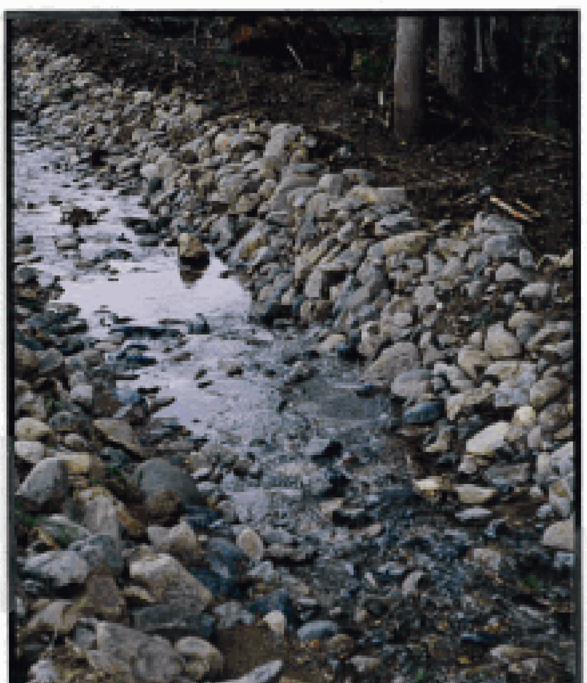
MANUAL OF
CONTROL OF EROSION AND SHALLOW SLOPE MOVEMENT



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Documentation Page

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Abstract: The erosion of soil materials as a result of highway construction activity can have serious impacts on the environment: pollution of surface water, damage to adjacent land, and degradation of streams and aquatic habitat.

In addition to the environmental effects, soil erosion causes increased costs for repair and rehabilitation, and delays in construction.

The intent of this manual is to provide information regarding the processes and mitigation of erosion so that environmental impacts can be lessened. It should be used in conjunction with, and not instead of, the knowledgeable advice of appropriate practitioners. It is hoped, however, that the document will assist those involved in highway construction in mitigating those conditions that adversely impact the environment.

The manual is divided into two main parts:

> **Part A** contains a summary of the processes involved in erosion and slope movement and provides some examples from highway projects.
> **Part B** contains a table summarizing control measures, and it is followed by detailed descriptions of each measure.

While most of the examples have been selected from the Vancouver Island Highway Project, the discussions and treatment methods generally apply to all highway construction and maintenance situations.

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INTRODUCTION

Erosion is a naturally occurring process that constantly moulds and alters landforms, removing materials from one place and depositing them elsewhere. Major problems arise when erosion from construction and development activity results in the transport of relatively large amounts of material.

The erosion of soil materials as a result of highway construction activity can have serious impacts on the environment, including:

- pollution of surface water,
- damage to adjacent land, and
- degradation of streams and aquatic habitat.

In addition to the environmental effects, soil erosion causes increased costs for repair and rehabilitation, and delays in construction.

The process of minimizing erosion resulting from highway construction begins in the design phase. By anticipating construction conditions, using geotechnical, topographical and other data, the designers can incorporate measures to minimize possible impacts.

During the construction period the actual soil and runoff conditions become apparent. This site information should be used to anticipate erosion control requirements when scheduling and executing subsequent site operations.

Given the variety of topography, soil and groundwater conditions that are encountered along a transportation route, it is often difficult to foresee all measures that should be taken before and during construction to prevent erosion and shallow slope movement. Adopting measures that eliminate all risk would increase construction costs significantly by providing measures that are not always required. For this reason, the conditions that can result in erosion must be properly evaluated in both the design and construction phases of the project, with the incorporation of appropriate erosion control measures when required.

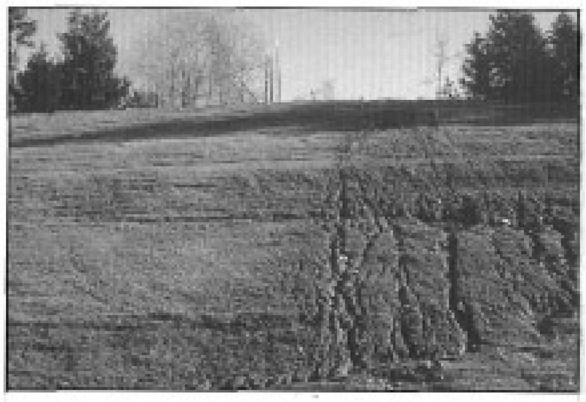

Fig. 1 A striking comparison: the area on the left was seeded during the growing period and provided erosion protection during winter, unlike the right side.

PURPOSE OF THE MANUAL

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David Polster provided many photographs and illustrations. Some illustrations were obtained from sources listed in the bibliography, in particular the Virginia Department of Conservation and Recreation, although specific reference is not given at the individual illustrations.

A – Processes

1. SOIL MOVEMENT PROCESSES

The manual refers to two types of soil movement processes: erosion and shallow slope movement. The following explanation indicates the differences.

Erosion involves the removal of particles of soil and transport by water and wind action. In this province, wind erosion is less significant on construction projects and only water erosion is considered in this manual.

Shallow slope movement is the mass movement of soil and included water along a slope. In the present context, it refers to that occurring within about a metre or so of the surface, and not deep movement that requires geotechnical engineering evaluation.

Erosion involves a higher water/soil ratio, and greater distance of soil transport, than does slope movement.

2. EROSION

2.1 Types of Erosion

Water erosion can be divided into several different types.

Raindrop erosion is the effect of dislodging soil particles by the impact of raindrops.

Sheet erosion results from shallow, broad, overland flow of water and is the initial mechanism for transport of soil dislodged by raindrop erosion.

Rill erosion begins when small variations in slope topography cause water from sheet flow to concentrate in defined channels. The higher water velocity and turbulence results in development of shallow, well-defined channels, with removal of soil particles from the bottom and sides of the channels.

Fig. 2 Example of rill erosion

Gully erosion occurs when rills join to form larger, deeper channels. Whereas rills can be repaired by shallow grading of the soil, repairing gullies requires large equipment and special construction techniques.

Channel erosion results from water in a stream channel removing material from the banks and bed.

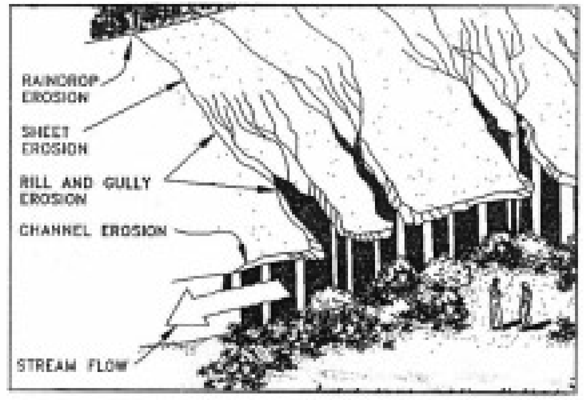


Fig. 3 Types of erosion

2.2 Factors in Erosion

Erosion potential is determined principally by the following factors:

- Rainfall and runoff
- Topography
- Soil erodibility
- Cover

Rainfall and Runoff

Flowing water is a major factor in dislodging soil particles, with the degree of erosion proportional to the amount and velocity of water flowing on the soil. Runoff can include water flowing to the construction site and that generated within the site by rainfall and groundwater sources.

The major factors in producing surface water are the intensity, frequency and duration of rainfall. Locally compiled weather data can provide information to assess the probability of rainfall of a particular intensity and duration occurring at a site. This probability is referred to as the Return Period, with shorter return periods indicating more frequent occurrence. An example is shown in Figure 4.

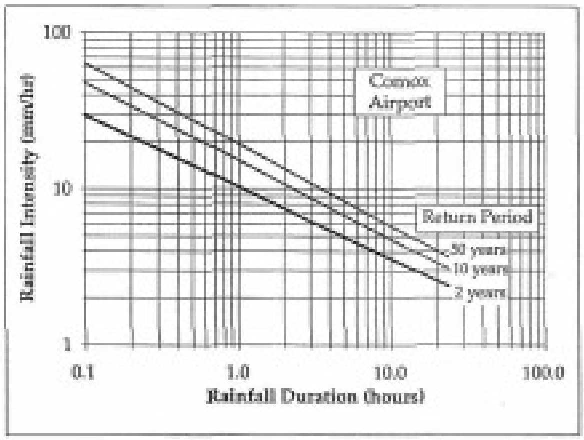


Fig. 4. Rainfall intensity-duration frequency plot (short duration events) for Comox.

Intense heavy rain has high energy and dislodges particles more easily than light rain.

High rainfall duration not only leads to greater surface flows, it increases water content of a soil and causes:

- decreased stability of soil slopes,
- greater surface flow because of reduced infiltration, and
- easier soil particle dislodgement.

Topography

The shape, size and slope characteristics of the upslope area influences the amount, rate and energy of runoff to the construction area. Minor depressions intersected by a cut slope can allow concentration of runoff.

Fig. 5 Severe gullying from concentrated surface flow at the top of a cut slope.

Erosion potential is directly related to the length and steepness of the slope. For the same vertical height, reducing a slope angle is beneficial, but results in a longer slope. The net effect of slope flattening is, on the whole, slightly advantageous.

The surface texture and minor undulations (humps and hollows) on a slope affects the velocity of flow and penetration of water into the soil. Erosion from a smooth compacted surface may be 50% more than that from a loose surface that has undulations of 300 mm.

Soil Erodibility

Cohesionless Soils are those that have little or no adhesion between the particles, although sometimes the particles form bonds by the presence of cementing agents or clay.

The potential for erosion for cohesionless soils increases as particle size decreases. Silt and fine sand particles are the most highly erodible. Moreover, finer particles are very easily transported by water and take the longest time to settle out of standing water, as shown in Figure 6.

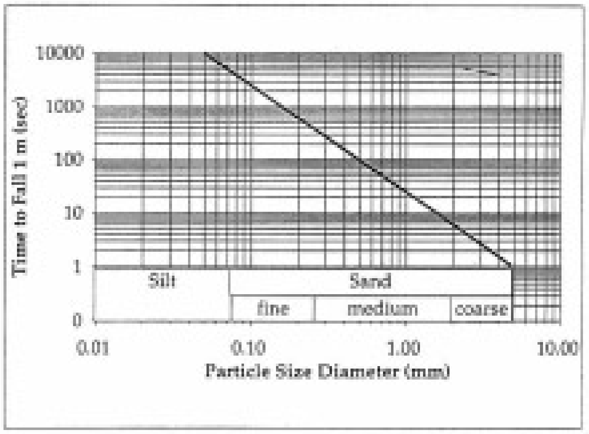


Fig. 6 Settling time for sand and silt in water.

Cover Condition

The effect of removing plant cover is easily seen when construction starts. Vegetation controls erosion by:

- reducing raindrop impacts on the soil,
- slowing runoff velocity, and
- increasing water infiltration into the soil mass.

Figure 7 illustrates how roots reinforce the strength of the soil mass and help maintain stability in this layer.

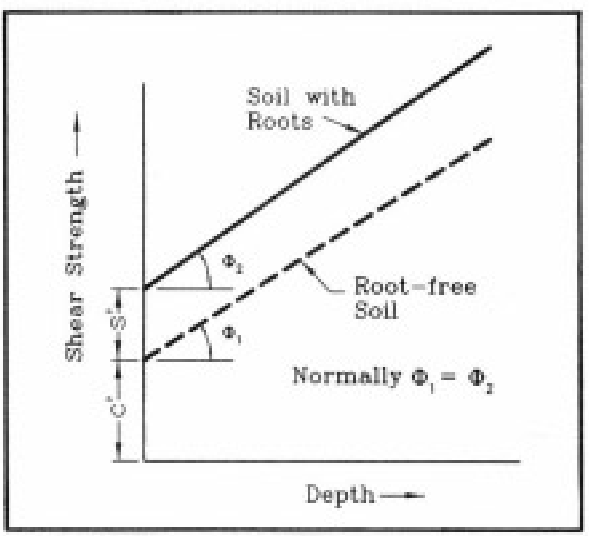


Fig. 7 Effect of root reinforcement on soil strength.

Roots in a soil provide fibres of high tensile strength within a material of lower strength. The strength of the soil/root system increases in direct proportion to the strength, depth and concentration of the roots. Other forms of cover protection for erodible soils include naturally occurring gravels and coarse outwash deposits.

2.3 Erosion Assessment

Assessing the amount of potential erosion for a site can be made by the ***Universal Soil Loss Equation***. This was developed for agricultural purposes and has been modified for assessing construction conditions. *The equation is shown here for illustrative purposes only; it is not intended that the calculations be made.* It shows how the amount of erosion is influenced by changes in the values of the individual factors (rainfall and runoff, topography, soil erodibility and cover condition). The values for each factor are determined for the site and used to estimate the total amount of soil loss. The equation is as follows:

Soil Loss = Area (A) x
Rainfall Factor (R) x
Soil Erodibility Factor (K) x
Topographic Factor (LS) x
Erosion Cover Factor (VM)

In general, erosion increases as the value of the individual factors increase.

Computing the ***rainfall and runoff factor (R)*** requires detailed statistics of rainfall. Although rainfall is not controllable, the surface runoff may be lowered by construction of diversion ditches. Rainfall and runoff should be considered when preparing the Sediment and Drainage Management Plan.

The ***soil erodibility factor (K)*** ranges from 0.1 to 0.7, with values above 0.3 representing very erodible soil. Soil properties affecting it are:

- particle size distribution, especially the percent silt and very fine sand (0.050 - 0.100 mm), and medium and fine sand (0.100 - 2.00 mm),
- soil structure (very fine granular to blocky),
- permeability (rapid to very slow), and
- percentage of organic matter.

Changes in silt and organic content have significant impacts on soil erodibility, as illustrated in Figure 8.

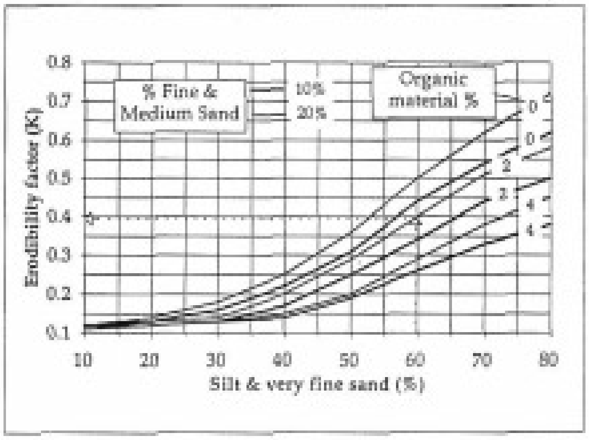


Fig. 8 Erodibility factor for silt and sand. Note the important effect of organic content.

Any natural silty deposit with more than about 50% passing the 0.100 mm screen is potentially highly erodible. Precautions should be taken to provide erosion protection of such soils as construction proceeds.

The ***topographic factor (LS)*** increases as the angle increases, and therefore erosion can be decreased by slope flattening. The effect of changing slope angle on the topographic factor is shown in Figure 9.

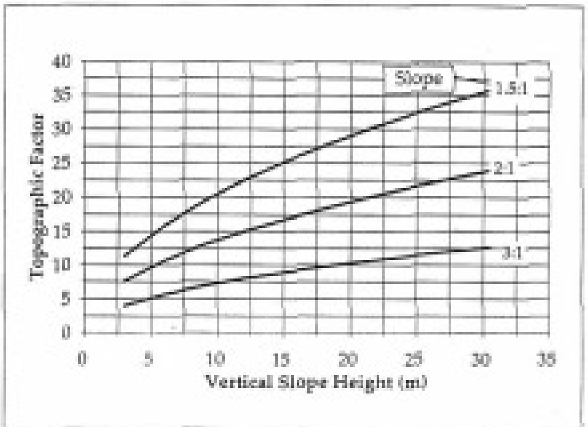


Fig. 9 Influence of slope angle on the topographic factor.

