and hydraulic radius. The properties in frequent use are defined below while Table F.1 provides formulae for the estimation of some of the properties for typical cross-sections.

Table F.1: Formulae for the Geometric Properties of Channels

Section	Area a	Wetted Perimeter p	Hydraulic Radius r	Top Width T
 Trapezoid	$bd+zd^2$	$b+2d\sqrt{z^2+1}$	$\frac{bd+zd^2}{b+2d\sqrt{z^2+1}}$	$b+2zd$
 Rectangle	bd	$b+2d$	$\frac{bd}{b+2d}$	b
 Triangle	zd^2	$2d\sqrt{z^2+1}$	$\frac{zd}{2\sqrt{z^2+1}}$	$2zd$
 Parabola	$\frac{2}{3}dT$	$T+\frac{8d^2}{3T}$ 1/	$\frac{2dT^2}{3T^2+8d^2}$ 1/	$\frac{3a}{2d}$

F.4 The Manning Equation for Uniform Steady Flow

A simple equation relating the velocity of flow under uniform conditions to the properties of a channel was developed by Robert Manning. The equation is:

$$V = (1 / n) \times R^{2/3} \times s^{1/2} \qquad \text{(Equation F.1)}$$

Where:
- V = velocity of flow (m/s)
- n = channel roughness (dimensionless)
- R = hydraulic radius, A/P (m)
- A = cross-sectional area of flow (m^2)
- P = wetted perimeter (m)
- s = channel bed slope (m/m)

From the above equation, the velocity of flowing water along the channel can be estimated under uniform flow conditions. The importance of this estimation lies in the fact that the amount of water flowing along any channel can be evaluated using the cross-sectional area of flow and the estimated velocity.

F.5 Manning Roughness Coefficient, n

This parameter is dependent on the degree of roughness provided by a channel surface. Estimates of the parameter have been made on an empirical basis for various materials and values obtained published for design purposes. Table F.2 provides a listing of values in current use for channels with various bed materials except vegetation. Roughness values for vegetation are obtained graphically as discussed below.

For most materials, the roughness value remains virtually constant when the flow depth exceeds 600 mm. However, in erosion control work along roadways, the flow depth is almost always less than 600 mm and appropriate ‘n’ values which change with flow depth must be used in design. In the case of rock riprap, gravels and many of the manufactured ditch lining materials, the change in n values with the flow depth is very pronounced.

Vegetation adds another dimension to the roughness problem along ditches. Stems projecting into the flow produce roughness as other materials do. The extent to which the vegetation allows the flow to go through varies with the magnitude of the flow and the type of vegetation. Thus the roughness of the ditch changes with the depth of flow through it and the type of vegetation along it.

Manning's n becomes an even more variable quantity with vegetated channels than with non-vegetated ones.

Table F.2: Manning's Roughness Coefficients (n)

Lining Category	Lining Type	n - value Depth Ranges		
		0-15 cms	**15-60 cms**	**> 60 cms**
Rigid	Concrete	0.015	0.013	0.013
	Grouted riprap	0.040	0.030	0.028
	Stone masonry	0.042	0.032	0.030
	Soil cement	0.025	0.022	0.020
	Asphalt	0.018	0.016	0.016
Unlined	Bare soil	0.023	0.020	0.020
	Rock cut	0.045	0.035	0.025
Temporary*	Woven paper net	0.016	0.015	0.015
	Jute net	0.028	0.022	0.019
	Fibreglass roving	0.028	0.021	0.019
	Straw with net	0.065	0.033	0.025
	Curled wood mat	0.066	0.035	0.028
	Synthetic mat	0.036	0.025	0.021
Gravel riprap	D_{50} = 2.5 cm	0.044	0.033	0.030
	D_{50} = 5 cm	0.066	0.041	0.034
Rock riprap	D_{50} = 15 cm	0.104	0.069	0.035
	D_{50} = 30 cm	-------	0.078	0.040

Note: Values listed are representative values for the respective depth ranges. Manning's roughness coefficient, n, varies with the flow depth.
* Some "temporary" linings become permanent when buried.

Source: Chen & Cotton, 1988; N. Kouwen, et al., 1980; A.G. Anderson, et al., 1970; R.L. Cox, et al., 1971; J.C. McWhorter, et al., 1968; K.G. Thibodeaux, 1982-85

To resolve the problems associated with estimates of flow through vegetation-lined channels, the Soil Conservation Service (SCS) of the U.S. Department of Agriculture has identified five classes of vegetation, designated retardance classes A to E as shown in a simplified generic classification Table F.3(a). All types of vegetation are assigned a classification based on growth height and stand density, and this grouping is used to determine an appropriate roughness value.

Other grasses have been given a retardence class by species detail; however, the species listed are not known to be naturally occurring within the Northwest Territories.

Table F.3 (a): Vegetation Retardance Classification

Vegetation Height and Density	Retardance Class
< 50 mm, good stand 50-150 mm, fair stand	E
50-150 mm, good stand 150-250 mm, fair stand	D
150-250 mm, good stand 250-600 mm, fair stand	C
250-600 mm, good stand > 600 mm, fair stand	B
> 600 mm, good stand	A

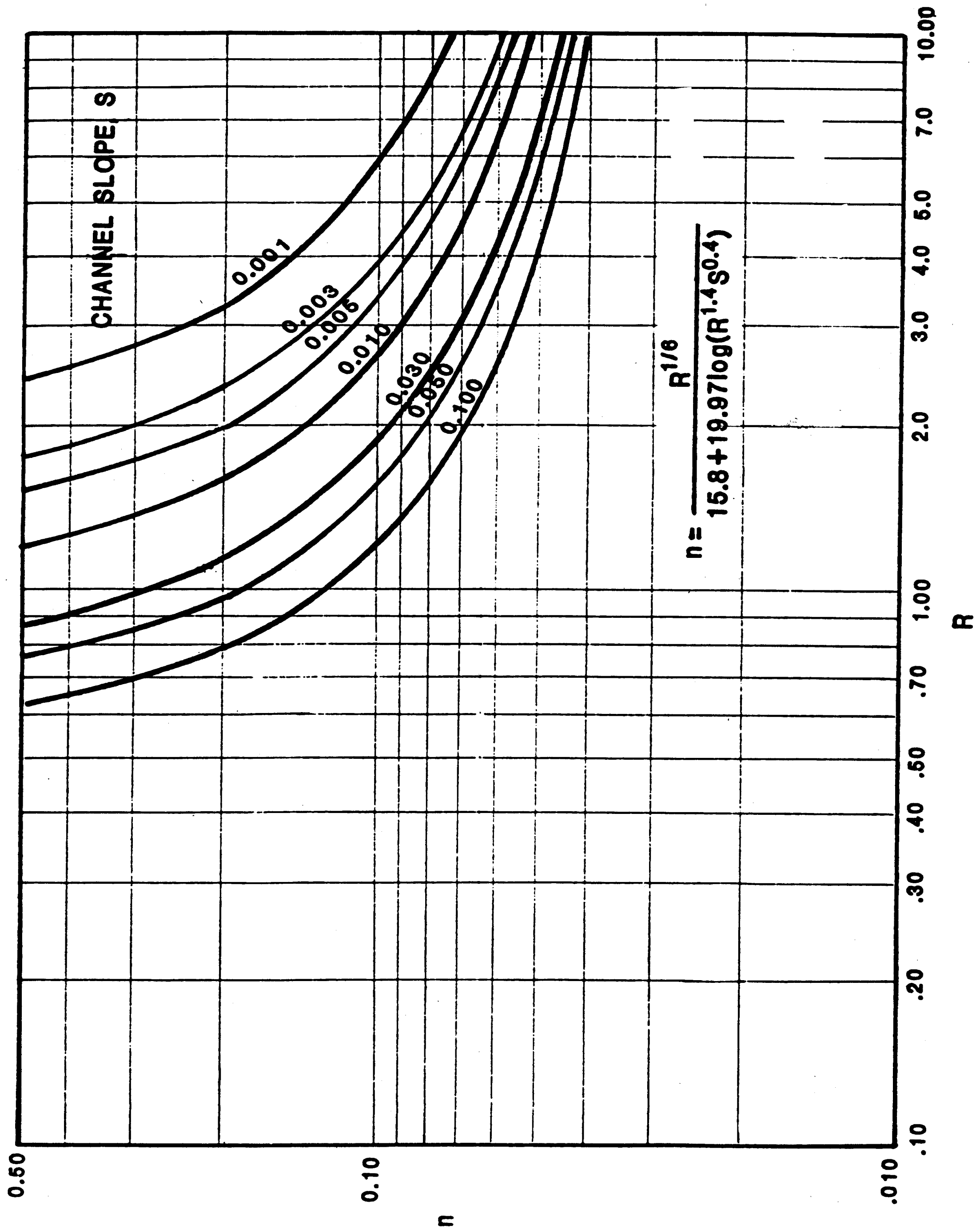


Figure F.2 Manning's n for Class A Vegetation

(Note: hydraulic depth (R) in feet)

Source: N. Kouwen *et al.* 1980

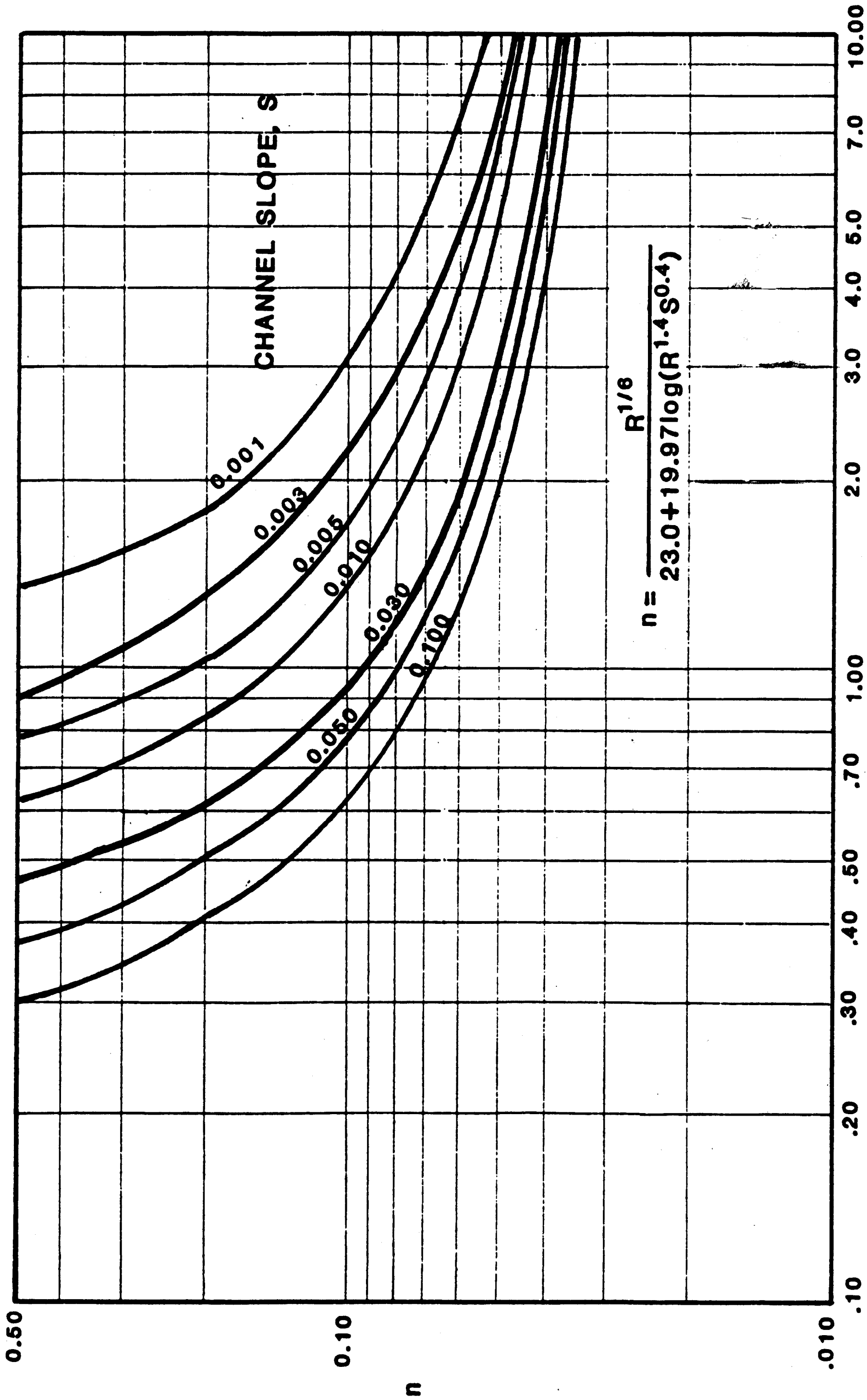


Figure F.3 Manning's n for Class B Vegetation

(Note: hydraulic depth (R) in feet)

Source: N. Kouwen *et al*. 1980

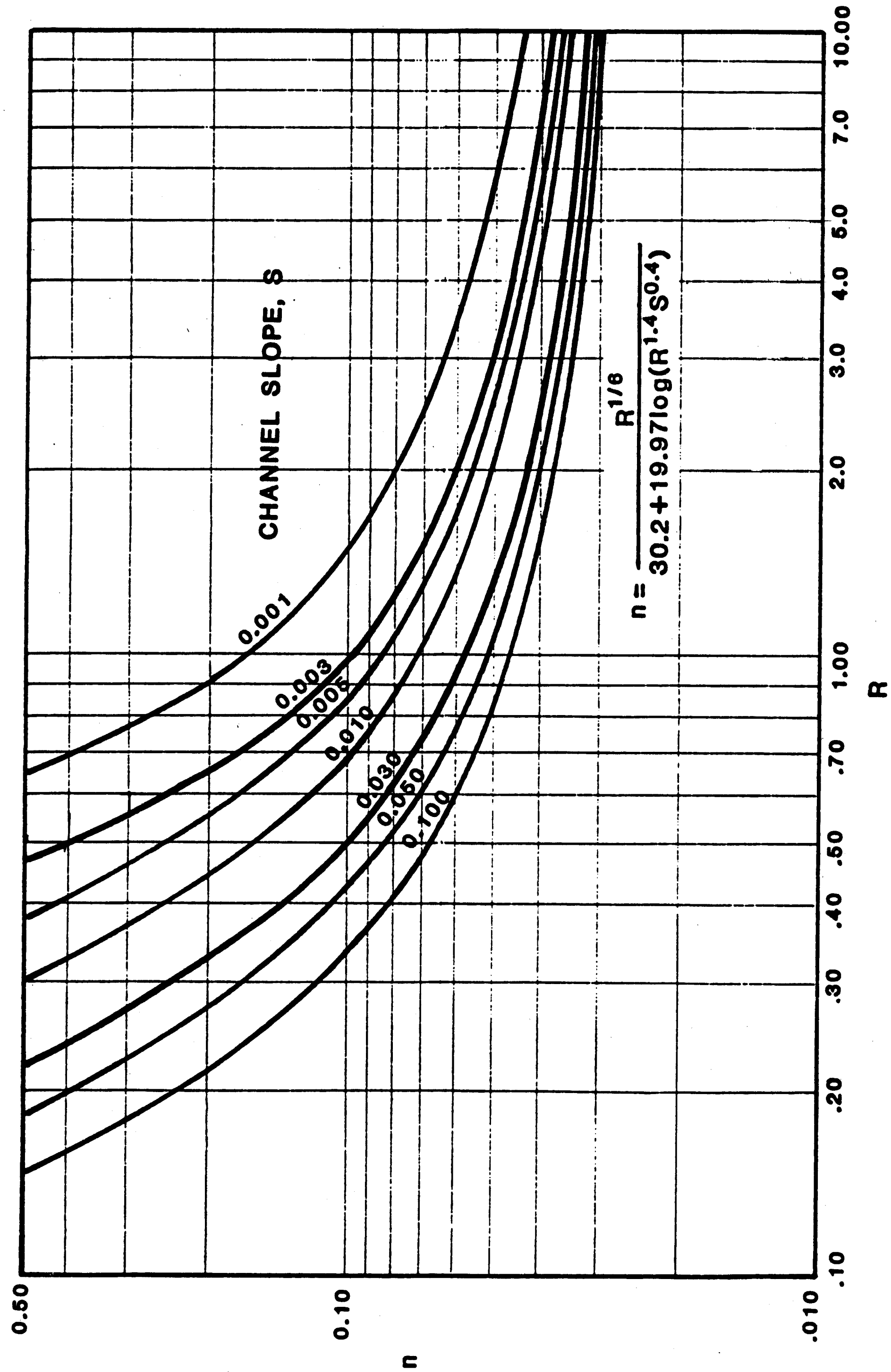


Figure F.4 Manning's n for Class C Vegetation

(Note: hydraulic depth (R) in feet)

Source: N. Kouwen *et al.* 1980

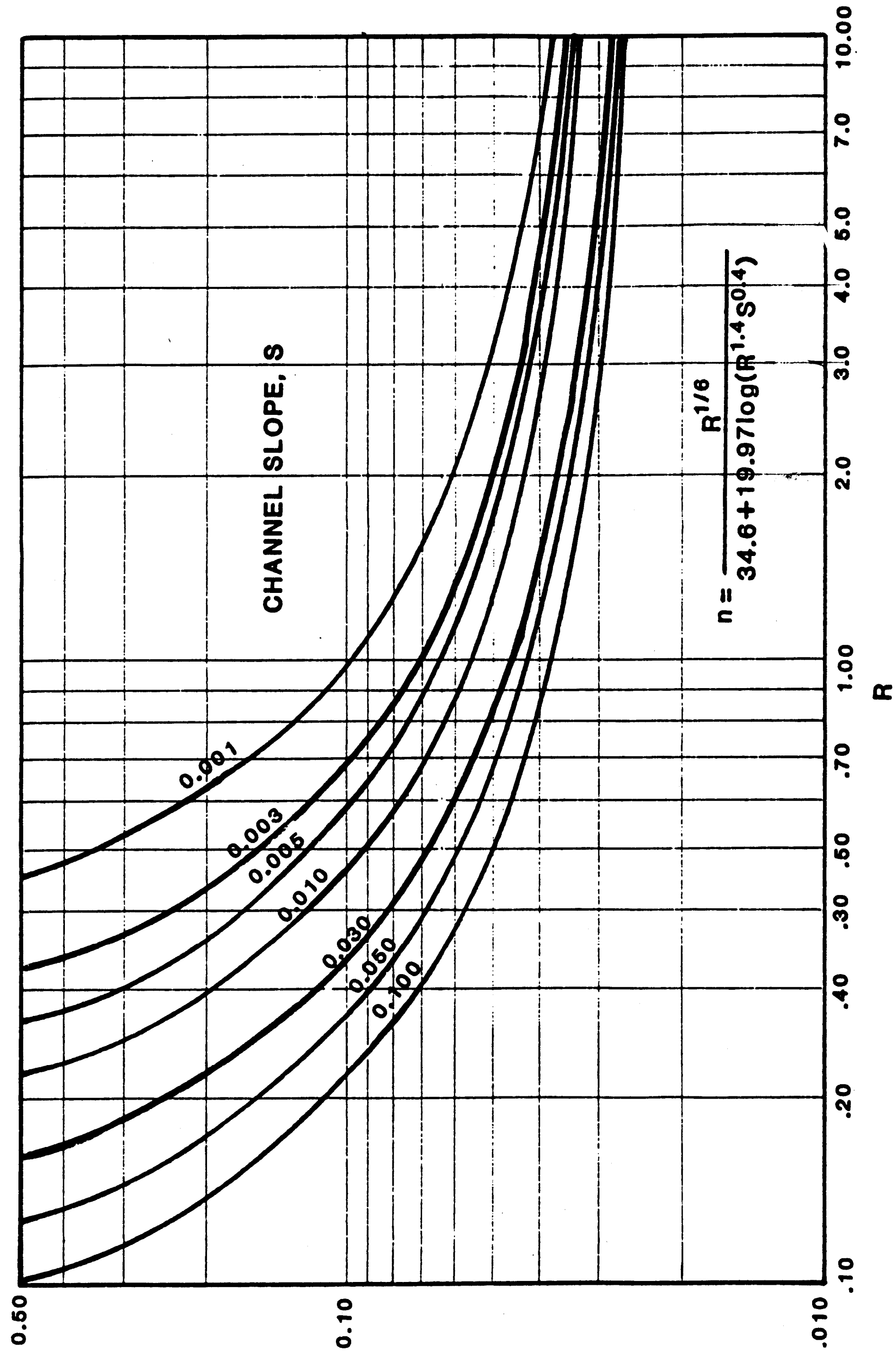


Figure F.5 Manning's n for Class D Vegetation

(Note: hydraulic depth (R) in feet)

Source: N. Kouwen *et al.* 1980

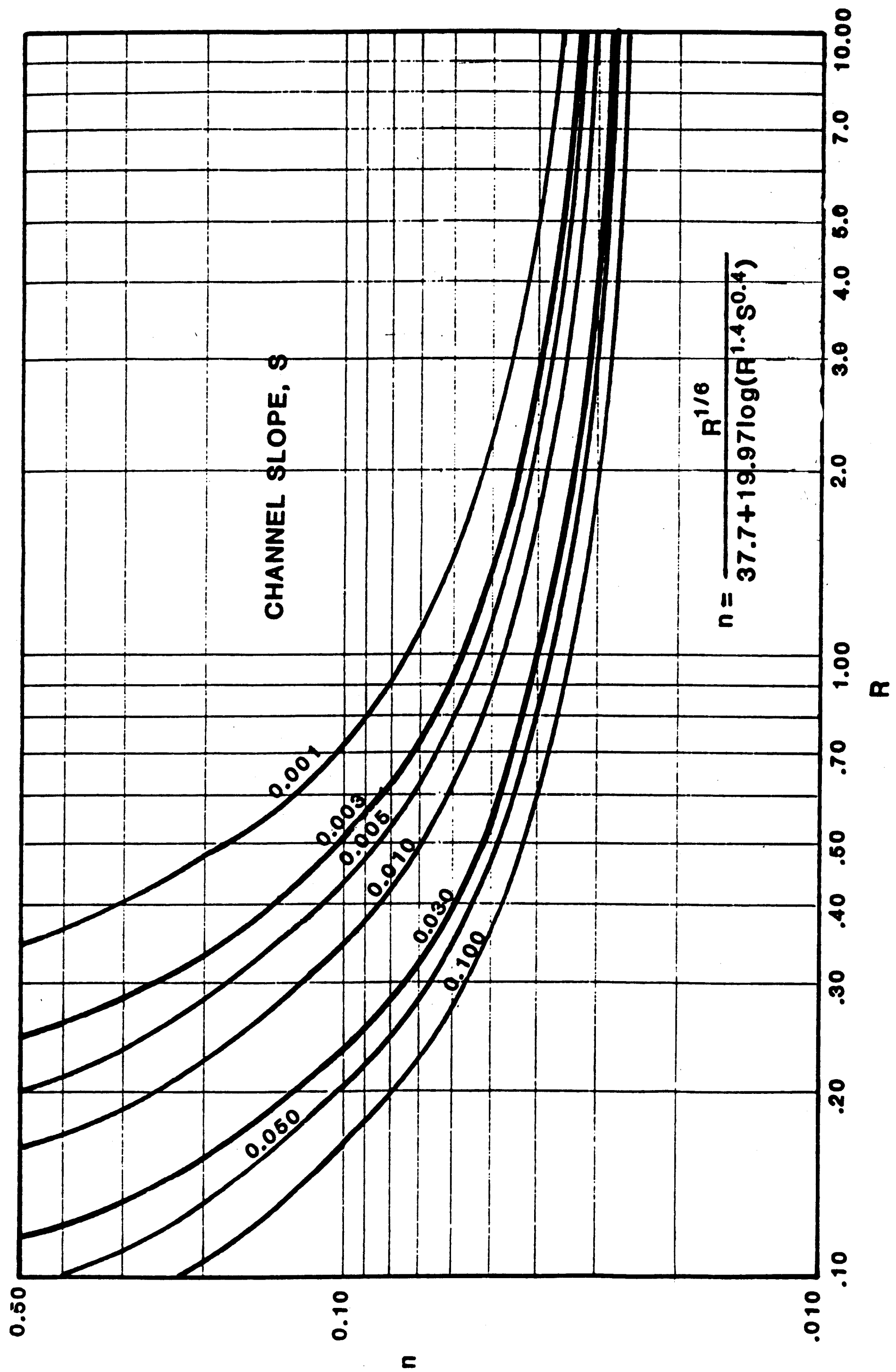


Figure F.6 Manning's n for Class E Vegetation

(Note: hydraulic depth (R) in feet)

Source: N. Kouwen *et al*. 1980

Table F.3(c): Maximum Permissible Shear – Stress Values and Velocities for Various Materials

Materials	Test Time (hr)	Performance Properties: Maximum Permissible Shear Stress (N/m^2)	Performance Properties: Maximum Permissible Velocity (m/s)
Bare soil[a] (see Figure F.12) (*Table F.3d)			
Noncohesive (Dia. = 0.1 – 25 mm)	NDG	1.5 – 20	0.46 – 0.76*
Cohesive (P.I. = 4 – 50) (see Figure F.11) (Table F.3d)	NDG	0.5 – 38	0.52 – 1.13* 1.8 (hard pan)
Gravel riprap[a] (*Table F.3(d))			
D_{50} = 25 mm (thickness t = $2D_{50}$)	NDG	15.8	0.76 – 1.13*
D_{50} = 50 mm (thickness t = $2D_{50}$)	NDG	31.6	1.13 – 1.22*
Rock riprap[a] (** Table F.3(e))			
D_{50} = 150 mm (thickness t = $1.5D_{50}$)	NDG	95.8	2.2 **
D_{50} = 300 mm (thickness t = $2D_{50}$)	NDG	191.5	3.0 **
Gabion Mattress (*** Table F.3(f))			$V_{critical} – V_{limit}$
thickness = 0.25 m; D_{50} = 120 mm	NDG	200	4.5 – 6.1 ***
thickness = 0.30 m; D_{50} = 150 mm	NDG	230	5.0 – 6.4 ***
thickness = 0.50 m; D_{50} = 190 mm	NDG	250	6.4 – 8.0 ***
Grass (established)[a] (Table F.3g)	NDG	16.8 – 177.2	0.8 – 2.4
Vegetative			
Class A Retardance	NDG	177.2	
Class B Retardance	NDG	100.6	
Class C Retardance	NDG	47.9	
Class D Retardance	NDG	28.7	
Class E Retardance	NDG	16.8	
Fiberglass roving[a] (SOP)			
Single	NDG	28.7	NDG
Double	NDG	40.7	NDG
Straw (loose) covered with net[a]	NDG	69.4	NDG
EROSION CONTROL MAT (ECM)			
Coconut material[c]	0.5	143	3.0 – 4.6
Wood excelsior material[a]	NDG	74.2	NDG
Jute net[a]	NDG	21.5	NDG
Straw blanket with sewn net[c]	0.5	95.7 – 105	1.8 – 3.0
Straw/coconut blanket[c]	0.5	120	3.0
TURF REINFORCEMENT MAT (TRM)			
Bare ground conditions[a,b]	0.5	239 – 287	5.5 – 8.2
	50	95.6	2.4
Vegetation established[b]	0.5	100 – 380	5.5
growth period ≥ 36 mos. & growth density dependent	50	100 – 239	3.0
COMPOSITE TURF REINFORCEMENT MAT (C-TRM)			
Bare ground conditions[b]	0.5	239	3.7
	50	95.6	2.1
Vegetation established[b]	0.5	382	6.1
	50	239	4.3

[a] From Chen and Cotton (1988)

[b] From IECA (1991, 1992, 1995)

[c] As reported by manufacturer

Notes:

i) NDG = No data given

SOP = Spray-on-Product (e.g. mulch)

V_c = Critical Velocity

V_l = Limit Velocity

ii) RECP types include ECM, TRM, C-TRM

For use of RECP products, product certification on performance and physical properties are required from suppliers.

Performance of RECP will depend on Final Density of Vegetation Growth after installation and the growth period specified.

iii) Relationship of shear stress not linear with flow velocity; select lining based on permissible tractive resistance.

iv) Performance values given are limited to flow of 1.4 m^3/s.

F.6 Channel Discharge Equation

The discharge (Q) of a channel is related to the velocity and the cross-sectional area of flow through the continuity equation:

$$Q = A \times V \qquad \text{(Equation F.2)}$$

Where: Q = discharge (m^3/s)

A = cross-sectional area of flow (m^2)

V = velocity of flow (m/s)

With uniform flow, V in above equation can be replaced by Manning's expression to arrive at the following revised continuity equation for uniform flow.

$$Q = A[(1 / n) \times R^{2/3} \times s^{1/2}] \qquad \text{(Equation F.3)}$$

Knowing the geometric shape of a channel and the depth of flow, the cross-sectional area, A, and the hydraulic radius, R, can both be evaluated. Additionally, if the bed slope, s, and the channel roughness, n, are known, the entire right half of the equation can be quantified, providing an estimate for the discharge, Q.

F.7 Design Channel Dimensions

Channel design involves a reverse process to the discharge estimation procedure outlined above. The discharge is known from hydrological calculations and appropriate channel dimensions have to be determined to ensure satisfactory flow conveyance.

