SEACAP 21/004

Mainstreaming Slope Stability Management

– Hazard and Risk Assessment –

to Lao Practitioners

Theme 10: Bio-engineering

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- 10.1 Functions of bio-engineering
- 10.2 Plants and their engineering capabilities
- 10.3 Nurseries and growing seasons
- 10.4 Bio-engineering application
- 10.5 Slope maintenance strategies
- 10.6 Field demonstrations

10.1 Functions of Bio-engineering

- **What is bio-engineering?**

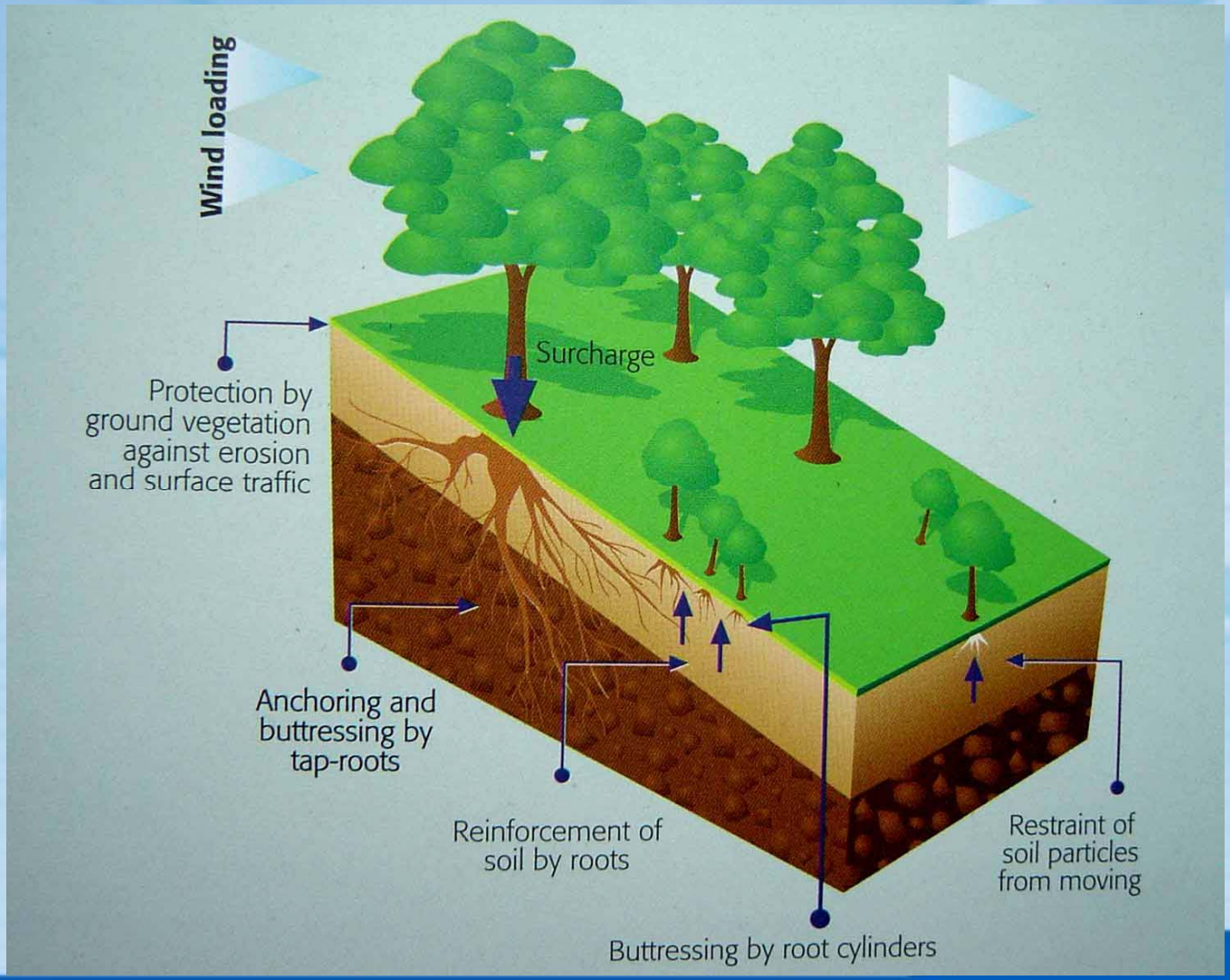
Bio-engineering is the use of living vegetation, either alone or in conjunction with civil engineering structures and non-living plant material, to reduce shallow-seated instability and erosion.

- **It is mainly about the use of plants to provide surface protection on slopes.**

Why Use Bio-engineering?

1. Reduce erosion and shallow instability (< 0.5 metre).
2. Increase a slope's factor of safety.
3. Physical flexibility: plants adapt and re-grow if there is settlement in a slope.
4. Versatility in application: different techniques give a solution to all slope protection problems.
5. It is the only solution to some problems: no other measures can protect surfaces over such a large scale.
6. Cost-effectiveness: the materials involved are cheap.
7. Environmentally advantageous.
8. Socially advantageous: labour-intensive; and gives plant products.