The benefits of slope flattening are offset, to some extent, by the slope lengthening that increases the **Area**. The *net benefit* is shown in Figure 10, where the total amount of erosion for various slope angles is compared to that for a 1.5:1 slope (horizontal:vertical).

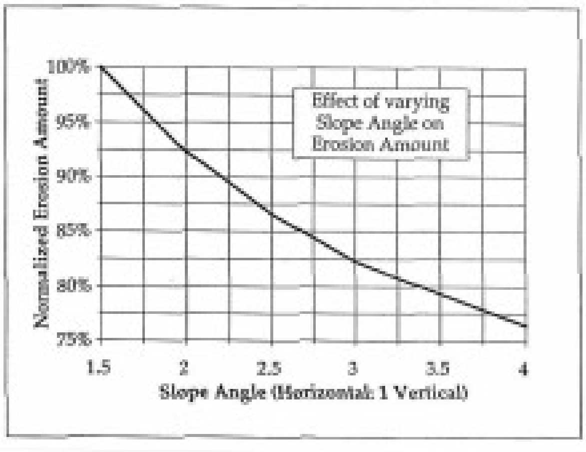


Fig. 10 Net reduction in erosion by slope flattening

Figure 10 shows that to achieve a 20% reduction in eroded amount, a 1.5:1 slope would have to be flattened to about 3.7:1.

The *cover factor (VM)* is a measure of the erosion protection provided by a cover on an erodible material. Covers include aggregate, manufactured blankets and vegetation.

The type of soil cover required depends on the site conditions: coarse granular material or rockfill may be necessary under situations where immediate protection is necessary. For most sites, use of vegetation is the most cost-effective method for protecting the soil.

Some typical cover factors are shown in Table 1. The change in the factor and in the amount of erosion are based on the freshly-disked ground condition.

Conditions	Factor (VM)	Erosion Change
Construction		
Freshly-disked ground	1.00	-
Compacted by dozer	1.30	+30%
Dozer tracked	0.90	-10%
Grass		
After seeding	0.64	-36%
After 12 months	0.38	-62%
Seedlings		
0 to 60 days	0.40	-60%
60 days to 1 year	0.05	-95%
After 1 year	0.01	-99%

Table 1. Typical cover factors.

When other erosion factors remain the same, this table shows that:

- a very large reduction in the amount of erosion can be achieved by using vegetation covers, and
- erosion diminishes significantly as vegetation becomes established.

2.4 Sensitivity of Factors

It is obvious that certain erosion control measures are more cost effective than others. From the foregoing, some general points can be made:

- The **Rainfall and Runoff Factor** can be minimized by controlling the amount of water entering the construction site (such as by diversion ditches and dykes). This can result in a proportional reduction in erosion potential and is therefore one of the most effective ways to minimize erosion.
- In very erodible soils (e.g. silt and very fine sand), incorporating a small amount of organics (~2%) into the surface layer can result in a significant reduction (~20%) in the **Erodibility Factor.**
- While the **Topographic Factor** can be lowered by slope flattening, a relatively small reduction in the factor requires a significant change in slope angle. Consequently, changing this factor is not a very effective way to control erosion on a construction project.
- Improving the **Cover Factor,** by appropriate selection of cover, is one of the best ways to lower erosion potential. For very sensitive conditions, where immediate protection is necessary, use of coarse aggregate cover may be required. Vegetation covers have a significant impact, particularly when fully established.

It is evident that using a combination of runoff control and placement of appropriate covers is the most viable method to mitigate erosion.

2.5 Erosion Control Management

The environment can be better protected by minimizing the amount of fine material entering surface water by using effective erosion control practices, than by trying to contain and treat sedimented water before it enters watercourses.

An effective way to manage erosion is through preparation of a **Sediment and Drainage Management Plan,** before carrying out construction. Such plans are being requested of contractors more frequently. They identify sensitive or potential problem areas, and provide a workplan strategy for anticipating and mitigating against siltation of the aquatic environment during the construction period. These plans should focus on:

- controlling water flows to and from the site,
- keeping runoff velocities low and retaining runoff on the site,
- timing the work for the most favourable weather period,
- keeping the exposure period short,
- minimizing the area exposed, especially for very erodible soils, and
- timing the application of slope covers to maximize their effectiveness.

It is important to compare continually the actual conditions with those originally anticipated. The plan must be revised to take account of changes that arise. These include changes in:

- subsurface conditions,
- runoff, and
- construction scheduling.

Subsurface Conditions

Subsurface conditions frequently change as construction proceeds. Soil materials may differ from those expected, and groundwater may be encountered in places or amounts that were not anticipated. Given the relatively small amount of subsurface information available before construction proceeds, variations in conditions can generally be expected. Not all subsurface changes, however, cause problems.

Runoff

The runoff into and at the construction site may not be well defined on plans, particularly for undeveloped areas. Excavations that intercept minor drainage courses may result in a significant increase in erosion potential. Such courses may require assessment, and perhaps diversion, to ensure protection of the work site.

Scheduling

When the construction schedule changes, the impact of the revised schedule on erosion potential must be considered. The increased risk of constructing in a more sensitive soil, the requirements for revegetation, and the possible impacts of working in a wetter time of year, must all be evaluated.

3. SHALLOW SLOPE MOVEMENT

3.1 Types of Movement

Shallow slope movement involves the *mass movement* of a soil slope, and includes slumping and flow of the mass. The principal impact is local, as the mass typically comes to rest a short distance from the base of the slope. The mass often enters or blocks drainage courses and ditches. Because the mass is loose, broken and sometimes fluid, it is easily eroded by surface water. Fines can be carried into adjacent watercourses or sedimentation ponds. The small size of fine soils require a long time to settle out. In addition to the surface runoff, water may come from groundwater sources and often cause shallow slope movement.

Fig. 11. Shallow slope movement into a ditch, leading to more erosion.

The purpose of this section is to outline briefly some slope movement situations typically encountered during and soon after the end of construction. These events often occur in the wet season between late fall and early spring. At such times they can lead to significant environmental damage since construction personnel are not always on site in winter and options to mitigate impacts may be limited.

3.2 Factors in Slope Movement

Shallow slope movement, or failures, are caused by the soil having insufficient strength to stand at the constructed slope angle.

The required slope angle to avoid failure conditions is a function of:

- soil type,
- moisture condition, and
- soil density.

For a particular soil type (gravel, sand, silt, clay or mixed soils), stability decreases with a rise in moisture content and a fall in soil density. The geotechnical designer is in the best position to determine the appropriate slope angle for an excavation or fill.

Typical required slope angles for compacted soils are given in Table 2.

Material		Slope Angle*
Gravel and sand		(horiz:vert)
%silt & clay	<30%	1.5:1
	30 - 50%	2:1 - 2.25:1
Silt, sandy silt		2:1 - 2.5:1
Silty clay		2.25:1 - 3:1

* The higher values are for higher moisture contents.

Table 2. Typical slope angles for various soils.

Changes in Soil Strength

Soil strength varies with time, primarily because the soil moisture is not constant. For that reason, a slope that has been constructed in summer when moisture conditions are low, may fail in winter as the material becomes wetter.

Groundwater

A high water table may be encountered during excavation. They are usually very obvious in a permeable material (sand or gravel) since the water will seep or flow out of the slope. In silt and clay soils, the effect is less obvious, and a high water table may be noted as sponginess of the soil.

3.3 Slope Movement Assessment

Predicting locations where shallow slope movement may occur is difficult. Such predictions are particularly difficult to make when observing construction during dry conditions.

A rise in groundwater after construction can lead to failure of excavated slopes below the water table, due to high hydrostatic and seepage forces. Slopes may be constructed during the low water level period in summer without incident, but fail in winter as the groundwater level rises. Excavated slopes that may be below the water table at any time of the year should be designed to prevent sloughing and erosion of the soil.

Fig. 12. Failure in a sand stratum with a high water table

In high groundwater, or potential high groundwater, conditions:

- *the slope angles used for normal conditions should be reduced by half (e.g. reduced from 2:1 to 3:1), unless adequate groundwater control is provided,*
- *construction procedures should be modified to ensure slope stability is maintained and water flow is controlled as the work proceeds,*
- *geotechnical advice should be obtained.*

4. EROSION AND SLOPE MOVEMENT IN CONSTRUCTION

Earthwork construction involves both cuts and fills that have different erosion and slope failure characteristics. For this reason, erosion and slope movement in cuts, fills and waste areas will be treated separately.

4.1 Excavations

During construction it is important to compare the actual conditions with the ones anticipated in design.

Particular note should be made of the following conditions:

Slopes

When runoff is allowed to flow down an excavated slope, the risk of erosion is high. This is particularly so when there is the possibility of concentrated flow (see Fig. 5), and when fine sands or silts are present (see Fig. 2). A combination of diversion ditches and slope blankets may be considered.

Groundwater

In summer, a granular layer may be dry but in winter it is often waterbearing. In these cases, groundwater may cause the granular soil to flow. When fine grained soil underlies the granular soil, there is a greater chance of seepage breakout at the interface, with consequent risk of erosion and slope movement. Similar conditions are likely when the strata consist of:

- Layered silt and sand, and
- Gravel or sand layers in silt or clay strata.

Silts and Clays

These soils often have high water tables, especially in wet regions. Appropriate slope angles and/or slope treatment should be anticipated for construction to decrease the risk of slope movement or erosion.

4.2 Fills

Post construction mass failure of fills is usually associated with some condition of the ground below the fill, such as a sloping surface, poor foundation soil, etc.

Shallow Failure

The outer surface of a fill is usually less compact than the remainder. During wet weather, the outer layer will increase in moisture content and the slope that has adequate stability in dry conditions can fail. This is often evident in fills with side slopes of 1.5:1 that are built from till or similar mixed soils with a fine-grained matrix.

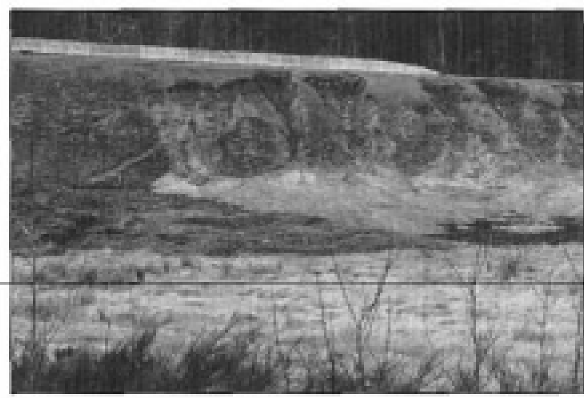


Fig. 13. Surface slumping on a fill slope in till.

Shallow failures often occur during the first winter after construction. Such failures take the form of shallow slumping and flow in the top 1-2 m from the fill surface. They can be mitigated by planting deep-rooting vegetation, with sufficient time to become established before winter.

Erosion

Rill and gully erosion on the sides of fills often results from runoff flowing over the crest of the slope. The flow also contributes to the conditions shown in Figure 13. Preventing such flows in the first instance and provision of appropriate slope covers are important in minimizing erosion.

Topsoil and Slope Dressing

These materials are usually placed in a loose condition, and movement and erosion problems can result.

a. Unroughened underlying slope

If the underlying material is impermeable, such as clay or till, and is left smooth, the conditions provide an excellent slip plane for the soil to move downslope. Slopes cut in hard and impermeable soils that are to be covered with topsoil or slope dressing should first be roughened.

b. Steep Slopes

Very often, slopes are "dressed" by blading uncompacted material on a cut slope to provide a better looking surface. This soil may be placed at a slope steeper than it is stable at and can result in a slump failure during wetter periods.

Unless a deep-rooting groundcover is placed, a topsoil layer placed at 2:1 is liable to slide in winter. Even an established cover of grass may be insufficient to bind the material to the underlying soil.

The solution is to use shrubs, cuttings and appropriate vegetation to form a mat that binds to the underlying soil. Again, the underlying soil should be scarified before topsoil placement.

Fig. 14. Failure of topsoil placed on a smooth, 1.5:1 slope.

c. Smooth surface

Dressed slopes should not be left in a smooth and "glazed" condition that prevents water infiltration. Grooving that runs down the slope, when shaping is done by buckets with teeth, promotes rill formation. Where possible provide a terracing effect by shaping *across the slope.*

4.3 Waste Areas

While these are outside the actual highway zone, they require equal consideration to the fills, cuts and drainage that form part of new highways.

Attention should be given to the location, placement and erosion protection features to minimize adverse impacts, particularly with respect to the overall drainage patterns.

The materials placed in a waste area may include:

- relatively *good material* that is surplus to the project, or
- material that is in a condition that makes it *unsuitable for construction.*

The latter includes soil that is too wet to be placed and compacted, or soil that includes a high proportion of organics.

In either case, the material is unlikely to be compacted, and probably only dumped and intermittently levelled with a dozer.

The lack of compaction means that whether the soil is good or unsuitable, the side slope should be relatively flat. For good material, the slope should be no steeper than about 3:1. For unsuitable material it should be 4:1 or less, depending on moisture conditions.

In addition to relatively flatter slopes, the material in waste areas should be placed to minimize risk of failure and environmental damage. Procedures could include:

Dyking

- Make a perimeter dyke of good material at some distance from the toe of the proposed waste fill, to trap any material that slumps or erodes from the waste fill.

- Where the waste is useable material, construct the outside layer of fill by making a dyke at the toe of the fill and compacting with construction traffic. Use a side slope at least 50% flatter than what would be used for compacted fill of the same material. Increase the height of the compacted dyke as the fill level is raised.

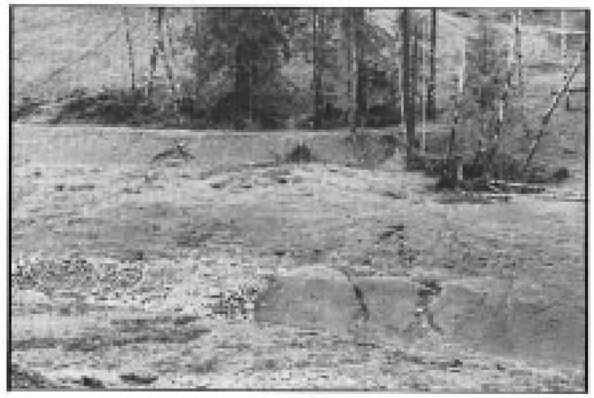


Fig. 15. A waste area with a protection dyke.

Drainage

- Maintain drainage around the perimeter of the waste area by ditching so water does not pond against the waste.

- Configure the waste pile to direct water around it to the drainage system.

- Slope the upper surface of the waste material at a low angle to shed water to an appropriate drainage ditch without causing erosion of the sides of the fill.

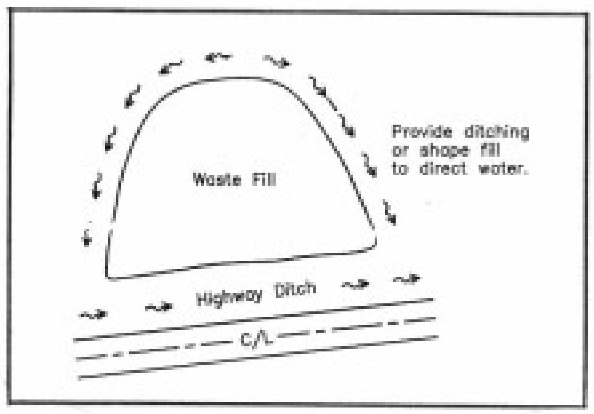


Fig. 16 Schematic drainage for waste areas

Revegetation

- Revegetate with grasses and live cuttings progressively as side slopes are stabilized, allowing adequate time for vegetation to become well established before winter.