Inputting known values of Q, n and s into the revised continuity equation leads to a value of the quantity, A x $R^{2/3}$, which cannot be solved directly to provide flow depth and bed width estimates. Thus the design of channels using Manning's equation requires an iterative process. Briefly the procedure is as follows:

- An appropriate channel shape and bed width is chosen, taking into consideration the geometric and other requirements of the roadway;
- Evaluate channel discharge using Manning Equation (Equation F.1) based on the assumed geometric properties;
- Compare evaluated discharge with design discharge;
- Adjust original geometric parameter assumptions and recalculate channel discharge;
- Continue this procedure until congruence between calculated and design discharges occur.

Various graphic methods and computer programs are available to assist in solving Manning's equation.

F.8 Approaches to Controlling Soil Erosion

There are two types of design approaches for the design of open channels depending on whether or not siltation or erosion is considerations in design. In the first approach, the material that comprises the channel and sideslopes is assumed to be in dynamic equilibrium with the silt-laden water of the stream. A regime state prevails with erosion and deposition occurring at the same rate over the long-term resulting in a stable channel section with no real loss or gain of material. This approach is called the Permissible Velocity Method.

Such an approach is necessary when sediment laden water is required to be handled in earthen channels as unacceptable erosion or deposition of bed material can occur. Typically this approach is applicable to drainage and irrigation systems, and river realignments.

The second approach, called the Tractive Stress Method, assumes that the material that comprises the channel boundary is capable of resisting soil loss through erosion, and the channel size will be determined for carrying the design flow. Most open channels carrying clear water, including roadside ditches, are designed using this approach.

With erodible bed material such as some natural soils, the design is completed by checking the assumption of non-occurrence of erosion. If erosion is found likely to occur, the channel is redesigned using larger channel sizes, gentler bed slope if possible, or armouring along the bed and sideslopes to resist any erosion.

F.9 Permissible Velocity Method

The need to check whether or not soil erosion will occur was recognized early in the design of open channels. Engineers originally approached the problem by defining limiting velocities to which a bed material can be subject to. Channel design proceeded by limiting the flow velocities along them to values lower than the permissible velocities. Alternatively, protection of the channel was provided using some form of channel lining.

If it is possible to design the channel so water flow occurs with a velocity less than the competent mean velocity of the native soil, soil erosion should not be a major problem. However, there may be erosion of the exposed earth due to rainfall and other weathering processes. Due to potential problems with silt that can occur, unlined channels must be regularly maintained.

The permissible velocity method was historically adopted for channel assessment. Recent developments recognized and utilized tractive stress method as an acceptable hydraulic assessment method (see Section F.10).

Table F.4: Competent Mean Velocities for Cohesive Soils*

Depth of Flow (m)	Soil Scourability **			Remarks
	High (m/s)	Medium (m/s)	Low (m/s)	Normal Ditch Flow for Highway
1.0	0.5	0.9	1.6	0.3
1.5	0.6	1.0	1.8	N/A
3	0.6	1.2	2.0	N/A
6	0.7	1.3	2.3	N/A
15	0.8	1.5	2.6	N/A

Source: RTAC Drainage Manual 1987

Notes:

* Competent velocities should be based on local experience whenever possible, taking into account saturation and weathering.

** It is not considered advisable to relate the tabulated values to soil property indices because of the strong effect of saturation and weathering on the scourability of the soils. However, the following tentative relationship to consistency is offered as a rough guide.

High scourability	- very soft to soft clays
Medium scourability	- firm to stiff clays
Low scourability	- stiff to hard clays, some glacial tills

See Table F.5 for soil consistency determination.

F.10 TRACTIVE STRESS METHOD

In the 1950s, it was recognized that the permissible velocity approach, though successfully used in the design of open channels, does not reflect the physical phenomenon of soil erosion. It was postulated that erosion occurs as a result of the shear force exerted by water flowing over the bed and sideslopes of a channel. While the velocity of flow bears a relationship to the shear force exerted, the relationship is not linear (e.g., equal increases in velocity do not produce corresponding increases in shear force).

Attention was then focused on the development of a method for the evaluation of the applied hydraulic shear and to ensure that the bed material is capable of withstanding the applied stress. This led to the development of the Tractive Stress Theory.

The Tractive Stress Theory, as related to stable open channels, simply states:

applied tractive shear stress $\leq$ critical shear stress

Under uniform flow conditions, the applied tractive stress exerted by flowing water is given by:

$$\tau = \delta \times R \times s \qquad \text{(Equation F.4)}$$

Where: τ = Tractive stress (kPa)

δ_w = Unit weight of water (kN/m^3)

R = Hydraulic radius (m)

s = Bed slope (m/m)

Maximum tractive stress induced by any flow occurs at the point of greatest depth or at the centre of any channel with horizontal bed is given by the equation:

$$\tau_{max} = \delta_w \times d \times s \qquad \text{(Equation F.5)}$$

Where: d = Depth of channel (m)

The critical shear stress is a property of the material comprising the channel boundary. It is defined as the limiting hydraulic shear stress that can be applied to a material to initiate significant soil erosion or material failure in the case of ditch linings.

Natural soils possess varying critical shear stress capacity and the process of design involves evaluating this capacity and limiting the tractive stress to a value less than the capacity evaluated. Similarly, various commercially available lining materials have differing critical shear stress capacities and hence the tractive stress must be limited in a similar manner to the critical stress of the lining.

The effect of concentrated flows in channels in terms of their erosion tendency on the materials (natural soil or erosion control lining) comprising the channel bed and sideslopes, is discussed in more detail in Sections F.12 to F.14.

F.11 Distribution of Tractive Stress

F.11.1 Straight Sections with Uniform Flow

In any given channel, the tractive stress is not uniform across the channel bed. Variations occur across the entire cross-section of the channel. Typically, for a trapezoidal channel, the stress variation occurs as shown in Figure F.2. Maximum values occur at the centre of the section and reduce gradually and then abruptly go to zero at each corner. Along the side slopes, maximum values occur at approximately two-thirds the depth of flow with magnitudes of $0.75\tau_{max}$.

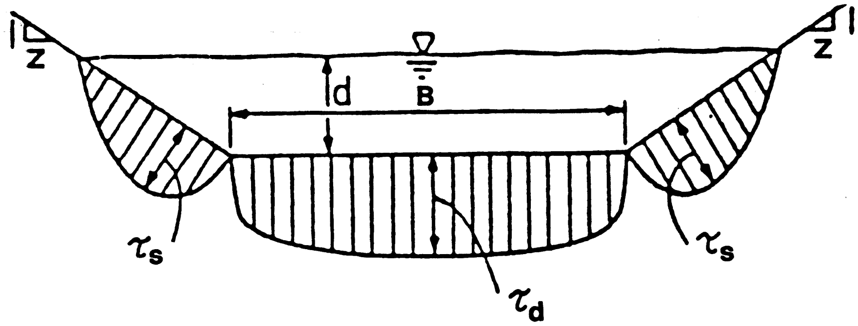


Figure F.7: Typical Shear Stress Distribution on Trapezoidal Channels

Note: τ_s = 0.75 δ ds = 0.75 τ_{max}

τ_d = 0.97 δ ds = τ_{max}

δ_w = Unit weight of water

d = Depth of water

s = Channel gradient

Source: Chow 1959

F.11.2 Bends

The changing flow paths along a bend in a channel induce additional shear stress at the shaded locations shown in Figure F.3. Upstream of a bend, the additional shear occurs along the inside, while downstream, the greater shear moves toward the outside. Downstream, the additional shear persists for some distance beyond the bend. Protection of the channel may be required for some distance, L_p, beyond the bend as given by the equation below.

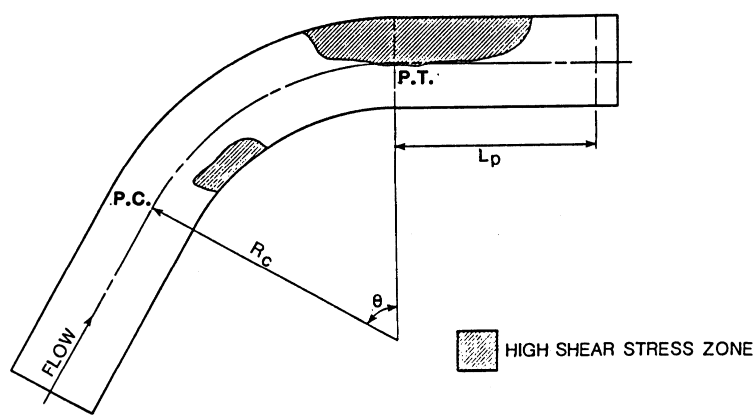


Figure F.8: High Shear Stress Zones in Bends

Source: Nouh & Townsend, 1979

$$L_p / R = (0.694 \times R^{1/6}) / n_b \qquad \text{(Equation F.6)}$$

Where: L_p = Length requiring protection

R = Hydraulic radius

n_b = Manning's roughness coefficient in bends

F.12 Resistance of Bare Soil to Erosion from Concentrated Flows

The behaviour of a soil is largely influenced by its composition. Such composition can range from completely granular material such as cobbles, gravel and sands to completely flat, plate-shaped, microscopic clay particles. Most soils comprise a mixture of granular and clay particles and the overall behaviour of such a soil will be dependent on the influence of each fraction comprising the soil.

Experience has found it convenient to separate naturally occurring soils into cohesive and cohesionless materials based on particle size distribution and plasticity. The convenience arises from the fact that many characteristics of a soil can be inferred from the plastic behaviour of cohesive soils and the grain size distribution of cohesionless soils.

F.12.1 Permissible Shear Stress

Any soil subjected to the flow of water it experiences a shear stress along its surface which acts to dislodge soil particles. Initially, with low shear stress, the soil may be capable of resisting the flow. Thus the bed and sideslopes remain stable. With increasing flow depth, there comes a time when the shear stress imposed by the flow on the channel bed is capable of dislodging soil particles into suspension. The shear stress at which this soil loss first occurs is referred to as the Critical Shear Stress and represents the maximum hydraulic shear stress to which the soil can be subjected. For design purposes, the critical shear stress is regarded as the Maximum Permissible Shear Stress.

As an extension of the concept, critical shear also occurs on manufactured channel linings. In this case, the critical shear is interpreted as either the hydraulic shear causing lining failure or rapid soil loss. Permissible shear is similarly taken as the maximum stress to which a lining can be subjected before the onset of failure.

F.12.2 Cohesive Soils

Numerous investigators have looked at the problem of cohesive soil erodibility in attempts to obtain correlations between the critical shear stress and the properties of a soil. Some of the properties identified as influencing soil erodibility are:

- Mineralogical composition
- Chemical composition of the fluid surrounding soil particles
- Sodium Absorption Ratio (SAR)

- Degree of compaction
- Plasticity

At present, no procedure exists for evaluating the critical shear stress that takes into consideration all the identified variables. Even if such a procedure existed, it would not be very valuable for design purposes as the many factors that affect soil erosion are difficult to determine. Costs would be the influencing factor.

An acceptable method using two parameters is available to evaluate the permissible shear stress of a cohesive soil. One of these parameters, the plasticity index, is routinely determined by the designer in their routine soil investigation and testing. The other parameter, compaction, as measured by the blow count, N, on the Standard Penetration Test is not as routinely evaluated. However, an estimate of the N value can be made by the feel of the sample when worked between the fingers. Alternatively, a simple hand-held soil investigation tool called a Pocket Penetrometer can be used as a more accurate determination. In theory, the penetrometer measures undrained shear strength which can be related to the blow count, N, as shown in Table F.6.

In the absence of any data on soil compactness, a subjective evaluation of the N parameter will be required. As a guide, the consistency of the soil can be determined in the field using simple test as given below. Then using Table F.6, an appropriate N value can be selected for use in Figure F.4 to determine the permissible tractive shear stress of the soil.

Table F.5: Field Soil Consistency Determination

Very soft	Easily penetrated several centimetres by the fist
Soft	Easily penetrated several centimetres by the thumb
Medium	Moderate effort to penetrate several centimetres by the thumb
Stiff	Readily indented by the thumb, but penetrated only with great effort
Very stiff	Readily indented by the thumb nail
Hard	Indented with difficulty by the thumb nail

Table F.6: Consistency of Cohesive Soils Related to Standard Penetration Test Value, N

Consistency	Standard Penetration Value, N
Very soft	0 - 2
Soft	2 - 4
Medium	4 - 8
Stiff	8 - 16
Very stiff	16 - 32
Hard	> 32

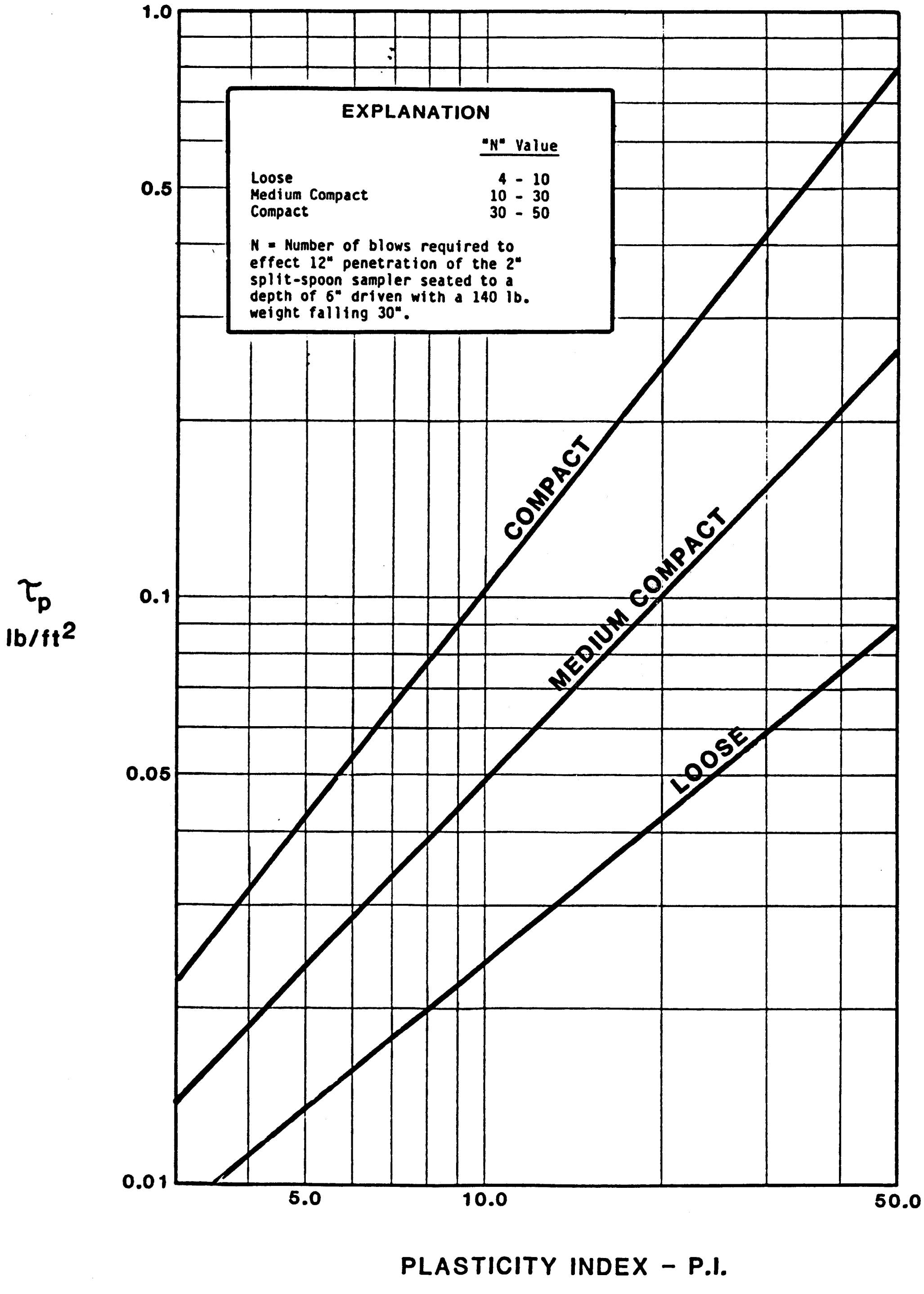


Figure F.9: Permissible Shear Stress for Cohesive Soils

Source: Smerdon & Beaseley, 1959

Note: 1 lb/ft^2 = 48 N/m^2

F.12.3 Cohesionless Soils

With cohesionless soils, the particles are relatively inert and erodibility is dependent mainly on the grain size distribution. Tests carried out on various cohesionless soil samples have shown that the permissible shear stress can be related to the mean particle size of the sample as shown in Figure F.5. Thus it is a simple matter of assessing the mean particle size from a grain size distribution curve to determine the permissible shear stress.

For particles larger than 100 mm, $\tau_{p,}$ can simply be evaluated by the equation:

$$\tau_p = 6.25 \times 10^{-4} D_{50} \qquad \text{(Equation F.7)}$$

Where: τ_p = permissible shear stress (kPa)

D_{50}= mean particle diameter (mm)

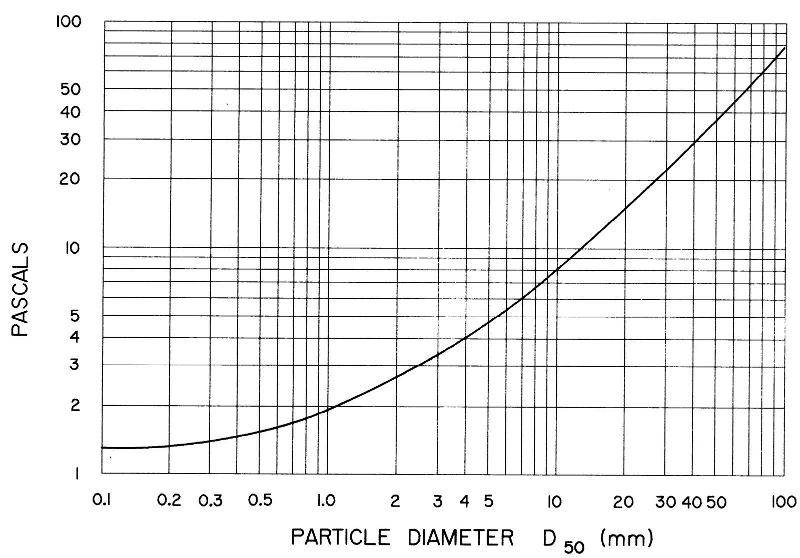


Figure F.10: Permissible Shear Stress for Cohesionless Soils

Source: Thibodeaux 1982-1985

F.13 Resistance of Vegetation to Concentrated Flow

The most widely-used method for permanently controlling soil erosion, both on slopes and along ditches, is the establishment of vegetation. Because of the relatively low cost, vegetation is the first and sometimes erroneously the only choice among soil erosion control practitioners.

There is a limitation of the extent to which vegetation will be successful in controlling soil erosion along ditches. Unless the limitation is defined, many instances will occur in which vegetation will be inadequate for the erosion control function intended.

The determination of the appropriateness of vegetation for soil erosion control along ditches is rather simple. It includes comparing the tractive resistance of the proposed vegetation with the shear stress exerted by the design flow. Vegetation will be adequate if the shear stress of the flow is less than the resistance of the vegetation.

There is one additional complexity in the calculation process introduced by a vegetative lining. The degree of flexibility and variations in growth height of various grasses and legumes normally used for the control of erosion vary with the different species. Further, the mowed height of the vegetation also affects roughness. As such, the roughness coefficient, n, an input into Manning's Equation, is not a constant.

F.14 Resistance of Non-Vegetative Linings to Soil Erosion

Non-vegetative ditch linings used for soil erosion control are of two types:

- Temporary; and
- Permanent.

Temporary linings are to be considered for use only at those locations in which vegetation growth is expected to take over the erosion control function in the future. Conversely, in sterile areas or those locations expected to experience larger hydraulic shear stresses than can be handled by vegetation, permanent erosion controls are required.

The approach to designing erosion control in either case is to compare the shear resistance of the lining with the tractive stress of the design flow. The lining selected should have a shear resistance greater than the flow shear stresses. However, when the channel gradient becomes steep (say greater than 10%) and the lining selected is a weighty material (such as gravels and rock riprap), special design procedures are required as the lining on the channel bed and more so on the sideslopes provides an additional de-stabilizing force component down slope. Procedures for such design are given in Section F.18.

Other permanent linings, such as articulating blocks that rely not only on their weight but also on their inter-connection with each other for their stability, must have their design based on the recommendations of the manufacturer. These recommendations will usually be derived from the results of hydraulic tests for performance evaluation carried out on the articulating blocks.

Many manufactured materials are currently available for soil erosion control. Most of them are bio-degradable although some permanent ones are also available.

F.15 Flexible Lining Design

Flexible linings, while not always applicable, are capable of handling most of the soil erosion problems along roadways. In addition, flexible linings are more versatile than rigid linings because of their ability to accommodate minor distortions in the subgrade without leading to failure. This property in particular makes them the preferred choice for lining ditches.

Caution should be taken when using of rigid or flexible lining materials. Linings should not be placed onto unstable slopes as the lining material will soon separate at one or more of the joint locations which would then expose the soils to erosion. The opening created will render the lining ineffective and may aggravate the instability of the slope by conducting water into the unstable mass.

The design procedure is a three step evaluation from which a decision is made at the end of each step regarding the need for the succeeding step. The three steps are given in the following paragraphs.

Step 1: Assess the capability of the soil to withstand the erosive forces of flowing water. If adequate, use seed, fertilizer, or mulch as required to establish vegetation. Sediment retention structures may be required to control sediment loss to areas beyond the site perimeter.

Proceed to Step 2 if soil cannot withstand erosion.

Step 2: Assess the capability of vegetation to control soil erosion. If adequate, provide temporary lining to control erosion while vegetation is being established.

Proceed to step 3 if vegetation cannot control the erosion.

Step 3: Design permanent erosion control measure (flexible or rigid), depending on local factors such as costs, ease of installation, availability of materials, maintenance costs, etc. The advantages and limitations of each lining type should be considered for situations of flow, slope, vegetation growth density, and soil type of specific soil conditions.

F.16 Rigid Lining Design

Rigid channel linings, because of cost, are only considered for erosion control when special conditions prevail that would preclude the use of other linings. Examples of such conditions are:

- Steep grade;
- Limited right-of-way;
- Appropriate flexible lining unavailable; and
- High probability of tampering by the public (i.e., removal of riprap or other measures).

As such, the first step in the design of a rigid lining is to determine the existence of any condition that may adversely affect the performance of the lining. Conditions to look for are:

- Unstable ground;
- Ground water seepage;
- Frost susceptible soil;
- Expanding clays; and
- Hydraulic uplift conditions.

The presence of any of the above will lead to distortions in the channel lining and eventual failure if the problem is not adequately addressed at the design stage. Such conditions may require the services of a hydrotechnical or geotechnical engineer during the design and construction phase.

When non-problematic ground conditions are present, the design is completed by estimating the design discharge and providing an adequate hydraulic section using the principals of open channel hydraulics presented earlier in this section.

The design discharge for permanent installations should correspond to the estimated runoff from an event with a return period of 1:10 years. A larger design event with a return period of 1:25 years or greater may be used in situations where it is judged that a safety hazard exists and that significant disruption of traffic will be caused by a structural failure of the installation.

F.16.1 Other Requirements

Rigid lining design requires considerations of upstream and downstream scour, hydrostatic uplift of the lining, anchorage to the slope and structural cracking. For small drainage areas less than 25 ha, the above requirements can be addressed by the following "rule-of-thumb" provisions:

- Utilize native consolidated soil or well-compacted fill for subgrade;
- Place a 150 mm thick drainage layer under the region of the downstream outlet;
- Provide a riprap apron with 150 mm diameter rock to a thickness of 225 mm for a length of 2 m;
- Provide cut-off walls at both the upstream and downstream end of the structure. Depth of cut-off should be 0.5 m across the entire width of the transition;
- Ensure that the structural thickness of the lining is a minimum of 75 mm; and
- Provide adequate freeboard.

F.17 Steep Gradient Channels

Steep gradient channels, defined herein as channels having gradients in excess of 10%, are sometimes required of the conveyance of water from one elevation to another at a significantly lower level. In cases of low flow conditions, a temporary lining will suffice to control any soil erosion until vegetation gets established. However, in situations of moderate flow, there will be the need for a permanent erosion control measure such as random riprap linings.

Permanent flexible linings (i.e., riprap lining) will be capable of handling most of the cases that cannot be resolved by vegetation. Rarely will a piped conduit (downdrain) or a rigid lining be required.

Materials commonly used for permanent flexible linings along steep gradients are riprap and gabions. Gabions include drop structures and mattresses. Hollow precast concrete blocks which interlock may sometimes be used if lower costs can be achieved. Generally, precast blocks tend to be more costly than riprap options.

For steep channels, drop structures are commonly used for flow control and energy dissipation.

F.17.1 Design Procedure

On steep channel bed slopes, temporary linings, which are usually of the blanket type, can be designed as outlined in Section F.15. Permanent rigid linings are to be designed according to Section F.16. In either case, there is a need to distinguish between steep and gentle gradients.

With permanent flexible linings, like riprap, gabion or concrete blocks, there are additional factors that must be taken into consideration when comparing the tractive stress of the design flow with the resistance of the lining. In none of the three types can a single permissible shear stress value be defined for steep gradient channels.

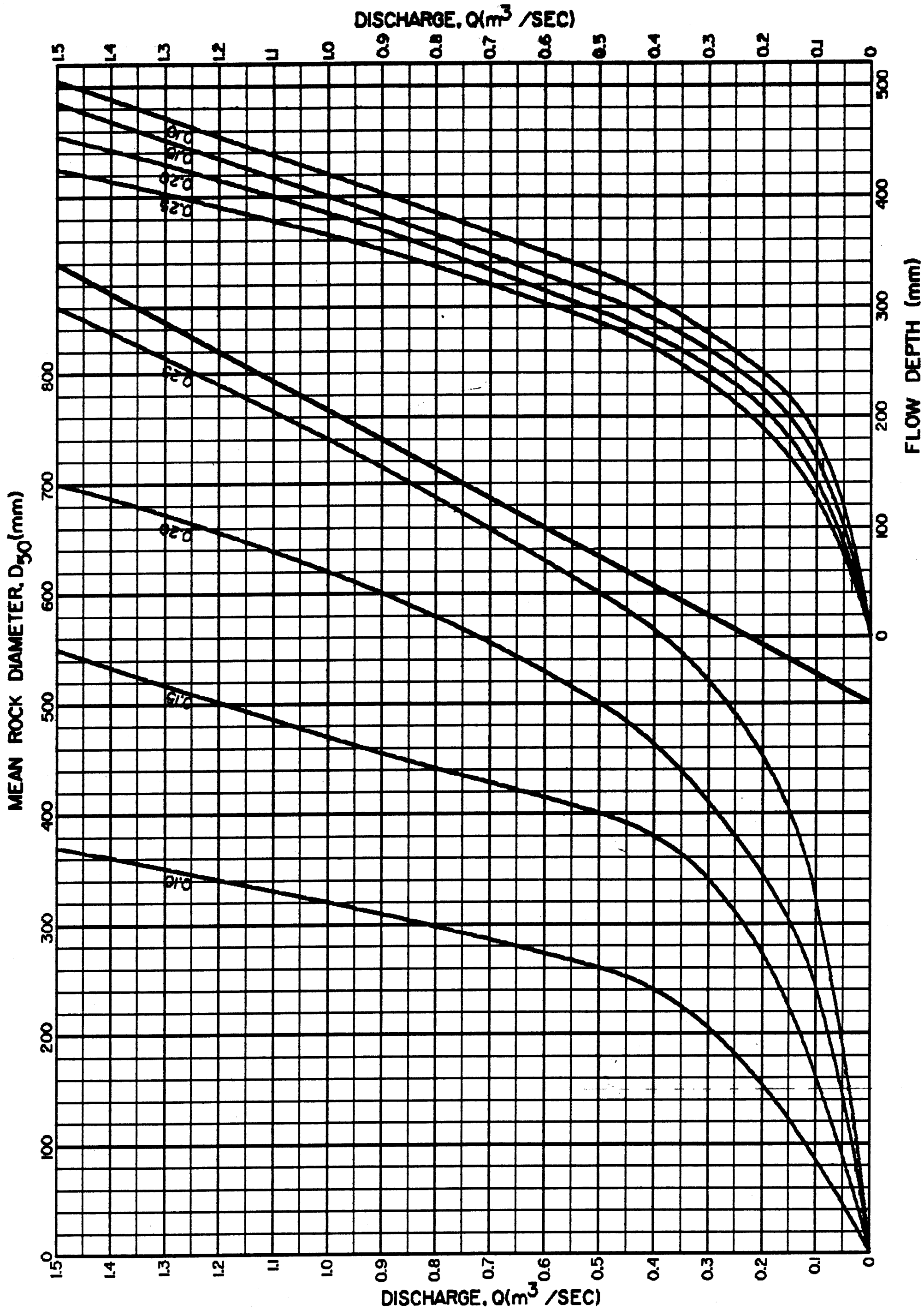
Physical factors to be considered are size and shape of the material comprising of the bed and sideslopes and channel geometry. Other factors are material buoyancy and the weight component down slope.