Functions of Plants on Slopes: Physical

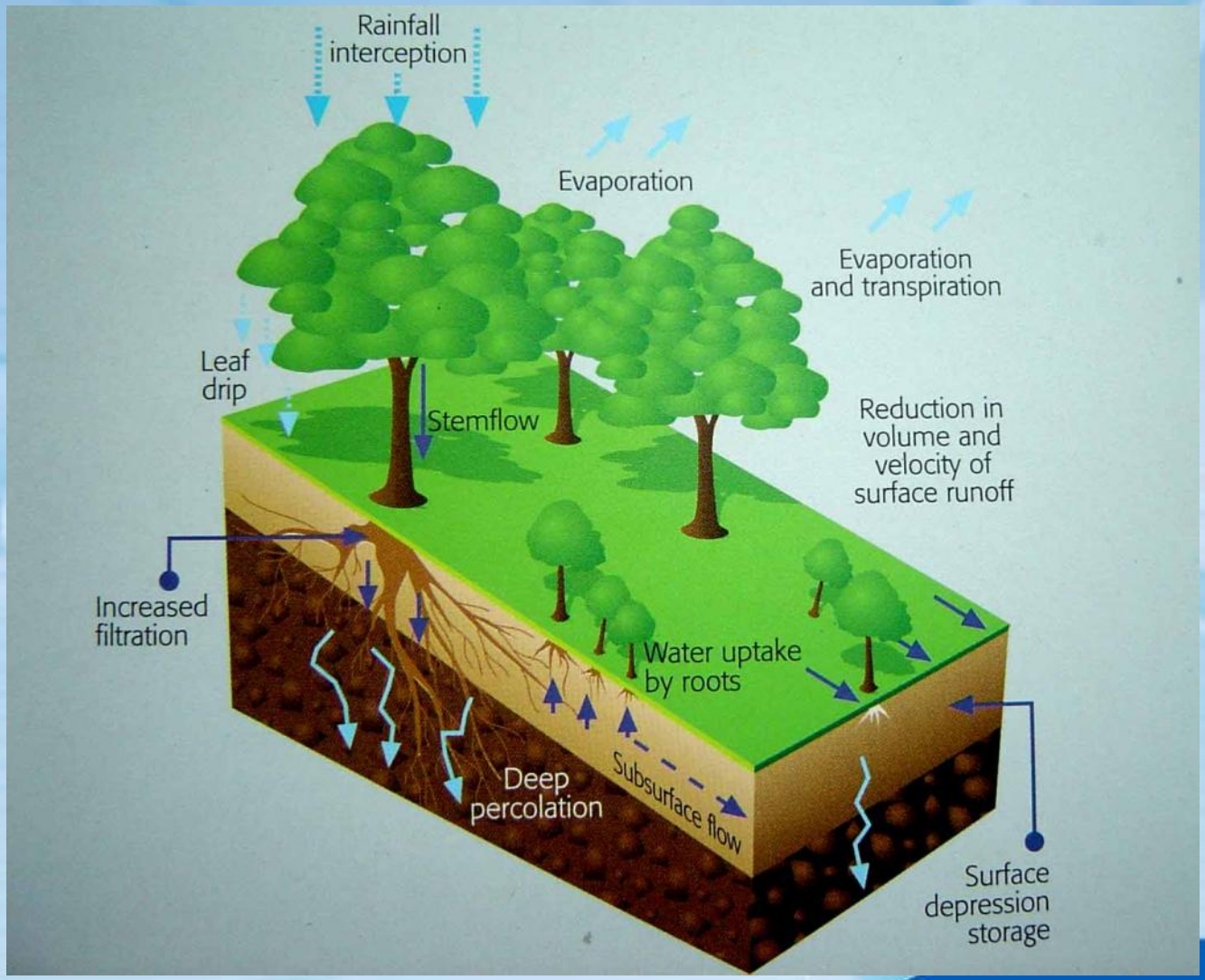


Engineering Mechanisms of Vegetation

Engineering mechanisms	Effect
1. Stems trap materials moving down the slope.	Good
2. Roots bind soil particles to the ground surface and reduce erosion.	Good
3. Roots penetrating through the soil cause it to resist deformation.	Good
4. Woody roots bind fragmented rocks together.	Good
5. Woody roots may open the rock joints due to thickening as they grow.	Bad
6. The root systems of trees support the slope above through arching.	Good
7. Big vertical roots penetrate into firm lower strata and pin down surface materials.	Good
8. Large trees exposed to wind transmit dynamic forces into the slope.	Bad

Note: 4 and 5 are determined by the different behaviour of different species of plants.

Functions of Plants on Slopes: Hydrological



Hydrological Effects of Vegetation

Hydrological mechanisms	Effect
1. Leaves intercept raindrops before they hit the ground.	Good
2. Water evaporates from the leaf surface.	Good
3. Water is stored in the canopy and stems.	Good
4. Large or localised water droplets fall from the leaves.	Bad
5. Surface run-off is slowed by stems and grass leaves.	Good
6. Stems and roots increase surface roughness and soil permeability.	Good
7. Roots extract moisture from the soil and release it through transpiration.	Good

Note: 4 is a problem where there are large plants without a low vegetation cover on the ground surface.

Engineering Functions of Plants

Engineering function	Bio-engineering requirements
Catch eroding material moving down the slope.	Plants with numerous strong and flexible stems.
Protect or **armour** the slope against surface erosion.	Dense surface cover of vegetation.
Reinforce the soil by providing a network of roots that increases the soil's resistance to shear.	Plants with extensive fibrous roots with many splits.
Anchor the surface material by extending roots through potential failure planes into firmer strata below.	Plants with strong, long, vertical roots.
Support the soil mass by the arching effect of the roots of big plants.	Extensive, deep and wide-spreading root systems.

Overview of Common Bio-engineering Techniques

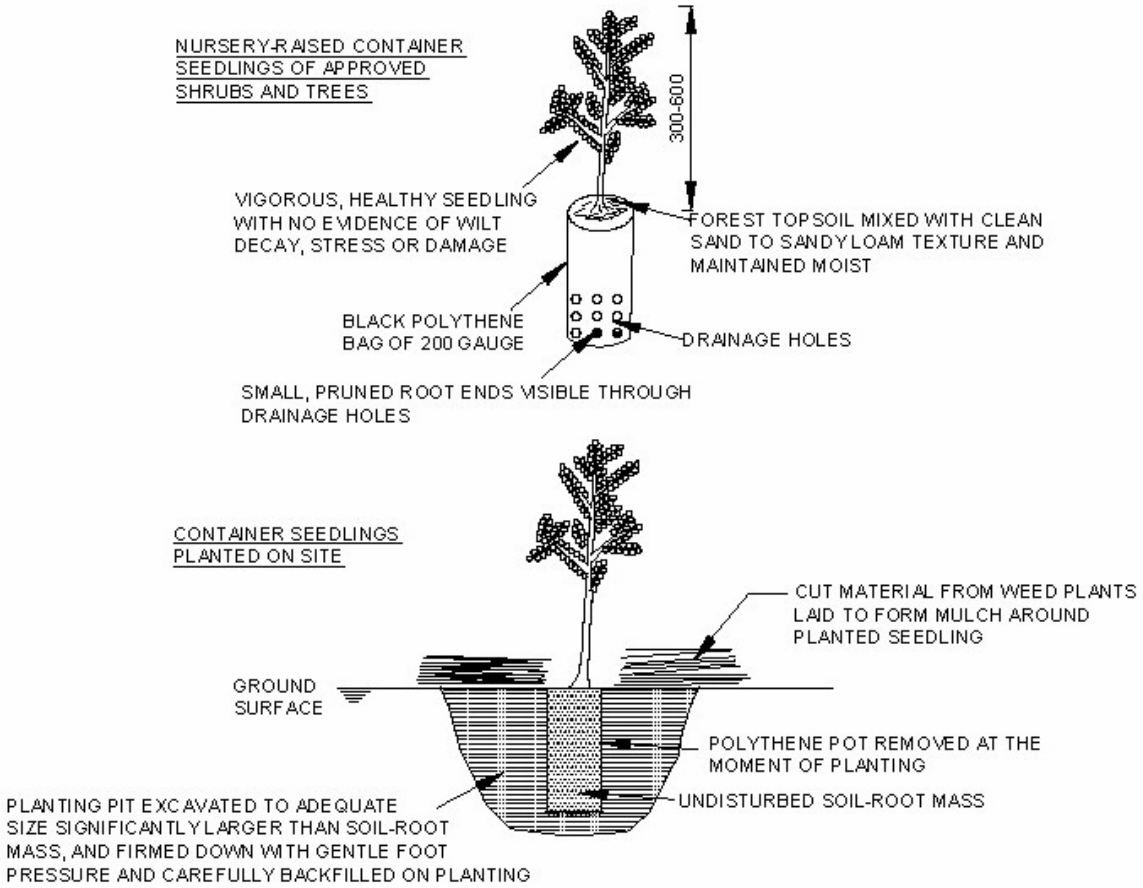
Brush Layers

Truncheon Cuttings

Live Check Dams

Seeding of Shrubs

Tree Planting



Engineering Functions of Bio-engineering Techniques

Bio-engineering technique	Function served
Grass cuttings planted in lines across the slope.	Protect and reinforce the surface with their roots and by providing a surface cover.
Grass is sown direct on to the site.	The main functions are to armour, and later also to reinforce. This allows easy coverage of large areas.
Turf placed on the slope (a small grass type plus the soil it is growing in).	Surface protection on gentle embankment slopes.
Shrubs or trees planted at regular intervals.	They create a dense network of roots to reinforce the soil and anchor to deeper layers
Shrub (or tree) seeds applied directly to the site.	As above, for very steep, rocky and unstable
Large bamboo planting.	Once large clumps are produced, they reinforce and support a slope.
Brush layering (woody cuttings laid in lines across the slope).	These form a strong barrier to protect the slope and trap material moving downwards.
Palisades (woody cuttings planted upright in lines across the slope).	As for brush layers, but not always as strong; easier on steeper slopes.
Live check dams (large woody cuttings planted across a gully).	These form a strong barrier to protect against erosion and trap material moving downwards.