5. EXAMPLES OF EROSION AND SLOPE MOVEMENT

Observation of erosion and slope movement situations that arise during construction may help to assess conditions that arise elsewhere. The following examples have been observed on construction projects.

a. Anticipated groundwater

Fig. 17 A slope designed to control groundwater

Situation
The strata encountered in an excavation included, in order: shallow waterbearing gravel, till, and water-bearing sand.

Solution
Figure 17 shows a granular blanket at 2:1 placed on the sand. A 300 mm perforated pipe in the ditch line runs about quarter-full in winter. An interceptor ditch at the top of the slope diverts a large volume of surface flow away from the slope. These conditions were anticipated in design.

b. Unexpected seepage conditions

Situation
Figure 18 illustrates a very unusual condition. It shows 1.5:1 fill slope of an embankment 10m high, where both sides of the highway are on fill. It shows significant seepage flow coming out of the slope. The problem occurred in late winter, after completion of work in the fall. A layer of rockfill partway up the slope was suspected of forming a reservoir for water. Water entering through the unpaved surface finally caused severe slumping of the sides.

Fig. 18 High seepage flows from a slope.

Solution
Water entering the rock layer from seepage from the fill surface would diminish when the road was paved and surface water controlled. The sideslope is very steep for the material used, and the fill slope would be marginally stable unless stabilized by a granular blanket, rock finger drains, or bioengineering (use of vegetation for soil stabilization).

c. Over steep slope

Situation
This is an example of how slopes that seem satisfactory in dry summer conditions, fail in wet winter conditions. Figure 19 shows a slope that was trimmed properly during construction in summer. A combination of increased moisture over winter, a fine-grained matrix, and a dressed but not sufficiently compacted surface, resulted in slumping.

Fig. 19 Surface slump in relatively low slope.

Solution

Stability could have been maintained using slope flattening, better compaction, or deep rooting vegetation. Alternatively the temptation to provide uniform shaping should have been resisted and a more natural form of slope warping or finishing accepted.

d. Ineffective blanket

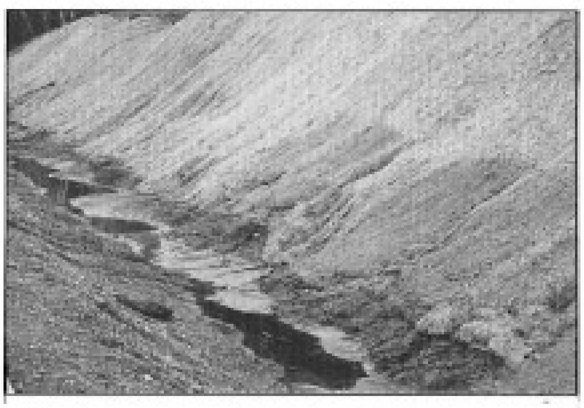


Fig. 20 Erosion under a manufactured blanket.

Situation

Figure 20 illustrates the limitations of blankets, and the fact that they must be used appropriately to be effective. The material under the blanket is an erodible sand at a slope of 1.5:1 that did not have an effective vegetation cover before wet winter weather.

The photograph shows that:

1. Blankets do not prevent erosion of the underlying soil from surface water flowing at the interface, or from groundwater flow.
2. Blankets must be installed correctly, particularly at the top of a slope where the material must be buried under the soil so water does not begin flowing on the soil surface under the blanket. While they can assist in protecting soil surfaces temporarily, blankets do not replace the effectiveness of grass roots in the soil.

Solution

Rather than using a blanket only, the very erodible sand could have been protected by:

- placing a covering such as unscreened mulch on the surface,
- seeding at a time that allows vegetation to become established before winter, or
- installing an interceptor ditch upslope of the cut.

e. Drainage from bridges

Fig. 21 Erosion from deck drainage.

Situation

Bridge end fill slopes often suffer from the effects of concentrated flow, either running off the deck, or from deck drains.

Solution

This condition can be mitigated by:

- blocking the surface drains on the bridge temporarily, until vegetation becomes established, in the meantime collecting the water in a controlled manner at the end of the deck or
- placing water impact protection such as sufficiently large pads of rockfill under the drains.

In either case the slope should be revegetated.

f. Failure of a slope gravel blanket

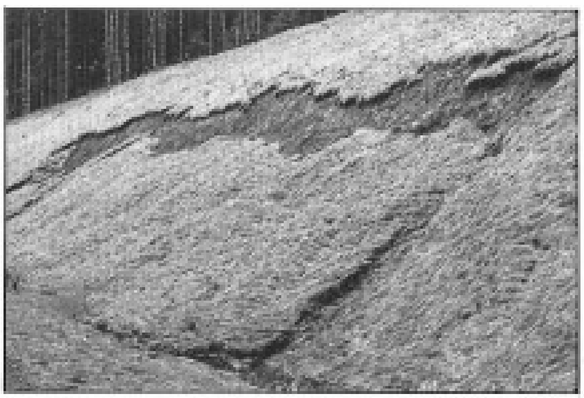


Fig. 22 Slippage along cut slope.

Situation

Figure 22 is of a 1.5:1 slope with a relatively thin sandy gravel blanket on woven geotextile that was placed on the natural silty soil. Over winter, the blanket material slid along the geotextile. The natural soil remained intact.

Solution

Grassed slopes provide good erosion protection, but do little to provide slope stability. In this instance, given the high seepage conditions, the blanket material is unstable at a 1.5:1 slope. It is difficult to get good compaction in such cases. An angular rockfill placed in a 1.5 m thickness would have been satisfactory, providing high internal stability for this slope angle and good drainage of the natural slope. Sandy gravel blankets should be placed no steeper than 2:1 where groundwater flow is present.

B – Control Measure

CONTROL MEASURES

Erosion control is most successful when measures are implemented to prevent the dislodgement of soil particles in the first instance. This goal cannot always be achieved during construction. Measures must then be adopted to capture water-borne particles in a controlled manner before undesirable damage is caused.

A variety of control techniques are given in this part of the manual. They typically are intended to address specific concerns or conditions. The control measures shown are not the only ones available, but are examples of commonly used procedures.

The table that follows provides a summary of possible control measures, with an indication of the appropriate application.

The measures are described in more detail in the individual sheets following the table and are organized in the same order. Each sheet is intended to provide a sufficient amount of detail to permit selection and design of an appropriate measure. Additional evaluation may be required in specific instances.

MEASURES FOR CONTROL OF EROSION AND SHALLOW SLOPE MOVEMENT			APPLICATION						
NO.	NAME	DESCRIPTION & PURPOSE	A: Slope Protection - Cuts B: - Fills C: -Bridge End Fills D: Sediment Traps E: Ditch & Watercourse Prot'n F: Stabilization G: Waste Areas						
			A	B	C	D	E	F	G
1	**Channels**								
1A	Diversion Ditches	A channel, usually with a ridge on the lower side, constructed to intercept and divert stormwater runoff to a stabilized outlet at non-erosive velocities.	+						+
1B	Fill Diversion Ditches	A channel with a supporting ridge on the lower side, constructed along the top of an active earth fill constructed to divert runoff away from the unprotected fill slope to a stabilized outlet or sediment trap. Typically has a short life until more permanent erosion protection becomes effective.		+					
1C	Lined Channels	A permanent channel designed to carry concentrated flows without erosion. Applicable to man-made channels, including roadside ditches, and natural channels that are modified to accommodate increased flows generated by construction.	+	+			+		
2	**Barriers**								
2A	Dykes	A ridge of compacted soil constructed at the top or base of a sloping disturbed area to divert off site runoff away from an unprotected slope, to divert runoff to a sediment trap, to act as a barrier should soil move, to form a starter dyke for waste areas, and to retain moving soil.	+	+				+	+
2B	Straw Bale Barriers	A temporary sediment barrier composed of straw bales placed across or at the toe of a slope to intercept sediment and decrease flow velocities from drainage areas of limited size; applicable where sheet and rill erosion may be a problem. Short effective life.	+	+					+
2C	Brush Barriers	A temporary sediment barrier composed of limbs, weeds, vines, root mat and other cleared materials pushed together to form a berm. Located across or at the toe of a slope to intercept and detain sediment and decrease flow velocities.	+	+					+
3	**Ditch Blocks**								
3A	Rock Check Dams	Small, temporary stone dams constructed across a drainage ditch to reduce the velocity of concentrated flows, reducing erosion of the swale or ditch. Limited to use in small open channels which drain 2 ha or less.				+	+		
3B	Straw Bales Blocks	A temporary barrier composed of straw bales placed in a ditch to filter sediment and decrease flow velocities from drainage areas of limited size. Typically has a short life until more permanent erosion protection becomes effective.				+	+		
4	**Temporary Slope Drainage**								
4A	Temporary Pipes	A flexible conduit (pipe or flume) used before permanent drainage structures are installed to conduct concentrated runoff safely from the top to the bottom of a disturbed slope, without causing erosion on or below the slope.	+	+				+	

MEASURES FOR CONTROL OF EROSION AND SHALLOW SLOPE MOVEMENT			APPLICATION						
NO.	NAME	DESCRIPTION & PURPOSE	A: Slope Protection - Cuts B: - Fills C: -Bridge End Fills D: Sediment Traps E: Ditch & Watercourse Prot'n F: Stabilization G: Waste Areas						
			A	B	C	D	E	F	G
5	**Groundwater Control**								
5A	Structural Methods	Control of seepage water using a variety of techniques including perforated pipes to remove the water before it breaks out on the surface, granular blankets or trench drains installed at intervals along the slope. Exiting water must be controlled to prevent erosion of the slope. The purpose is to draw down the water table in a localized area. Generally applicable to large slope failures, but can be used locally.	+					+	
5B	Bioengineering Methods	This is the use of plant material for engineering applications, including soil reinforcement, stabilization, and drainage. Groundwater control applications include the use of live pole drains (bundles of live cuttings placed in trenches to intersect and collect moisture) in slopes where shallow instability has resulted from seepage conditions. Used in conjunction with other vegetative procedures: cuttings (10A), brush layers (10B), wattle fences (10B) for stabilization. Applicable to shallower instability than (5A). With time, establishment and growth of the vegetation improves the stability of the surface. Assess for cuts near highway for aesthetic and wildlife reasons.	+	+				+	
5C	Subsurface Drains	Perforated pipes installed beneath the ground to intercept and convey groundwater out of the slope. Prevents sloping soils from becoming excessively wet and subject to sloughing, and improves the quality of the vegetative growth medium in excessively wet areas by lowering the water table. Applicable to fill and cut slopes.	+	+				+	
6	**Filtration**								
6A	Geotextile Silt Fences	A temporary sediment barrier constructed of posts and geotextile placed across or at the toe of a slope or in a minor drainage course to intercept and detain sediment and decrease flow velocities from drainage areas of limited size. Applicable where sheet and rill erosion or small concentrated flows may be a problem. Sometimes combined with straw bales to supply support.				+	+		
6B	Live Silt Fences	Cuttings installed in a water course to decrease erosion by reducing water velocities and promoting growth of a vegetation mat. A permanent erosion control measure that becomes increasingly effective with establishment of the vegetation.				+	+		
7	**Slope Blankets and Covers**								
7A	Granular / Rock Blankets	A permanent, erosion-resistant ground cover of large, loose, angular stone installed wherever soil conditions, water turbulence and velocity, expected vegetation cover, etc., are such that soil may erode under design flow conditions.	+	+	+			+	
7B	Plastic	A temporary cover to protect soil slopes from rainfall erosion, or to conduct ditch flows over bare soil. Requires adequate securing to a slope with gravel or rocks or other ways to prevent being caught by a wind.	+	+	+		+		+

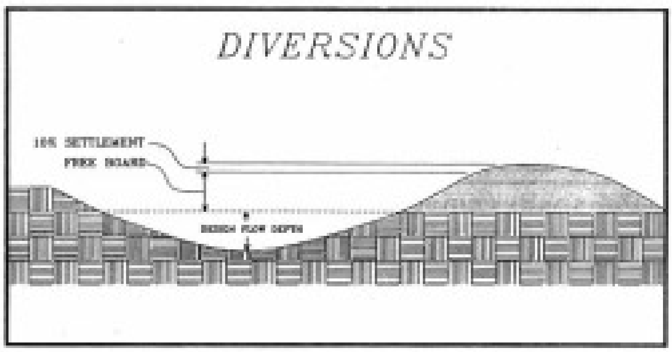
MEASURES FOR CONTROL OF EROSION AND SHALLOW SLOPE MOVEMENT			APPLICATION						
			A: Slope Protection - Cuts B: - Fills C: -Bridge End Fills D: Sediment Traps E: Ditch & Watercourse Prot'n F: Stabilization G: Waste Areas						
NO.	**NAME**	**DESCRIPTION & PURPOSE**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
7	**Slope Blankets and Covers (continued)**								
7C	Manufactured Blanket	A blanket covering usually, supplied in rolls, applied and pinned to the soil surface in strips, often along a slope. They can be of synthetic fabric, jute, straw, coconut fibre, or combinations thereof, and have variable lifespans depending on the material. They provide a protective covering fro seed and assist in preventing surface soil erosion by absorbing raindrop splash impact, and checking surface water flow. They must be kept in close contact with the slope surface by staking or other methods and properly installed to be effective. can be used in a variety of applications as liners or wraps in conjunction with other products.	✚	✚	✚		✚		✚
7D	Stabilization Matting	A 3 dimensional, plastic structure filled with soil prior to planting. Structure tends to reduce flow velocity and cause sediment to be captured in the spaces. Non degradable and can be used in permanent work such as ditches. Applicable to slopes where a greater amount of erosion protection than that given by a blanket is required.	✚	✚	✚		✚	✚	
8	**Vegetation Covers**								
8A	Topsoiling	Provides a suitable growth medium for vegetation used to stabilize disturbed areas. Not recommended for slopes steeper than 2:1 unless other measures are taken to prevent erosion and sloughing. Placement on a rough, textured surface minimizes slipping downslope.	✚	✚	✚				✚
8B	Sodding	Stabilizing fine-graded areas by establishing permanent grass stands with sod. Provides immediate protection against erosion, and is especially effective in grassed swales and ditches or in areas where an immediate aesthetic effect is desirable. Should be staked to the underlying surface when placed on slopes of 2:1 or steeper.	✚	✚	✚		✚		
8C	Seeding	Establishment of temporary or permanent vegetative cover on disturbed areas. Remains the most effective and economical method for large-scale application and surface erosion control. Ensure adequate time for germination and establishment before winter, and protection from erosion for initial 2 months. Appropriate selection of seed for the location and the application is essential. Use mulch, fertilizer and tackifier to speed germination and assist in germination.	✚	✚	✚				✚
8D	Mulching	Application of plant/organic residues or other suitable materials to disturbed surfaces to prevent erosion and reduce flow velocities. Fosters plant growth by increasing available moisture and providing insulation against extreme heat or cold. Should be applied to all seeding operations, other plant materials which do not provide adequate soil protection by themselves, and bare areas which cannot be seeded due to the season, but which still need protection to prevent soil loss.	✚	✚	✚				
8E	Plantation Areas	Establishment of trees, shrubs, ground covers and mulches on disturbed areas. Typically used for premium rural and higher standard landscape applications, and for reclamation purposes on right-of-way. On slopes and at locations such as bridge end fills, landscape plantation treatments provide immediate surface soil protection, particularly in conjunction with use of mulches and stabilization matting. Long term soil reinforcement develops as plant roots become established.	✚	✚	✚				

MEASURES FOR CONTROL OF EROSION AND SHALLOW SLOPE MOVEMENT			APPLICATION A: Slope Protection - Cuts B: - Fills C: -Bridge End Fills D: Sediment Traps E: Ditch & Watercourse Prot'n F: Stabilization G: Waste Areas						
NO.	NAME	DESCRIPTION & PURPOSE	A	B	C	D	E	F	G
9	Slope Surface Texturing								
9A	Woody Debris	Leaving a rough surface on fill slopes to decrease velocity of runoff and assist in revegetation. Incorporate debris from grubbing into the outer fill layer.	✚	✚					✚
9B	Roughening	Grooving slopes or leaving slopes in a roughened condition by not grading them smooth. Reduces runoff velocity, provides sediment trapping and increases infiltration, and facilitates establishment of vegetation on exposed slopes. Applicable to all slopes steeper than 3:1 or that have received final grading but will not be stabilized immediately. Also use for other exposed slopes with flatter grades.	✚	✚					
10	Slope Reinforcement								
	The following bioengineering applications require select plants that root readily from woody stems, such as willow, cottonwood and others.								
10A	Live cuttings	Improving the stability of the upper 1 - 2 m of a slope by insertion of cuttings of appropriate species (e.g. willow).	✚	✚				✚	
10B	Brush Layers	Incorporation of layers of live brush in slots or benches cut along the contour of a slope. Used for rehabilitating eroded slopes and gullies and stabilizing fills during construction.	✚	✚				✚	
10C	Wattle Fences	Installation of interwoven branches and cuttings in low (<0.5m) barriers on a slope. Cuttings installed at intervals to improve surface mat. Effective in reducing velocity of run-off, retention of sediment behind fences, and promoting revegetation.	✚	✚				✚	
11	Bank Protection								
11A	Live Bank Protection	The establishment of appropriate vegetation on stream banks to prevent the banks from erosion. A variety of techniques, including wattle fences and live silt fences may be involved.					✚	✚	
11B	Structural Bank Protection	Stabilizing stream banks with permanent structural measures such as aggregate/rockfill dyke or walls to protect the banks from erosion. Particularly applicable to watercourses which must pass increased flows due to upstream construction.					✚	✚	
12	Soil Improvement								
12A	Compaction	Improving the stability of the surface layer of a fill slope by increasing the density. Subsequent roughening may be required to improve revegetation. May be appropriate (before revegetation) for summer repair of surface slumps that develop on uncompleted slopes over winter.		✚				✚	

DETAILS OF CONTROL MEASURES

CHANNELS
DIVERSION DITCHES

Type: 1A



Description
A channel constructed across a slope.