With proprietary concrete block systems (in which size, shape and surface roughness vary with each type of block), a generalized channel design procedure cannot be presented. Designs incorporating these materials must be completed according to the recommendations of the manufacturer.

However, with riprap and gabions, extensive hydraulic testing and theoretical evaluations have been carried out on material gradation normally used for such purposes and design procedures were evolved which are presented below. A comparison of the relative thickness of riprap versus gabion mattress was once investigated to indicate that a smaller (2 to 3 times) thickness of gabion mattress can be utilized under identical severe hydraulic conditions.

F.17.2 Riprap Design

Investigations into the use of riprap on steep slopes have led to rather complex equations which may not be of practical value in design. By making simplified assumptions regarding the typical gradation of riprap and by conducting hydraulic tests, charts given in Figures F.11 to F.14 have been produced from the complex formulation to simplify the design process. The charts can be used for bed slopes varying between 10% and 25% and bed width increasing from 0 to 1.5 m. Linear interpolation will be required for bed slope and bed width intermediate between the limits given on the charts. Riprap used as a ditch lining on either gentle or steep grades needs to be sufficiently thick to ensure minimal loss of the underlying material. Additionally, a filter consisting of a suitably graded granular material or geosynthetic fabric of appropriate strength is required under the riprap to prevent piping failure of the underlying material.



Source: Chen & Cotton, 1988

Figure F.11: Steep Slope Riprap Design
(Bed Width = 0 m, Sideslope = 3:1*)

* Typical slopes for highway construction in the Northwest Territories range from 3:1 to 6:1.

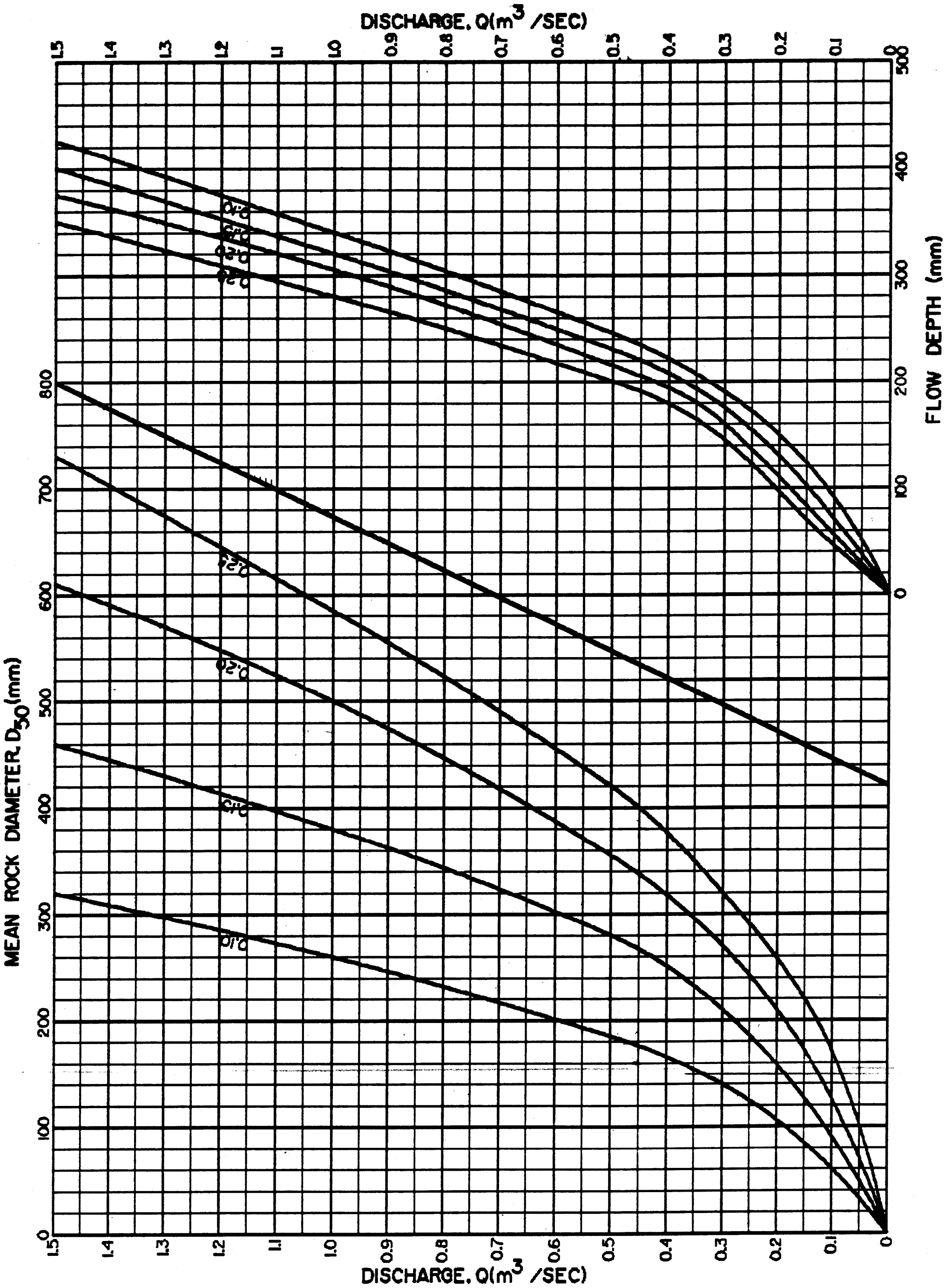


Figure F.12: Steep Slope Riprap Design
(Bed Width = 0.5 m, Sideslope = 3:1*)

Source: Chen & Cotton, 1988

* Typical slopes for highway construction in the Northwest Territories range from 3:1 to 6:1.

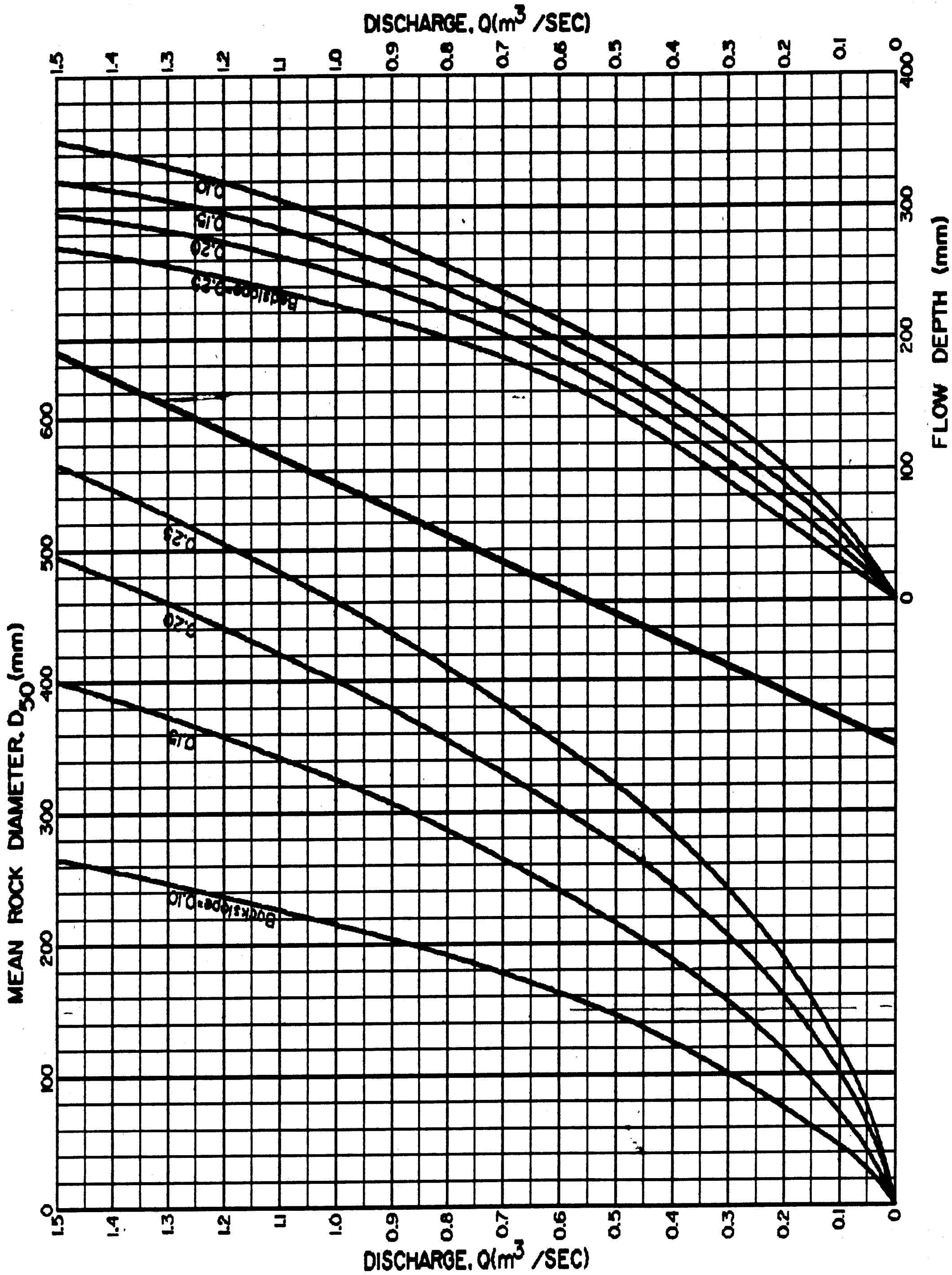


Figure F.13: Steep Slope Riprap Design
(Bed Width = 1.0 m, Sideslope = 3:1*)

Source: Chen & Cotton, 1988

* Typical slopes for highway construction in the Northwest Territories range from 3:1 to 6:1.

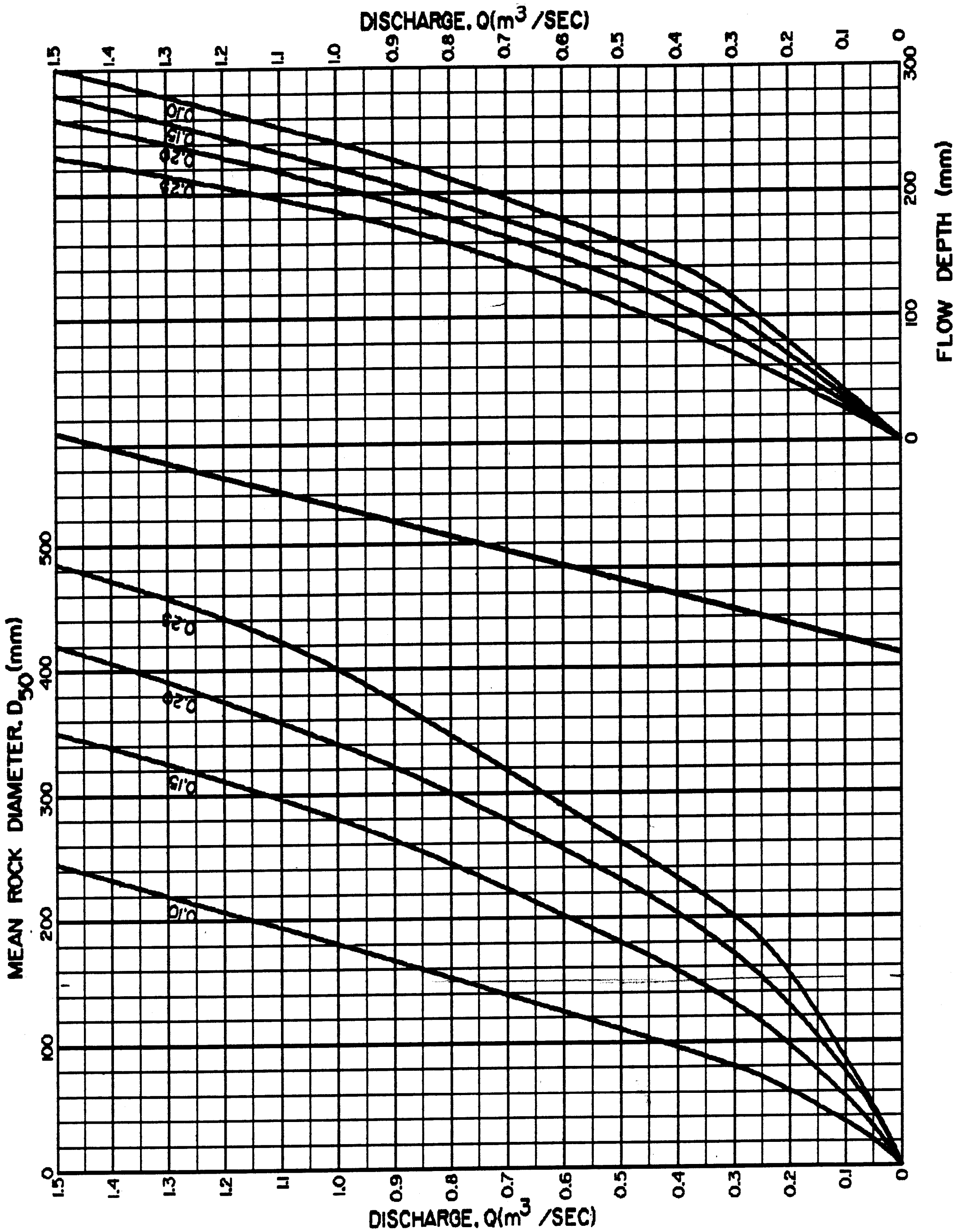


Figure F.14: Steep Slope Riprap Design
(Bed Width = 1.5 m, Sideslope = 3:1*)

Source: Chen & Cotton, 1988

* Typical slopes for highway construction in the Northwest Territories range from 3:1 to 6:1.

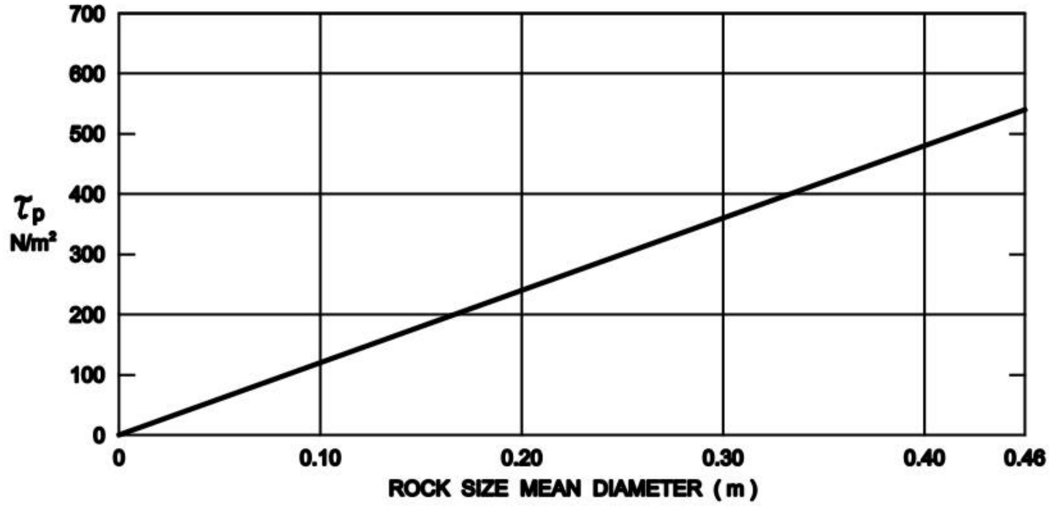


Figure F.15: Permissible Shear of Gabion Mattress vs. Rock Fill Size

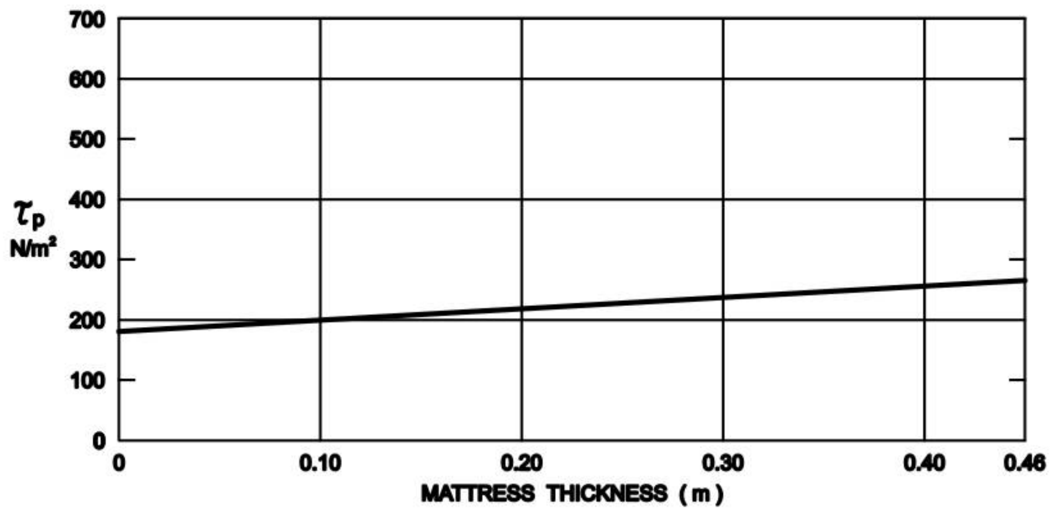


Figure F.16: Permissible Shear of Gabions vs. Mattress Thickness

Source: Chen & Cotton, 1988

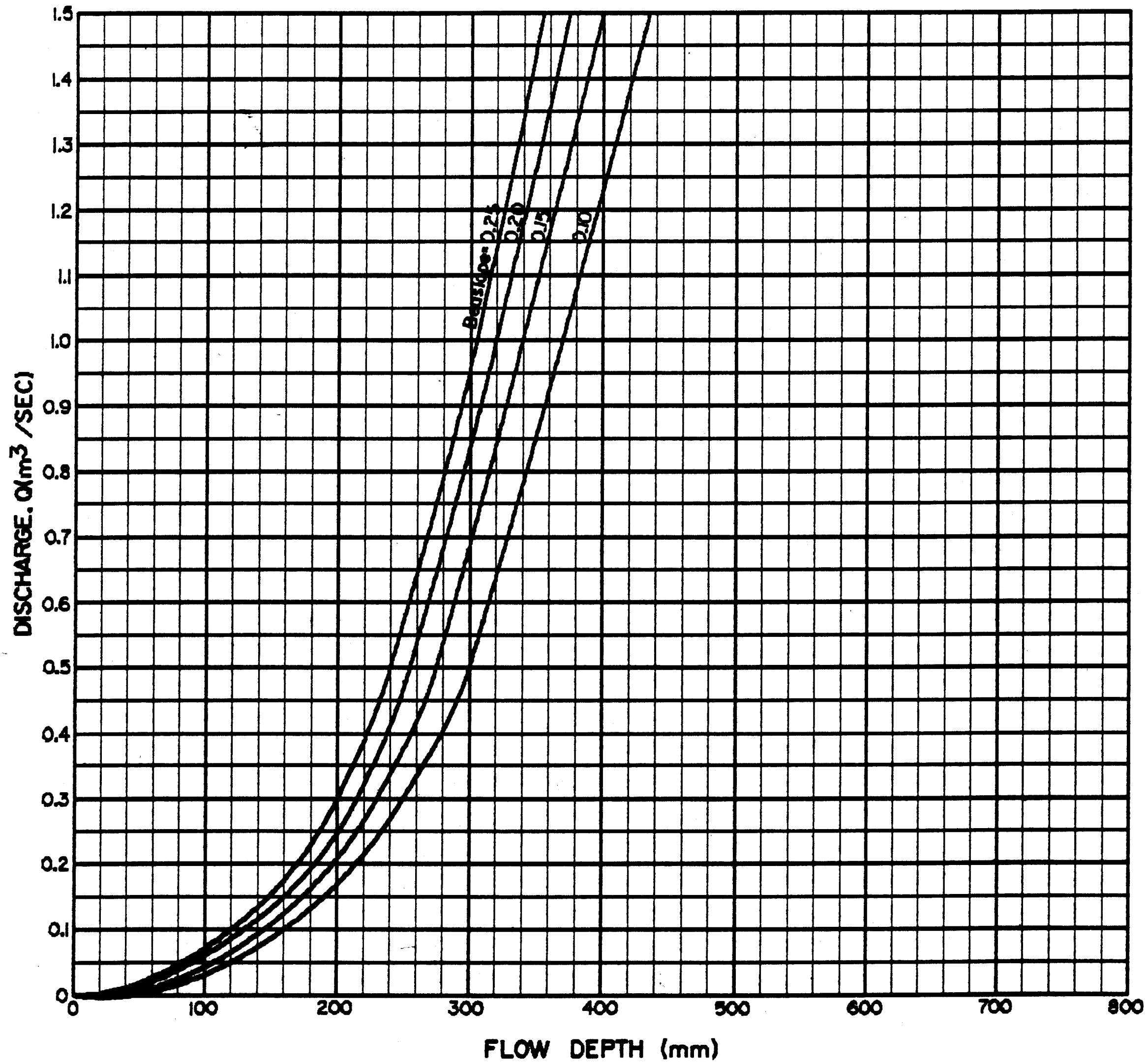


Figure F.17: Steep Slope Gabion Design
(Bed Width = 0 m, Sideslope = 3:1*)

Source: Chen & Cotton, 1988

* Typical slopes for highway construction in the Northwest Territories range from 3:1 to 6:1.

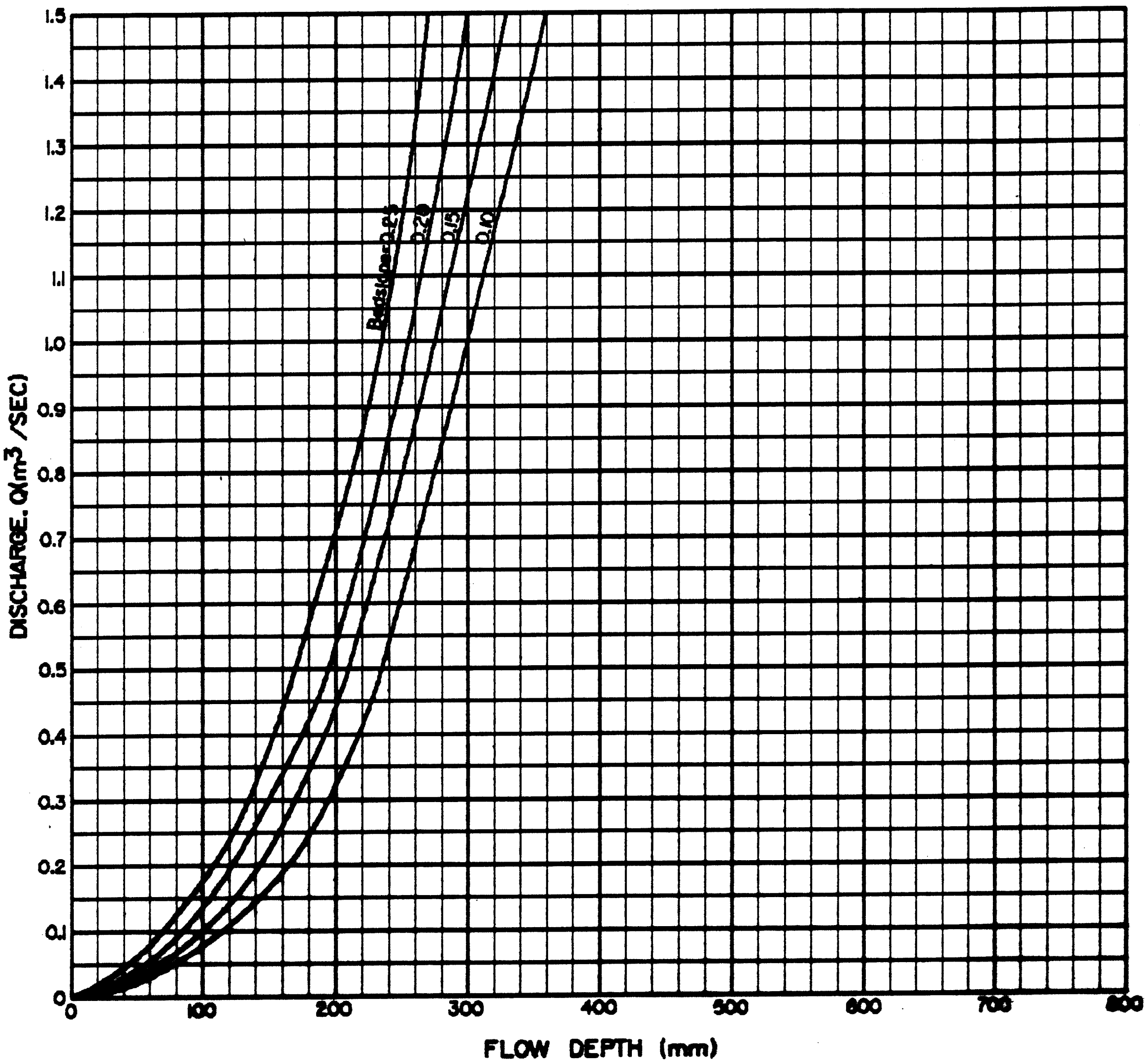


Figure F.18: Steep Slope Gabion Design
(Bed Width = 0.5 m, Sideslope = 3:1*)

Source: Chen & Cotton, 1988

* Typical slopes for highway construction in the Northwest Territories range from 3:1 to 6:1.

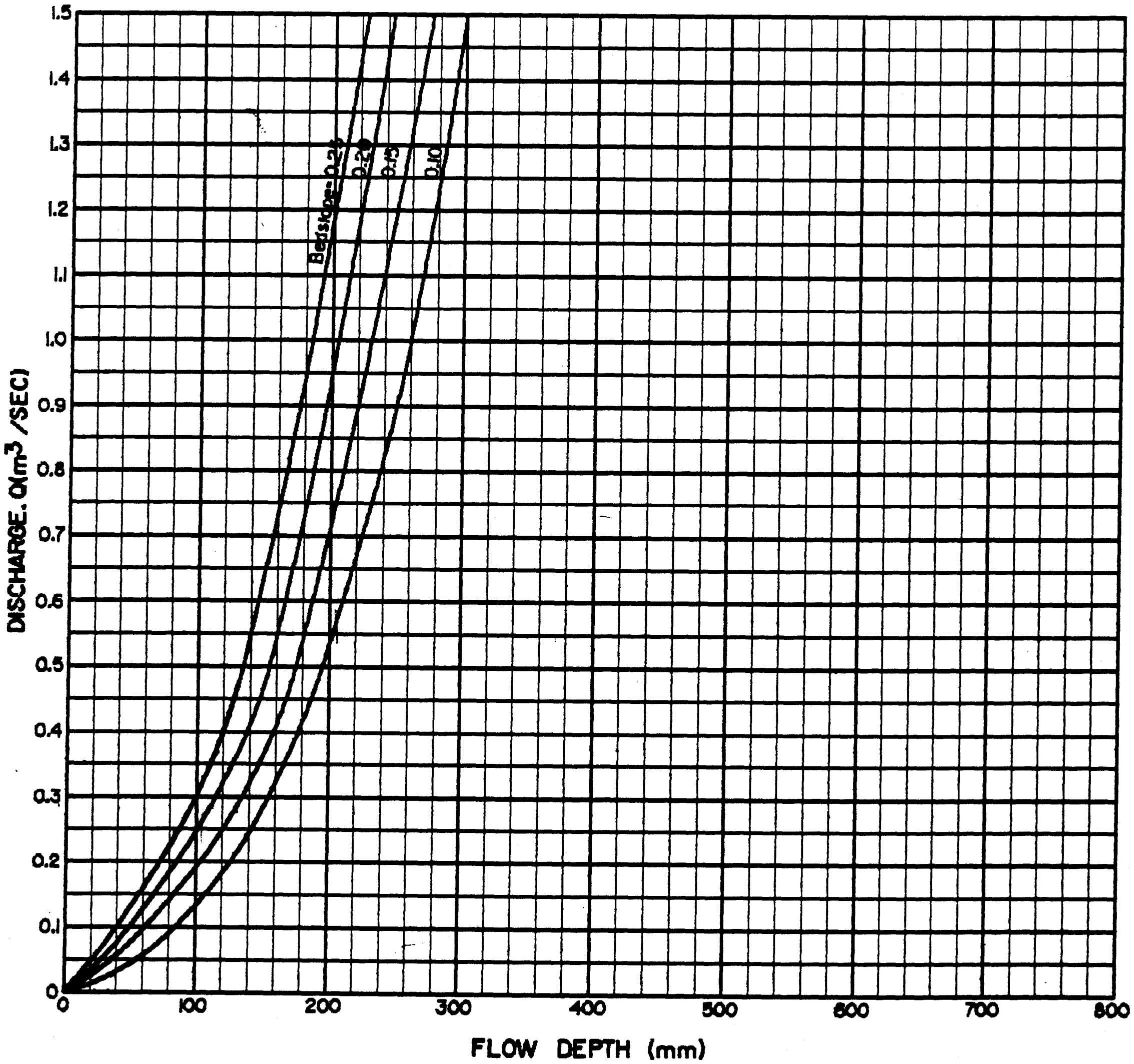


Figure F.19: Steep Slope Gabion Design
(Bed Width = 1.0 m, Sideslope = 3:1*)

Source: Chen & Cotton, 1988

* Typical slopes for highway construction in the Northwest Territories range from 3:1 to 6:1.