Depth and Type of Bio-engineering Effect

Plant type	Maximum effective rooting depth	Characteristics of roots
Small grass	100 mm	Fine, shallow roots of low strength.
Large grass	0.5 to 1 metre	Strong fibrous roots, forming a cone-shaped mass.
Large bamboo	1 metre	Both tubular and fibrous; extent limited beyond clump.
Shrubs (from cuttings)	1.5 metres	Woody, spreading roots, mainly horizontal.
Trees (from seedlings)	2 metres	Strong woody roots, forming a cone-shaped mass.

Summary of the Role of Bio-engineering in Slope Works

- For eroding surfaces, bio-engineering alone is usually adequate
- In all failure types, bio-engineering is important to prevent surface erosion
- Bio-engineering plants increase the resistance of the surface soil

- Do not expect plants to achieve the impossible: bio-engineering works cannot usually stop deeper slope failures

10.2 Plants and their Engineering Capabilities

The engineering capabilities of plants depend mainly on the following:

- Method of planting (i.e. bio-engineering technique)
- Rooting characteristics of plants
- Propagation methods (i.e. cutting or seed)
- Ability of plants to grow in particular locations (climatic and soil characteristics)
- Farmers' uses and likely damage by fire and animals

How Bio-engineering Really Works in Practice

Grass Planting

Grass planting: rooted slips of large grasses are planted in lines across a soil slope. Slips are made by splitting out the clumps to give a small section of both root and shoot. Lines are usually horizontal or diagonal, depending on material.

Grass Planting

What it offers	Limitations
• The best and quickest way to create a surface vegetation cover on a bare slope. • Effective on almost all soil slopes up to 2V:1H. • Robust protection and shallow reinforcement of the surface soil.	• Requires a slope with at least 30% soil. • Slow to establish on rocky cut slopes. • Where contour lines are used on less permeable materials, slowed runoff can increase infiltration to cause shallow slumping. • Where diagonal lines are used on very weak, non-cohesive materials, small rills may develop.

Direct Seeding

Direct seeding: the seeds of shrubs and small trees are inserted into crevices in slopes composed of moderately weathered rock.

What it offers	Limitations
• The best way to establish vegetation on rocky slopes.	• Slow to provide a coverage good enough to resist erosion.

Brush Layers

Brush layers: woody cuttings from shrubs or small trees are laid in shallow trenches across slopes formed in unconsolidated debris. These can be installed on slopes up to about 1V:1.25H.

What it offers	Limitations
• Instant physical barrier that interrupts runoff. As the plants root and grow, they provide strong protection and soil reinforcement. • Stronger than grass. • Often successful on stony debris, however loose. • Most shrubs will tolerate some shade, so this method can often be used under tree canopies where grasses will not grow.	• Can only be installed on slopes of 1V:1.25H or less, on unconsolidated materials. • Construction causes considerable disturbance to the slope.

Truncheon Cuttings

Truncheon cuttings: big woody cuttings from trees are inserted upright at intervals in slopes formed in deep or poorly stabilised and unconsolidated debris.

What it offers	Limitations
• Relatively strong plant material on slopes that are still unstable. • Withstand damage from moving debris.	• Takes a long time to establish a complete cover. • Needs a lot of planting material.

Live Check Dams

Live check dams: small check dams with structural elements made from the woody cuttings of trees are placed at intervals in erosion gullies.

What it offers	Limitations
• Low cost, flexible structures to reduce erosion where water flow is concentrated. • Relatively limited disturbance to the slope, particularly on weak, unconsolidated materials.	• Not as strong as check dams of gabion or masonry. • Require careful supervision.

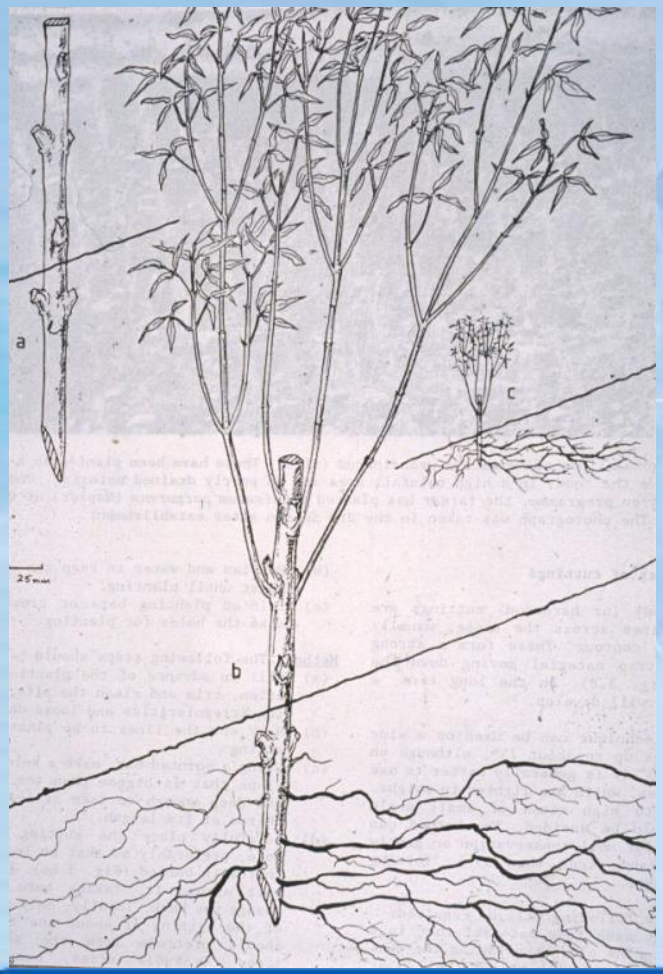
Tree Planting

Tree planting: potted seedlings from a forest nursery are planted at intervals across a soil slope.

What it offers	Limitations
• Restoration of a forest mix of trees in the long term.	• Takes a relatively long time (5 years or more) to contribute significantly to slope strengthening or establish a complete cover. • Seedlings are vulnerable to grazing, so care and protection are required in the first 3 years.