Purpose
To intercept and divert runoff water before it reaches the construction area or sensitive slopes and conduct the water at non erosive velocities to a stabilised outlet.
On the upslope side of construction areas where runoff may cause erosion or other damage.

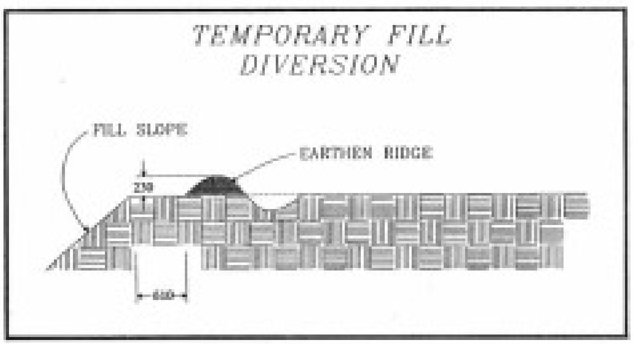
Application
An effective way to divert sheet runoff before it can concentrate and cause erosion especially on cut slopes.

Design
Ensure the channel is sufficient to carry the flow.
The velocities must not cause erosion of the channel, if necessary by using channel blocks.
The outlet must be non-erodible.
The discharge area must provide sufficient retention or sedimentation before the water reaches a stream.

Installation
Construct from the uphill side.
Woody debris from the excavation may be placed in the ditch to reduce velocity of flow.
Silt and fine sand are erodible at low slopes (>1%) and require protection by lining (see Method 1C).

CHANNELS
FILL DIVERSION DITCHES

Type: 1B



Description

A channel with a ridge on the downslope side built along the top of a fill that is being constructed.

Purpose

Keeps water from flowing over an unprotected fill face and causing erosion.

Used for controlling the water that falls within the construction area.

Application

Where a diversion ditch is impracticable in keeping water from the construction area, because it would be regularly covered by fill placement.

Design

The minimum effective height of the channel should be ~300 mm.

Provide positive means for removing the water at the end of the ditch.

Installation

Use a grader or dozer to form the ditch at the end of the day, about 600 mm from the slope face.

Slope the ditch to divert water to a stabilized outlet. Keep the water velocities low to prevent erosion of the channel, using straw bales or other blocks.

Ensure the concentrated flow does not breakout from the channel over the face. Ensure construction traffic does not cross the ditch as this will cause concentrated flow on the face.

CHANNELS
LINED CHANNELS

Type: 1C

Description

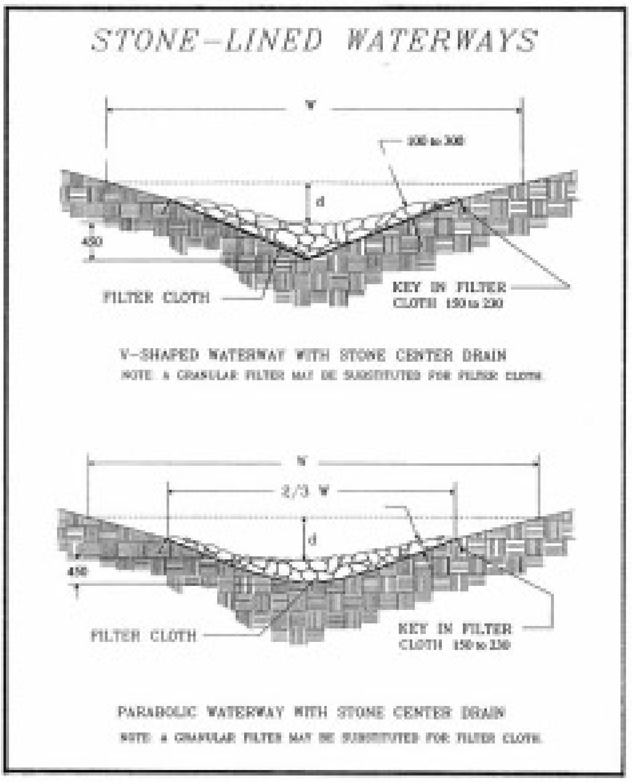
Permanent channel with a ground cover of large loosely laid cobbles or riprap.

Purpose

Carries water without erosion of the underlying natural soil, and reduce velocity of flow.

Application

Where erodible soils are present, and water velocity is significant.



Design

High flow conditions require engineered design to ensure stability of lining.

Lining may consist of blasted rock (riprap) or cobbles ("overs"). Use well-graded angular riprap where water velocity and volume of flow is high. Material should consist of large stones with smaller ones filling voids. For general ditch applications, 10 kg class riprap is usually adequate (see Standard Specifications).

Rounded cobbles are less stable than riprap, but usually satisfactory for ditches.

Protect the subsoil by a non-woven geotextile, or granular filter

Gradation criteria

$$d_{15}\text{ (filter)}/d_{85}\text{ (soil)} < 5$$
$$5 < d_{15}\text{ (filter)}/d_{15}\text{ (soil)} < 40$$
$$d_{50}\text{ (filter)}/d_{50}\text{ (soil)} < 40$$

where

d_{50} = diameter of 50% size

filter is the material over the soil being protected.

Installation

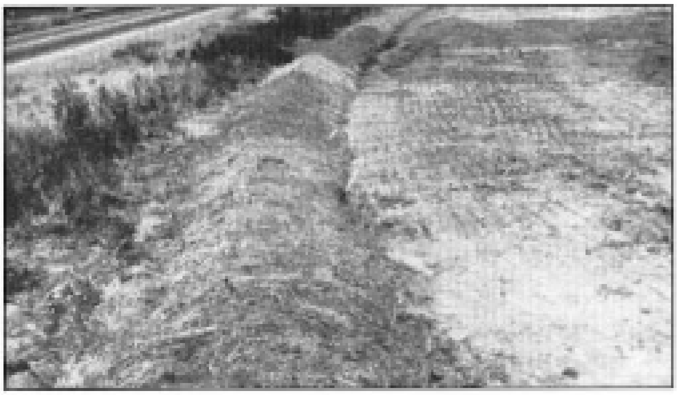
Since lining is placed where erosion potential is high, it should be placed with minimal delay.

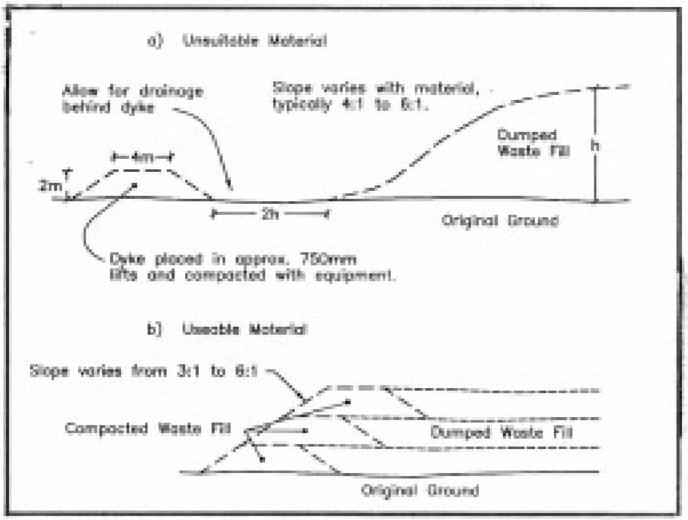
Place geotextile on a prepared channel. Overlap by >300mm. Dig a 300 mm deep trench on the upstream side, place the end of fabric in the trench and backfill with lining. Installation of geotextile must be properly done, and is critical in highly erodible soils and steep gradients to prevent erosion under the geotextile.

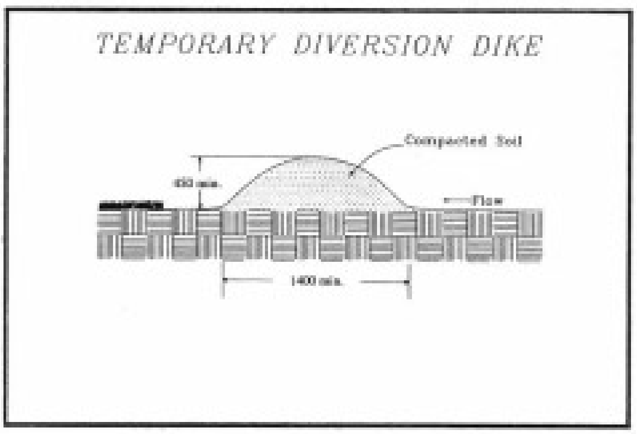
Place stone immediately on fabric to full thickness in one operation, without tearing it.

BARRIERS
DYKES

Type: 2A







Description
A berm or barrier constructed to contain water or soil.

Purpose
Intercepts and diverts runoff water before it reaches the construction area or sensitive slopes
Retains moving soil.

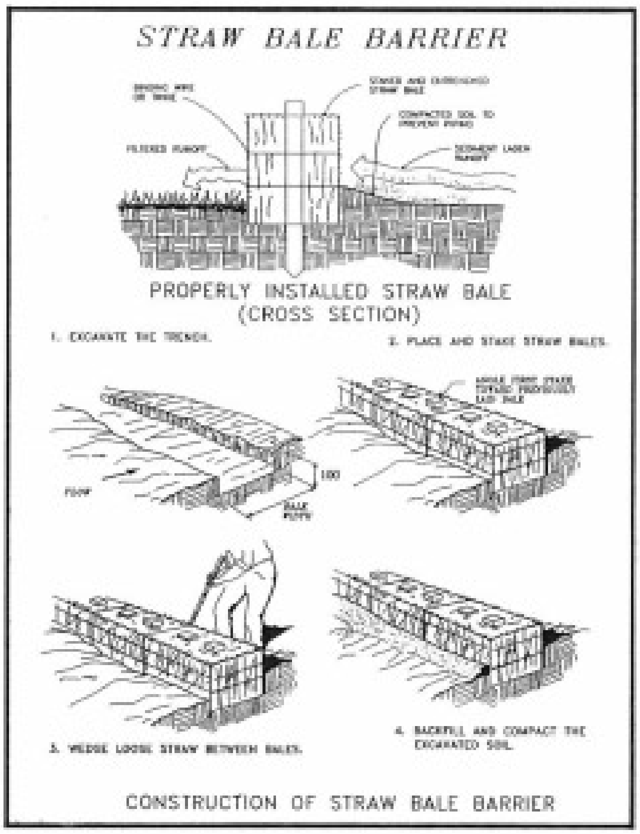
Application
Forms a compacted dyke for waste fills.
Used instead of, or with, Diversion Channel (1A).
Prevents moving soil from reaching sensitive sites.

Design
Low berms and dykes should have slopes suited to the material: 1.5:1 for granular soil, 2:1 or flatter for mixed and fine-grained soil, when compacted. Slopes should be flattened by 50% for uncompacted fine grained soil.
Slope of berm must be stable under saturated conditions and erosion resistant.
Geotechnical design required for sensitive locations and higher berms (>4m) in fine grained or mixed soil.

Installation
Construct from the bottom by placing in lifts.
Ensure it will not be overtopped by impounded water.

BARRIERS
STRAW BALES

Type: 2B



Description
Temporary barrier consisting of a row of straw bales placed at the toe of a slope.

Purpose
To intercept minor runoff from exposed slopes and construction areas and prevent sediment from leaving the site.

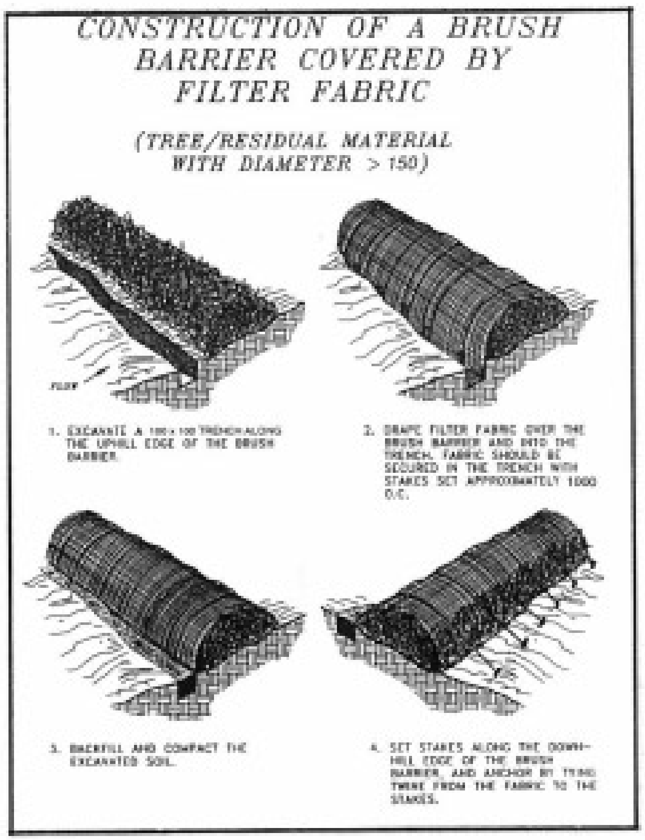
Application
Below areas subjected to sheet and rill erosion. Requires soil foundation for anchorage, unsuitable where the surface is bedrock.

Design
These are not as effective as generally supposed:
- without adequate seating in the soil, erosion can take place around or under the bale, and
- they are not good filters.

Installation
Place as a single row along the contour in a 100 mm deep trench.
Backfill about 100 mm higher than the original ground on the uphill side.
Secure with two 50x50x1000 mm stakes per bale.
Chink between bales with loose straw.
Ensure water does not flow under the bales.