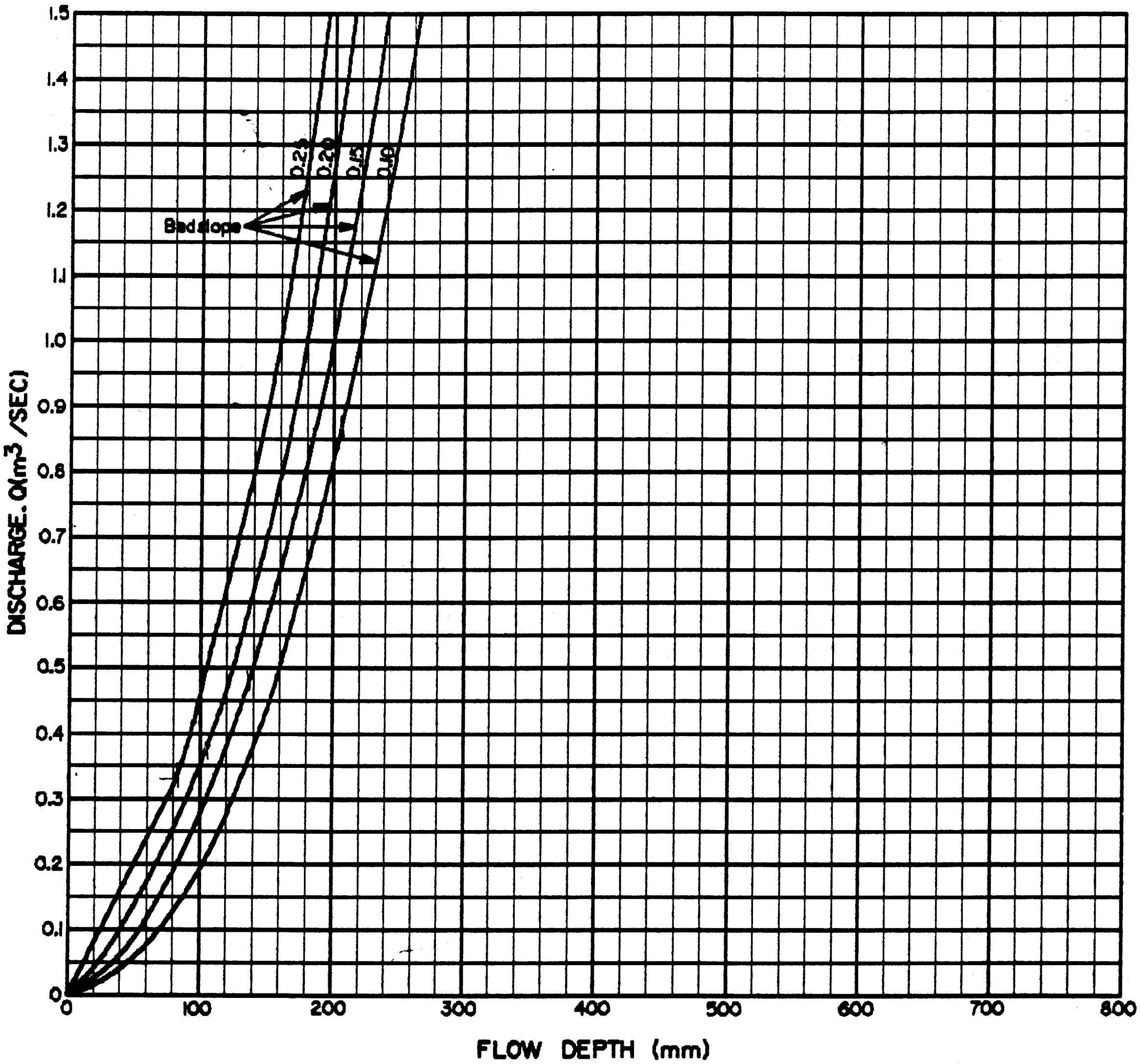


Figure F.20: Steep Slope Gabion Design
(Bed Width = 1.5 m, Sideslope = 3:1*)

Source: Chen & Cotton, 1988

* Typical slopes for highway construction in the Northwest Territories range from 3:1 to 6:1.

F.17.3 Gabion Design

Gabions are somewhat different from riprap in that the rocks are bound together by a wire mesh box, which removes the potential for rocks to become dislodged. The gabion structures can accommodate higher discharges than an equivalent-sized riprap channel.

Gabions are commonly used as drop structures for flow control and energy dissipation. Changing the channel slope from steep to gentle, by placing drop structures at intervals along the channel reach, results in a continuous steep slope being transformed into a series of gentle slopes and vertical drops. Instead of slowing down and transferring high erosion producing velocities into low non-erosive velocities, drop structures control the slope of the channel in such a way that the high, erosive velocities never develop. The kinetic energy or velocity gained by the water as it drops over the crest of each structure is dissipated by a specially designed apron or stilling basin which may be constructed of gabion mattress (FHWA HEC #14).

One potential failure mode is the rearrangement of the rocks within the gabion structure through the shear action of flowing water. Another mode is the scouring of the material underneath and behind the gabions. Both failure modes must be addressed in the design to ensure a functional structure. In this regard, charts given in Figures F.17 and F.18 have been prepared to guide both rock size selection and structure thickness evaluation.

The hydraulics of gabion structures has also been investigated (Chen & Cotton 1988). To assist in design, charts shown in Figures F.17 to F.20 have been prepared which relate discharge with depth of flow and bed slope. Bed widths considered are 0 to 1.5 m and bed slopes varying between 10 and 25% with sideslopes fixed at 3:1.

The charts can be extended to other channels with stable sideslopes by first designing an equivalent bed width channel with 3:1 sideslopes. The flow depth in the channel to be designed is then adjusted by equating flow areas. Gabions used as ditch lining on either gentle or steep grades, need to be sufficiently thick to ensure minimal loss of the underlying material. Additionally, a filter consisting of suitably graded granular material or geosynthetic of appropriate weight is required under them to prevent piping failure of the underlying material.

F.17.4 Filter Material

In most applications, a filter layer comprised of well-graded granular material is placed between the base soil and the riprap or gabion system. The intent is to ensure sufficient permeability to allow seepage to take place out of the underlying soil while at the same time minimizing the size of the voids in the filter to prevent the underlying material from migrating into the armour layer.

In current engineering practice, the granular filter blanket is largely replaced by a geotextile filter which performs essentially the same functions. Specific requirements for each type of filter area are:

Granular Filter:

(1) $$\frac{D_{15}(filter)}{D_{85}(soil)} < 5 < \frac{D_{15}(filter)}{D_{15}(soil)} < 40$$ (Equation F.8)

(2) $$\frac{D_{50}(filter)}{D_{50}(soil)} < 40 \; (U.S.\,Army\,Corps.\,of\;\; Engineers, 1955)$$

(3) Filter thickness ≥ $1xD_{100}$ (filter) or 150 mm minimum thickness, whichever is greater.

Where:

D_{50} = particle size diameter (m/mm) corresponding to 50% passing by mass

Geotextile Filter Fabric:

In selecting a geotextile filter fabric, the fabric should be able to transmit water from the soil and also have a pore structure that will hold back soil. The following properties of an engineering filter fabric are required to assure that the performance is adequate as a filter under riprap and gabion rock:

1. The fabric must be able to transmit water faster than the soil.
2. The following criteria for the apparent opening size (AOS) must be met:
   a) For soil with less than 50 percent of the particles by weight passing a 0.075 mm opening (U.S. No. 200) sieve, AOS < 0.6 mm (greater than U.S. No. 30 sieve).
   b) For soil with more than 50 percent of the particles by weight passing a 0.075 mm opening (U.S. No. 200) sieve, AOS <0.297 mm (greater than U.S. No. 50 sieve).

The above criteria only apply to non-severe or non-critical installations. Severe or critical installations should be designed based on permeability and gradient ratio testing.

F.17.5 Lining Thickness

The minimum thickness of gabion or riprap structures should be the size of the largest stone to be used. Obviously, an isolated large stone which is not representative of the overall material should be discarded and not taken as a measure of the structure thickness. For most rocks used for ditch lining purposes, the criterion will translate into the following:

Lining thickness = (2 to 3) x D_{50} (Equation F.9)

F.17.6 Gradation

Both riprap and gabion stone should be uniformly graded meeting the requirements below:

$3 > D_{100} / D_{50} > 1.5$; and

$3 > D_{50} / D_{20} > 1.5$ (Equation F.10)

The criteria will allow some smaller rock sizes in the armouring, which will fill the voids between the larger rocks, to form a compact layer.

A further requirement, applicable only to gabion structures, is that the largest rock should not be less than 2/3 of gabion thickness nor should the smallest rock be smaller than the mesh opening size.

APPENDIX G

SEDIMENT CONTAINMENT SYSTEM DESIGN RATIONALE

FIGURES

TABLES

G.1 Sediment Containment System Design Rationale

The following design rationale is considered reasonable to evaluate the effectiveness of containment system (Type I and II) for use at high to medium risk areas.

- An inflow quantity (Q_i) is assessed based on runoff volume (Q) from a 24-hour intensity rainfall, a 1:2 year storm. (Runoff from a 1:10 year storm will be approximately 2.5 times that for a 1:2 year storm. Thus, it is impractical to provide such large storage volume, especially if revegetation of disturbed area is to be achieved in 1-2 years and deactivation of the basin/trap considered for rural highways.)
- The sediment delivery ratio (SDR, ranges from 0 to 1) is the mass of sediment eroded divided by the mass of sediment actually delivered from a drainage area. In the absence of actual measurements, it must be estimated. To be conservative, SDR is assumed to be 1 when a high risk water body is connected immediately downslope of an erosion source (i.e. assume all eroded sediment is delivered to the containment system).

Runoff (Q) and Inflow (Q_i) Estimation *(1:2 yr. storm, 24hr intensity rainfall, soil type, area of disturbance)*

$$Q_i = SDR \times Q \qquad \text{(Equation G.1)}$$

Where: Q_i = Inflow to sedimentation pond (m^3/s)

SDR = Sediment delivery ratio (dimensionless)

Q = Natural runoff (m^3/sec)

Runoff is estimated using:

- Precipitation of a 24 hour rainfall intensity from a 1:2 year storm;
- Effect of ground absorbency of different soil types affecting runoff. For various soil types, a general relationship between precipitation and runoff per hectare can be assessed. (see Figure G.1);
- Some jurisdictions (such as EPA) assume 25 mm runoff as minimum parameter;
- 150-250 m^3/ha of disturbed land;
- Amount of fine sediment-laden runoff close to high risks: SDR=1

The quantity of runoff from precipitation is affected by the absorbance, permeability and texture of the surficial soils (Figure G.1).

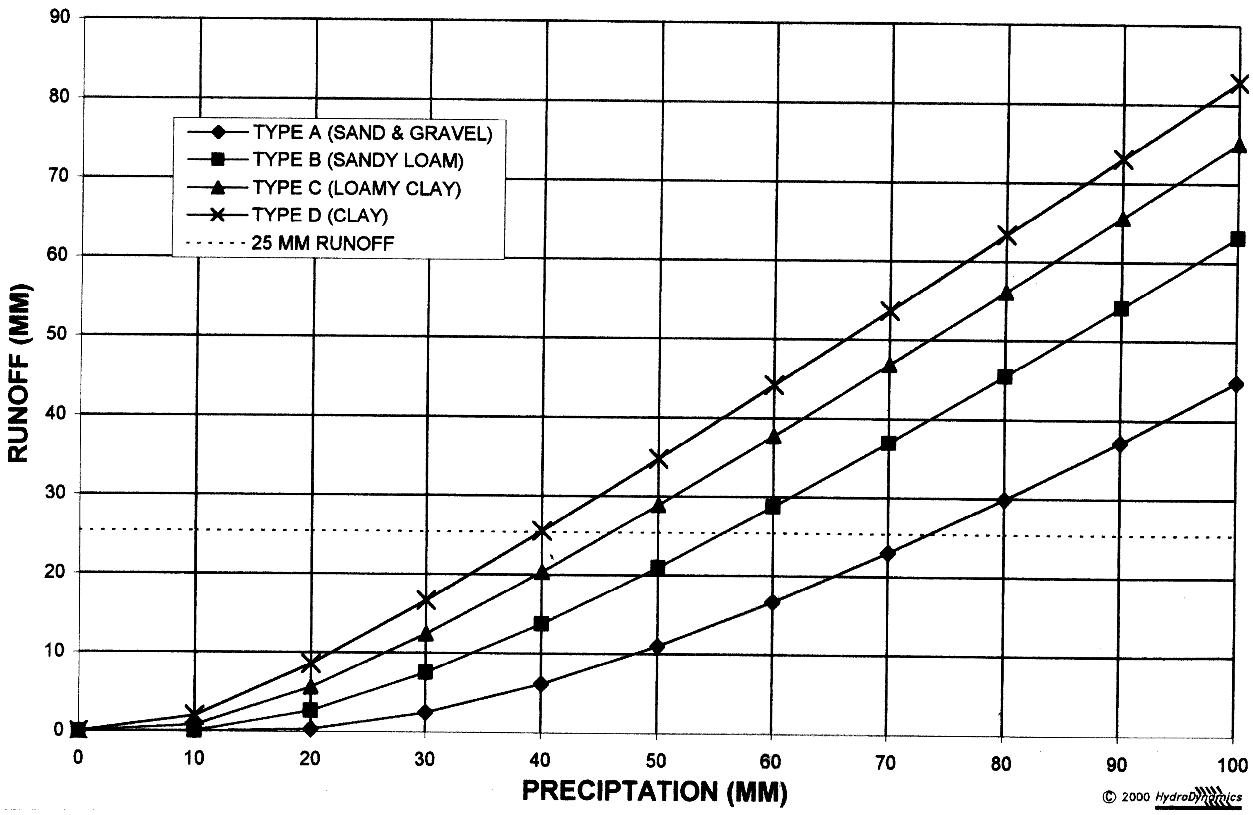


Figure G.1: Estimated Runoff from Precipitation over Different Soils

Source: Fifield, 2001

Settling Velocity (Vs) for Soil Particles

A particular soil particle size (D_S) can be targeted within the sediment-laden runoff and its percentage by weight is determined from a hydrometer gradation curve of local soil materials. Different size particles exhibit different settling velocities with smaller particles requiring a longer time to settle. The different settling velocities for sand to silt to clay size particles are presented in Table G.1. The times required for the clay to sand size particles to settle in vertical distances in water are presented in Figure G.2 and it shows that clay size particles require a very long settling time.

Chemical coagulants, such as polyacrylamide (PAM), are available to promote settling in sedimentation ponds. Coagulants cause the small clay particles to group into larger particles, thereby increasing their settling velocity and effectively reducing the settling time. Guidance on coagulants has not been included in this manual because their application is best guided by the manufacturer's instructions, tailored to the specific application. However, PAM or other coagulants are an option available for use in site specific cases. Applications for the use of PAM, as a coagulant within a sediment pond, may be approved on a site specific basis by the NWT Environment and Natural Resources and/or Department of Fisheries and Oceans, Canada. The use of PAM must be carefully monitored as it may be toxic to fish if application rates are not closely adhered to.

The settling velocity (V_s) is assessed for a target soil particle size

$$V_s \ \alpha \ D_s \quad \textbf{(Stokes' Law)}$$

Where:

D_s = Diameter of a target particles size (cm)

Stokes' Law

$$V_s = g \times (S - 1) \times d^2 / (18 \times \mu) \qquad \text{(Equation G.2)}$$

Where: V_s = Settling velocity (cm/sec)

g = Acceleration of gravity (981 cm/s^2)

μ = Kinematic viscosity of a fluid (cm^2/s^2)

S = Specific gravity of a particle

d = Diameter of a particle (cm) (assuming a sphere)

Table G.1: Settling Velocities (V_s) for Suspended Particles (Specific Gravity = 2.65) in Water at Different Temperatures, as Calculated by Stokes' Law

Diameter (mm)	Settling Velocity in Centimetres per Second					Particle
	0°C	5°C	10°C	15°C	20°C	
0.01	0.005	0.006	0.007	0.008	0.009	Fine Silt
0.02	0.020	0.023	0.027	0.031	0.035	Medium Silt
0.03	0.044	0.052	0.060	0.069	0.078	
0.04	0.078	0.092	0.107	0.122	0.139	Coarse Silt
0.05	0.122	0.143	0.167	0.191	0.217	
0.06	0.176	0.207	0.240	0.275	0.313	
0.07	0.239	0.281	0.327	0.375	0.426	Very Fine Sand
0.08	0.312	0.367	0.427	0.490	0.556	
0.09	0.395	0.465	0.540	0.620	0.704	
0.11	0.488	0.574	0.667	0.765	0.869	
0.11	0.590	0.694	0.807	0.926	1.051	
0.12	0.703	0.826	0.960	1.101	1.251	
0.13	0.825	0.970	1.127	1.293	1.468	Fine Sand
0.14	0.956	1.125	1.307	1.499	1.703	
0.15	1.098	1.291	1.501	1.721	1.955	
0.16	1.249	1.469	1.707	1.958	2.224	
0.17	1.410	1.658	1.928	2.211	2.511	
0.18	1.581	1.859	2.161	2.478	2.815	
0.19	1.761	2.072	2.408	2.761	3.136	
0.20	1.952	2.295	2.668	3.060	3.475	
	32°F	41°F	50°F	59°F	68°F	

Source: Fifield, 2001

Commonly Used Conversion Factors

- 1.0 cm/sec. = 0.0328 ft/s or 0.3937 in/s
- 1.0 m = 3.281 ft or 39.37 in
- 1.0 in. = 2.54 cm = 25.4 mm
- 1.0 ha = 2.471 ac = 107,637 ft^2 = 10,000 m^2
- 1.0 m^3 = 35.3 ft^3
- °C = 5/9(°F - 32°)

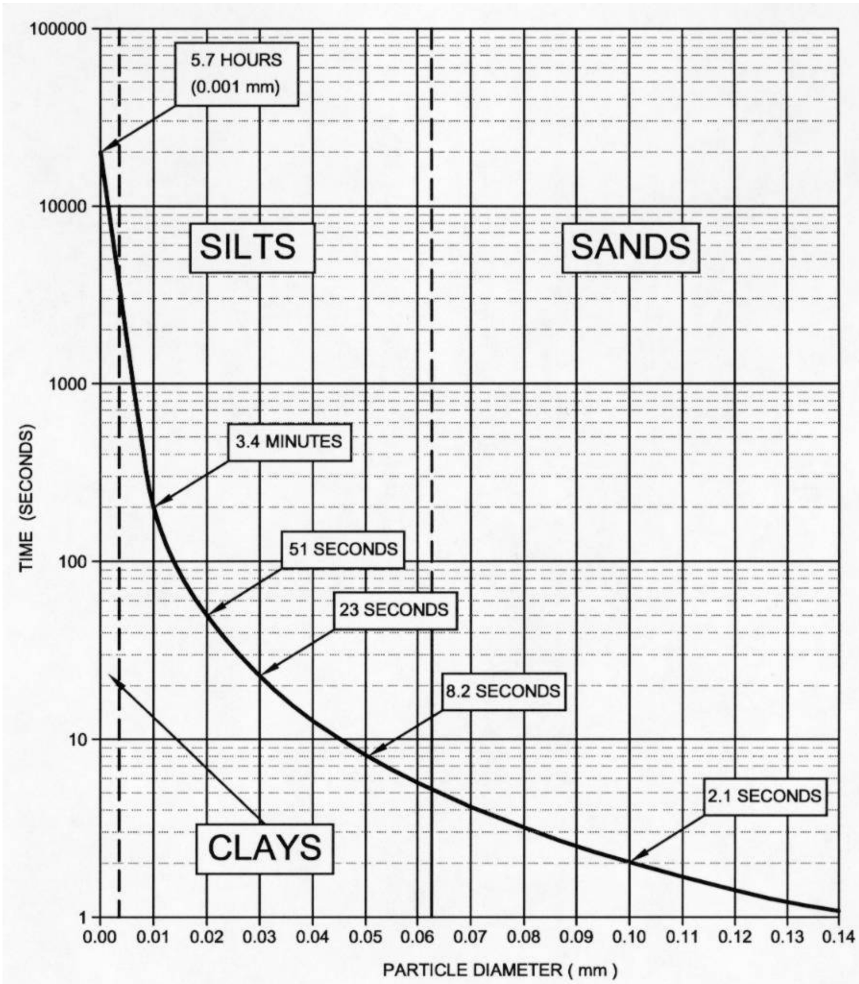


Figure G.2: Time for Suspended Particles to Fall 1 cm in Water at 0°C (Stokes Law)

Source: Fifield, 2001

From Figure G.2, the smaller diameter (D_S) soil particle (such as fine silt and clay) yields a very slow settling velocity (V_S), thus requiring a long duration containment system to settle clay-size particles.

The efficiency of a containment system is proportional to the settling velocity (V_s) and the particle size (D_s).

Outflow capacity (Q_o) of the containment system can be designed, based on free-draining properties of an outflow system which normally functions through a seepage or filter drainage outlet of the containment system. The outflow capacity is designed to be equal to or smaller than the inflow volume. The pond functions to provide sufficient flow path and containment time to effect sedimentation of a target size particle. During the time of containment, the target size particle will have sufficient detention time to settle to the bottom of the pond system. Generally, the outflow design of these systems is a free draining granular berm, or a combination of perforated pipes, or a riser system functioning as filter/seepage structures and the size/configuration of the system will allow sufficient settling time for sediments to collect within the containment system. An example of the containment systems (Type I and II) is presented in Figures G.3d, G.3e and G.3f, as discussed below.

The general criteria for the selection and functioning of a containment pond system are presented in Section 12.2. The selection is dependent on the size of disturbed land, amount of runoff into the pond (Q_i) and target particle size (D_s) for settlement in order that an assessment of pond size/surface area (SA) can be estimated. The outflow capacity (Q_o) of the pond outlet is a function of structural and permeability design.

Generally, the runoff inflow (Q_i) is determined by a hydraulic or hydrotechnical professional or engineer. For the efficient settling operation of a pond, the inflow (Q_i) is equal to or less than the outflow (Q_o) to allow for sufficient settlement time for a low lateral flow passage within the pond chambers. Therefore, the rationale of settlement pond design assumes inflow (Q_i) equals outflow (Q_o).

$$Q_o = Q_i \qquad \text{(Equation G.3)}$$

Where:

Q_o = Outflow capacity of containment system

Q_i = Inflow

Outflow System

Two options of an outflow system: (1) Permeable Rock Berm Outlet Option; (2) Riser Outlet Option. They are discussed below. For both options, effects of ice formation must be considered in the design.

Overflow Section System

An overflow section installed in the berm of sediment containment system is not recommended as the primary means of discharging water due to potential for erosion of the containment berms. However, an overflow section is considered appropriate as an auxiliary outflow system for use in the event that the primary permeable rock outlet system (described in the following paragraph) should become blocked. Erosion protection at the outlet and on the berm slope is to be designed by an engineer. The overflow section is to be dimensioned at a minimum width of 1.5 m per 250 m^2 of pond area.

Permeable Rock Berm Outlet Option

One type of granular berm system is considered appropriate for use to allow seepage flow to exit from a sediment containment system. The following relationship (Jiang *et al.* 1998) can be used. The seepage outflow through drainage rock (25 mm to 100 mm diameter) in a gabion basket is modeled and can be applied to a granular berm outlet of a sedimentation pond/trap as illustrated in Figure G.3a and G.3b. The parameters and porosity of drainage rocks are shown in Figure G.3c.

$$Q_o = 0.327\, e^{1.5S} (g\, D_{50} / T)^{0.5}\, \rho W\, H^{1.5} \qquad \text{(Equation G.4)}$$

(Jiang *et al.* 1998)

Where: Q_o = Outflow capacity of containment system (m^3/s)

g = Acceleration due to gravity = 9.8m/s^2

D_{50}= Mean diameter of the rock (m)

W = Total width of the barrier (m)

ρ = Porosity of the rock barrier

T = Thickness of the barrier (m)

H = Hydraulic head (m)

s = Slope of channel (%) (generally varies from 0% to 7% for highway gradeline profiles)

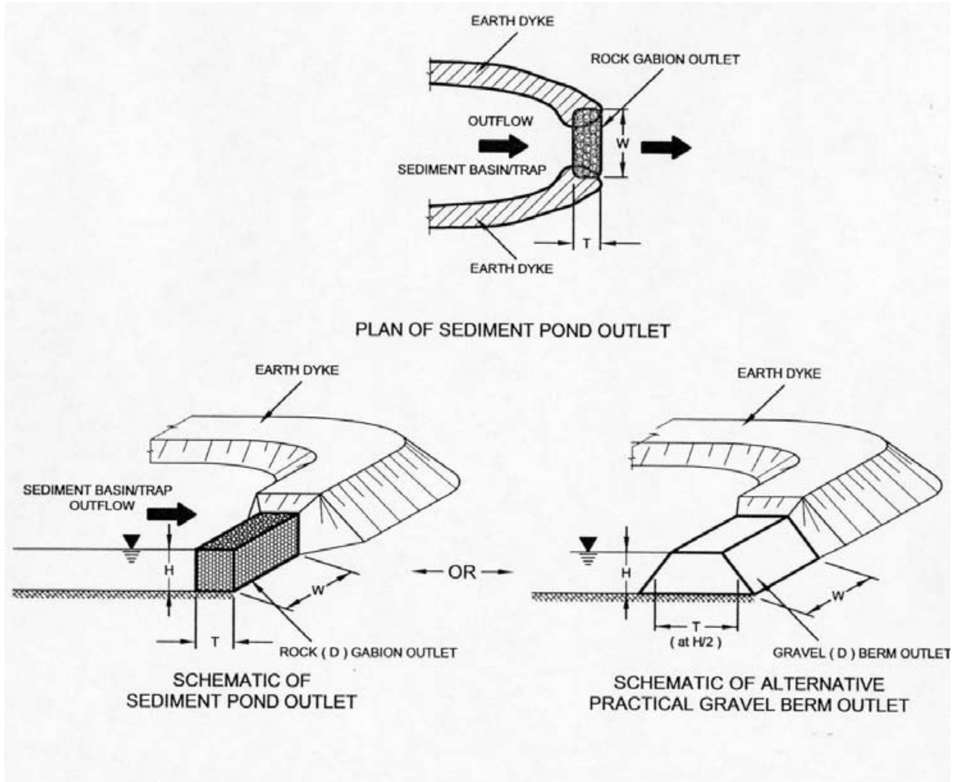


Figure G.3a: Model of Drainage Outlet of Sediment Pond

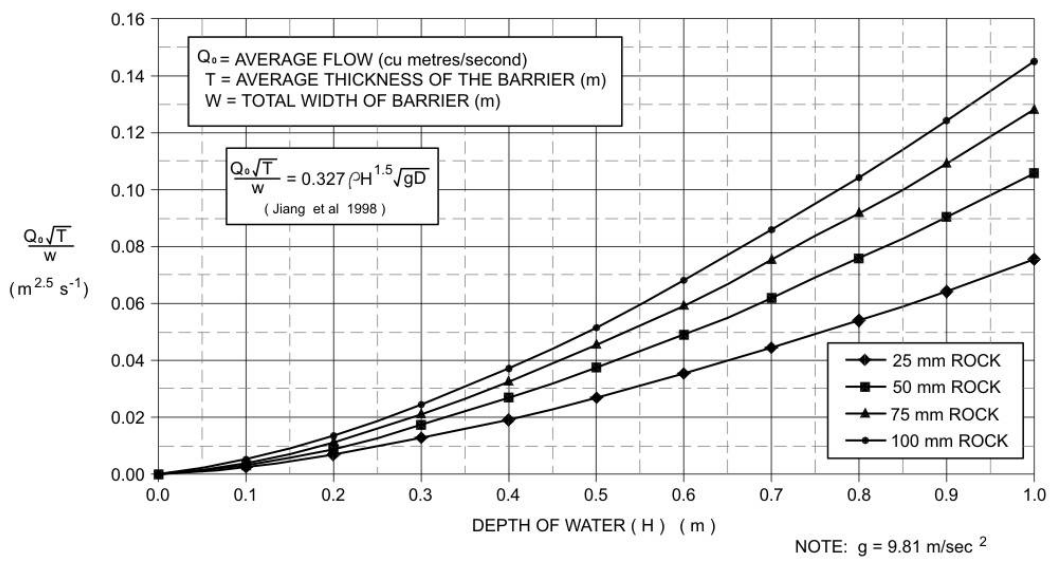


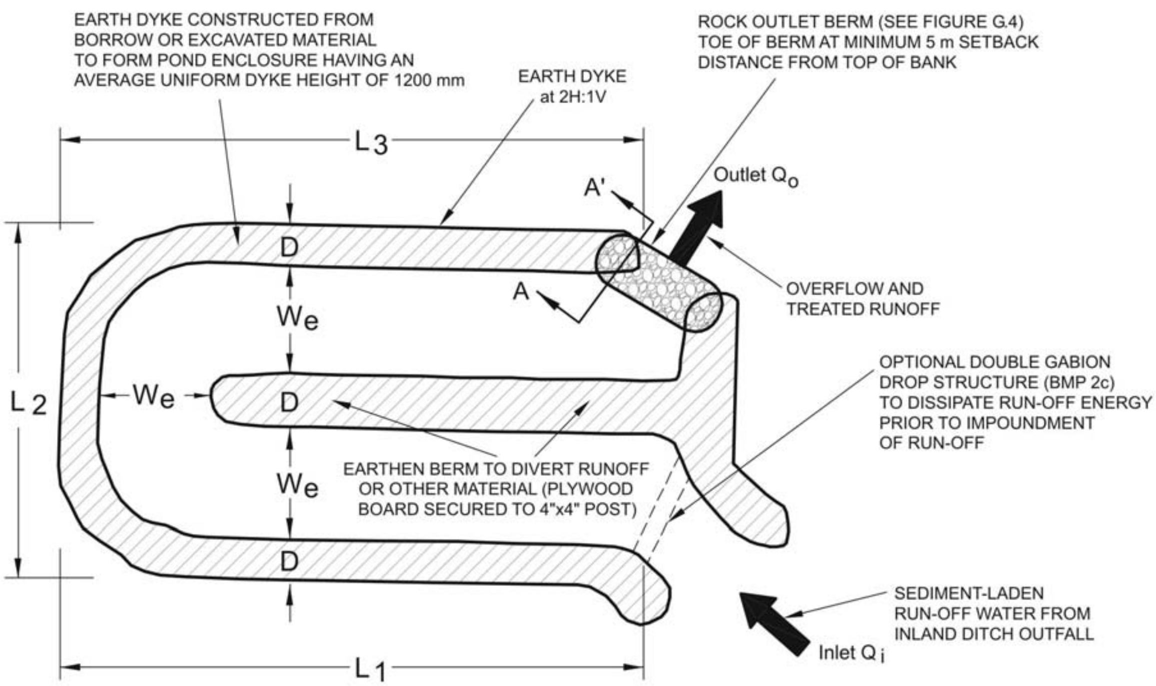
Figure G.3b: Flow (Q) Through an Outlet Barrier of Various Diameter (D) Rocks in Gabion Basket