Propagation Method

From cuttings

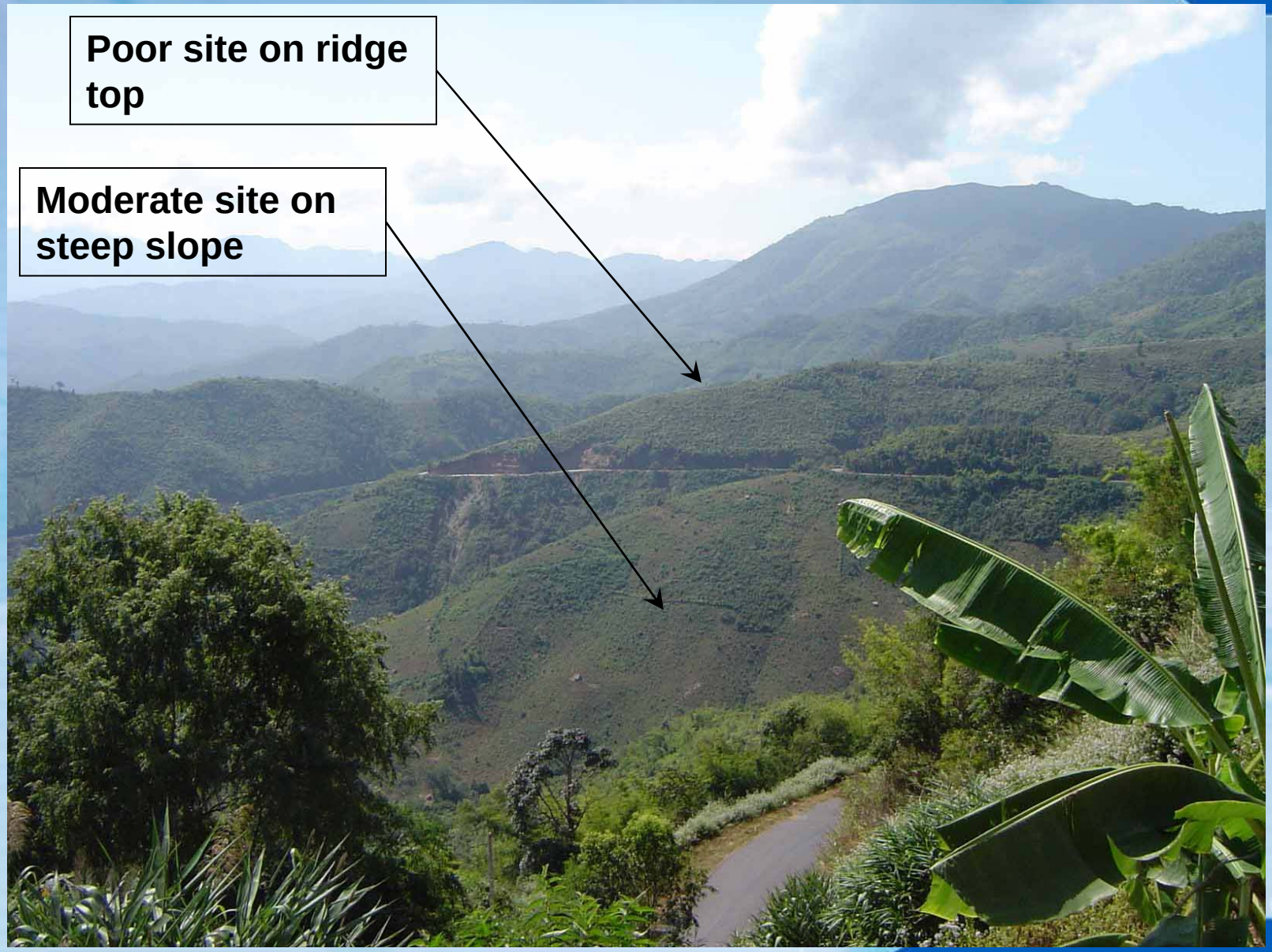


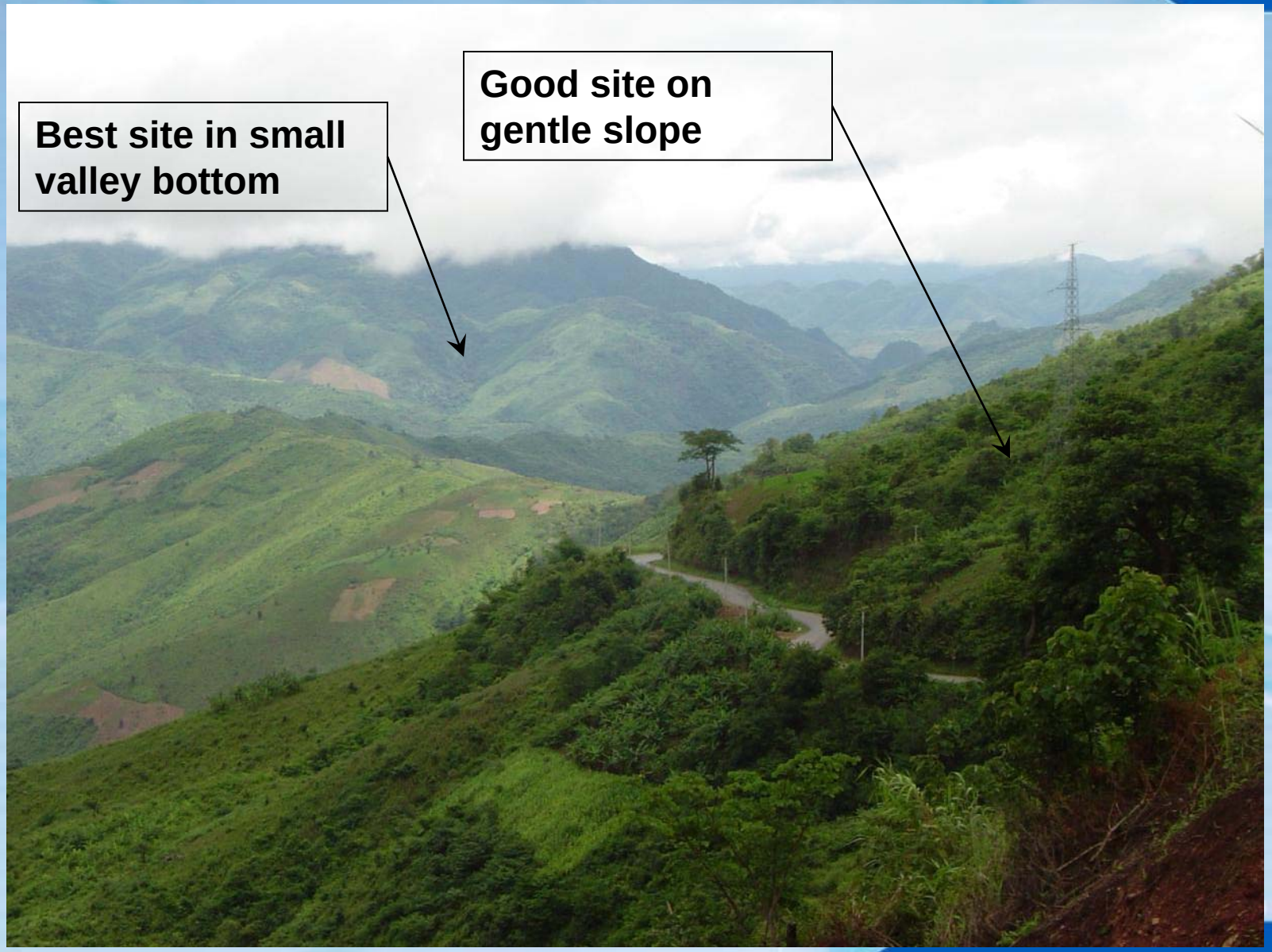
From seeds

Site Characteristics (where a plant grows)

The capability of a plant to grow on a particular site depends mainly on the following:

- **Climatic conditions**
  - **Altitude (temperature)**
  - **Rainfall**
  - **Aspect (direction of facing)**
- **Soil conditions**
  - **Depth of soil**
  - **Stoniness**
  - **Soil fertility**
  - **Soil hydrology (availability of water)**
- **Human conditions**
  - **Management of the land (e.g. cultivation and grazing)**


Poor site on ridge top
Moderate site on steep slope


Best site in small valley bottom
Good site on gentle slope

Uses of Plants and Chances of Survival

Additional considerations:

- **Farmers' uses of plants**
  - **Economic potential of plant products**
  - **Management to avoid over-exploitation**
  - **Combining slope protection with helping local farmers**
  - **Particular problems of shifting cultivation**
- **Survival challenges**
  - **Ability to survive fire**
  - **Grazing by animals**
  - **Resistance to damage from landslides and erosion**

The Grazing Problem on Roadside Slopes

Decision Tree in Plant Selection

Which bio-engineering techniques will address the specific problems on site?

↓

What plant types are appropriate for those techniques and how will they be propagated?

↓

Which species fulfil these requirements and are best suited to the environmental conditions on site?

↓

Is it also possible to select species that will both perform the required functions on site and also be of use to local farmers?

↓

Which species can be made available at the right place, at the right time and in the right quantities?

Bio-engineering Plants: Suitable Grasses

Bio-engineering Plants: Broom Grass

Bio-engineering Plants: Suitable Shrubs

10.3 Nurseries and Growing Seasons

Production of bio-engineering plants

A bio-engineering programme requires a large number of the same plants at the same time. There are two ways to provide these.

- **Collect them from nearby areas.**
- **Produce them in a nursery.**

For small areas, the first is often feasible. However, for large bio-engineering programmes (for example on a new road or after a big disaster), the second becomes essential.