BARRIERS
BRUSH BARRIERS

Type: 2C



Description

A temporary sediment barrier constructed at the perimeter of a disturbed area using the waste materials available from the clearing and grubbing operations.

Purpose

Intercept and retain sediment from the disturbed area.

Application

Below disturbed areas subject to sheet and rill erosion where sufficient material is available.

Drainage area behind the barrier should be <250 m^2 per 25 m of barrier.

Design

Use material <150 mm diameter, or use geotextile wrapping to promote filtration.

Installation

Have the height of barrier ~1 m.

Incorporate brush, stone, root mat and other material from clearing and grubbing.

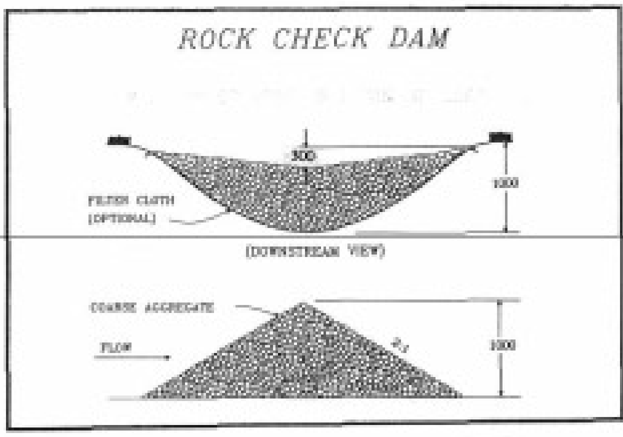
Do not use material >150 mm diameter since large voids in the barrier render it ineffective unless geotextile is used.

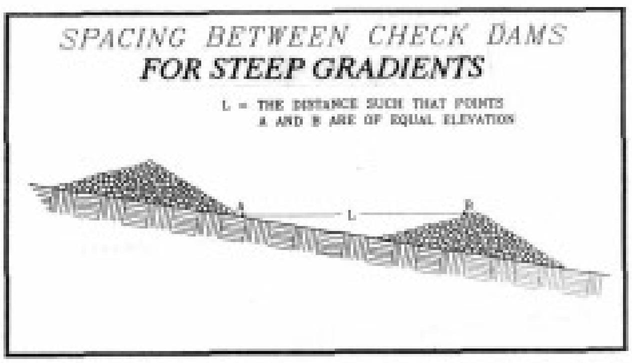
If geotextile cover is used, dig a shallow trench on the uphill side and bury the end of the geotextile.

Remove geotextile at end of construction.

DITCH BLOCKS
ROCK CHECK DAMS

Type: 3A





Description
Mounds of rockfill placed across drainage ditches.

Purpose
To reduce the velocity of water flowing in the ditch and thereby minimize erosion. Traps sediment from runoff.
More effective than silt fences or straw bales for stabilizing more major ditches.

Application
Temporary ditches.
Permanent ditches that have not been stabilized by vegetation.
Ditches in more erodible soil (sand, silt) and those on steeper gradients.

Design
The centre should be lower than the edges so it acts as a weir.

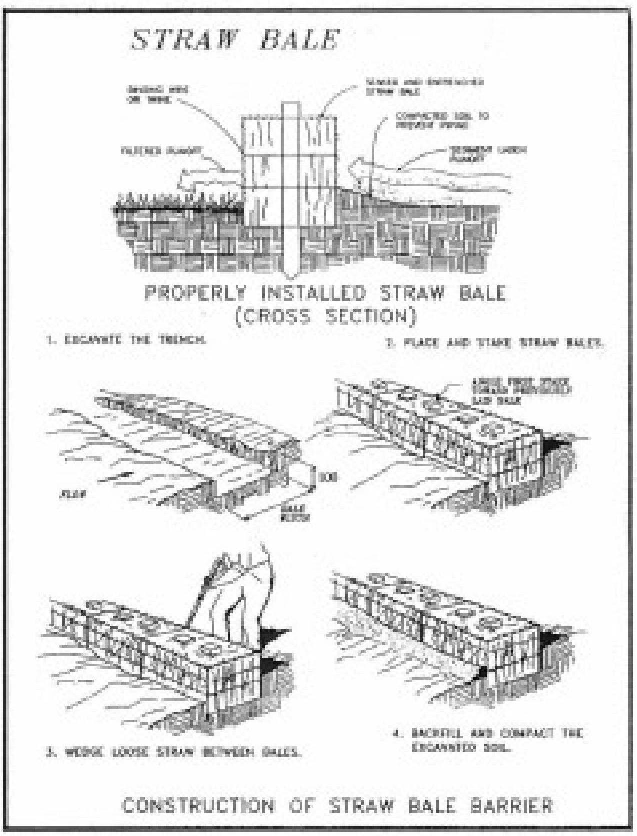
Installation
Use stone having a range of sizes to promote filtration and protection of underlying soil.
Maximum size should be about 250 mm.
Maximum height should be less than 1 m.
Use side slopes of 2:1 on both sides.

DITCH BLOCKS — Type: 3B
STRAW BALES

Description
Temporary barrier consisting of bales placed in a ditch.

Purpose
To slow water velocities and promote sedimentation behind the bale, while allowing water to pass through the bale.

Application
Use on minor drainage ditches where there is little flow.



Design
These are not as effective as generally supposed:
- without adequate seating in the soil, erosion can take place around or under the bale,
- high velocities can move bales, making them ineffective,
- they are not good filters.

Installation
Placement on the surface is not satisfactory, lay in an excavated 100 mm deep trench, and backfill.
Backfill about 100 mm higher than the original ground on the uphill side.
Secure with two 50x50x1000 mm stakes per bale.
Chink between bales with loose straw.

TEMPORARY SLOPE DRAINAGE
TEMPORARY PIPE

Type: 4A

Description

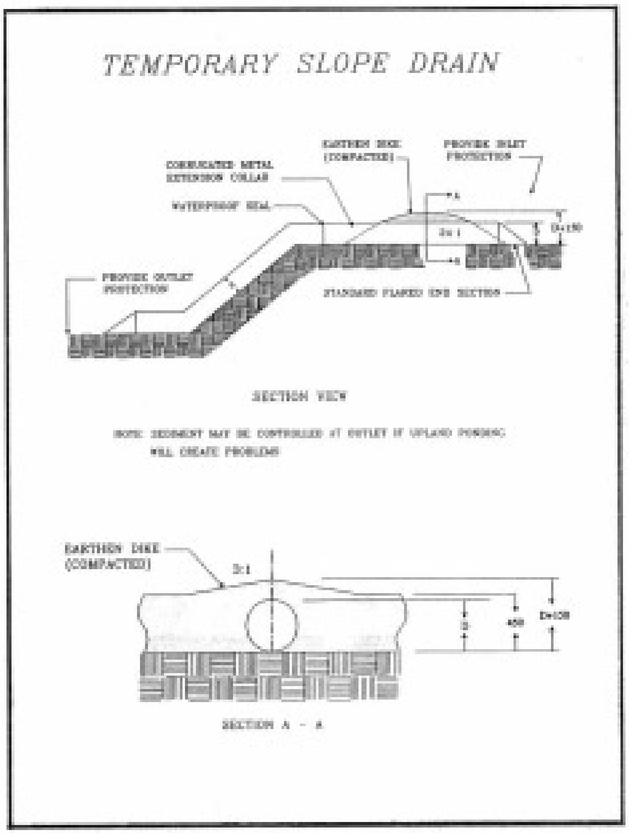
A flexible pipe extending from the top to the bottom of a cut or fill slope.

Purpose

To conduct runoff water temporarily down a slope to miminise erosion on or below the slope.

Application

On cut or fill slopes where there is potential for upslope water to flow over the face of the slope causing erosion and preventing adequate stabilization.



Design

Ensure pipes are adequate to handle the flow.
Design inlet to ensure water enters the pipe.
A dyke is required to control flow into pipe.

Installation

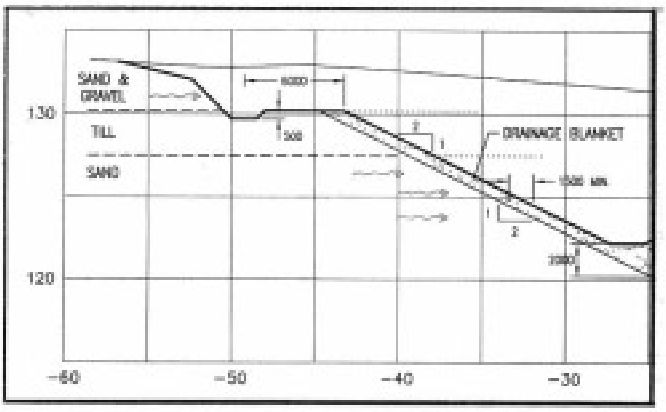
Place on well compacted fill.
Tamp soil under and around the entrance to the top of the dyke to prevent piping failure around the inlet.
For low flow only, use coiled rolls.
Stake to pipe to the slope.
Provide erosion protection at the outlet.
Remove the pipe at the end of construction.

SIZE OF SLOPE DRAIN

Maximum Drainage Areas (ha)	Pipe Diameter (mm)
0.2	300
0.6	450
1.0	530
1.4	600
2.0	760

GROUNDWATER CONTROL STRUCTURAL METHODS

Type: 5A



Description
Intercepting and conducting groundwater from a slope.

Purpose
Preventing breakout of seepage water on the face of an erodible slope.

Application
In excavations where the final grade will be lower than the groundwater table *at some period of the year.*
Where (seasonally) perched water tables may be found in stratified soil.

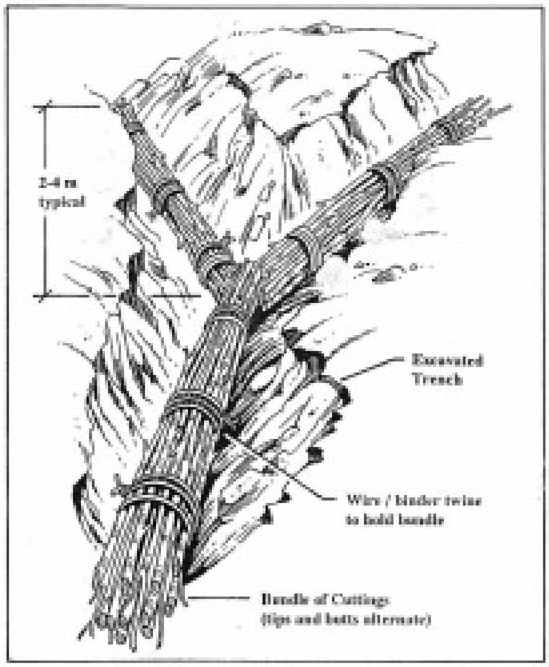
Design
Solutions may include perforated pipes drilled or pushed into the slope (horizontal drains), subsurface slope drains, granular or rock blankets.
Blankets must not allow removal of the soil being retained. Use a graded filter, or use geotextile if seepage quantities are not great.

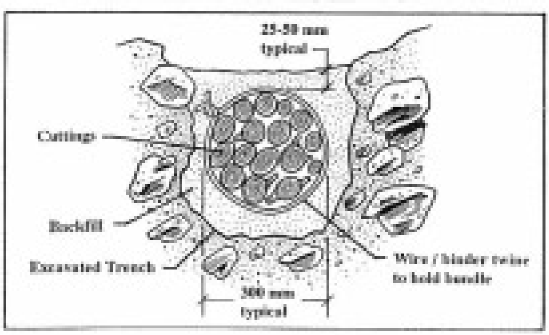
Seepage forces decrease the stable slope angle of a soil. Geotechnical design may be required for faces >3 m or where high seepages encountered. Slope blankets must be internally stable and allow flow. Since they are usually placed with little compaction, use a clean, angular well draining material, preferably rockfill.

Installation
If signs of seepage are encountered when opening up a cut, be prepared for slope treatment as work proceeds.
Carry out the work as soon as possible to mitigate soil loss.
Carry out work in the period of low groundwater (mid July - mid September).

GROUNDWATER CONTROL BIOENGINEERING METHODS

Type: 5B





Description

Intercepting and conducting groundwater from a slope using vegetation.

Purpose

Preventing breakout of seepage water on the face of an erodible slope.

Decrease the soil moisture and improve surface stability.

Provide a mat of vegetation (trees/shrubs) to hold the surface (1-2m)

Application

Remediation of near-surface instability in cuts and fills.

Use of trees and shrubs may not be appropriate for engineering, aesthetic or safety reasons in a cut, close to the highway.

Design

Use a variety of vegetative methods, with or without structural methods, for effective treatment of areas where groundwater may pose problems. Species suitable include willow, poplar, and red osier dogwood.

Plan installation using live pole drains, cuttings, wattle fences, or brush layers.

Installation

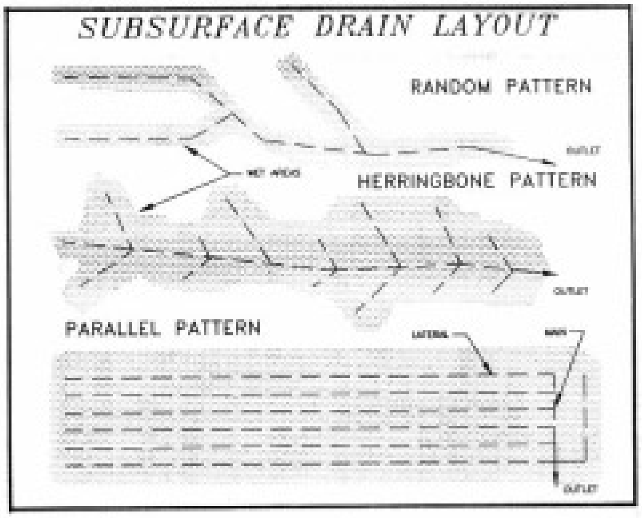
Not suited to areas of high seepage flows which are actively eroding.

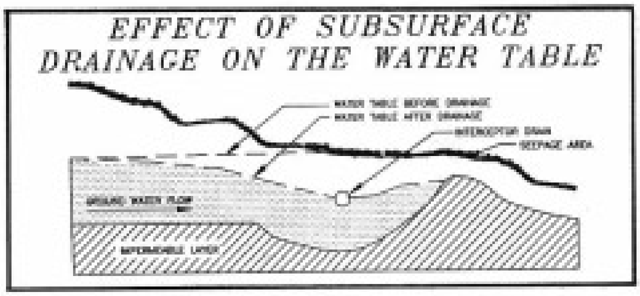
Best used in mixed or finer grained soils with low seepage conditions, that may be only seasonally active.

Bioengineering methods are best used in the dormant season (October - March).

GROUNDWATER CONTROL
SUBSURFACE DRAINS

Type: 5C





Description

Pipes that intercept and collect water along their length, such as perforated pipes, and convey the water away from the area.

Purpose

1. Interceptor Drains capture water entering a slope.
2. Relief Drains reduce the amount of water exiting from the surface of a slope by lowering the water table, either locally or over a wide area. (French or finger drains)

Application

Use where surface slumping (upper 1-2 m) occurs on cut or sidehill fills composed of fine grained or mixed soils e.g. till.

Use in sand and silts where ground water seeps from the face causing erosion.

Design

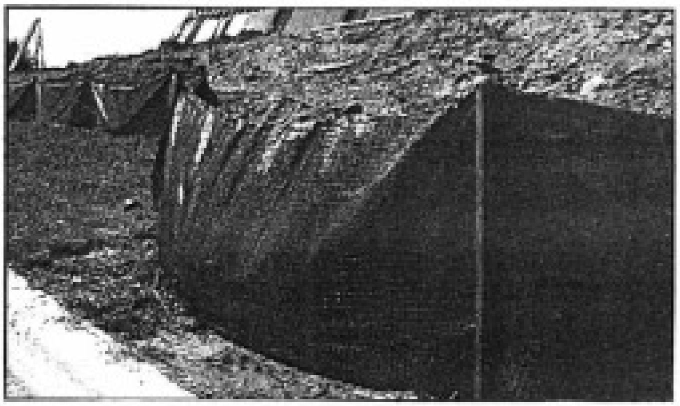
1. Locate interceptor drain across slope where a permeable soil overlies a less permeable one. Place where a Diversion Ditch would be used except that water is deeper.
2. Relief drains follow the slope.
3. For both types, size the pipe for the flow. Ensure erosion at exit does not occur.
4. Protect the soil from eroding through the holes in perforated pipe ir voids in a blanket by using a nonwoven geotextile.