Source: Fifield, 2001

Mean Diameter (D) (mm)	Rock Density (kg/m^3)	Bulk Density (kg/m^2)	Porosity of Rock Fill (ρ)
25	2648	1593	0.398
43 - 50	2675	1446	0.459
75 - 88	2657	1461	0.450
100	N/A	N/A	N/A

(Source: Jiang et al 1998)

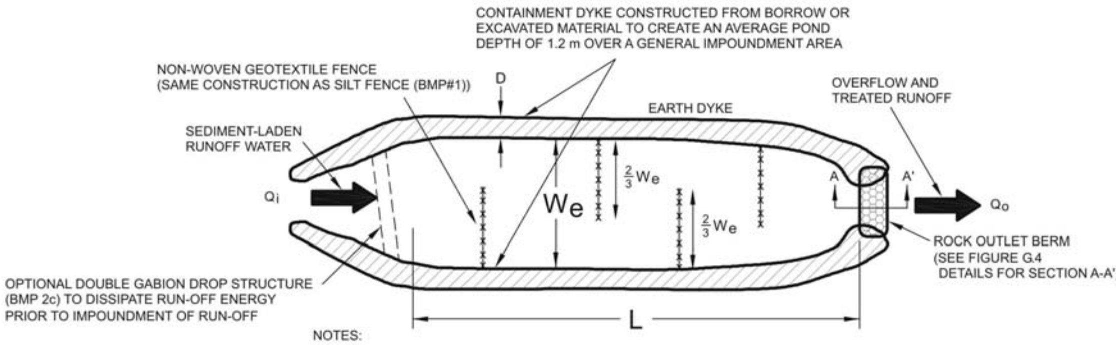
Figure G.3c: Parameters and Porosity (ρ) of Rocks



NOTES:

1. CONTRIBUTING RUNOFF AREA CAN BE LARGER THAN 2.0 ha BUT LESS THAN 40.0 ha.
2. EFFECTIVENESS APPROPRIATE FOR REMOVING MEDIUM TO COARSE SILT PARTICLES SUSPENDED IN RUNOFF.
3. FLOW PATH L = L1+ L2+ L3; FLOW WIDTH We = 6 m MINIMUM
4. PROVIDE 1 TO 2 m (1 TO 2% GRADE) ELEVATION DROP BETWEEN INLET AND OUTLET GRADES.
5. SHAPE OF POND TO CONFORM TO LAND WITH OUTLET AT MINIMUM 5 m SETBACK FROM TOP OF BANK.
6. CONSTRUCTION TO ENSURE SWALES AND BAFFLES ARE TO CHANNEL WATER INTO THE PROPOSED SEDIMENT PONDS.

Figure G.3d: Type I Sedimentation Pond Containment Structure (Sediment Basin Plan)



NOTES:

1. CONTRIBUTING RUNOFF AREA SHOULD BE OR SMALLER THAN 2.0 ha.
2. EFFECTIVENESS APPROPRIATE FOR REMOVING MEDIUM TO COARSE SILT PARTICLES SUSPENDED IN RUNOFF.
3. L/W_e RATIO 3:1 CAN BE APPROPRIATE.
4. W_e = 8 m MINIMUM BOTTOM WIDTH.
5. NON-WOVEN GEOTEXTILE FABRIC WITH A0S < 0.15 mm.

Figure G3.e: Type II Containment Structure (Sediment Trap Plan)

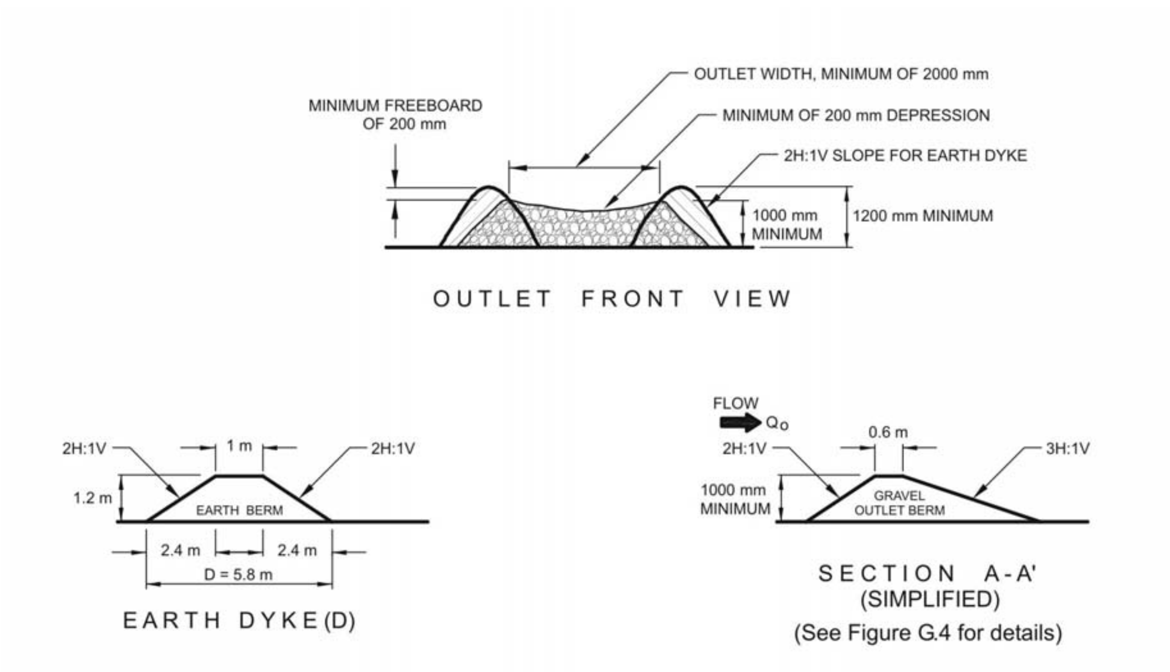


Figure G.3f: Simplified Sections of Dyke/Outlet

Source: Fifield, 2001

The outflow filter capacity of a rock barrier appears not sensitive to channel slopes varying from 0 to 6% (Jiang *et al.* 1998). The equation (Jiang *et al.* 1998) can be used for rock checks along channel with properly sized rocks for appropriate flow velocity (a nominal gradation can be: top size 250 mm, average size 150 mm, and bottom size

25 mm diameter) to provide stability to flow impact. A typical permeable outlet structure (with rock filter and perforated pipe) for sediment basin/trap is presented in Figure G.4 for practical highway constructions.

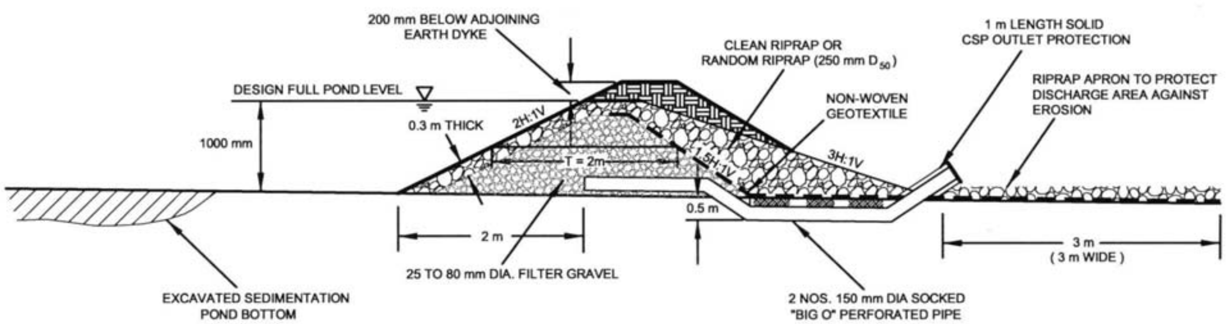


Figure G.4: Typical Sedimentation Basin/Trap Outlet Permeable Structure with Rock Filter Barrier and Perforated Pipe

Riser Outlet Option

A riser outlet is a circular overflow spillway that is connected to a culvert that passes through the containment berm. The riser pipe is fabricated from corrugated steel pipe conforming to CSA Standard CAN 5-G401-M81. The outlet pipe passing through the containment berm consists of a horizontal pipe welded to a 45° elbow (mitre joint) connecting to the riser pipe. The riser outlet system is equipped with a trash rack to minimize debris blockage.

100 mm diameter drainage holes are cut in the base of the riser pipe to form a perforated section near the elbow. A steel mesh is tack welded over it to form a screen. The portion of the riser pipe and elbow with the 100 mm diameter drainage holes and mesh is to be backfilled with gravel. The size of the mesh covering the 100 mm diameter holes should be fine enough to filter granular material but coarse enough not to impede flow. Similar 100 mm diameter drainage holes can be provided along the riser pipe immediately above the elevation of the projected maximum sediment level.

The design of a riser pipe outlet can be completed by a hydrotechnical engineer to ensure the system has adequate capacity to discharge design flows without the risk of overtopping. Furthermore, a geotechnical engineer should design the culvert passing through the containment berm if the risk consequences of berm failure are significant.

Pond Area

The pond area (SA) size is based on the outflow capacity (Q_o) of the outlet structure (Figure G.3d and G.3e) and the settling velocity (V_s) of a target size particle. The outflow capacity (Q_o) is designed based on the runoff inflow quantity (Q_i) (Equation G.3).

$$SA = 1.2\ Q_o / V_s \qquad \text{(Equation G.5)}$$

Where:

- SA = Pond area (m^2)
- Q_o = Outflow capacity for an outflow structure (m^3/s)
- V_s = Settling velocity of a target particle size (m/s)
- 1.2 = 20% extra capacity allowed for pond size

Pond Configuration

The size and configuration of a containment system is designed to provide sufficient volume and flow path to allow the target soil particles within the sediment-laden runoff to settle during the time of impoundment.

Pond configuration entails length (L) and width (We) can be evaluated from pond area (SA).

$$L = SA / We \qquad \text{(Equation G.6)}$$

Multiply both sides by L, $L^2 = (SA \times (L / We))$

$$L = (SA \times (L / We))^{0.5} \qquad \text{(Equation G.7)}$$

Where:

- We = Width of Pond Chamber (m)
- L = Length of Pond Chamber (m)
- SA = Surface Area of Settling Pond (m^2)

L/We = 10 is recommended for 100% apparent efficiency (A_{eff}) to minimize short-circuiting and maximize settling area (Goldman 1986). However, the exact behaviour of L/We in determining 100% A_{eff} can be subjective. Space limitations do not normally allow a large size pond to be constructed to an L/We ratio of 10. The following practical L/We ratios can be considered appropriate for the following structures:

Containment Structure	L/We
Sediment Basin (Type I)	8
Sediment Trap (Type II)	3

Pond Efficiency

The net efficiency (N_{eff}) of the containment system can be assessed based on model suggested by Fifield (Fifield 2001) utilizing the following concepts.

A_{eff} (%): Apparent Efficiency

PEG (%): Particle Size Equal to and Greater than a target size soil particle of a substrate soil (reverse presentation of hydrometer gradation curve)

A_{eff} is modeled on pond dimensions (Fifield 2001) and the L/We ratios are estimated (Goldman 1986). The dimensions of a pond to be designed are compared to dimensions of a model pond where 100% A_{eff} can be achieved for a target soil particle size.

PEG is a form of presentation of the gradation curve (hydrometer results of the fines portion) of an erodible substrate soil showing the percentage of coarser particles (Figure G.5) in the runoff that can be settled out in comparison to a target size soil particle (e.g., medium silt of 0.04 mm diameter). The soil tested for sedimentation PEG is usually taken from erodible soil sources of cutslope or borrow material used as fills on highway projects.

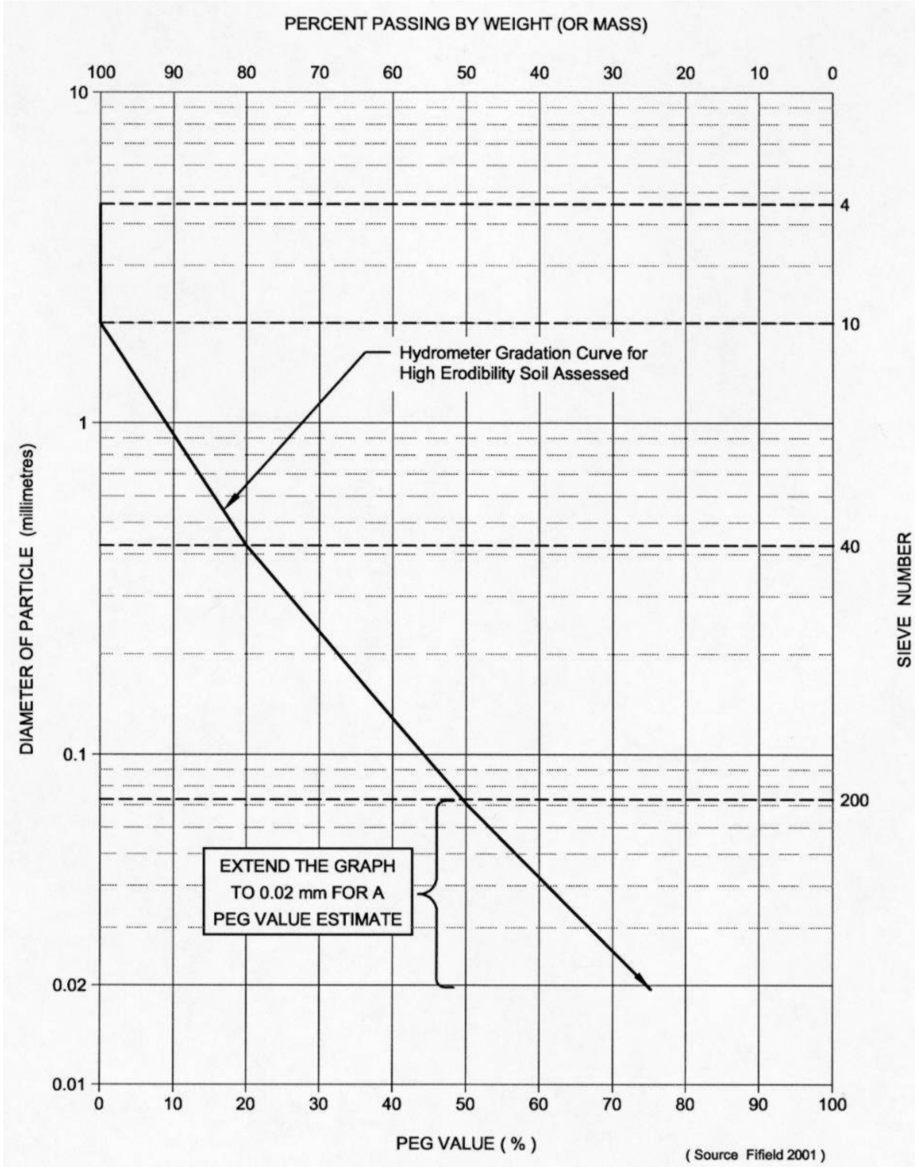


Figure G.5: Hydrometer (Particle Size) Gradation Curve to Determine PEG

Source: Fifield, 2001

Apparent Efficiency (A_{eff}) is modeled from the ratio of a 2-dimensional (length and height of flow area) design pond (A_c) to a model pond (A_{tc}) with an idealized design outfall capacity. A proportionality factor (K) of 0 to 1 is proposed for the ratio of realistic pond area of sediment capture to the model pond area (A_{tc}) of sediment capture. Within the containment pond, the flow path (L) is sized utilizing a lateral flow velocity (V_a) and a vertical settling velocity (V_s) of a target size soil particle allowing sufficient time for the particle to settle within the containment system (Fifield 2001). An illustration of the Apparent Efficiency (A_{eff}) model is presented in Figure G.6. The vertical distance of settlement is suggested by some investigators at 0.67 m for minimum height for a pond dyke. However, for design purposes with a factor of safety of 1.8, it is prudent to use 1.2

m for pond dyke to provide an extra freeboard of 0.2 m above the outlet permeable berm.

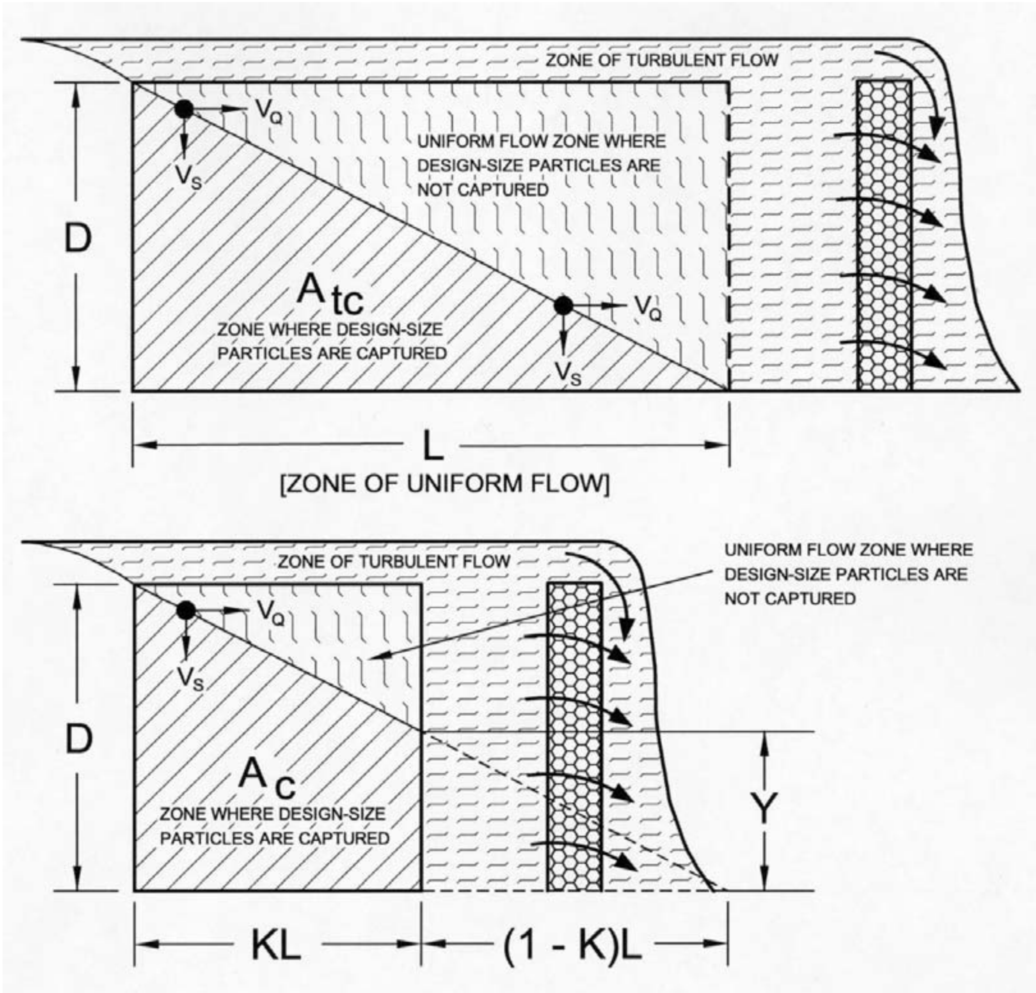


Figure G.6: Concept of Sedimentation Apparent Efficiency (A_{eff}) for Suspended Particles in Zones of Uniform and Turbulent Flows at Permeable Berm of a Containment System Outlet

Source: Fifield, 2001

$$A_{eff} = (A_c / A_{tc}) \times 100 \quad \text{(Equation G.8)}$$

$$A_{eff} = (2K - K^2) \quad \text{(Equation G.9)}$$

$$K = 0.1 (L / We) \quad \text{(Equation G.10)}$$

$$N_{eff} = A_{eff} \times PEG \quad \text{(Equation G.11)}$$

Where: D = particle fall distance

A_{eff} = Apparent Efficiency (%)

K = A factor of 0.1 to 1, based on L/We ratio of 0 to 10 (10 is 100% A_{eff})

N_{eff} = Net Efficiency (%)

PEG = % of Particles Equal to and Greater than a target size particle determined from hydrometer gradation curve (see Figure G.5)

L = Length of a containment (chamber) system

We = Width of a containment (chamber) system

= 8 m bottom width is considered appropriate for highway construction application

Incorporating the above relationship, the $\mathbf{A_{eff}}$ can be estimated from the following curve (Figure G.7).

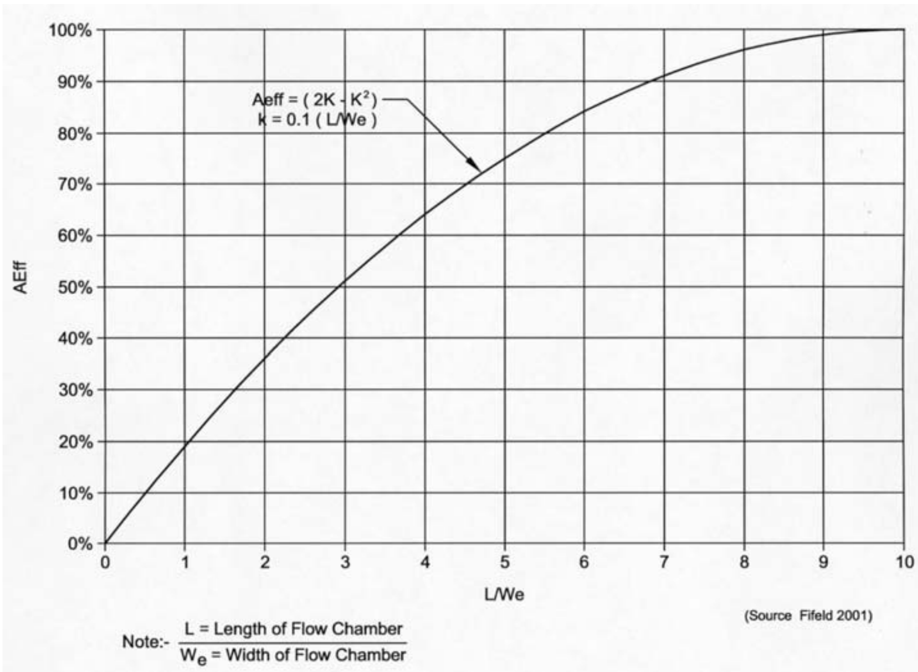


Figure G.7: Apparent Effectiveness (A_{eff}) of a Sediment Containment System

Source: Fifield, 2001

Design Example

A simple design example is presented in Appendix H as H.16.

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APPENDIX H

DESIGN EXAMPLES

H.I Introduction

This section is adapted from the Alberta Transportation ESC Manual and is intended to illustrate erosion control designs. Future versions of this manual may include NWT-specific examples. Seventeen design examples are included to illustrate the successive stages involved in the design of erosion measures required in a grading project.

The different phases of erosion control calculations and design, and the corresponding examples, are shown in the following table.

Description		Example
Erosion Potential	Single Slope	H.1, H.6
	Irregular (bench) Slope	H.4, H.5
	Low Embankment Slope	H.7
	Variation with Soil Types	H.3a, H.3b
	For Varying Site Hazards	H.2
Channel Protection	Vegetative Lining	H.8
	RECP Mat (soil covering) Lining	H.9
	Gravel Lining	H.10
	Riprap Lining	H.11
	Concrete Lining	H.12
	Gabion Mat Lining	H.13
Flow Depth Estimation		H.14
Sediment Barriers – Storage Capacity		H.15
Sediment Basin/Trap		H.16

Example H.1 (Erosion – Single Slope)

A highway construction site requires the excavation of a large uniform cut-slope approximately 30 m in length at a 3H:1V slope (roughly 33%). Excavation and grading of the slope is to occur through the spring and summer (May through August) and the site will be highly disturbed during the course of the construction period. Topsoil placement and seeding is scheduled to take place at the end of August.

The exposed soils are expected to be normally consolidated and consist of silty clay. Supporting field investigation information for the soil indicates the following:

Agriculture Soil Data	Geotechnical Soil Data
Classification: CL	Classification CL-ML
50% Silt and Very Fine Sand	Plasticity Index (PI) = 15
10% Sand >0.1 mm	Plastic Limit (PL) = 27
0% Organic Matter Content	Moisture Content = 26%

Using the RUSLE, determine the Site Erosion Potential for this particular construction site.

1. Determine the appropriate Rainfall Factor (R_t) for the Construction Area.

   From published data the R-factor for the project area is 350 (MJ mm ha^{-1} year^{-1}) and the corresponding winter adjustment value (Figure B-3) R_s is 20 (MJ mm ha^{-1} year^{-1}). The total rainfall factor R_t is therefore 370 (MJ mm ha^{-1} year^{-1}).

2. Determine the Monthly Distribution of the Rainfall Factor (R_t).

   The monthly distributions are summed for the period of anticipated construction that the soil is expected to be exposed (e.g., without top soil/vegetation). In this example, topsoiling and seeding is scheduled to occur at the end of August.

   The summed monthly distributions are expressed as a percentage of the total annual value.

   From the supporting information (Table B-1 and Figure B-4) shown in Appendix B. The monthly distribution (Figure B-4) of the Rainfall factor for the site over the construction months is as follows: May (10%), June (20%), July (25%) and August (15%). Therefore, R_t for this particular site over the construction period noted is equal to 240 (MJmm ha^{-1} year^{-1}), which is about 70% of the total annual value.

3. Determine the Slope Factor (LS).

   The slope factor table, which supports the equation for a uniform slope is shown on Table B-3.

   For an average slope length of 30 m with a slope gradient of 33% a corresponding slope factor of approximately 5.4 is interpolated.

   Applying the suggested Topographic Adjustment factor ($Ø_{LS}$) of 0.8 (see Section 6.2.3.2) results in an adjusted LS of 4.3.

4. Determine the Soil Erodibility Factor (K) for the Soil to be exposed during Construction.

   From Figures B-6 and Figure B-7, Clay Loam has a corresponding Structure Code of 4 and a Permeability Code of 4.

   Using the Soil Erodibility Nomograph in Figure B-5 for the given soil structure, permeability and composition, the exposed soil is estimated to have an Erodibility Factor (K) of 0.047.

   Applying the suggested Soil Erodibility Adjustment factor ($Ø_K$) of 0.8 (see Section 6.2.2.2) results in an adjusted K of 0.038.

5. Determine Management (C) and Support Practice (P) Factors.

   This slope is expected to produce a highly disturbed surface that is relatively compacted and smooth from the excavation and grading process. Furthermore no treatments are being applied to the slope, therefore the C Factor (Table B-6) and P Factor (Table B-7), for this site follow that for a bare soil (packed and smooth) and are both equal to 1.0.

   It should be noted that some immediate reduction (from 1.0 to 0.9) can be made to the Support Practice (P) Factor if the slope is roughened during the excavation grading process. Roughening of the slopes is considered a Minimum Measure for all slopes.

6. Calculate the Soil Erosion Potential (Soil Loss) for this Construction Site.

   A summary of the RUSLE parameters is as follows:

   Rt = 240 (MJ mm ha^{-1} $year^{-1}$) (adjusted for construction season 0.70 of annual)

   K = 0.038 (adjusted by $Ø_K$ = 0.8) (MJ mm ha^{-1} $hour^{-1}$)

   LS = 4.3 (adjusted by $Ø_{LS}$ = 0.8)

   C = 1.0

   P = 0.9 (with slopes roughened)

   Using RUSLE: **Estimated Soil Loss (A) = R x K x LS x C x P**

   Soil Loss (A) = 35.3 (tonnes ha-1 year -1)

   This value represents the estimated soil loss from this site over the period of construction prior to placement of top soil and seeding.