Sometimes a combination of both is the best option.

Collection from Nearby Areas

Advantages

- **Plants are well adapted to the local micro-climate and soil type.**
- **Transport costs are minimised.**
- **The employment of local people can be maximised.**

Disadvantages

- **Limited control over availability.**
- **Risk of damage to nearby forest.**
- **Risk of conflict with local people.**

What are Nurseries?

A nursery is a factory to supply plants. It provides:

- enough plants of the right species,
- in good, healthy condition,
- in the form required for planting;
- at the right time; and
- at a reasonable cost.

Young plants are delicate. Their production is a skilled business. Therefore nurseries require careful organisation and operation.

Because plants are delicate living organisms, care and quality control are more important than for civil engineering materials.

What Happens in Bio-engineering Nurseries?

Planning a Nursery

- Number of plants of each type to be produced each year
- Location of the planting sites that the nursery must supply
- Availability of land

The following are the main technical factors that *must be satisfied* when establishing a nursery.

- Water supply
- General location
- Physical features (e.g. aspect, avoidance of flooding)
- Availability of materials (e.g. forest topsoil) and labour
- Adequate space
- Adequate labour availability

Types of Nursery Beds

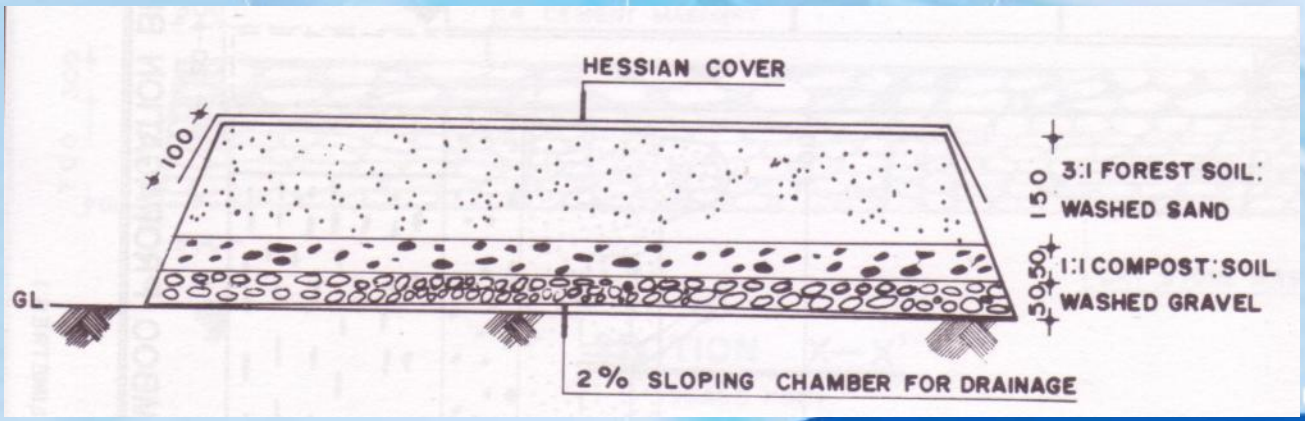
There are three main types of bed

- Grass beds: for producing grass slips
- Seed beds: very finely prepared beds for germinating small shrub and tree seeds
- Stand out beds: frames in which to stand potted seedlings

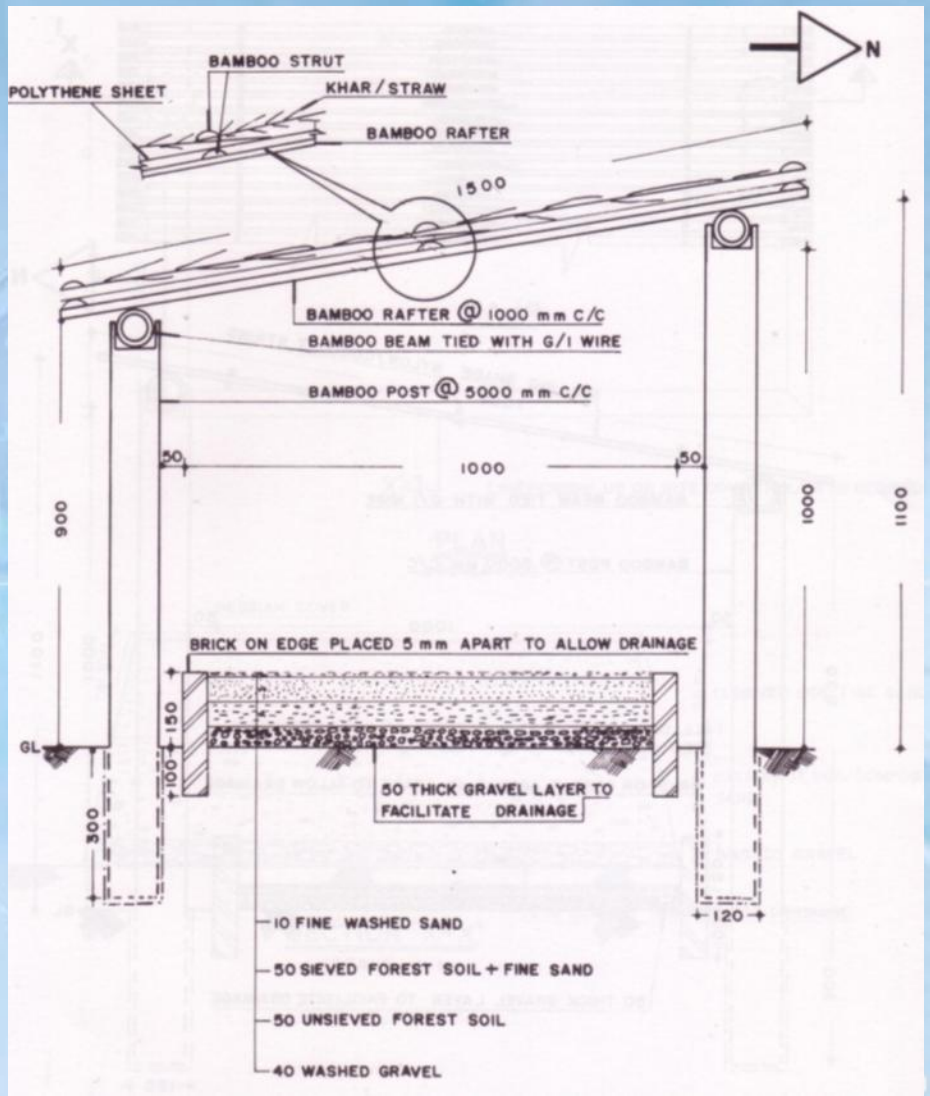
Nursery Bed Construction Details

Bed type	Grass beds	Seed beds	Stand out beds
Bed size *	1000 mm wide × 250 mm high	1000 mm wide × 170 mm high	1000 mm wide × 150 mm high
Details of construction	50 mm of washed gravel placed above the ground; then 50 mm of 1:1 mix of sieved soil and compost; and topped with 150 mm of 3:1 mix of sieved forest topsoil and washed sand.	50 mm of washed gravel placed above the ground; then 50 mm of unsieved forest soil; 50 mm of 1:3 mix of sieved forest soil and washed sand; and topped with 20 mm of washed, sieved and sterilised sand.	50 mm drainage layer of gravel placed above compacted ground. A flat stone or brick surround.
Shade type	No shade; hessian sheet can be laid on the surface if required	Complete top shade of thick thatch and polythene sheet	Removable top shade of rolling bamboo slats, made from split culms