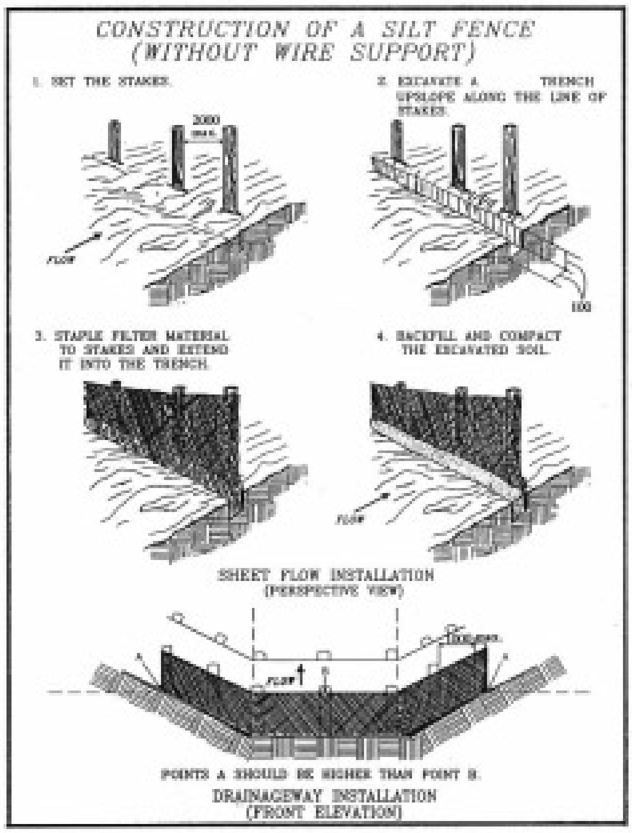
Installation

1. Use clean coarse gravel or rockfill around pipe to maximize inflow.
2. Place as deeply as is practical to capture the water, but at least 1000 mm.
3. In general, space relief drains at 15 m apart on a slope.

FILTRATION
GEOTEXTILE SILT FENCE

Type: 6A





Description

A vertical, filter fabric barrier supported by posts and buried/anchored at the lower edge.

Purpose

Intercept and retain sediment from disturbed areas during construction.
Decrease velocity in channels with low to moderate flow (<0.03 cu.m/s).

Application

At the base of unprotected cuts and fills where sheet and rill erosion may form.
In minor ditches where the drainage area is less than about 1ha and the maximum gradient behind the barrier is ~2:1.
A fence is a more effective filter than straw bales if properly installed, but passes lower water volumes:

	Flow rate (L/sq.m/min)	*Filter Efficiency %*
Straw	240	67
Fabric	12	97

Design

Geotextile criteria:

Filtering Efficiency	*ASTM 5141*	*>75%*
Flow Rate	*ASTM 5141*	*>8L/sq.m/min*
Tensile Strength	*ASTM D4632*	*>120kN*

Installation

Locate about 2 m beyond the base of the slope.
Secure posts at <2 m spacing.
Overlap joins by 200 mm.

FILTRATION **Type: 6B**

LIVE SILT FENCE

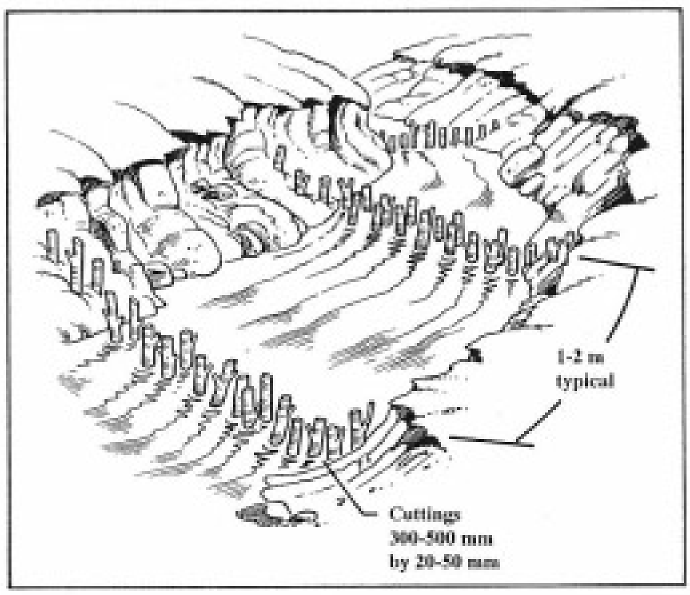
Description
Planted vegetation, including live cuttings, in ditches and drainage courses.

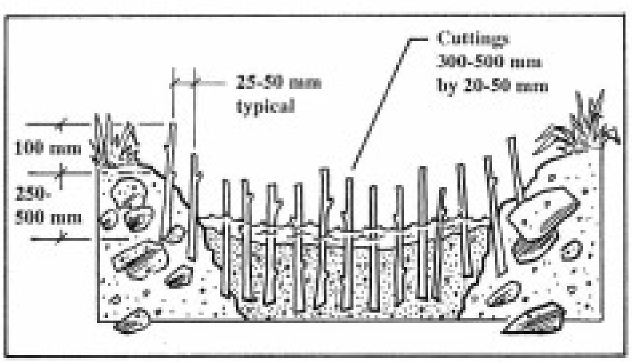
Purpose
Binds the surface layer and the growing vegetation slows and filters the flowing water.

Application
Drainage courses away from the highway.

Design
Species should be suited to the conditions, e.g. willow, poplar and dogwood.

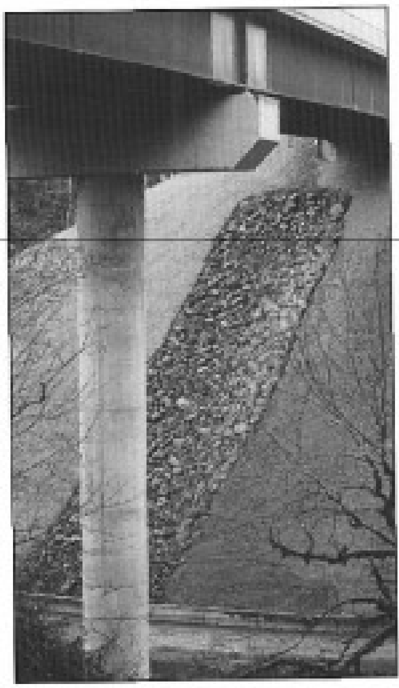
Installation
Plant cuttings in rows about 1 m apart with 25 to 50 mm between cuttings.
Bioengineering methods are best used in the dormant season (October - March).





SLOPE BLANKETS AND COVERS
GRANULAR AND ROCK BLANKET

Type: 7A



Description
Cover of gravel or rockfill placed on an erodible cut or fill slope.

Purpose
Protect from raindrop impact and from surface flow that result in sheet erosion or gully erosion. Prevent removal of soil particles by groundwater that is exiting a slope.

Application
Place on highly erodible slopes, particularly silt and fine sands that cannot be stabilized by vegetative methods.
Use when a blanket must be placed immediately to prevent erosion due to groundwater in an excavation.
For repairing an eroded slope.

Design
1. For protection due to groundwater, ensure natural soil will not flow through the blanket (see gradation criteria).
   Otherwise use non-woven geotextile under the blanket.
2. In sloping conditions where the blanket becomes saturated, stable slope angle is less than for non saturated conditions. A sandy gravel blanket may meet filter criteria, but not stability criteria. For best success, use angular shot rock with a geotextile underlay. Use a blanket thickness not less than 1 m.

Installation
Grade slope and place geotextile or filter gravel. Place the blanket to a reasonably uniform thickness.

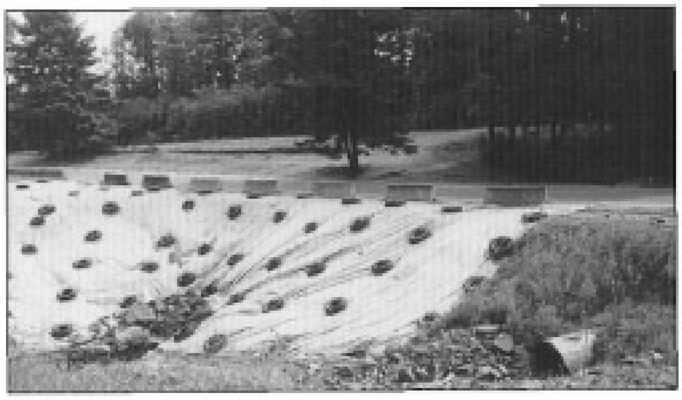
Gradation criteria

$$\mathbf{d}_{15}\ (\text{filter}) / \mathbf{d}_{85}\ (\text{soil}) < 5$$
$$5 < \mathbf{d}_{15}\ (\text{filter}) / \mathbf{d}_{15}\ (\text{soil}) < 40$$
$$\mathbf{d}_{50}\ (\text{filter}) / \mathbf{d}_{50}\ (\text{soil}) < 40$$

where
$\mathbf{d}_{50}$ = diameter of 50% size
filter is the material over the soil being protected.

SLOPE BLANKETS AND COVERS
PLASTIC SHEETING

Type: 7B



Description
A temporary, impermeable cover of polyethylene or other material.

Purpose
Placement on bare soil to prevent erosion from surface water and rain drop impact.

Application
Used to protect small areas of soil.

1. Slope covering in locally sensitive areas.
2. Conducting water over bare soil in a temporary ditch or steam.

Design
Polyethylene sheeting at least 6 mil thickness.

Installation
The surface must be reasonably uniformly graded with no sharp objects embedded e.g branches.

On slopes:

Surface water must not be allowed to run under the sheeting: redirect by ditching or berms.

Provide adequate securing of the sides to prevent wind lifting the edges.

In temporary ditches:

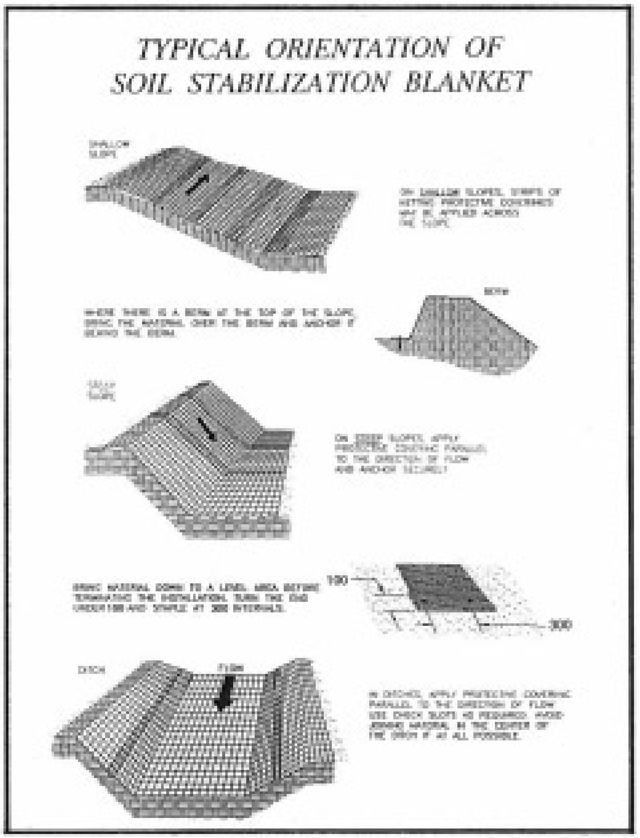
Lay in one width, with no longitudinal join.

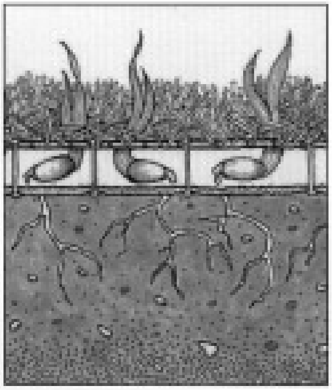
Overlap and seal transverse joins to prevent water flowing through.

Secure in place with sandbags.

Remove when construction is finished.

SLOPE BLANKETS AND COVERS Type: 7C
MANUFACTURED BLANKET





Description
A permeable blanket or netting, made from synthetic fibre, jute, straw, coconut fibre, or other produc,t through which grasses can penetrate. Some products are pre-seeded.

Purpose
Usually provides a temporary cover to protect a slope from raindrop splash and to check surface flow. Some provide a mulch and protect seeds until grass cover is established. Stronger materials provide longer term reinforcement, while natural materials are bio-degradable and have a short life.

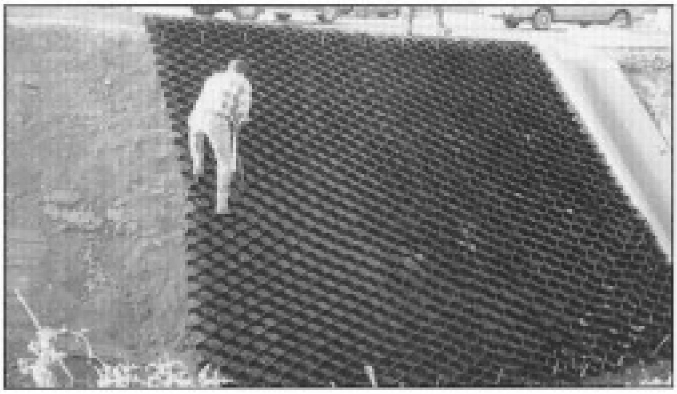
Application
Placed on slopes of cuts and fills, and for some ditch applications, immediately after seeding. Blankets should only be used where conventional seeding and hydromulching practices are considered inadequate due to wrong season or exceptional site conditions.

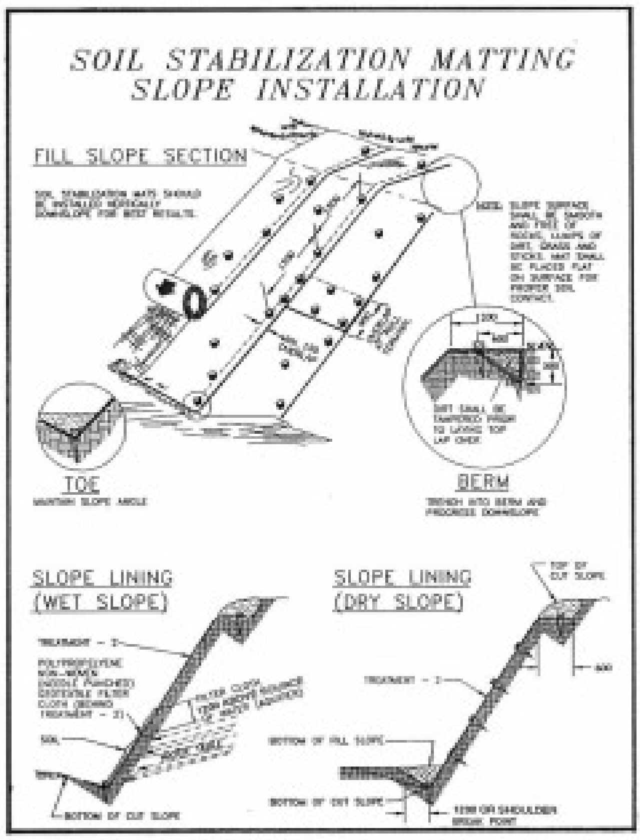
Design
Many different products are available. Review suppliers' information to determine product applicability and placement procedures.