Example H.2 (Erosion Potential and Site Hazard)

1. Determine the Site Erosion Hazard Classification for the soil loss evaluated in Example H.1 where Soil Loss (A) = 29.7 tonne ha^{-1} $year^{-1}$.

Based on the estimated site erosion potential for the period of construction noted, and the general hazard classes shown in Table 6.1, a HIGH site hazard class is indicated for this particular slope.

RUSLE Erosion Hazard Classification		Site Hazard Evaluation	
Soil Erosion Potential (A) (tonnes/ha/yr)	**Site Hazard Class (RUSLE)**	**Soil Loss (tonne/ha/yr)**	**Hazard Class**
<6	Very Low		
6-11	Low		
11-22	Moderate		
22-33	High		
>33	Very High	35.3	Very High

Example H.3a (Variations of Erosion Potential for Soil Types using RUSLE (Section 6.2)

Various Soil Types:

Using the average K values (from Table B-2, Appendix B) for various soil textures and multiply by $Ø_R$, similar evaluation are assessed for varying soils for the similar site condition in Example H.1. The following table provides a summary of various soils types for the same construction site to show the sensitivity of site erosion potential classification to various types of soil.

Table Comparing Various Soils and Erosion Potential

Soil Type	Average Erodibility Factor (K) x $Ø_K$	Soil Loss Potential (A)	Site Erosion Potential
Very Fine Sand	0.057 x 1.0 = 0.057	52.9	Very High
Silt Loam	0.050 x 0.8 = 0.040	37.1	Very High
Clay Loam	0.040 x 0.8 = 0.032	29.7	High
Clay	0.03 x 0.8 = 0.024	22.3	Moderate to High
Sandy Loam	0.017 x 0.8 = 0.014	13.0	Moderate
Heavy Clay	0.02 x 0.8 = 0.016	14.9	Moderate
Coarse Sandy Loam	0.009 x 0.8 = 0.007	6.5	Low to Very Low
Sand	0.001 x 1.0 = 0.001	0.9	Very Low

Note: Soil Loss Potential (A) in tonnes/ha/year

Note that for the same soil type (e.g., Clay Loam to Sandy Clay Loam), two different erodibility factors and subsequently site erosion potentials are calculated. This demonstrates the sensitivity of the soil class and the importance of determining the proper soil classification based on all available information such as geotechnical assessments and lab testing. It is noted that for sand material, no modifications to Erodibility is applied (i.e. $Ø_R$=1). The use of typical values for determining the soil erodibility factor (K) is only recommended when specific soil information is unavailable or cannot be obtained.

Example H.3b (Variation of Erosion Potential for Project Soils – Preliminary Estimate using USCS Chart (Figure 4.3) and Common Soil Testing Data for Highway Construction)

In this example, typical highway soil testing (grading design only) are presented to show that a preliminary measurement of soil erodibility potential can be assessed from plasticity and gradation data. Only a portion of the site area is presented for illustration.

Soil type variations across construction sites are a function of a geological deposition process and geomorphology at the locations of highway construction. Soil investigation surveys for grading construction generally provide the following general and additional soil information for highway designs:

A) General Information	1. Plasticity Index (PI) 2. Soil Classification (USCS) 3. Field Moisture (M.C.) (%) 4. Estimated Optimum Moisture (OMC) (%) 5. Estimated Proctor Density (kg/m^3)
B) Additional Information (if required)	1. Gradation – coarse granular soil 2. Hydrometer gradation – fine grained and/or cohesive soil

Example H.4 (Erosion Potential of Irregular (Benched) Slope)

The effect of slope shape with multiple slope segments in reducing erosion potential is demonstrated in the following example:

- A long slope with narrow benches at the top and in the middle of the excavation is to be constructed at the same site as defined in the above example (i.e., similar soil and location). The total length of the slope is roughly 70 m and is divided into 4 segments with the following geometry.

Slope Description Summary

Slope Segment *	Slope Length	Slope Gradient
1 – Top Bench *	5.5 m	2%
2 – Mid-Slope	30 m	33% (3:1)
3 – Mid-Bench	3 m	2%
4 – Base Slope	30 m	33% (3:1)
Note *	The effect and inclusion of the top bench (Slope Segment #1) as one slope segment can provide an under-estimate of slope erosion potential; therefore the top slope segment is ignored and only 3 segments of slope are considered (#2, 3 and 4).	

For each of the three effective slope segments, the slope factor (LS), slope length exponent (m) and appropriate soil loss factor (SLF) needs to be determined. These values can be easily taken from the supporting tables provided in Appendix B. Once a value for each segment has been derived, the actual slope factor (LS) for the separate segments can be determined as shown in the following summary:

Summary of Slope Factors for Slope with 3 Segments of Benched Slope

Slope Segment #	Slope Factor (LS) Table B-3	Slope Length Exponent (m) Table B-4	Soil Loss Factor (SLF) Table B-5	Segment LS (LS x SLF)
1 – Top Bench (N/A)	0.2	0.24	0.71	0.14 (N/A)
2 – Mid-Slope	4.3	0.66	0.87	3.74
3 – Mid-Bench	0.2	0.24	1.11	0.22
4 – Base Slope	4.3	0.66	1.50	6.45
				∑ Segments (LS) = 10.41 **Benched Slope Average LS = 10.41/3 = 3.5**

Once the Slope Factor (LS) has been determined for each of the slope segments, the total LS for the slope is determined by summing the LS Segments (10.41) and dividing it by the number of effective slope segments (3). For this particular benched slope, the averaged LS is about 3.5. In comparison with a base slope of half height (Slope Segment #4, base slope with Segment LS = 6.45), the erosion potential (LS = 3.5) of a benched slope of twice the height is approximately 54% (i.e., LS ratio @ 3.5/6.45). In comparison with the mid-slope (Segment #2) with half height at LS = 3.74, the ratio of erosion potential of the benched slope of twice the height is approximately 93% (i.e., LS ratio @ 3.5/3.74).

This example shows the benefit of irregular slope configurations with intermediate benching can effectively reduce the erosion potential close to the equivalent of a single slope at the top half of the bench slope. It also shows that the lower portion of a benched high slope have higher erosion potential (LS = 6.45) compared with the top portion of the benched high slope (LS = 3.74).

Example H.5 (Erosion Potential of Benched Slope)

It is proposed to reduce the soil erosion on a 15 m high simple 3:1 slope by providing a 3 m wide berm at midslope (Fig. H.5). Estimate the percentage reduction in sediment yield for:

- single slope vs. benched slope
- single slope (15 m height) vs. single slope (7.5 m height)

Is benching of slope more advantageous to reducing slope height?

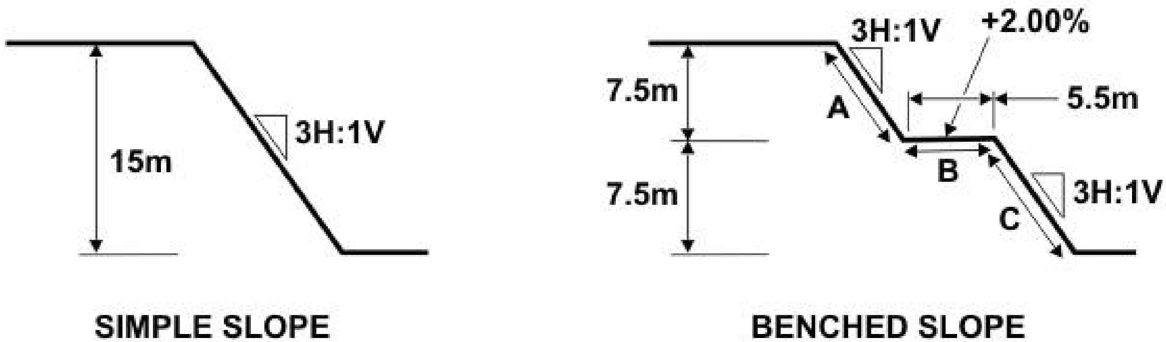


Figure (Example H.5): Cross-section with and without a bench

Step 1: Topographic Soil Loss Factor (LS) from un-benched simple slope

Length along the slope face, L = 15 x 3.2 = 48 m

For L = 48 m and slope = 33.33%, LS = 7 (from Table B-3, Appendix B)

Step 2: Topographic Soil Loss Factor (LS) from benched slope

Slope Segment	Vertical Height (m)	Inclined Length Along Slope (m)	Slope (%)	LS Factor (Table B-3 App. A)	m Factor (Table B-4 App. A) Moderate	SLF (Table B-5 App. A)	LS x SLF
A	7.5	23.7	33.3	4.7	0.66	0.5	2.35
B	0.0	3.0	2	0.18	0.24	1.02	0.18
C	7.5	23.7	33.3	4.7	0.66	1.46	6.86
							$\sum$ = 9.39

$$Bench\ Slope = \frac{9.39}{3} = 3.1$$

Step 3:

Compare two cases:

a) Single slope vs. benched slope

Percentage soil loss from benched slope = LS bench slope/LS single slope = 3.1/7 = 53%

LS percentage reduction = (100% - 53%) = 47% reduction of soil loss (slope design component)

b) Single slope (15 m high) vs. single slope (7.5 m high)

Percentage soil loss from low height single slope = LS lower slope/LS high single slope = 4.7/7 = 67%

LS percentage reduction = (100% - 67%) = 33% of soil loss (slope design component) reduction.

Step 4:

In comparison with a single long slope (3H:1V), the benching of slope (full 15 m height) yields a 47% reduction in sediment yield; whereas the reduction of slope height (to ½ height at 7.5 m) only yields a 33% reduction in sediment yield. The benching of slope is more effective in reducing the percent erosion and sediment yield in comparison with reducing slope height.

Example H.6 (Erosion Potential of a Low Cutslope – Seasonal)

A simple 3:1 backslope in this site is to be constructed in a medium plastic (CI) clay having the grain size distribution given. If the configuration of the slope is as shown in Figure (Example H.6), estimate the mean annual soil loss. What would the soil loss during the construction season from July to October?

Grain size distribution:

Fraction	Percentage
Sand (2 - 0.1 mm)	7
Very fine sand (0.1 - 0.05 mm)	10
Silt (0.05 - 0.002 mm)	49
Clay (< 0.002 mm)	34

Organic Content = 0%
Sand Structure = Blocky Platy Massive
Permeability = Slow

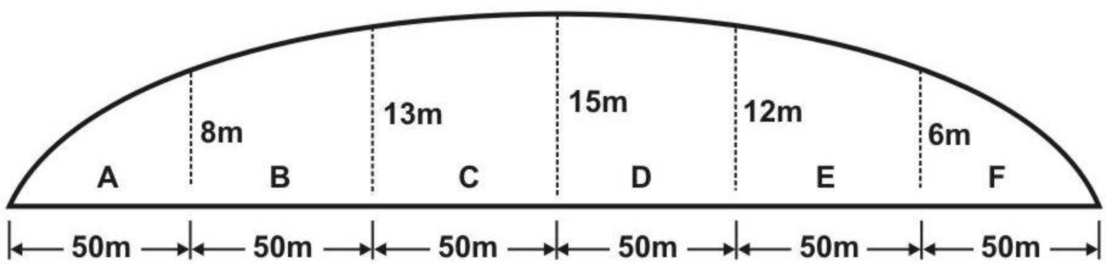


Figure (Example H.6): Elevation of Slope

Solution:

Soil loss	= R.K.LS.C.P (from Equation 6.1)
R	= 385 (from Figures B-1, Appendix B)
K	= 0.032 (clay from Table B-2, Appendix B)
$Ø_K$	= 0.8 (highway modification factor suggested for K)
$K_{highway}$	= 0.8 x 0.032 = 0.026
CP	= 1.0 (from Tables B-6a and B-7)
LS	= variable with each slope segment = $LS_{average}$ = 4.8
$Ø_{LS}$	= 0.8 (highway modification factor suggested for LS)
$LS_{highway}$	= 0.8 x 4.8 = 3.8
Area	= Length x average slope length = 50 m x (4+10.5x14+13.5+9+3)m
	= 50 m x 54 m = 2700 m² = 0.27 Ha

Slope Segment	Mean length along the slope face (m)	Slope (%)	LS factor (Fig. 6.4)
A	12.6	33.3	2.6
B	33.2	33.3	6
C	44.3	33.3	6.5
D	42.7	33.3	6.5
E	28.5	33.3	5.0
F	9.5	33.3	2.6
Average:	28.5	33.3	4.8

Note: 1 Ha = 100 m x 100 m = 10,000 m²

Mean annual soil loss = R.K.CP.LS.Area ($K = K_{highway}$; $LS = LS_{highway)}$

= 385 x 0.026 x 1.0 x 3.8 x 0.27 Ha

= 10.3 tonnes/yr

Refer to Figure B-3, Appendix B (monthly rainfall distribution) for the site.

Total percentage of soil loss from July to October = 14 + 18 + 10 + 5 = 47%.

Hence, expected soil loss from July to October = 0.47 x 10.5 = 4.8 tonnes.

Example H.7 (Erosion Potential of a Low Fill Embankment)

A soil classified as low plasticity silt (ML) according to the Unified Soil Classification System is used to construct a secondary highway embankment (Example H.7). Estimate the mean annual soil loss from typical low fill (1m @ 4H:1V) embankment in the construction area and the grain size distribution is as given below:

Fraction	Percentage
Sand (2.0 – 0.10 mm)	22%
Very fine sand (0.10 – 0.05 mm)	5%
Silt (0.05 – 0.002 mm)	54%
Clay (<0.002 mm)	19%
Organic	0%

- To Find Soil Erodibility k = 0.064

  Use of Erodibility Nomograph (Figure B-5, Appendix B)

  % Sand + % Silt = 59%

  % Sand = 22%

  % Organic = 0%

  Soil Structure = blocky, platy, massive (4)

  Permeability = Slow to Moderate (4)

- To Find Soil Erodibility Rating (use Figure 4.2, Section 4.4.3)

  USCS Soil: ML – Erodibility Rating = High

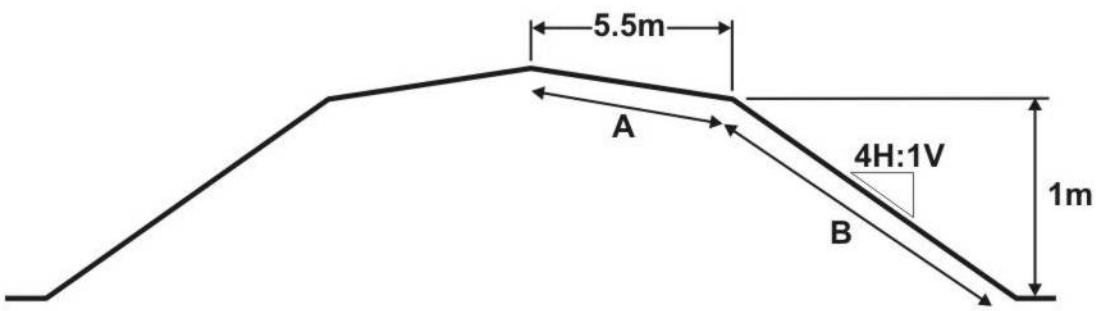


Figure (Example H.7): Secondary Highway Embankment Cross-Section

Solution:

Soil loss/hectare (A) = R K LS CP (from Equation 6.1)

R = 350 (from Figures B-1 and B-2, Appendix B)

K = 0.064 for the given soil information (Figure B-4, Appendix B)

CP = 1.0 (from Tables B-6a and B-7, Appendix B)

Equivalent LS value calculations (for half of the road cross-section):

Slope Segment	Vertical Height (m)	Inclined length Along Slope Face (m)	Slope (%)	LS factor (Table B-3) (Appendix B)	Remarks
A	0.0	5.5	2	0.12 (N/A)	Treated as simple slope, neglect the top segment.
B	1.0	4.12	25	1.77	This LS value is for a simple slope.

Hence, Soil Loss = R.K.LS.CP

= 370 x 0.064 x 1.77 x 1.0 = 41.9 tonnes/ha/yr (agriculture soil loss)

Therefore, Soil Erosion Potential (41.9 tonne/ha/yr) is very high (Table 6.1) in agriculture practice.

Hence, for highway construction, apply suggested highway modification factor ($Ø_K$ and $Ø_{LS}$) for K and LS:

$Ø_k$ = 0.8 to K

$Ø_{LS}$ = 0.8 to LS

Soil Loss (highway) = 41.9 t/ha/yr x 0.8 x 0.8 = 26.9 tonne/ha/yr $\leftrightarrow$ High Erosion Hazard

Therefore, Soil Erosion Potential (26.9 tonne/ha/yr) is high (Table 6.1) in the highway construction practice. Erosion control measures such as scheduling can be adopted to effect completion of short sections of roadway in a few months followed by speedy topsoiling and seeding. This will reduce the soil erodibility for the whole year (370 tonne/ha/year) to part of a year (240 tonne/ha/year) as shown in Example H.1. Thus, with speedy construction scheduling, it will reduce the Soil Erosion Potential to Moderate for 17.4 tonne/ha/half year period (i.e., 240/370 of 26.9 tonne/year).

Example H.8 (Channel Protection – Vegetation Lining)

A roadside ditch having the geometric properties listed below is required to discharge 1 in 10 year storm estimated at 0.1 m^3/s (Figure Example H.8). Determine whether unmowed, full grown grasses having a height of 250 mm will be adequate as a ditch lining.

Bed width = 3.5 m Sideslope = 4:1

Backslope = 3.1 Ditch grade = 5% = 0.05

Solution:

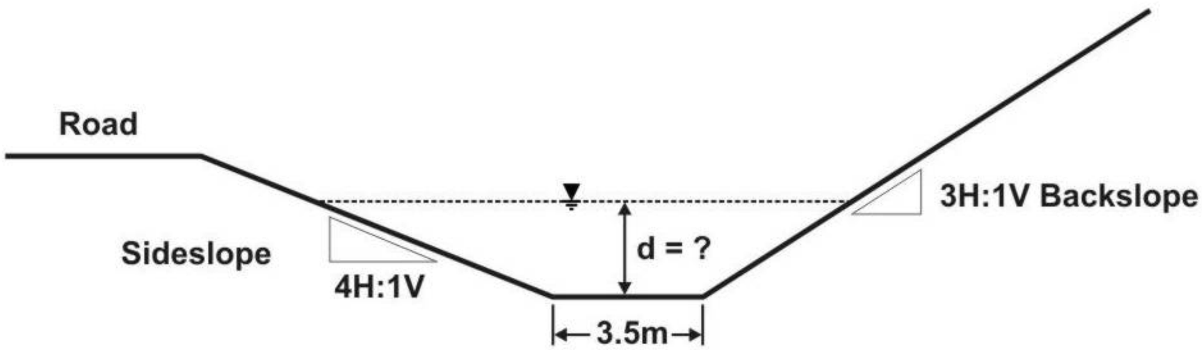


Figure (Example H.8): Typical Cross-Section

Step 1: Find the classification for the grass.

From Table F.3(a), vegetative retardance class could be either upper end of Retardance C or lower end of B; assume Retardance C.

Step 2: Estimate the depth of flow.

Trial 1:

Assume flow depth, d = 0.075 m

Top width of flow = 3.5 + 4 x 0.075 + 3 x 0.075 = 4.025 m

Cross-sectional area, A = 0.5 x 0.075 (3.5 + 4.025) = 0.282 m^2

Wetted perimeter, P = 3.5 + 0.075 (3.162 + 4.123) = 4.046 m

Hydraulic radius, R = A/P = 0.282/4.045 = 0.0697 m

From Figure F.4, for R = 0.228 ft, slope = 0.05, Manning's n = 0.28 (for Vegetation C)

Discharge, Q = $(1/n)\ A\ R^{2/3}\ s^{1/2}$ (from Equation F.3)

= $(1/0.28)\ (0.282)\ (0.0697^{2/3})\ (0.05^{1/2})$

= 0.038 m^3/s < 0.100 m^3/s, required

Hence, increase assumed flow depth.

Trial 2:

Revised flow depth, d = 0.10 m

Top width flow area = 3.5 + 4 x 0.1 + 3 x 0.1 = 4.2 m

Cross-sectional area, A = 0.5 x 0.1 x (3.5 + 4.2) = 0.385 m^2

Wetted perimeter, P = 3.5 +0.1 (3.162 + 4.123) = 4.228 m

Hydraulic radius, R = A/P = 0.385/4.228 = 0.091 m = 0.298 ft

From Figure F.4, for Vegetation Class C, R = 0.298 ft, slope = 0.05, Manning's n = 0.18

Discharge, Q = $(1/n)\ A\ R^{2/3}\ s^{1/2}$ (from Equation F.3)

= $(1/0.18)\ (0.385)\ (0.091^{2/3})\ (0.05^{1/2})$

= 0.096 m^3/s < 0.100 m^3/s, required

The estimated discharge and the required discharge are very close and a flow depth of 0.1m is acceptable.

Step 3: Check the shear resistance of the grass lining.

Tractive shear stress of flow, $\tau_p = \rho$ d s (from Equation F.5)

= 9.81 x 0.100 x 0.05

= 0.049 kPa

(since, s = slope of channel = 0.05

d = depth of flow = 0.100m

δ_w = unit weight of water = 9.81 KN/m^3)

Shear resistance of Vegetation Class C = 0.048 kPa (from Table F.3(c))

Hence, the grass lining is considered adequate.

Example H.9 (Channel Protection – Mat (soil covering) Lining

Design a temporary ditch lining for the channel conditions in Example H.8. Assume the exposed natural ground in the ditch is incapable of resisting soil erosion in the ditch (Figure Example H.9).

Channel geometry: Sideslope = 4:1 Backslope = 3:1

Bed width = 3.5 m Ditch grade = 5% = 0.05

Discharge = 0.100 m^3/s

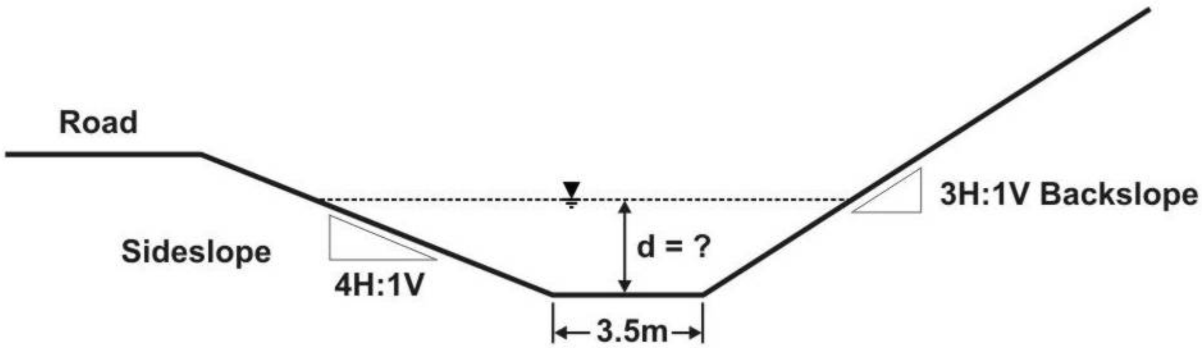


Figure (Example H.9): Typical Cross-Section

Solution:

Assuming use of a straw or wood excelsior mat

Manning's n = 0.065 (from Table F.2)

Step 1: Estimate the depth of flow.

Trial 1:

Assume depth of flow = 0.075 m

Top width of the flow = 3.5 + 4 x 0.075 + 3 x 0.075 = 4.025 m

Cross-sectional area, A = 0.5 x 0.075 x (3.5 + 4.025) = 0.282 m^2

Wetted perimeter, P = 3.5 + 0.075 (3.162 + 4.123) = 4.045 m

Hydraulic radius, R = A/P = 0.282/4.045 = 0.0697 m

$$\text{Discharge, } Q = (1/n)\, A\, R^{2/3}\, s^{1/2} \text{ (Equation F.3)}$$

$$= (1/0.065)\,(0.282)\,(0.0697^{2/3})\,(0.05^{1/2})$$

$$= 0.161\ m^3/s > 0.100\ m^3/s$$

Hence, revise the depth of flow to a lower value, say, d = 0.060 m

Trial 2:

Top width of the flow = 3.5 + 4 x 0.060 + 3 x 0.060 = 3.92 m

Cross-sectional area, A = 0.5 x 0.060 (3.5 + 3.92) = 0.222 m^2

Wetted perimeter, P = 3.5 + 0.060 (3.162 + 4.123) = 3.93 m

Hydraulic radius, R = A/P = 0.222/3.93 = 0.0564 m

Discharge, Q = $(1/n)\ A\ R^{2/3}\ s^{1/2}$

= $(1/0.066)\ (0.222)\ (0.0564^{2/3})\ (0.05^{1/2})$

= 0.112 m^3/s > 0.100 m^3/s

Hence, the depth of flow is close to 0.060 m, may be like 0.058 m.

Step 2: Check the shear resistance of the erosion control mat.

Tractive shear stress of flow, $\tau_p = \delta\ d\ s$ (Equation F.5)

= 9.81 x 0.060 x 0.05

= 0.029 kPa = 29 Pa

Permissible shear stress of manufactured mat (such as Excelsior mat) = 74 Pa (from Table F.3(c)).

Hence, curled wood mat (Excelsior mat) is more than adequate as a temporary ditch lining.

Example H.10 (Channel Protection – Gravel Lining)

A roadside ditch, similar in cross-section in Example H.9, is required to carry a 1 in 10 year storm discharge of 0.15 m^3/s (Figure H.7). Determine the mean diameter of granular material that is required to permanently control soil erosion.

Ditch cross-section information:

Bed width = 3.5 m	Sideslope = 4:1
Backslope = 3:1	Grade = 5%

Solution:

Assume using rock riprap, D_{50} = 150 mm

Corresponding value of Manning's n = 0.104 (from Table F.2)

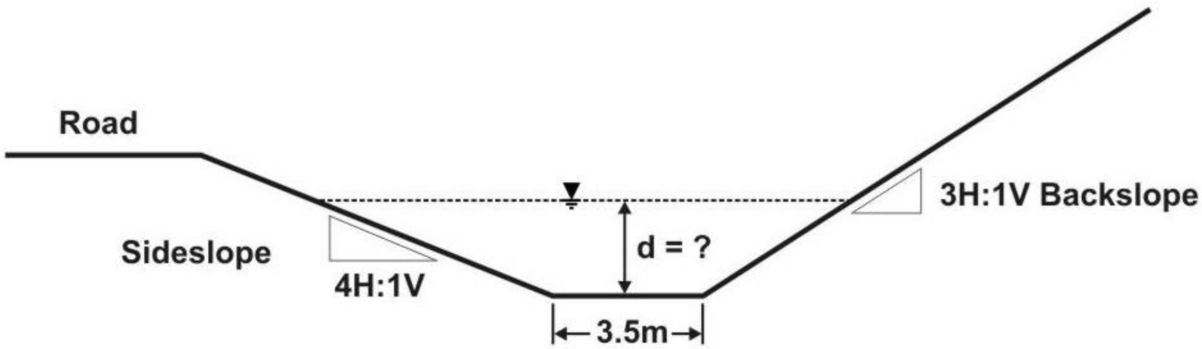


Figure (Example H.10): Typical Cross-Section

Step 1: Estimate the depth of flow.

Trial 1:

Flow depth (say) = 0.10 m

Top width of flow area = 3.5 + 4 x 0.1 + 3 x 0.1 = 4.2 m

Cross-section area, A = 0.5 x 0.1 (3.5 + 4.2) = 0.385 m^2

Wetted perimeter, P = 3.5 + 0.1 (3.162 + 4.123) = 4.228 m

Hydraulic radius, R = A/P = 0.385/4.228 = 0.091 m

Discharge, Q $= (1/n)\ A\ R^{2/3}\ s^{1/2}$ (from Equation F.3)

$= (1/0.104)\ (0.385)\ (0.091^{2/3})\ (0.05^{1/2})$

$= 0.167\ m^3/s > 0.15\ m^3/s$, required

Try another depth slightly smaller than 0.10 m.

Trial 2:

Flow depth (say) = 0.09 m

Top width of flow area = 3.5 + 4 x 0.09 + 3 x 0.09 = 4.13 m

Cross-section area, A = 0.5 x 0.09 (3.5 + 4.13) = 0.343 m^2

Wetted perimeter, P = 3.5 + 0.09 (3.162 + 4.123) = 4.155 m

Hydraulic radius, R = A/P = 0.343/4.155 = 0.082 m

Discharge, Q = (1/n) A $R^{2/3}$ $s^{1/2}$

= (1/0.104) (0.343) ($0.082^{2/3}$) ($0.05^{1/2}$)

= 0.139 m^3/s < 0.15 m^3/s, required

Hence, the actual depth of flow would be in between 0.09 m and 0.10 m. Take 0.10 m for simplicity in further calculations.

Step 2: Check the shear resistance of the gravel lining.