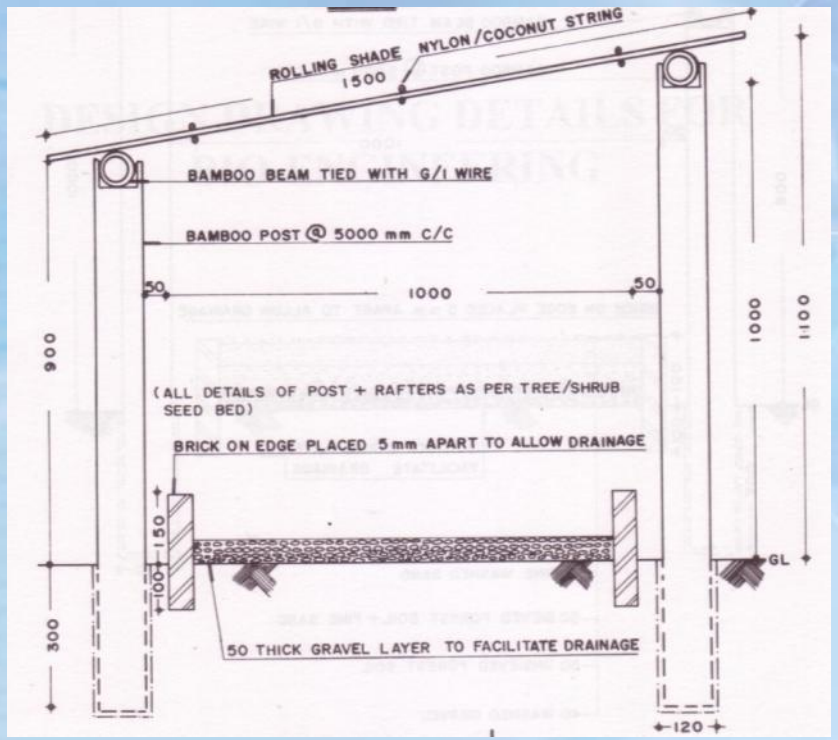
Grass Bed



Seed Bed



Standout Bed



Essential Information on Nursery Management

Environment management

- **Shading**
- **Watering**

Restriction of pests and diseases

- **Weeds**
- **Insect and mammal pest control**
- **Fungal diseases control**

Preparing plants to leave the nursery

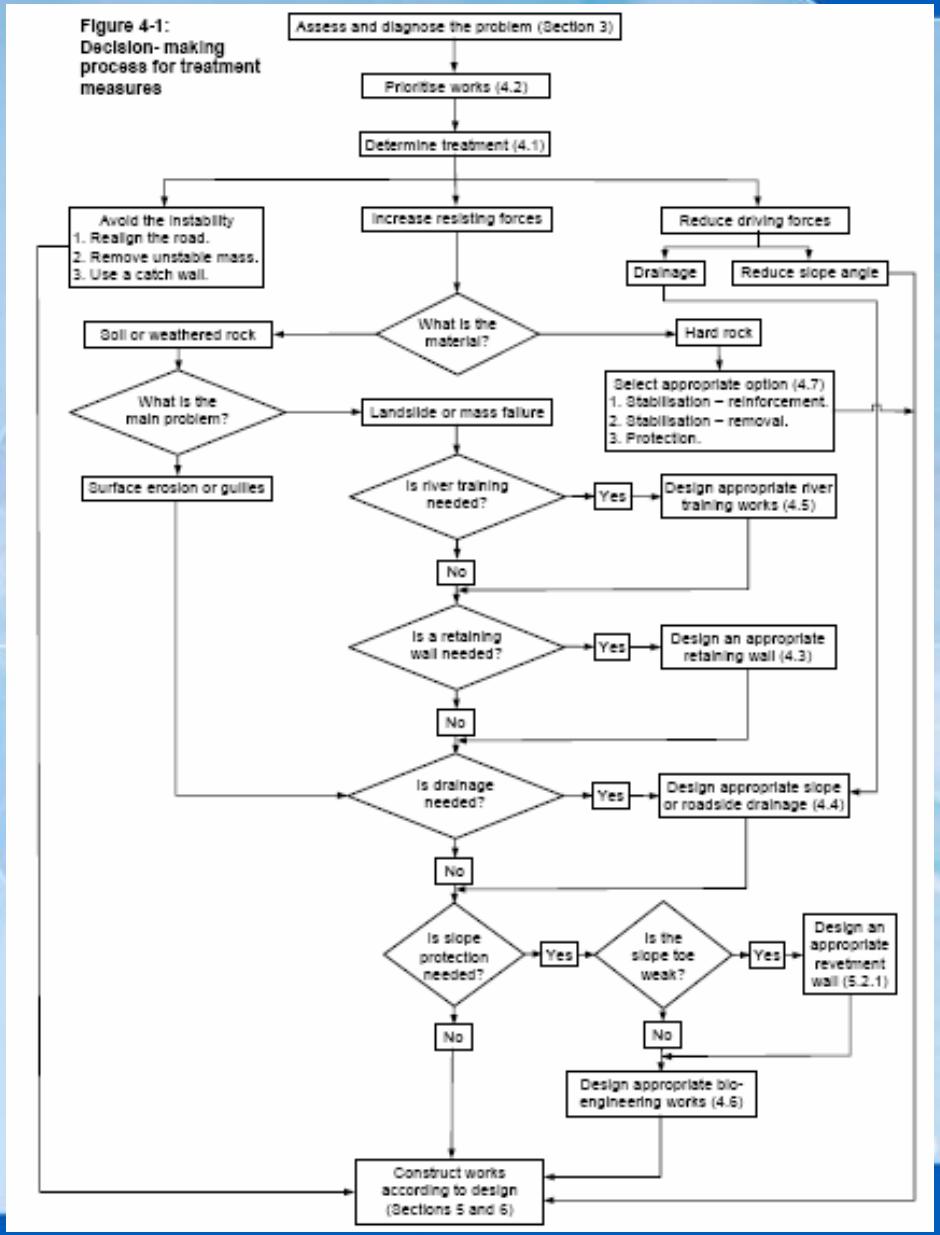
- **Hardening-off**
- **Culling**

Record keeping

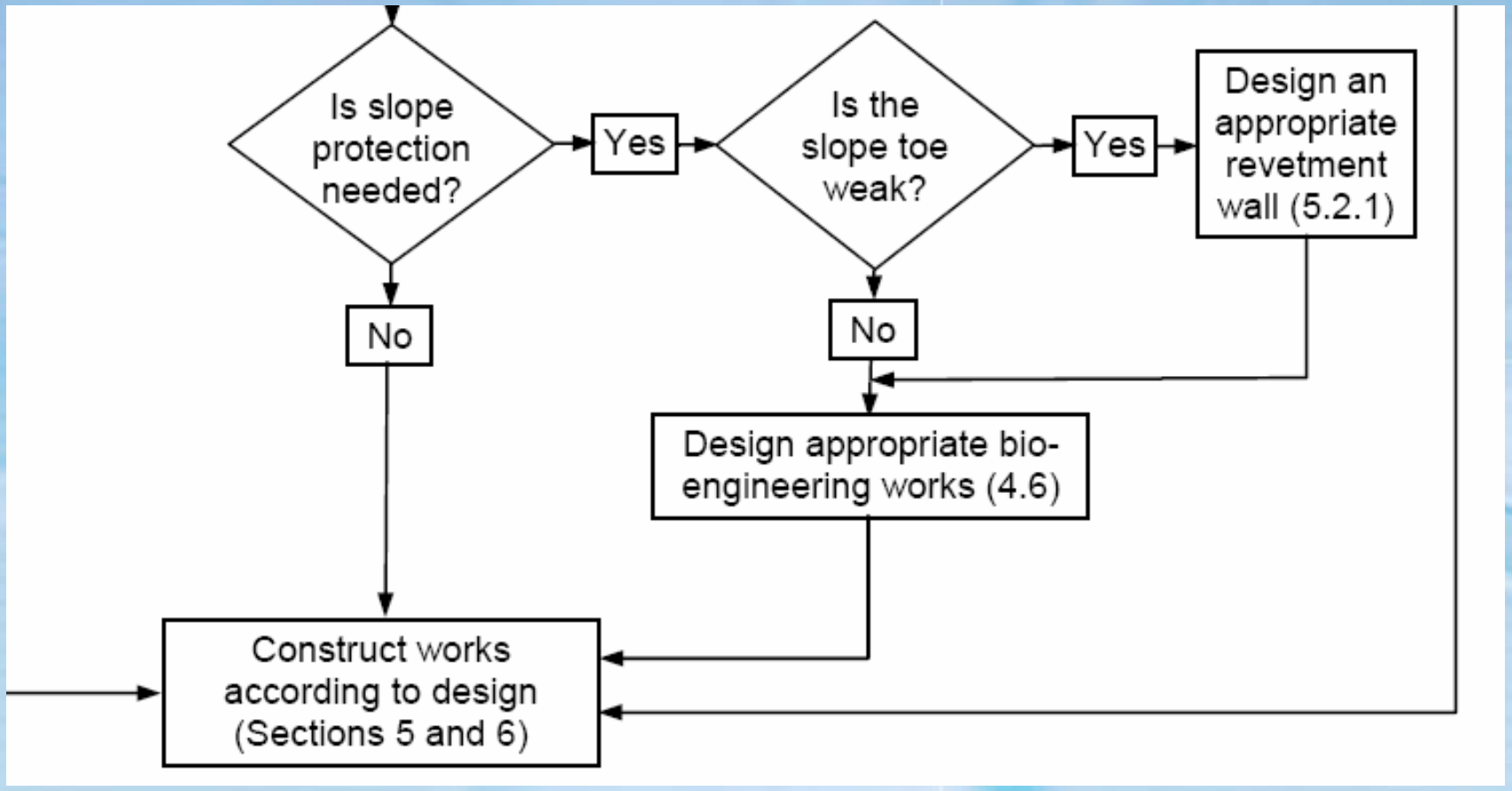
Annual Timing of Bio-engineering Works

Month	Main activities
September	End-of-monsoon survey of problem areas.
October	Prioritise and plan for remedial works.
November	Arrange seed collection. Prepare for physical site works.
December	Seed collection. Prepare for physical site works.
January	Preparation of nurseries. Civil engineering site works.
February	Start nursery production. Sow seeds. Civil engineering site works.
March	Nursery operations in full swing. Civil engineering site works.
April	Nursery operations in full swing. Finish civil engineering works.
May	Nursery operations. Prepare materials for site planting. Sow seeds.
June	Nursery operations continue. Site plantation works.
July	Site plantation works. Observe new work and maintain as required.
August	Observe new work and maintain as required.

10.4 Bio-engineering Application



The Position of Bio-engineering in Slope Works



Determination of Techniques (1)

Site characteristics	Recommended techniques
Sites mainly above roads	
Cut slope in soil, very highly to completely weathered rock or residual soil, at any grade up to 2V:1H.	Grass planting in lines, using slip cuttings.
Cut slope in colluvial debris, at any grade up to 1V:1H (steeper than this would need a retaining structure).	
Trimmed landslide head scarps in soil, at any grade up to 2V:1H.	
Roadside lower edge or shoulder in soil or mixed debris.	
Cut slope in mixed soil and rock or highly weathered rock, at any grade up to about 4V:1H.	Direct seeding of shrubs and trees in crevices.
Trimmed landslide head scarps in mixed soil and rock or highly weathered rock, at any grade up to about 4V:1H.	

Determination of Techniques (2)

Site characteristics	Recommended techniques
Sites mainly below roads	
Fill slopes and backfill above walls without a water seepage or drainage problem: these should first be regraded to be no steeper than about 1V:1.5H.	Brush layers using woody cuttings from shrubs or trees.
Debris slopes underlain by rock structure, with the slope grade between 1V:1H and 1.75V:1H.	Palisades using woody cuttings from shrubs or trees.
Other debris-covered slopes where cleaning is not practical, at grades between 1V:1.5H and 1V:1H.	Brush layers using woody cuttings from shrubs or trees.
Fill slopes and backfill above walls showing evidence of regular water seepage or poor drainage: these should first be regraded to be no steeper than about 1V:1.5H.	Fascines using woody cuttings from shrubs or trees, configured to contribute to slope drainage (e.g. in a herringbone pattern).
Large and less stable fill slopes more than 10 metres from the road edge.	Truncheon cuttings (big woody cuttings from trees).
The base of fill and debris slopes.	Large bamboo planting; or tree planting using nursery seedlings.

Determination of Techniques (3)

Site characteristics	Recommended techniques
Other sites	