Installation
Lay on graded slope that allows good contact with the underlying soil surface. Follow manufacturer's instructions for specific product. Generally blankets are installed along a slope, from top to bottom, overlapping at the edges, and pinned in place. It is important to bury the uphill end in a trench not less than 150 mm deep, and the backfill tamped to ensure that water flow beginning at the top of a slope goes over the blanket, not underneath it.

SLOPE BLANKETS AND COVERS
STABILIZATION MATTING

Type: 7D





Description
A 3-dimensional, plastic matting filled with soil prior to planting.

Purpose
Adds permanent reinforcement to vegetation mat.

Application
Provides increased erosion resistance on slopes and in ditches as an alternative to granular or riprap blankets, where water velocities are <3 m/sec.

Design
Check manufacturers' information for criteria and applicability.

Installation
Lay on graded slope that allows good contact with the underlying soil.
Lay from top of the slope downwards.
Refer to product specifications.

VEGETATIVE COVERS
TOPSOILING

Type: 8A

Description
Preserving and reusing the surface layer of undistrubed soil, often enriched with organic matter, on constructed slopes.

Purpose
To provide a suitable growing medium for vegetation.

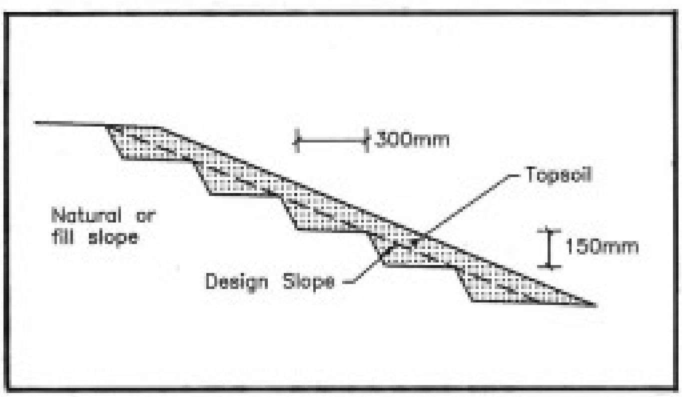
Application
Where the existing soil is unsuited for growing, e.g. gravels, highly acidic soils.

Design
Use on slopes not steeper than 2:1.
It may not be required on fine grained soils where other methods such as hydro seeding are more economical.

Installation
Preserve the natural soil removed during the site preparation by placing in stockpile sites where it does not interfere with the operations. Use woody, unscreened material except where high quality turf is required.
Bonding to the existing slope by terracing the slope to key the topsoil to the underlying material and permit better infiltration of water.
Many natural slopes allow seepage of groundwater, that may not be apparent when topsoiling. Placing clay soil on more permeable soil slope, such as sand, may cause build up of water at the interface and sloughing of the topsoil layer.
Place to 50-75 mm depth when lightly compacted on 2:1 slopes, and 100-150 mm on 3:1 slopes.

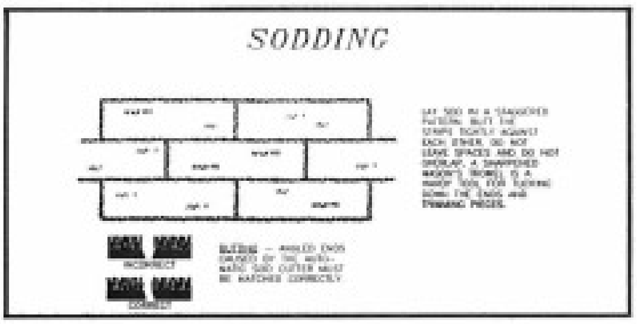
TOPSOIL APPLICATION RATES

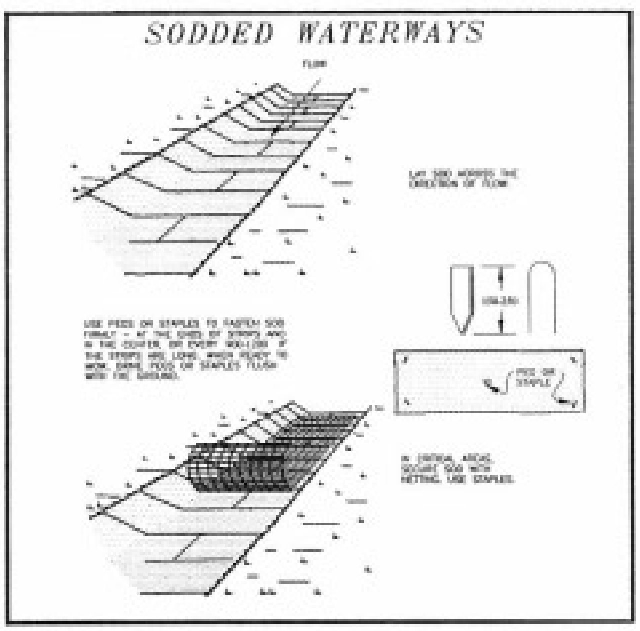
DEPTH (mm)	RATES (cu.m)	
	Per Hectare	Per 100 sq. m.
50	500	5
75	750	7.5
100	1,000	10
150	1,500	15



VEGETATIVE COVERS
SODDING

Type: 8B





Description
Placing established grass sods on disturbed areas.

Purpose
Provide immediate revegetation and prevent erosion on slopes and drainage courses.

Application
Areas that are to be revegetated with grass but construction operations do not permit seeding, or insufficient time is available for establishing an adequate cover from seed.

Design
Because of expense, determine area to be covered with some accuracy.

Installation
Provide a flat, even, moist surface.

Apply fertilizer to the prepared surface and work into the top 75 mm. In the absence of other information, use 5-10-10 at a rate of 10 kg/100 sq.m.

Do not cut or lay sod in excessively dry or wet weather.

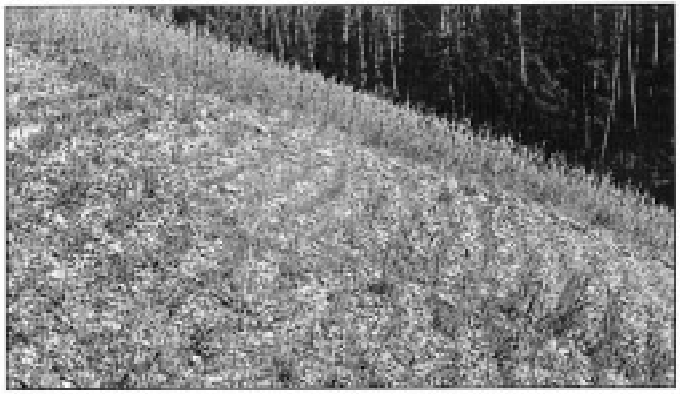
1. On slopes steeper than 3:1, or where erosion may be a problem, lay with a staggered joint pattern and stake or staple to slope at frequent intervals.

   Lay over the crest of slopes to minimise water flow between the sod and underlying soil.
2. In waterways, lay sod perpendicular to the direction of flow.

Roll and tamp to bond sod to the underlying soil.

VEGETATIVE COVERS
SEEDING

Type: 8C



Note how grass seedlings are establishing in horizontal grooves, due to good preparation

Description

Establishing a cover of grasses and other herbaceous/woody perennials for temporary or permanent ground cover, by dry (hand, mechanical, aerial) or hydraulic seeding.

Purpose

To provide rapid and economical vegetative soil cover. The early establishment of grasses remains the most effective solution to mitigating surface erosion on a large scale.

Application

Usually applied to slopes immediately after finish grading. Temporary seeding of cover crops should be provided when disturbed areas are to be left unfinished for extended periods.
Preferably allow at least two months of good growing conditions to allow grass establishment for erosion control. (early spring and early fall)

Design

Select seed type suited to local conditions and specific application requirements.
Seed mixes will usually be a mixture of perennial grasses and legumes with a proven performance in an area. (see Ministry of Transportation and Highways, Standard Seed Mixes)
Use rapidly growing nurse crops (e.g. annual fall rye) to provide early erosion protection when growth windows are minimal.

Installation

Prepare areas properly before seeding by: scarifying underlying soil, placement of topsoil, and provision of soil amendments (e.g. organic matter) when possible. Minimize slope gradient, avoiding the need for slope stabilizing products. Leave soil surface friable to permit root growth.

VEGETATIVE COVERS MULCHING

Type: 8D

Description

Application of plant residue or other suitable material to the soil surface.

Purpose

Prevent erosion from rain drop impact and reducing velocity of overland flow.

Promote revegetation by increasing the availability of moisture and providing insulation against extremes of heat and cold.

Application

Apply to areas immediately after seeding.

If area cannot be seeded, organic mulching can provide some protection to the soil until seed is applied.

Design

A surface mulch is one of the most effective ways of controlling runoff and erosion on disturbed land.

Organic mulches such as straw, wood chips, bark, and fibre mulches are the most effective.

Chemical soil stabilizers and soil binders should not be used alone for mulch, but used with organic mulch.

Installation

Use woodfibre, not paper variety, with hydroseeding at a rate of 1000-1500 kg/ha.

Incorporate fertilizer as for topsoil.

ORGANIC MULCH MATERIALS AND APPLICATION RATES

MULCHES	RATES		NOTES
	Per Hectare	Per 100 sq. m.	
Straw or Hay	3 - 4 t (Minimum 4 t for winter cover)	30 - 40 kg.	Free from weeds and coarse matter. Must be anchored. Spread with mulch blower or by hand.
Fiber Mulch	Minimum 1.5 t	15 kg.	Do not use as mulch for winter cover or during hot, dry periods.* Apply as slurry.
Wood Chips	8 - 12 t	80 - 120 kg.	Free of coarse matter. Air-dried. Treat with 6 kg nitrogen per tonne. Do not use in fine turf areas. Apply with mulch blower, chip handler, or by hand.
Bark Chips or Shredded Bark	90 - 125 cu. m.	1 - 2 cu. m.	Free of coarse matter. Air-dried. Do not use in fine turf areas. Apply with mulch blower, chip handler, or by hand.

* When fibre mulch is the only available mulch during periods when straw should be used, apply at a minimum rate of 2 tonnes per hectare or 20 kg. per 100 sq. m.

VEGETATIVE COVERS PLANTATION AREAS

Type: 8E

Description
Establishment of trees, shrubs, ground covers and mulches on disturbed areas. Typically used for premium rural and higher standard landscaping applications and for general reclamation purposes on highway right-of-way.

Purpose
To provide immediate surface soil protection in planted areas, particularly in conjunction with use of mulches and stabilization matting and to provide long term soil reinforcement as plants become established.

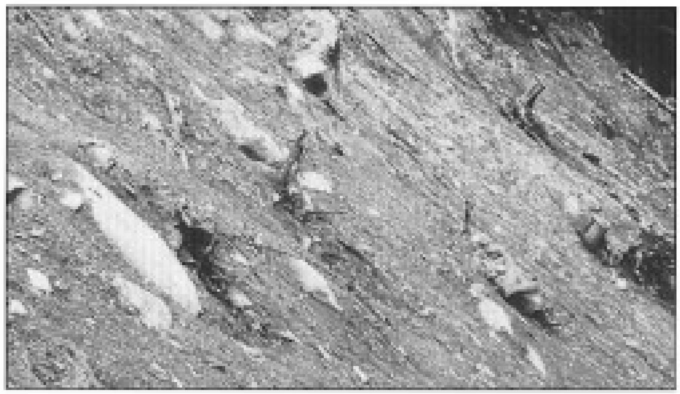
Application
Usually for traditional landscaping applications at bridge end fills, urban slopes, sound attenuation berms. Also for rural reclamation planting in right-of-way, waste areas and pits.

Design
High standard urban landscape development will use plants, mulches, and structural elements (e.g. walls) usually designed for visual appeal, but will offer erosion protection.
Rural applications usually combine tree seedlings and shrub plantings with hydroseeding and mulching for long term soil stabilizing.

Installation
Urban plantations will conform to the Standard Specification for Highway Construction Section 751 - Topsoil and Landscape Grading, and Section 754 - Planting of Trees, Shrubs and Ground Covers.
Rural plantings, and plantings in non-irrigated areas should be made in late fall or late winter.

SLOPE TEXTURING
WOODY DEBRIS

Type: 9A



Description

Provide a rough surface by incorporating woody debris from clearing and grubbing operations on the outer layer of fill slopes.

Purpose

Aid establishment of vegetation cover.
Reduce velocity of runoff.
Increase surface infiltration.
Trap sediment on the slope.

Application

Fill slopes steeper than 3:1 that will not be mowed.

Design

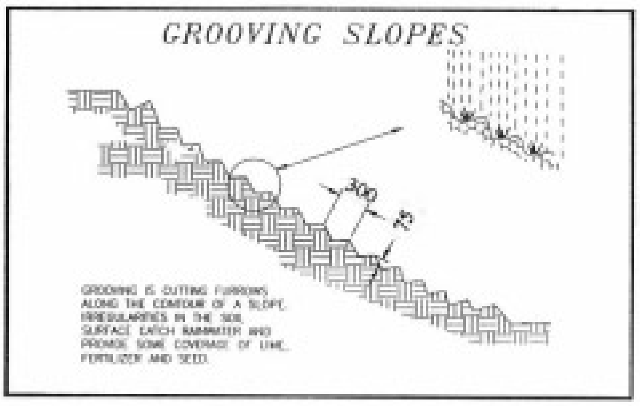
Used only in the outer 1 m layer.

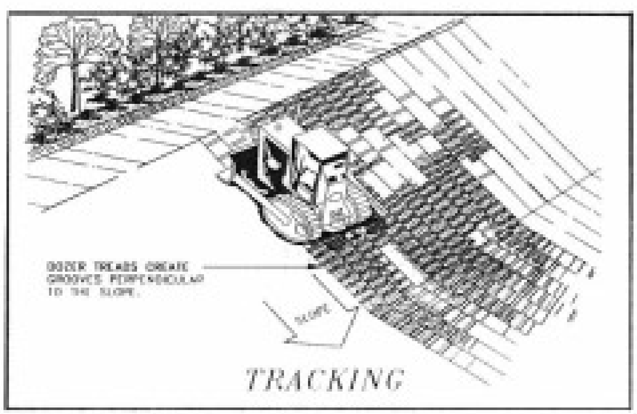
Installation

Debris should not protrude unduly from the face, maximum amount ~ 300mm.
More suited to the lower portion of slopes by using a dozer to push grubbing material onto the slope.

SLOPE TEXTURING ROUGHENING

Type: 9B





Description

Provide a rough surface with horizontal depressions along the contour using construction equipment, or leave roughened by not smooth blading.

Purpose

Aid establishment of vegetation cover.
Reduce velocity of runoff.
Increase surface infiltration.
Trap sediment on the slope.

Application

Cut and fill slopes steeper than 3:1, in silt, clay and mixed soils.
Areas that will not be immediately vegetated or otherwise stabilized.
Where the slope will not be mowed.

Design

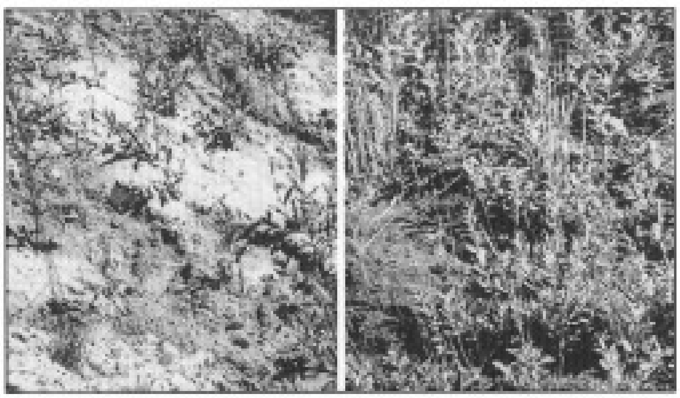
If used, contour grooves should be ~100 mm to 200 mm deep.