Trial 1:

Tractive shear stress of flow, $\tau_p = \delta$ d s

= 9.81 x 0.10 x 0.05

= 0.049 kPa = 49 Pa

Permissible shear stress of 150 mm diameter rock riprap = 0.096 kPa = 96 Pa (from Table F.3(c)).

Hence, D_{50} = 150 mm diameter riprap is more than adequate.

Try using smaller rock size riprap if possible from cost-effective considerations.

Trial 2:

Assume riprap D_{50} = 50 mm = 0.050 m, corresponding Manning's n = 0.066 (from Table F.2)

Assume depth of flow = 0.075 m

Top width of the flow = 3.5 + 4 x 0.075 + 3 x 0.075 = 4.025 m

Cross-sectional area, A = 0.5 x 0.075 x (3.5 + 0.025) = 0.282 m^2

Wetted perimeter, P = 3.5 + 0.075 (3.162 + 4.123) = 4.045 m

Hydraulic radius, R = A/P = 0.282/4.045 = 0.0697 m

Discharge, Q = (1/n) A $R^{2/3}$ $s^{1/2}$

= (1/0.066) x 0.282 x $0.0697^{2/3}$ x $0.05^{1/2}$

= 0.166 m^3/s > 0.150 m^3/s, required

Tractive shear stress of flow, $\tau_p = \delta$ d s

$= 9.81 \times 0.075 \times 0.05$

$= 0.036$ kPa = 36 Pa

Permissible shear stress of 50 mm diameter rock riprap = 0.031 kPa = 32 Pa (from Table F.3(c)).

Hence, D_{50} = 50 mm riprap does not satisfy the limiting permissible shear stress values marginally.

Trial 3:

Try using riprap with slightly higher D_{50} = 60 mm.

To find permissible shear stress for D_{50} = 60 mm size rock, interpolate between the permissible shear stress values of 50 mm and 150 mm size rock (from Table F.3(c)).

$$\tau_p = 32 + (96 - 32)\,(60 - 50) / (150 - 50) = 38.4 \text{ Pa}$$

Hence, riprap with D_{50} = 60 mm is adequate.

Thickness of riprap lining = (1.5 to 2.0) D_{50}

= 90 to 120 mm

Use thickness of 100 mm of riprap with D_{50} = 60 mm

(Note: 100 mm is assumed since it is a simple fraction of a metre)

Example H.11 (Channel Protection – Riprap Lining)

Estimate the mean riprap diameter that will adequately convey a discharge of 0.5 m^3/s down a channel having 15% slope (Figure Example H.11). Assume the channel bed width is 1 m and the sideslope is 3:1. Also estimate the flow depth.

Solution:

Discharge, Q = 0.5 m^3/s Bed slope, s = 0.15 m/m

Bed width, w = 1.0 m Sideslopes = 3:1

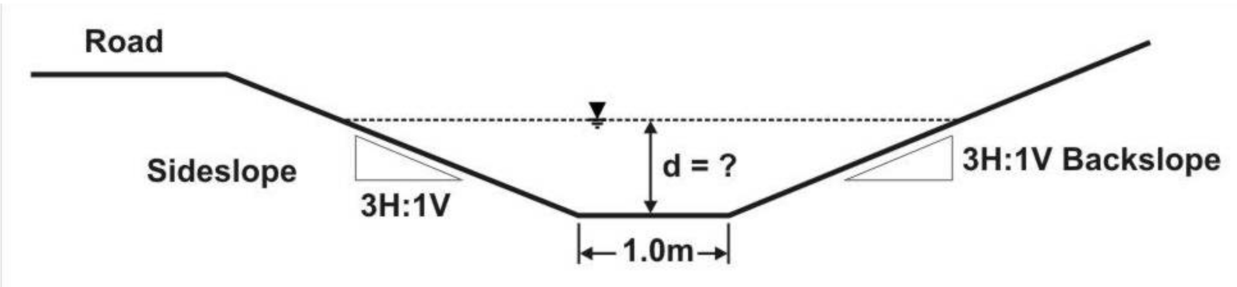


Figure (Example H.11): Typical Cross-Section

Enter Chart of Figure F.13, for, Q = 0.5 m^3/s

Flow depth = 180 mm

Riprap mean diameter D_{50} = 220 mm

Example H.12 (Channel Protection – Concrete Lining)

Design a concrete lining for a channel to carry a discharge of 1.5 m^3/s down a steep stable slope of 3H:1V (Figure Example H.12).

Solution:

Step 1: Find the depth of flow.

Trial 1:

Assume channel dimensions: Bed width = 1.0 m, Sideslope = 2:1, Flow depth = 0.3 m

Manning's n = 0.013 (from Table F.2) for 30 cm flow depth for concrete

Top width of flow area = 2 x 0.3 + 1.0 + 2 x 0.3 = 2.2 m

Flow cross-sectional area, A = (½) (0.3) (1.0 + 2.2) = 0.48 m^2

Wetted perimeter, P = 1.0 + 2 x 0.3 x 2.236 = 2.34 m

Hydraulic radius, R = A/P = 0.48/2.34 = 0.205 m

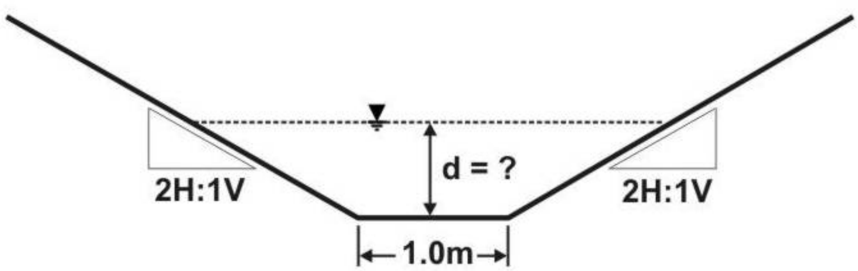


Figure (Example H.12): Typical Cross-Section

Discharge, Q (from Manning's equation)

$$Q = (1/n)\, A\, R^{2/3}\, s^{1/2} \text{ (Equation F.3)}$$

$$= (1/0.013)\,(0.48)\,(0.205^{2/3})\,(0.33^{1/2})$$

$$= 7.38\ m^3/s$$

This section is too large for the desired discharge, hence revise bed width and flow depth.

Trial 2:

Assume, Bed width = 0.5 m   Flow depth = 0.2 m

Top width of flow area = 2 x 0.2 + 0.5 + 2 x 0.2 = 1.3 m

Cross-sectional area, A = (½) (0.2) (0.5 + 1.3) = 0.18 m^2

Wetted perimeter, P = 0.5 + 2 x 0.2 x 2.236 = 1.39 m

Hydraulic radius, R = A/P = 0.18/1.39 = 0.129 m

Discharge, Q = (1/n) A $R^{2/3}$ $s^{1/2}$

= (1/0.013) (0.18) ($0.129^{2/3}$) ($0.33^{1/2}$)

= 2.04 m^3/s > 1.5 m^3/s, required by a slight margin

Hence, bed width = 0.5 m and Flow depth = 0.2 m are adequate.

Add freeboard = 0.2 m (equal to depth of flow), hence, required total depth of channel = 0.4 m

Example H.13 (Channel Protection – Gabion Mat Lining)

Estimate the rock size and gabion thickness required to discharge of 0.3 m^3/s down a channel with a 20% gradient (Figure Example H.13). Assume the bed width of the channel = 1.5 m and sideslopes = 3:1.

Solution:

Step 1: Find depth of flow.

Discharge, Q = 0.3 m^3/s   Bed slope, s = 0.20 m/m

Bed width, w = 1.5 m   Sideslopes = 3:1

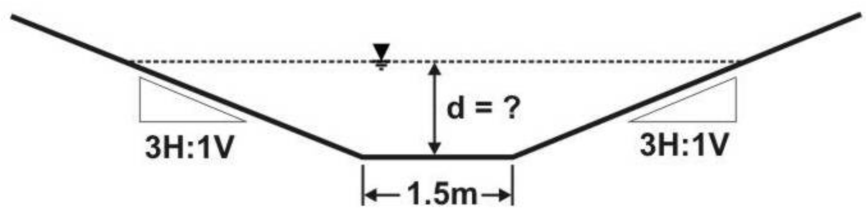


Figure (Example H.13): Typical Cross-Section

Enter Chart of Figure F.20, for Q = 0.3 m^3/s, and Flow depth = 90 mm

Step 2: Determine the size of gabion filling rock.

Tractive shear stress of flow, $\tau_p = \delta$ d s

τ_p = 9.81 x 0.090 m x 0.20

= 0.176 kPa = 3.676 lbs/ft^2 (assume 1 kPa = 20.886 lbs/ft^2)

From Figure F.15, for τ_p = 0.176 kPa, mean rock size diameter = 0.5 ft = 150 mm

Step 3: Find thickness of gabion mattress:

a) From Figure F.16, for τ_p = 0.176 kPa

Minimum thickness = 0.25 ft = 0.076 m

b) From the guidelines mentioned in Section F17.1

Mattress thickness = (2 to 3) times D_{50}

= 300 mm to 450 mm if D_{50} = 150 mm rock used

c) Gabion mattress thickness as manufactured is from 0.25 m to 0.45 m

Hence, adopt 0.30 m thickness, which is close to 2 times D_{50}.

Example H.14 (Flow Depth Estimation)

What would be the flow depth in Example H.11, if the sideslope is 4H:1V (Figure Example H.11)?

Solution:

From Example H.11, flow depth = 180 mm = 0.180 m bed width = 1.0 m

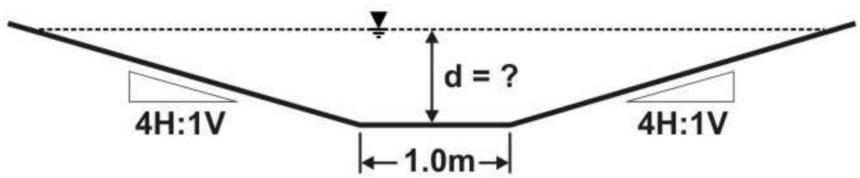


Figure (Example H.14): Typical Cross-Section

Top width of flow area = 1.0 + 3 x 0.180 + 3 x 0.180 = 2.08 m

Area of flow = 0.5 x 0.180 (1.0 + 2.08) = 0.277 m^2

Let d be the depth of flow, then top width of flow = 1.0 + 4d + 4d = 8d + 1

Area of cross-section = 0.5 x d x (8d + 1 + 1) = $4d^2 + d$

Equating the areas of 3:1 and 4:1 sideslope of the ditch configurations, $4\ d^2 + d = 0.277\ m^2$

Solving the equation for d, d = 0.163 m < 0.180 m, marginally

Example H.15 (Sediment Storage Capacity for Sediment Barriers)

Assume a typical secondary highway roadside ditch section with the geometric properties given below (Figures Example H.15a and H.15b). Determine the appropriate ditch barrier spacing to control the sediment loss from the site. Assume a mean annual sediment yield of 40 m^3/ha.

Bed width = 3.5 m	Barrier height = 0.5 m	Backslope = 3:1 (horiz : vert)
Ditch grade = 4%	Ditch depth = 1 m	Sideslope = 4:1 (horiz : vert)

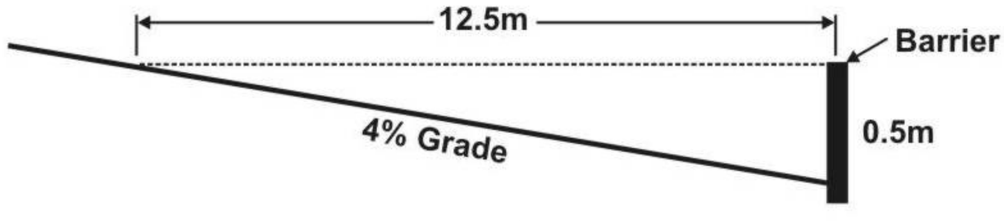


Figure (Example H.15a): Longitudinal Profile

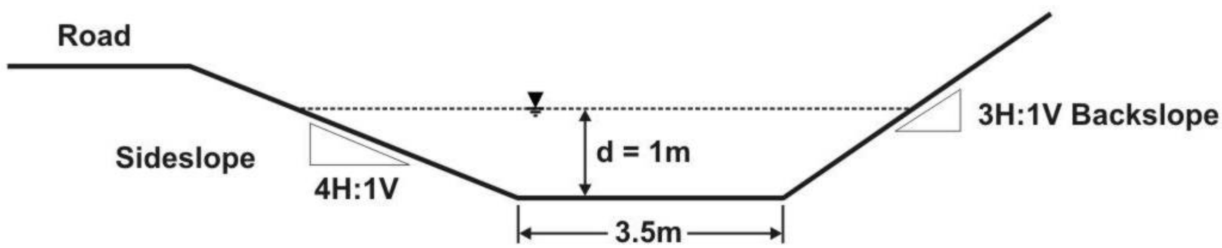


Figure (Example H.15b): Cross-Section

Solution:

Step 1: Calculate the length of sediment spread behind a barrier.

Since the ditch grade is 4% and the height of a barrier is 0.5 m, the sediment will be stored over a ditch length of 12.5 m behind the barrier.

Also, note that, while calculating the likely sediment volume behind a barrier, the cross-section of the deposited sediment changes from one location to another within this 12.5 m distance.

Step 2: Calculate the volume of sediment storage behind a barrier.

From Figure H.15a,

Top width of the storage area at the barrier = 3.5 + 4 x 0.5 + 3 x 0.5 = 7 m

Top width of storage at 12.5 m away from and behind the barrier = 0 m

Area of cross-section at the barrier = 0.5 x 0.5 x (3.5 + 7.0) = 2.625 m^2

Area of cross-section 12.5 m behind the barrier = 0.0 m^2

Hence, volume of storage (assuming a linear variation between the two locations)

= 0.5 x (2.625 + 0) x 12.5 = 16.4 m^3

Assume only half of this volume is allowed to be filled up by sediment. Reason: the remaining will be like a buffer space for erosion during unanticipated very heavy rainfall seasons or, if cleaning is done in alternate years.

Hence, sediment volume likely to be deposited behind a barrier = 8.2 m^3

Area served by one barrier = 8.2/40 = 0.205 ha

Likely width of disturbed area = 6+ 4 x 1 + 3.5 +12.6 = 26.1 m (from Figure H.15c), assuming the ground is disturbed up the backslope by a distance of 12.6 m.

Note: 1 ha = 10,000 m^2

Hence, spacing = 0.205 x 10,000/26.1 = 78.5 m, say, 75 m spacing for convenience of construction. For practical and conservative purposes, a spacing of 60 m (every 3 stations of 20 m) can be considered.

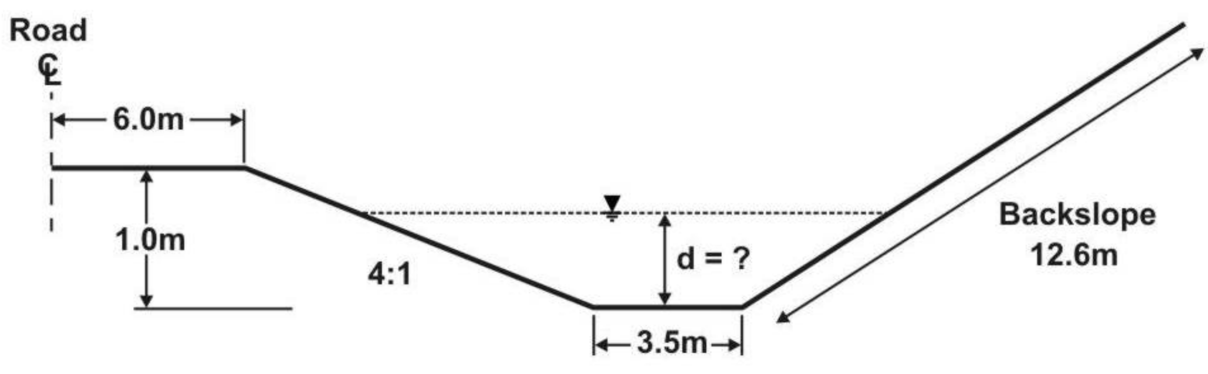


Figure (Example H.15c): Cross-Section Profile up the Backslope

Example H.16 (Design of Sedimentation Pond/Trap)

In this project area, the construction of a highway alignment down a river valley exposed a cutslope of 3 hectare area of bare soil surface. The average cutslope is a single slope at 3H:1V and 25 m length. The cutslope was stipulated for surface texturing with track walking up/down slope. The contactor will schedule to excavate the slope to follow with topsoiling and seeding within the 3 months of July, August and September. The alignment traverses the river course and there is direct connectivity to a fish bearing stream of high environmental sensitivity. The soil types of the area consist of 60% silty low plasticity clay (ML to CL) and 40% high plasticity clay (CH). No rainfall gauge station is available for the immediate area and the hydraulic/hydrotechnical engineer's assessment on inflow runoff quantity into the sedimentation pond is not available. Soil sampling of the ML soil was undertaken at mid height of cutslope and a hydrometer gradation analysis of the ML soil was carried out in preliminary recognition of the erodibility of the ML material.

Hydrometer Gradation (see Figure Example H.16c)

Soil Particles	Percent	Other USCS Properties (Figure 4.1)	
Clay	14	Plasticity Index	PI = 10%
Silt	43	Liquid Limit	LL = 24%
Sand	41	ML to CL material	
Gravel	2		

Note: This design follows the design approach of Fifield 2001 with engineering modifications.

Questions:

1) **What is preliminary soil erodibility assessment?**

2) **What is the amount of erosion sediment from the cutslope?**

3) **What is the hazard rating of the site; appropriate action if required?**

4) **If sedimentation pond is required, what storage volume of sediment laden runoff can be anticipated?**

5) **How to develop the requirement for the design of a sedimentation pond?**

6) **Design of sedimentation control (as a perimeter control measure adjacent to high risk area).**

Question (1): Evaluate the preliminary soil erodibility:

Determine preliminary Soil Erodibility based on USCS from Figure 4.2.

For CH soil, soil erodibility is considered LOW – no concern

For ML soil, soil erodibility is considered HIGH – concern

Answer: For ML soil, erodibility is considered **HIGH** (Figure 4.2) and of concern

Hydrometer gradation analysis is necessary

Question (2): What is the amount of erosion sediment (SOIL LOSS) from the cutslope?

Construction Conditions:

a) Erodible Soil Distribution Area: 60% of the area is ML soil of high erodibility

b) Construction Schedule 3 months: Soil Erodibility (K) reduction by 35%

(July + Aug + Sept = 41 + 17 + 7 = 65% of annual Erodibility Factor (R))

SOIL LOSS (A): evaluate using RUSLE formula (Equation 6.1) with highway modification factors

$RUSLE_{highway}$

$$A = R \times K_{highway} \times LS_{highway} \times C \times P \qquad \text{(Equation 6.1)}$$

= 325 x 0.07 x 4.1 x 1 x 0.9

= 84 tonne/ha/yr Soil Loss Hazard: very high (Table 6.1)

x 0.6 erodible soil distribution area in (a)

x 0.65 construction schedule time distribution per year in (b)

Therefore,

$A_{construction\ period}$ = 84 x 0.6 x 0.65

= 32 tonne/ha/construction period Soil Loss Hazard = high (Table 6.1)

Where:

$R = 325\ MJ\ mm\ ha^{-1}\ h^{-1}\ y^{-1}$ (Figure B-1; Appendix B)

$K_{agriculture} = 0.088\ MJ^{-1}\ mm^{-1}$ tonne hr (Figure B-5; Appendix B)

$K_{highway} = 0.070$ ($K_{agriculture}$ x 0.8 (highway modification factor $Ø_K$) see Section 6.2.2.2)

% silt + sand = 84 (use 70%; maximum value in Figure B-5; overestimation of K is possible)

% sand = 41

% OM = 1 (assume 1 for using Figure B-5)

Soil Structure = 4 (blocky, platty, massive)

Permeability = 3 (slow to moderate)

$LS_{agriculture} = 5.2$ (Table B-3; Appendix B)

$LS_{highway} = 4.1$ ($LS_{agriculture}$ x 0.8 (highway LS modificator factor $Ø_{LS}$) see Section 6.2.3.2)

Single slope

33% Slope (3H:1V)

Slope length = 25 m

C = 1 (Table B-6a; bare soil with no mulch)

P = 0.9 (Table B-7; bare soil freshly rough)

Answer: SOIL LOSS (A)

A_{annual} = 84 tonne/ha/yr

$A_{construction\ period}$ = 32 tonne/ha/construction period

Question (3): What is the hazard rating of the site?

Answer:

A_{annual}	= 84 tonne/ha/yr	Soil Loss Hazard: Very High (Table 6.1)
$A_{construction\ period}$	= 84 x 0.6 x 0.65	
	= 32 tonne/ha/construction period	Soil Loss Hazard: High (Table 6.1)

Answer:

The rating of soil loss hazard per year is very high:

- Therefore scheduling of construction to minimize bare soil exposure and speedy topsoiling and seeding are required to lower the annual soil loss hazard rating.
- The rating of soil loss hazard per construction season is still high after scheduling of the construction.
- Therefore the design of sediment pond at perimeter of site is required.

Question (4): If sedimentation pond is required, what storage volume of sediment laden runoff can be anticipated? How to develop the requirements of a sedimentation pond?

If available runoff estimate is not available, it is appropriate to use 250 m^3/ha of disturbed soil areas for estimating storage volume of sedimentation pond. This is based on 25 mm runoff per hectare (EPA requirements; (Fifield 2001)). The 25 mm runoff per hectare is appropriate for 40 to 45 mm precipitation over loamy clay (Type C) to clay (Type D) (see Figure 4.5).

In areas of severe land constraint, a minimum size of sedimentation pond at 150 m^3/ha of disturbed land may be considered in accordance with the risk level of the site. Thus, a pond size of 450 m^2 may be a minimum requirement for 3 ha of land disturbed.

Answer:

A 750 m^3 storage volume as preliminary estimate is appropriate for 3 ha of disturbed area.

Question (5): How to develop the requirement for the design of a sedimentation pond?

The following parameters should be available.

Steps to determine:

1) Target size particle (D_s) for settlement performance
2) Settling velocity (V_s) of target size particle (D_s)
3) Outflow (Q_o) performance and capacity of outflow structure of Sedimentation Pond

4) (i) Inflow (Q_i) Runoff Estimation based on affected area, and (ii) Estimate of Width (W) requirement of outflow structure
5) What is surface area (SA) of sedimentation pond using 1m retention depth?
6) What is gradation (PEG) of the material coarser than the target size particle for sedimentation?
7) What is the efficiency of the sedimentation pond?

Step 1: Target size particle (D_s) for settlement

D_s = 0.03 mm medium size silt is targeted for sedimentation.

Step 2: Settling velocity (V_s) of target size particle

Result:

V_s = 0.06 cm/s for D_s = 0.030 mm size medium silt particles @ 10°C water temperature (Table G.1)

Step 3: Outflow performance and outflow capacity (Q_o) of Sedimentation Pond

The outflow capacity (Q_o) of sedimentation seepage flow from outflow structure of a sedimentation pond can be more accurately assessed with the use the following properties of construction material and design geometry (Refer to Figure G.3a for pictorial of the following dimensional properties).

1) porosity (ρ) and permeability of filter system
2) average rock diameter (D) of gravel berm
3) width (W) of permeable berm
4) flow length (T) through filter system
5) height (H) of water under retention

Equation G.4 (proposed by Jiang *et al.* 1998) on relationship on outflow performance provides reasonable results for a permeable berm outlet system was considered appropriate for use in sedimentation retention (Fifield 2001). See Section 12 for details.

$$Q_o = 0.327\, e^{1.5S} (g\, D_{50} / T)^{0.5}\, \rho W\, H^{1.5} \qquad \text{(Equation G.4)}$$

(Jiang *et al.* 1998)

Where:

Q_o = Outflow capacity of containment system (m^3/s)

g = Acceleration due to gravity = 9.8 m/s^2

D_{50} = Mean diameter of the rock (m); for this equation

W = Total width of the barrier (m)

ρ = Porosity of the rock barrier

T = Thickness of the barrier (m)

H = Hydraulic head (m)

S = Slope of channel (%) (generally varies from 0% to 7% for highway gradeline profiles)

The concept of Equation G.4 is presented in Figure G.3 and a typical detail of permeable gravel outlet berm option is presented in Figure G.4.

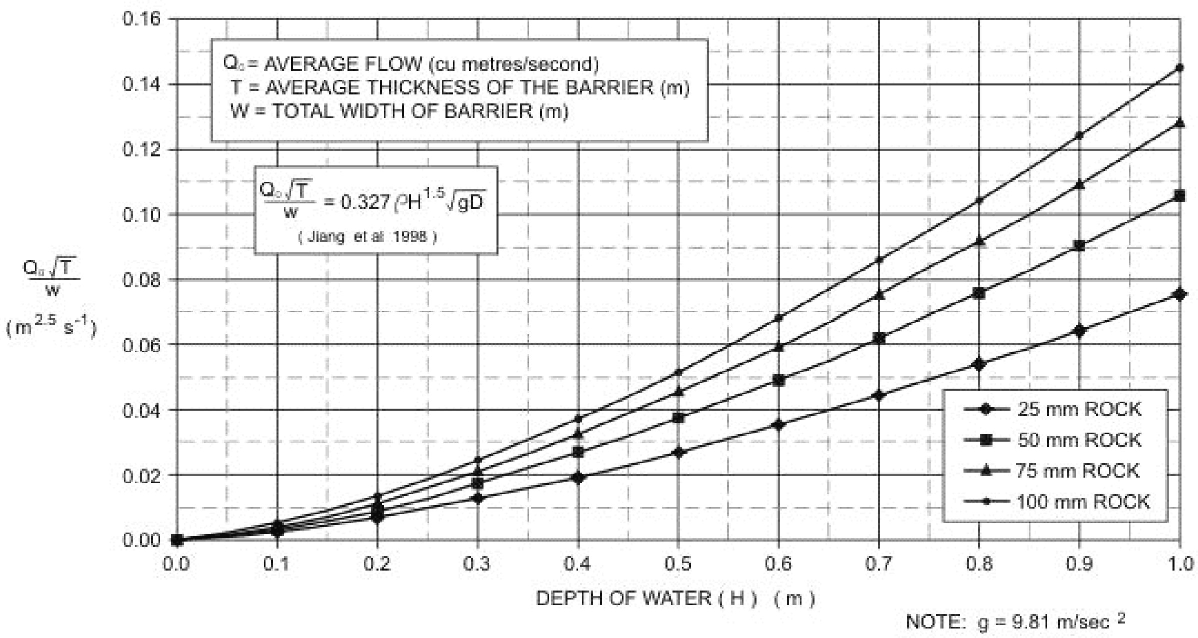


Figure (Example H.16a)

Figure G.3b: Flow (Q) through an Outlet Barrier (g) of various Diameter (D) Rocks in Gabion Basket

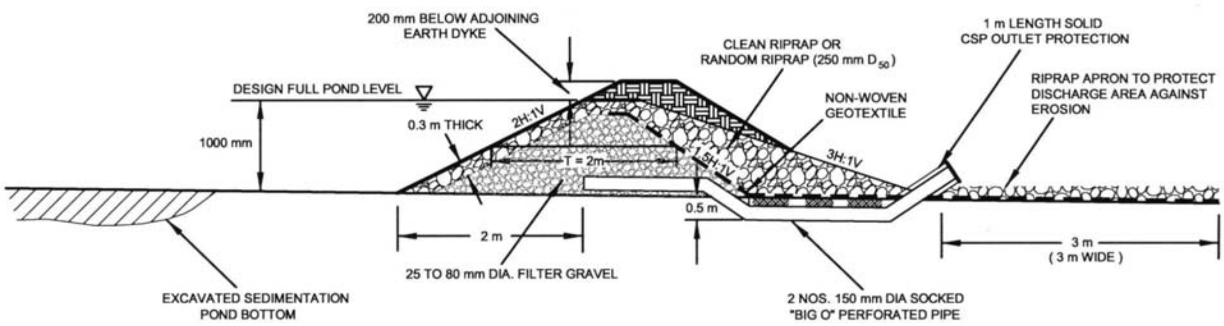


Figure (Example H.16b)

Figure G.4: Typical Sedimentation Basin/Trap Outlet Permeable Structure with Rock Filter Barrier and Perforated Pipe

From Figure Example H.16a (Figure G.3b), a derived version outflow capacity ($Q_o\ T^{0.5} \div W$) result of sedimentation pond outlet construction of permeable gravel berm can be read off. The outflow (Q_o) can be calculated from construction parameters as follows:

Assumed typical parameters and properties of permeable rock berm:

Porosity (ρ) = 0.45

Gravel berm average clean rock size (D) = 80 mm = 0.08 m

Average width of berm (W) - W to be determined

Average thickness of berm (T) = 2 m (see Figure Example H.16b) (i.e., Figure G.4)

Maximum height of runoff retention = 1 m

Thus, from Figure Example H.16a (Figure G.3b):

for H = 1m

$Q_o\ T^{0.5} \div W = 0.11\ (m^{2.5}\ s^{-1})$

Where:for T = 2 m

$$Q_o = \frac{0.11W}{1.41} = 0.08W$$

Results:

Outflow capacity (Q_o) of permeable gravel berm $Q_o = 0.08W\ m^3\ s^{-1}$

Step 4: i) Inflow runoff estimation based on affected area

ii) Estimate of width requirement of outflow structure

The hydrologist or hydrotechnical engineer should assess the terrain drainage and the affected area of construction to assess the amount of sediment laden inflow runoff (Q_i) into the sedimentation pond area. The inflow is compared with the estimate outflow capacity (Q_o) of the permeable outlet to design the width (W) of the permeable outlet.

use: $Q_i = 0.5\ m^3\ s^{-1}$ (assumed)

at full storage: $Q_o = Q_i = 0.5\ m^3\ s^{-1}$

then for: $Q_o = 0.08W$

$W = 6.3$ m

Results:

For pragmatic design consideration for permeable outlet, a practical outlet width (W = 6.3 m) can be considered to provide an outflow capacity ($Q_o = 0.5\ m^3/s$).