Stream banks where minor erosion is possible.	Large bamboo planting.
Gullies or seasonal stream channels with occasional minor discharge.	Live check dams using woody cuttings of shrubs and trees.
Gullies or seasonal stream channels with regular or heavy discharge.	Stone pitching, probably vegetated. Gabion check dams may also be required.
Other bare areas, such as on the land above landslide head scars, on large debris heaps and stable fill slopes.	Tree planting using potted seedlings from a nursery.

Implementation of Bio-engineering Works

- final slope preparation
- preparation of plant materials
- construction of the bio-engineering works

Final Slope Preparation

Slope Preparation (1)

- Finish all construction first!
- Slopes composed of soil (or any weak material) need to be finished to an even grade
- This is to improve stability, provide a sound basis for bio-engineering and improve the appearance
- Slopes should be trimmed to a straight profile: there should never be a pronounced convex or concave profile, as these are prone to failure starting at a steep point
- Cut slopes should be finished to a slope angle of between 1V:1.5H (particularly at the tops of slopes which often comprise weak soils) and 2V:1H (in certain cases the angle may be steeper, but this should be carefully reviewed in each case)
- Fill slopes should be finished to a grade of 1V:1.5H

Slope Preparation (2)

- Trim off steep sections of slope, whether at the top or bottom
- Avoid an over-steep lower section, since a small failure at the toe can destabilise the whole slope above
- Remove all small protrusions and unstable large rocks
- Eradicate indentations that make the surrounding material unstable by trimming back the whole slope around them
- Remove all debris and loose material from the slope surface and toe to an approved tipping site
- If there is no toe wall, a finished cut slope must consist entirely of undisturbed material

Slope Preparation (3)

- Where retaining walls are constructed on or at the base of slopes, the excavated material can often be used for backfilling
- During backfilling, compact the material in layers, 100 to 150 mm thick by ramming it thoroughly with tamping irons
- Create a finished slope of maximum 1V:1.5H
- This must be done while the material is moist
- Dispose of excess spoil carefully, in an approved tipping site
- Always include adequate provision in work estimates for haulage of spoil to an approved safe tipping area, and make sure it is used

Preparation of Plant Materials

Preparation of Plant Materials (1)

Grass slips

- Grass slips are small sections of a grass plant, made by splitting up a large clump
- The stems are cut down to a height of 100 to 200 mm and the roots cut back to 40 to 80 mm
- There should be 2 or 3 stems per slip

Preparation of Plant Materials (2)

Woody cuttings

- Woody cuttings are taken from the branches of certain types of small trees
- They are cut to be between 450 and 600 mm long, and the diameter should be between 20 and 40 mm in diameter
- Shoots and leaves are trimmed off
- For live check dams, cuttings are needed that are 2 metres in length

Preparation of Plant Materials (3)

Truncheon cuttings

- **Truncheon cuttings are made from the branches of large trees**
- **They should be about 2 metres in length and 50 to 80 mm in diameter**