Installation

1. Naturally Roughened
   Use equipment that does not unduly compact the surface.
   Leave the surface rough during final grading.
2. Grooving
   Use agriculture equipment or grading equipment with teeth.
3. Tracking
   Tracked equipment run up and down slope provides some roughening, but not as effective as other methods because soil becomes compacted.
   Keep passes to a minimum.

SLOPE REINFORCEMENT LIVE CUTTINGS

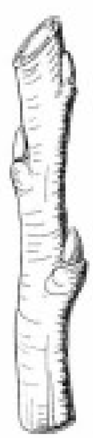
Type: 10A



Direct planting of Poplar and Willow cuttings

VEGETATION REQUIREMENTS:
- use dormant native plant's previous season's growth
- must have clean cuts with unspilt ends
- must be straight, healthy and robust

CUTTING PROCEDURES:
- cut with a sharp knife or good quality shears
- avoid the terminal top 10 cm
- keep length of 15-20 cm or more
- ensure mid-stem diameter is 2 cm minimum
- maintain at least two healthy buds



Description
Embedding live cuttings randomly on the face of a slope.

Purpose
Promotes development of a surface mat and breaks up the water velocity on bare slopes. Reduces soil moisture.

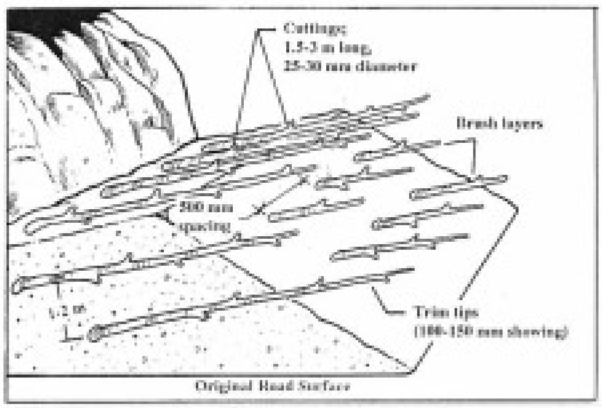
Application
Used in conjunction with other applications to revegetate and stabilize cuts and fills.

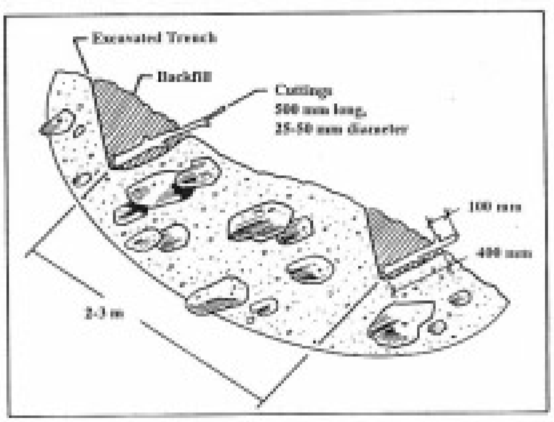
Design
Select species indigenous to the area, easily propagated, and adapted to the site.
Survival rate for unrooted live cuttings is about 50-70% provided proper species selection and planting time are observed.
Plants may be damaged by wildlife.

Installation
1. Plant in the dormant season in late fall after buds have set, or spring.
2. They may be randomly planted, in a 1x1 m grid, or in rows with a high density about 1m apart.
3. Plant with as little stem exposed as possible (about 15% of the length), but still showing at least 2 buds above ground. Firm so it cannot be readily moved or pulled out.
4. Cuttings should be about 300 mm long and 5 to 40 mm diameter.

SLOPE REINFORCEMENT BRUSH LAYERS

Type: 10B





Description

Embedding live branches on successive horizontal rows on the face of a slope.

Purpose

Rehabilitating eroded slopes and gullies. Promotes revegetation and breaks up the water velocity on bare slopes.

Application

Stabilizing cuts and fills.

Design

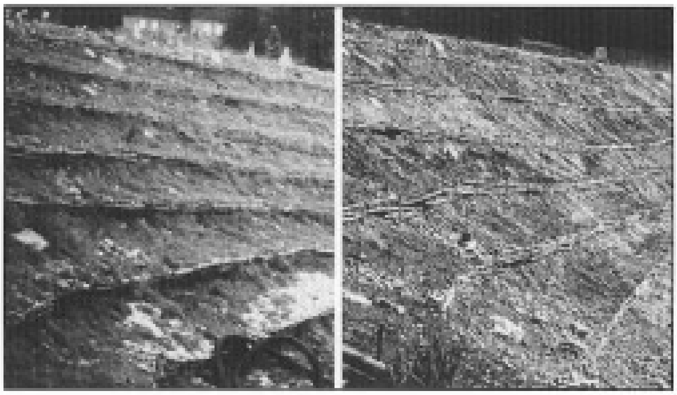
Select species adaptable to the site, generally willow, poplar, red osier dogwood.

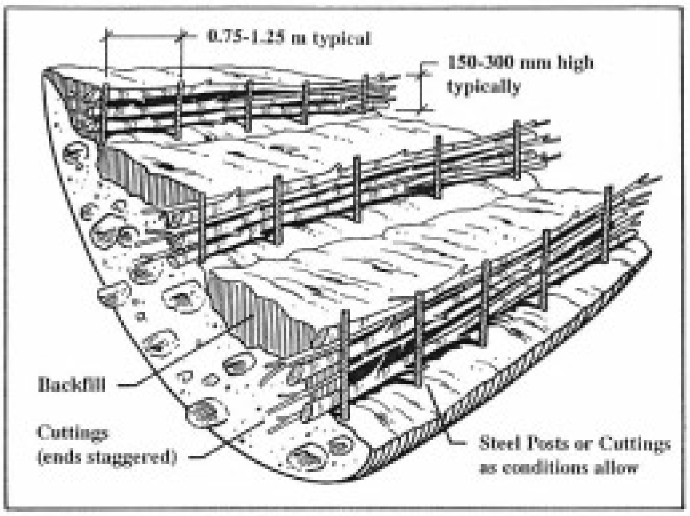
Installation

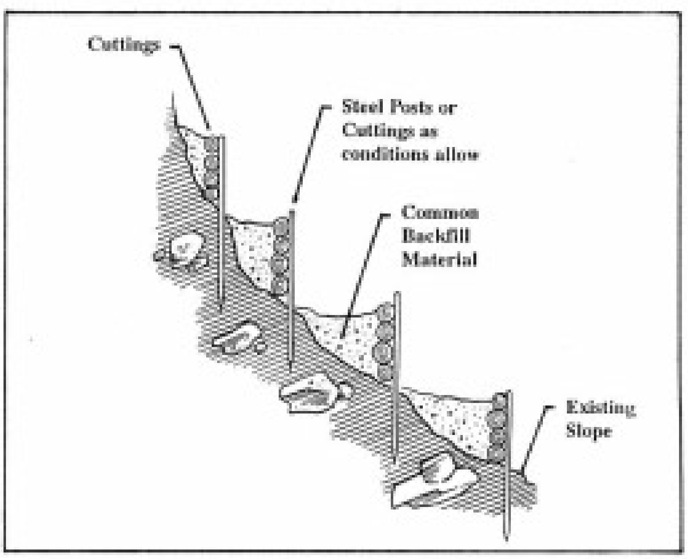
1. From bottom of slope, dig terraces ~ 1 m wide by hand or machinery. Slope upwards at about 10^0.
2. Use branches about 1 m long, with a mixture of different ages, species thicknesses and length. Longer (>2m) branches are better for fills.
3. Place branches along the terrace in a crosswise fashion, with only ~25% of their length protruding.
4. Cover with soil from terrace above and tamp.
5. Seed the slope.

SLOPE REINFORCEMENT WATTLE FENCES

Type: 10C







Description

Loose of flexible interwoven live cuttings supported by posts.

Bundles of live branches placed in shallow trenches along the contour of slopes.

Purpose

Promotes revegetation and breaks up the water velocity on bare slopes.

Application

Effective on loose surface soil exhibiting sheet and gully erosion.

Cut or fill slope stabilization.

Design

Determine row spacing on a site specific basis.

Erodible slopes require closer fence spacing.

Select species, e.g. willow, poplar, red osier dogwood.

Installation

1. Install stakes on the contour, using hand level. Drive stakes about 500 mm long to firm hold.

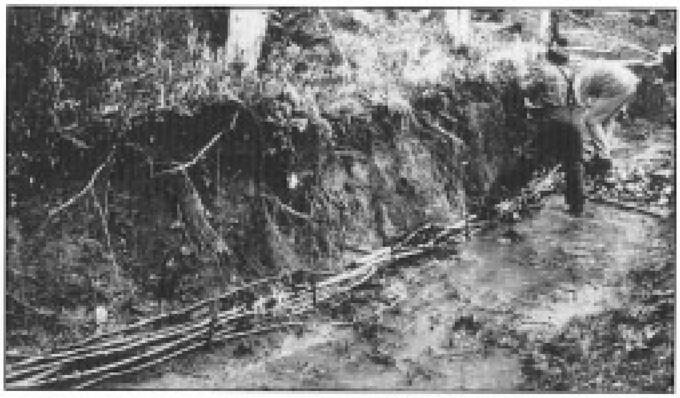
2a. Insert loose cuttings behind posts as in figure. Backfill to the top of the wattle fence.

2b. Trench above stakes about ½ bundle diameter. Material from trench covers wattles on lower row. Place bundle in trench. Insert stake through bundles close to bundle ties. Cover with soil and tamp.

3. Seed the slope.

WATTLE BUNDLE PREPARATION
• **A WATTLE** resembles a cigar-shaped bundle of alternating live branches that root easily, with slender tips extending 40 cm beyond the larger butt ends.
• **BRUSH STEMS** are 5 cm or larger in diameter; 1 m and longer in length (approximately 3 m long is best)
• **THE BUNDLE** is compressed to approximately 20 cm in diameter and tied every 30-40 cm.

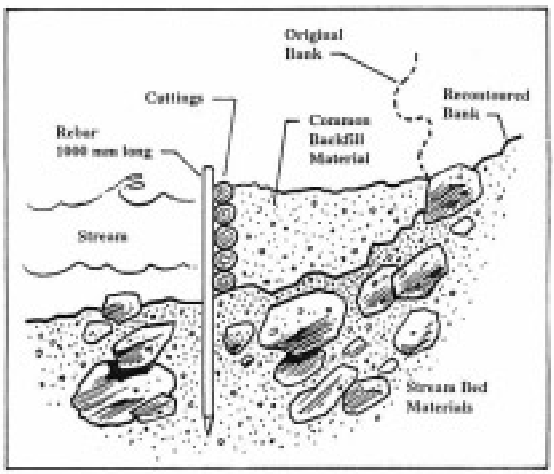
BANK PROTECTION — Type: 11A
LIVE STREAMBANK PROTECTION



Description
Vegetative method to promote stabilization of non-tidal streambanks.

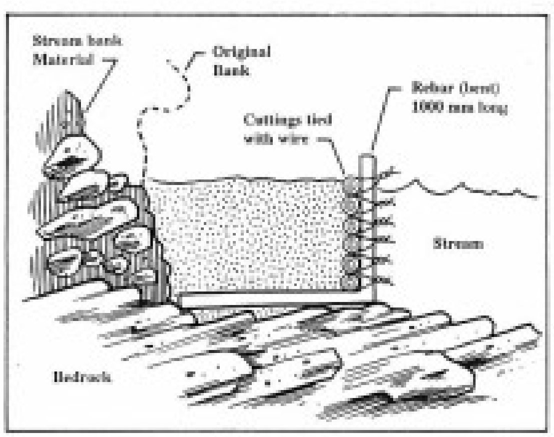
Purpose
Protect from erosion due to stream flows.

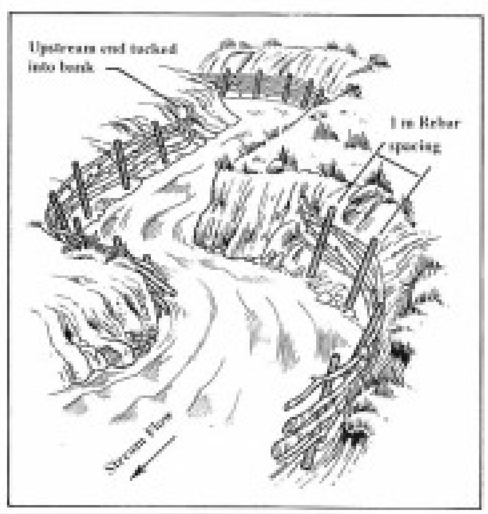
Application
Along banks of streams and creeks subject to erosion from runoff, and where water velocities are <1.5 m/s under full flow conditions.



Design
Use plant species that are native or adaptable to the site (see 11).
May reduce the channel capacity.
For velocities >1.5 m/s, structural protection is usually required.

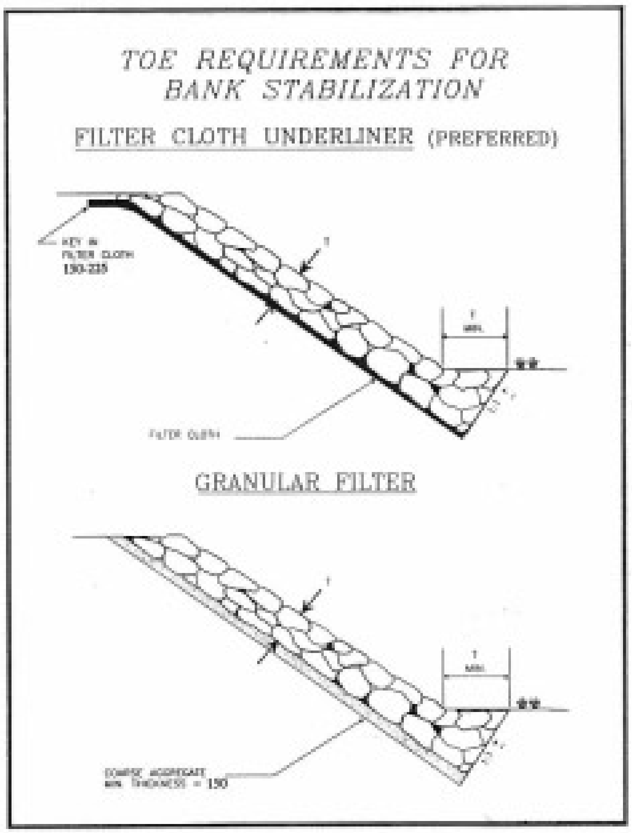
Installation
Insert staking (~1m long rebar) at about 1 m intervals along bank following the channel.
Place live cuttings as a wattle fence or bundles behind the stakes.
Backfill with natural soil.
Insert live cuttings into the backfill, and seed.





BANK PROTECTION
STRUCTURAL STREAMBANK PROTECTION

Type: 11B



Description

Using permanent structural measures to stabilize streambanks.

Purpose

Protect streambanks from erosion forces.

Application

Where:

water velocities exceed 1.5 m/s.

at lower flow velocities where live protection methods are inappropriate or will not become effective in the time period available.

Design

Use established engineering procedures.

Structures include riprap, gabions, concrete walls, etc.

Size of riprap must be sufficient to prevent it being moved under high flow conditions.

Installation

Place angular riprap meeting the requirements of the Standard Specifications. The outer face should be manipulated by equipment to provide a uniform surface.

Geotextile, if used under riprap, must be properly installed for satisfactory performance.

Check gradation of coarse aggregate, if used, using gradation criteria in Method 1C.

Gabions and walls require engineered detailing for construction purposes.

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