Step 5: What is surface area of sedimentation pond

It is appropriate to consider:

1) inflow (Q_i) equal to outflow (Q_o) (in Step 4)

$$Q_i = Q_o \qquad \text{(Equation G.3)}$$

2) and/or minimum storage volume of 250 m^3 /ha disturbed land for design of sedimentation pond

Thus, Inflow Runoff Volume (Q_o) = 0.5 $m^3\ s^{-1}$ (from step 4), then find surface area of pond (SA)

Pond Surface Area:

$$SA = 1.2\ Q_o \div Vs \qquad \text{(Equation G.5)}$$

$$= 1.2\ (0.5\ m^3\ s^{-1}) \div 0.0006\ cm/s$$

$$= 1000\ m^2$$

Where: V_s = 0.06 cm/s = 0.0006 m/s (see step 1)

Step 6: What is Percentage Material Equal to or Greater (PEG) (i.e., gradation of the material coarser than the target size particle for sedimentation)

From hydrometer gradation curve results (see Figure Example H.16c) for:

Where:

D_s = 0.03 mm medium to fine size silt as target size particle

PEG = 55% (or 45% smaller in hydrometer gradation curve)

Step 7: What is the efficiency and design of the sedimentation pond?

Apparent efficiency (A_{eff}) can be determined by configuration of sedimentation using L/We ratio concepts.

Net efficiency (N_{eff}) is the combined effect of pond configuration settling velocity of target size particle as assessed in PEG.

$$N_{eff} = A_{eff} \times PEG \qquad \text{(Equation G.11)}$$

$$= 0.92 \times 0.55$$

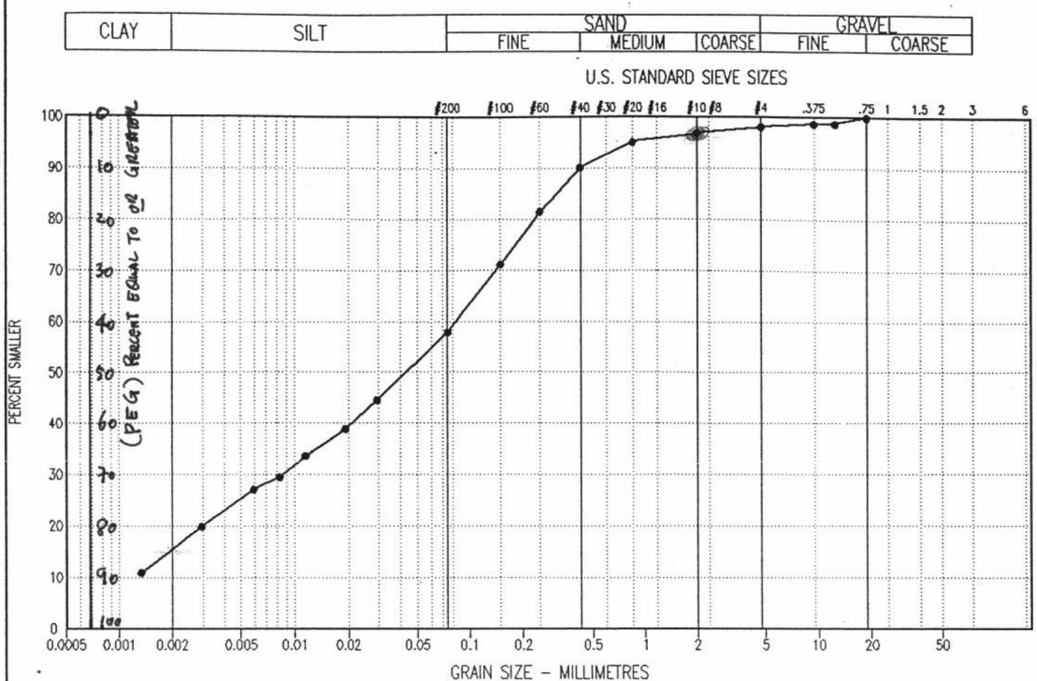
$$= 50\%$$

Where : A_{eff} = 92% using L/We = 7 (Figure G.7)

PEG = 55% for D_S = 0.03 mm (medium to fine silt) (Step 6)

EBA Engineering *FIGURE EX 14.16 PEG (GRADATION) ASSESSMENT*

PARTICLE SIZE – ANALYSIS OF SOILS



SYMBOL	BOREHOLE NUMBER	DEPTH (m)	DESCRIPTION CLAY %	SILT %	SAND %	GRAVEL %	Cu	Cc	U.S.C
•——•	4	32.50 – 33.50	14.0	43	41	2	–	–	

Project: 0104-7100023 Date Tested: 02/03/14 BY: SK

Tested in accordance with ASTM D422 unless otherwise noted.

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The testing services reported herein have been performed by an EBA technician to recognized industry standards, unless otherwise noted. No other warranty is made. These data do not include or represent any interpretation or opinion of specification compliance or material suitability. Should engineering interpretation be required, EBA will provide it upon written request.

Figure (Example H.16c): PEG (Gradation) Assessment

Results:

Design of Sedimentation Pond (Figures 12.1, G.3a and G.4)

1) Medium size silt (D = 0.03 mm) as design particle for settlement efficiency goal
2) L/We ratio = 7 (Figure 12.1)
3) Pond area = 1000 m²; flow chamber width (We) = 12 m; chamber length (L) – 84 m (Figure 12.1)
4) Earth dyke height = 1.2 m (Figure G.3a and G.4)

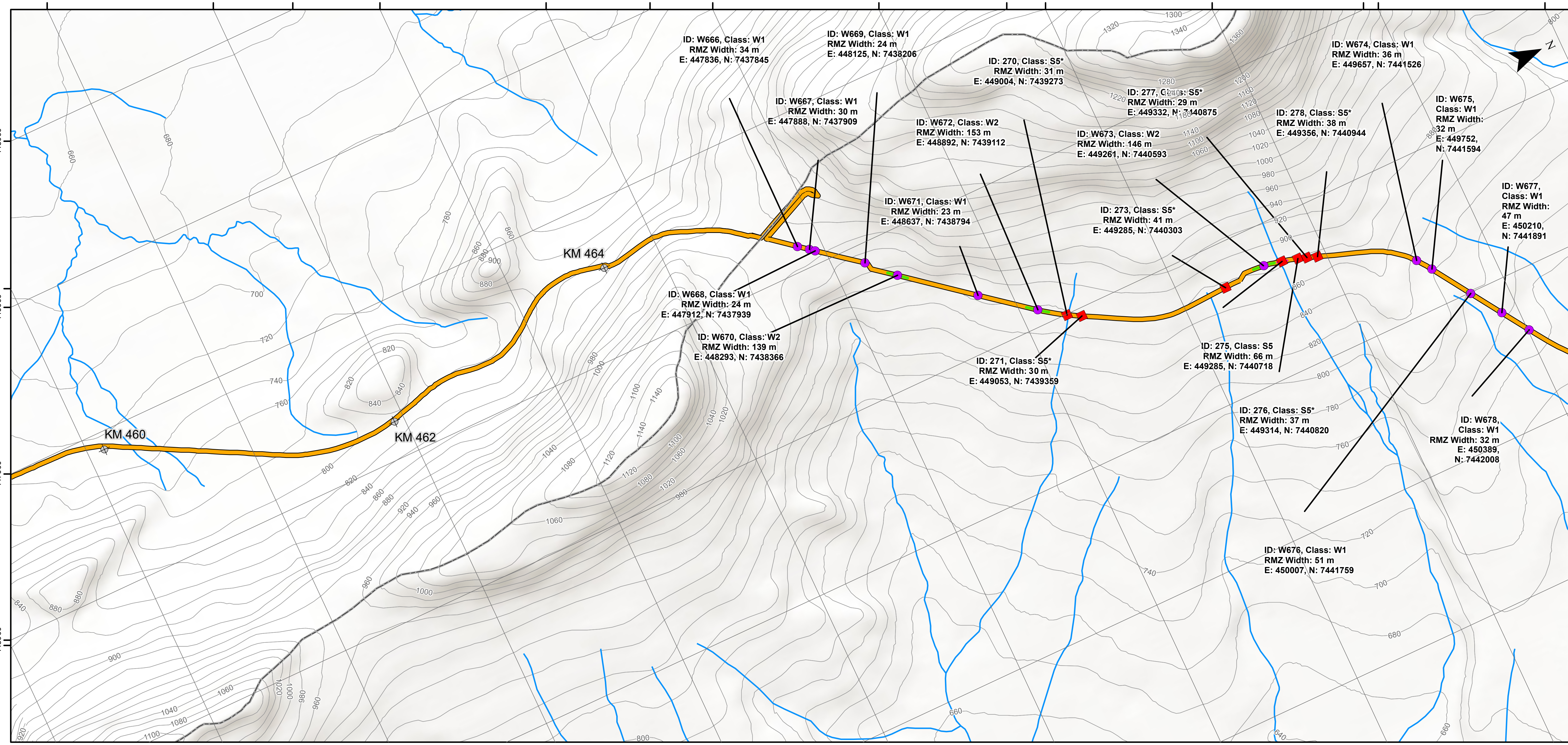
(5a) Outlet berm height = 1.0 m (Figure G.3a and G.4)

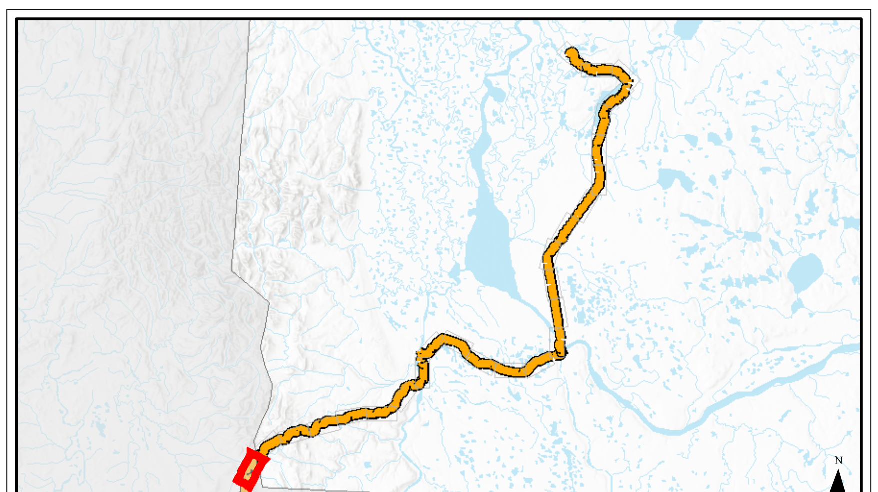
(5b) Outlet berm width (W) = 6.3 m

6) Outlet berm average thickness = 2 m (Figure G.4)
7) Outlet berm average rock size (D) 100 mm diameter
8) Apparent Efficiency (A_{eff}) = 92%
9) Net Efficiency (N_{eff}) = 50%

APPENDIX C

Example Site Maps





Legend

- Watercourse/Waterbody
- Wetland
- Riparian Management Zone (Waterbody/Watercourse)
- Riparian Management Zone (Wetland)
- Yukon Border
- Highway Kilometre Marker
- Dempster Fibre Line Alignment
- Watercourse
- Contour (20m intervals)

Data Sources

• Inset map. National Geographic. Service Layer Credits: Airbus,USGS,NGA,NASA,CGIAR,NCEAS,NLS,OS,NMA,Geodatastyrelsen,GSA,GSI and the GIS User Community
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community
• Inset map alignment overview. Terrain hillshade. Airbus,USGS,NGA,NASA,CGIAR,NCEAS,NLS,OS,NMA,Geodatastyrelsen,GSA,GSI and the GIS User Community
• Roads, watercourses, waterbodies, contours and wetlands. Topographic Data of Canada, CanVec 1:50,000. Government of Canada

Map 45 of 70

Disclaimer
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0 250 500 750 1,000
Metres

Map Scale = 1:25,000 (printed on 11 x 17)
Map Projection: NAD 1983 UTM Zone 8N

Drawn: O. Leblanc	Checked: M. Power/P. Tobler	Date: 2022-05-31

ROHL GLOBAL NETWORKS EDI

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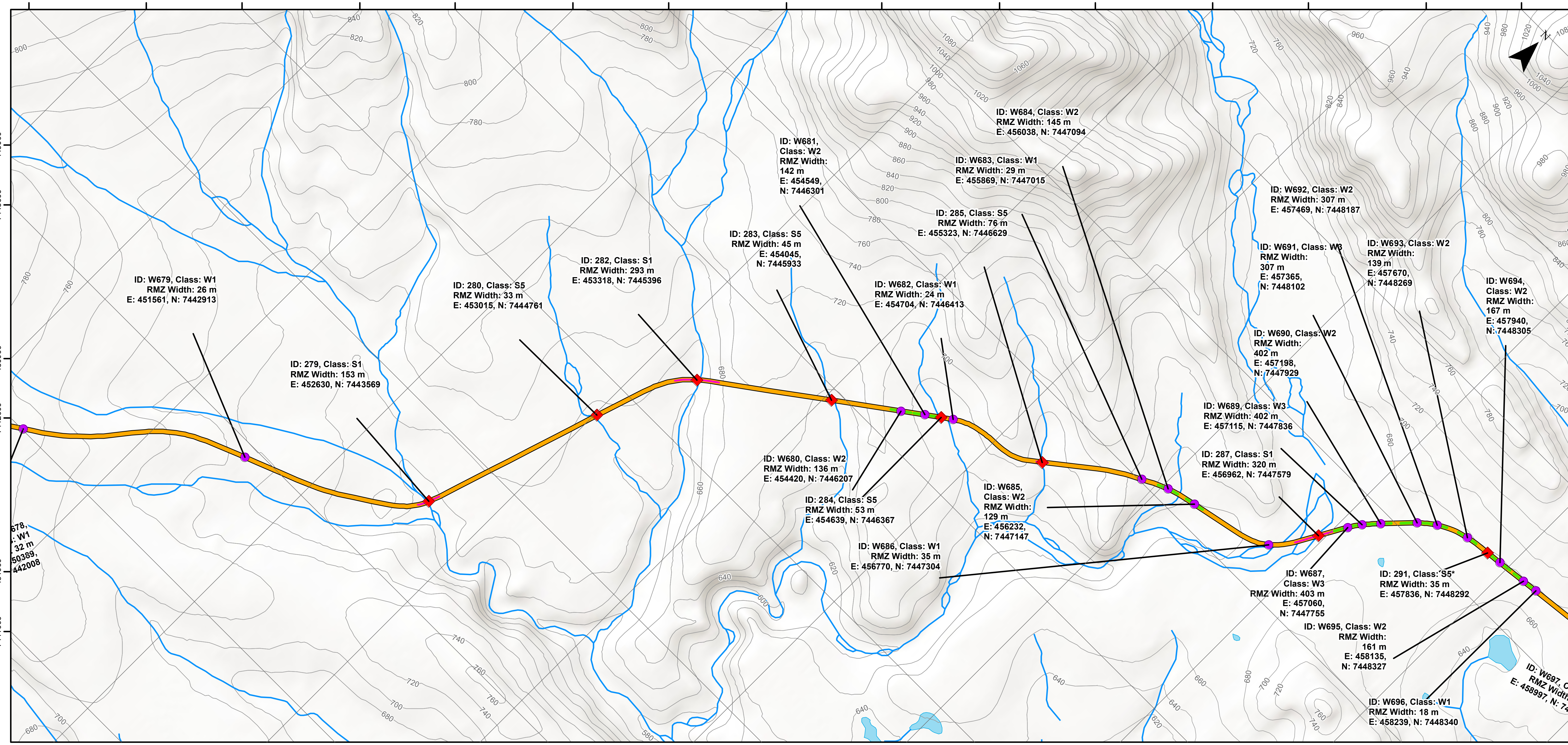

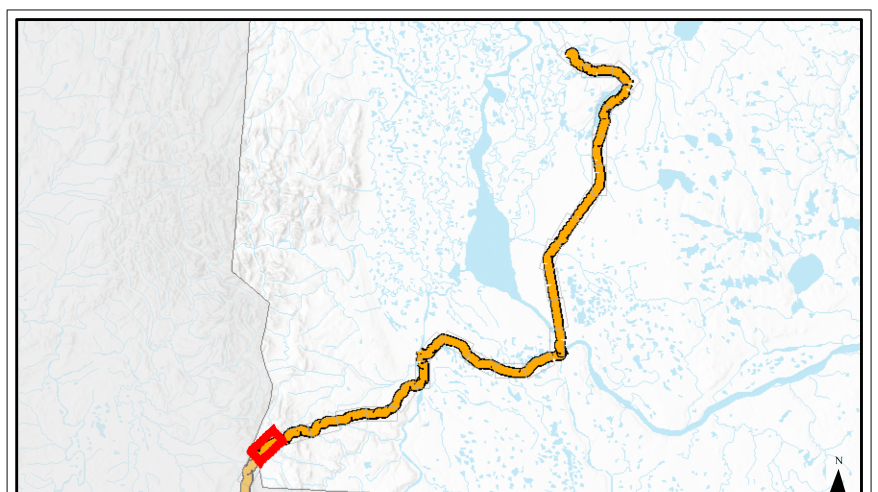

Legend

- Watercourse/Waterbody
- Wetland
- Riparian Management Zone (Waterbody/Watercourse)
- Riparian Management Zone (Wetland)
- Dempster Fibre Line Alignment
- Watercourse
- Contour (20m intervals)
- Waterbody

Data Sources

- Inset map. National Geographic. Service Layer Credits: Airbus,USGS,NGA,NASA,CGIAR,NCEAS,NLS,OS,NMA,Geodatastyrelsen,GSA,GSI and the GIS User Community
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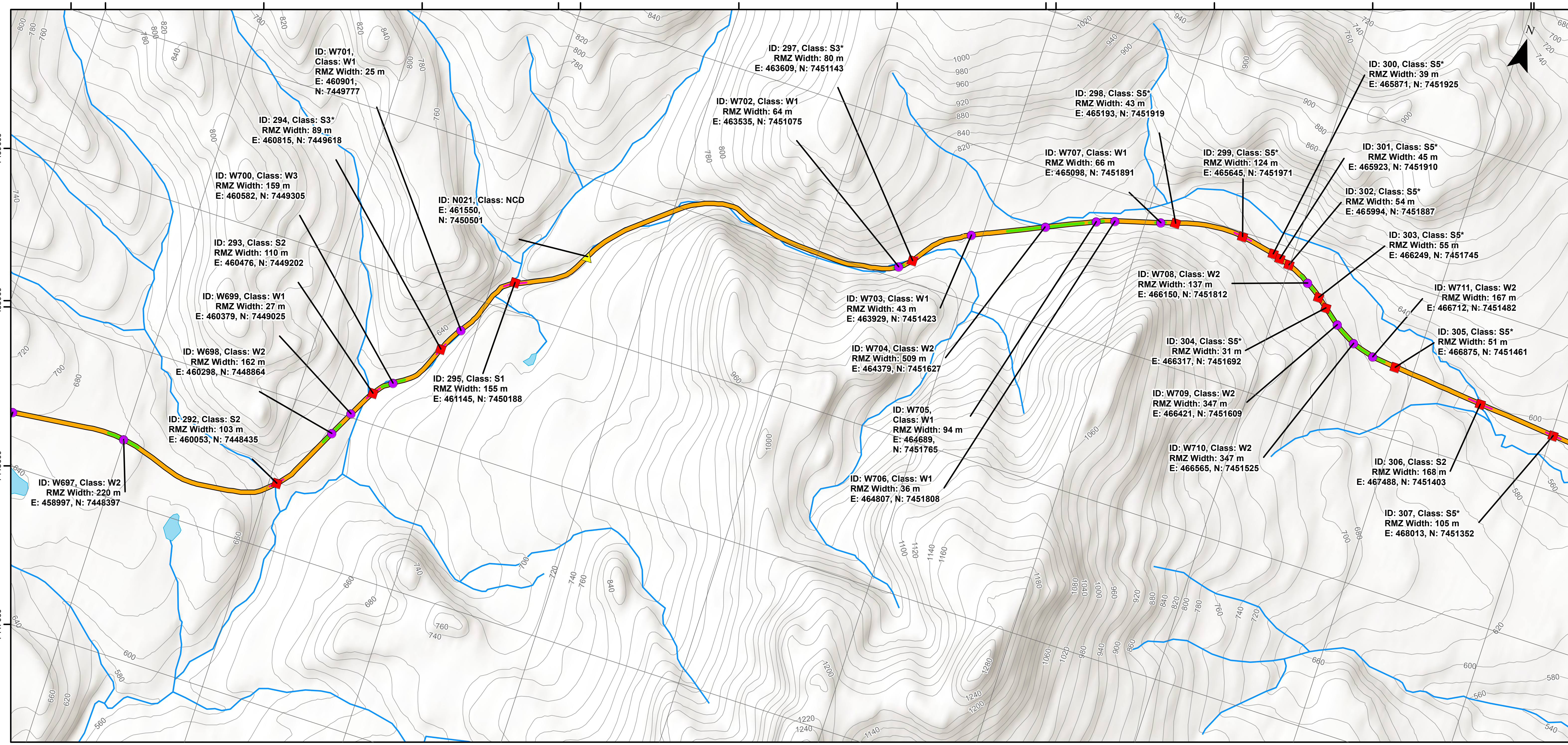

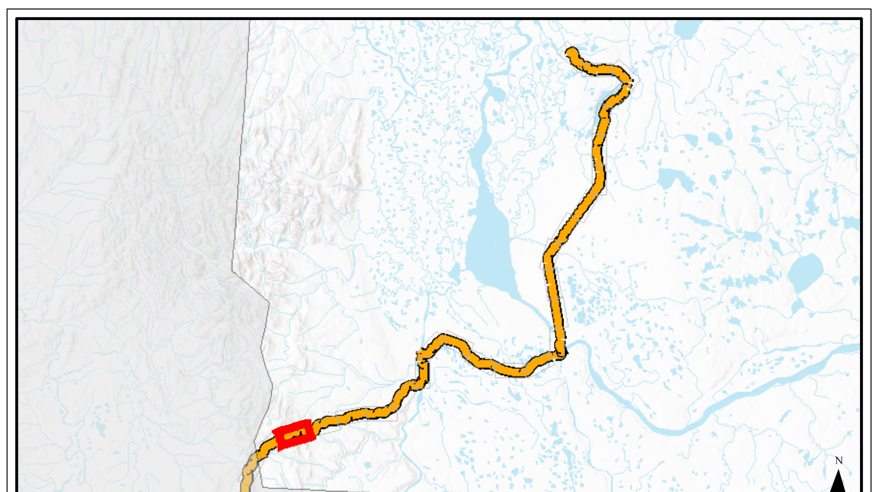

Legend

- Watercourse/Waterbody
- Wetland
- Non-Classified Drainage
- Riparian Management Zone (Waterbody/Watercourse)
- Riparian Management Zone (Wetland)
- Dempster Fibre Line Alignment
- Watercourse
- Contour (20m intervals)
- Waterbody

Data Sources

• Inset map. National Geographic. Service Layer Credits: Airbus,USGS,NGA,NASA,CGIAR,NCEAS,NLS,OS,NMA,Geodatastyrelsen,GSA,GSI and the GIS User Community
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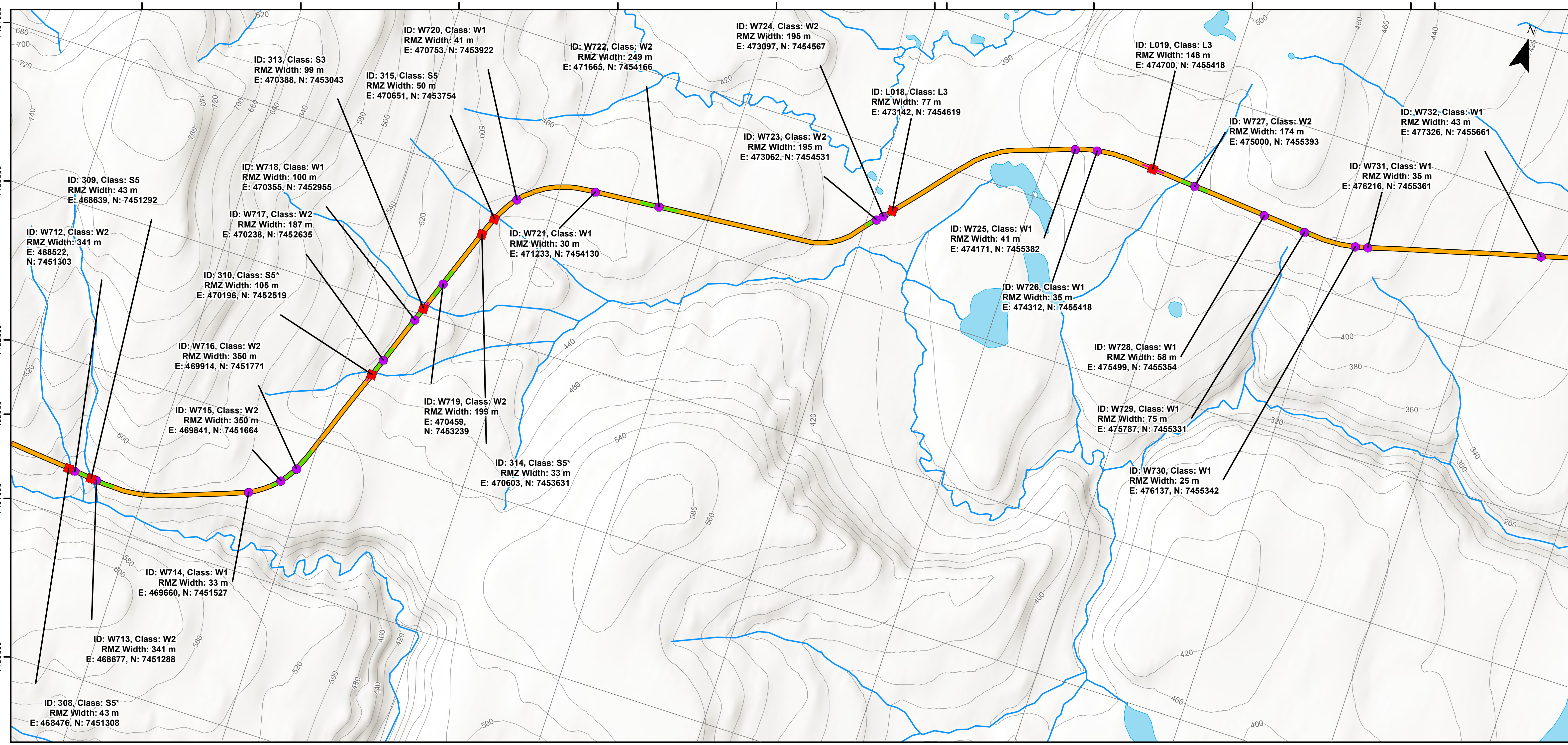

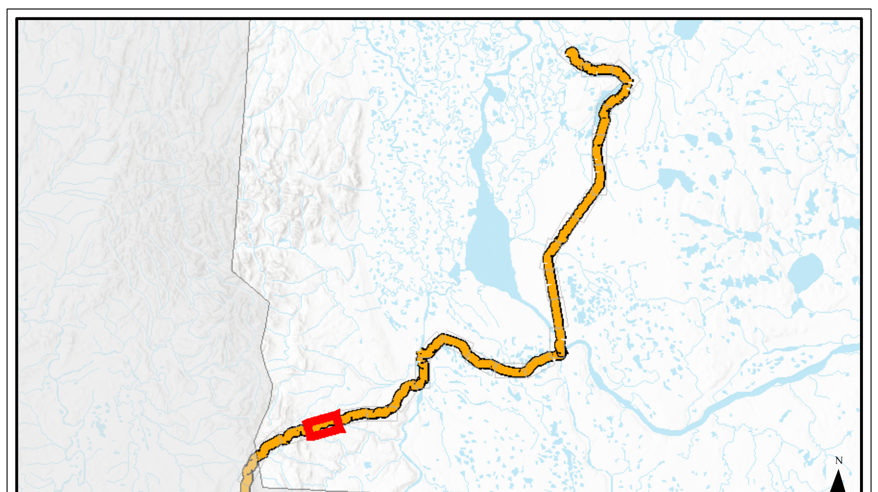

Legend

- Watercourse/Waterbody
- Wetland
- Riparian Management Zone (Waterbody/Watercourse)
- Riparian Management Zone (Wetland)
- Dempster Fibre Line Alignment
- Watercourse
- Contour (20m intervals)
- Waterbody

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