- **It is very important that plant materials for bio-engineering are kept cool and damp when they are being moved and prepared**

Preparation of Plant Materials (4)

Plants suitable for bio-engineering

Species for grass slips	Species for woody cuttings	Species for direct seeding
Nyar khaem, dok khaem (broom grass) Nyar kha Nyar phaek Nyar khaem lao (2 different species) Nyar phaek, fek hom (vetiver)	Mak koh (chestnut) Korbai leuam(chestnut) Posa (paper mulberry) Mak nhiao (“diesel nut”) Peuak meuak, toutiang Khee nok, khee hen, ngen (simali) Mai mook Thorng	Khileckdong Koun Khathin Tiou dam Pohou Hookatai Phak nao Som poi Phak thon

... plus many other plants not yet fully investigated and tested

Construction of Bio-engineering Works

Construction of Bio-engineering Works (1)

Grass planting

- Grass slips are planted in lines across the slope
- The best results usually come from lines that are at 45^{o} to maximum slope
- Start from the top and work downwards
- Mark out the lines on the slope
- Then plant the grass slips to the original depth
- Slips to be 100 mm apart
- Gently firm the soil back around them

Construction of Bio-engineering Works (2)

Brush layers

- Start from the bottom and work up
- Mark out horizontal lines every 2 m on the slope
- Dig shallow trenches along the lines, 350 to 450 mm wide
- Lay the cuttings across the trenches with the bottom inwards and 80 to 100 mm of the top protruding
- Cuttings should be 50 mm apart
- Place a small amount of soil over the cuttings and then lay another line of cuttings
- Replace and firm down the soil

Construction of Bio-engineering Works (3)

Truncheon cuttings

- **Use a crowbar to make a vertical hole that is about 20 mm wider than the cutting and at least 1 metre deep**
- **Place the cutting in the hole and gently fill around it with loose soil**
- **Truncheon cuttings are usually planted 1 metre apart on deep debris slopes**

Construction of Bio-engineering Works (4a)

Live check dams (1)

- **Select places on the gully where interruptions to water flow are most likely to stop erosion**
- **Dig a horizontal trench right across the gully, 100 mm deeper than the gully bed and extending at least 300 mm into the gully sides**
- **Place truncheon cuttings at a spacing of 200 mm, in two lines 200 mm apart, along the trench**
- **Weave long woody cuttings in and out between the truncheon cuttings**
- **Start from the bottom and weave the woody cuttings on alternate sides**

Construction of Bio-engineering Works (4b)

Live check dams (2)

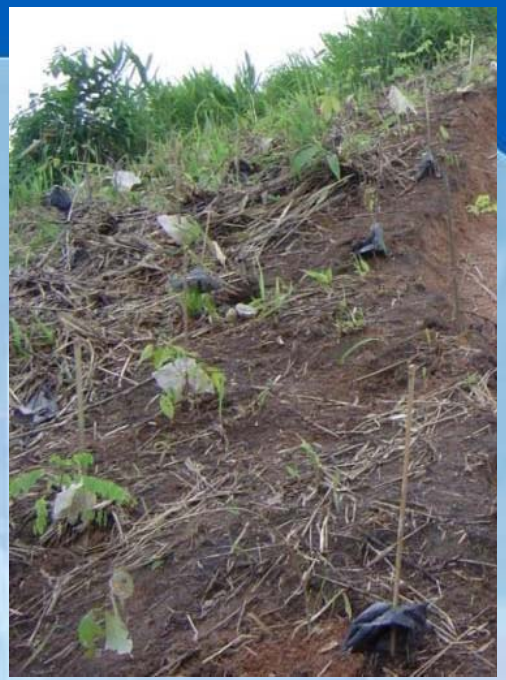
- You will need 25 to 40 cuttings, 2.0 m long, per metre of check dam height, for each line of weaving
- Carefully fill between and around the check dam with soil and stones, and firm it down gently
- Weave cuttings higher between the posts at the ends, so that the middle of the check dam is lower for water to flow through

Construction of Bio-engineering Works (5)

Direct seeding

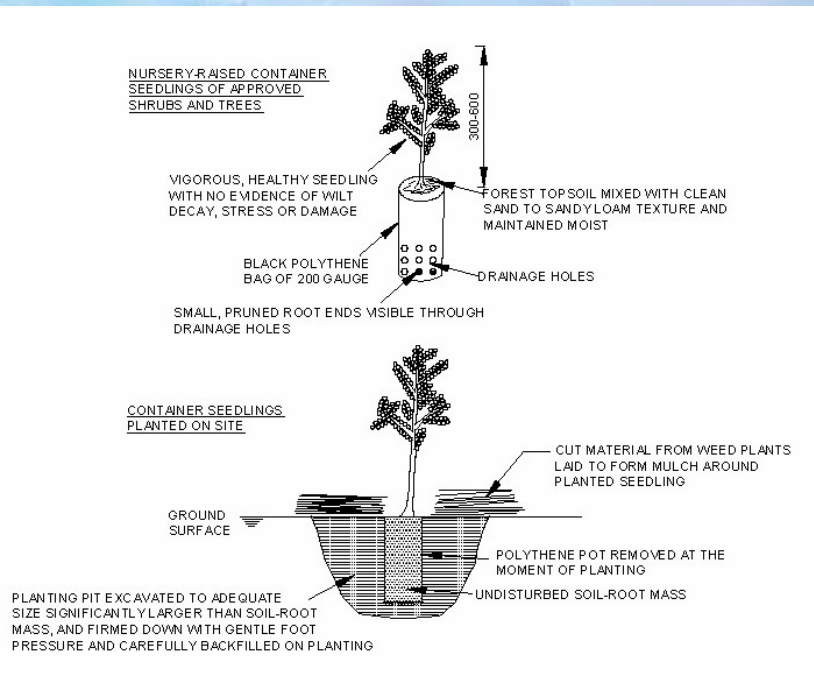
- **Start at the top and work downwards**
- **A small hole is made in the slope surface using a steel bar, between stones and soil**
- **Next, 2 seeds are inserted to a depth of about 20 mm**
- **The seeds are then covered with 5 to 10 mm of soil and firmed in**
- **This is repeated at 50 to 100 mm centres across the slope**

Construction of Bio-engineering Works (6)



Planting potted tree seedlings

- A hole is dug that is at least 300 mm in diameter and 300 mm deep
- The pot is removed from the seedling and the seedling is planted in the hole, with care taken to fill soil gently but firmly around the root mass
- This is repeated at 1.5 metre centres across the slope



Quality Checking of Bio-engineering Works (1)

Why is quality important?

- **Plants are low cost but delicate.**
- **High quality work is needed to ensure that the desired engineering effects are achieved.**

Whole sites

- **Has the site been completely treated, with no gaps?**
- **Is the site evenly covered with the right plants?**
- **Has the site been fully tidied up, with no loose debris?**
- **Does the site show no signs of instability?**
- **Is it stable enough to survive the early rains while plants get established?**
- **Does it generally look good, complete and healthy throughout?**

Quality Checking of Bio-engineering Works (2)

Individual plants

- **Are the plants of bright, healthy colours?**
- **Do the plants show no signs of wilting?**
- **Are they well proportioned (*i.e.* not stunted or very tall and thin)?**
- **Are they growing fast, with a number of long new shoots?**
- **Are the plants without signs of discoloration on the leaves?**
- **Are they without signs of insect attack on the leaves or shoots (*e.g.* holes eaten in the leaves)?**
- **Are they without any obvious signs of disease?**
- **Are they undamaged?**
- **Are the plants not yellowed (except in the later part of the dry season)?**

Quality Checking of Bio-engineering Works (3)

Grass lines

- **Are the lines complete, with plants at the spacing specified within the rows?**
- **Is the distance right between the rows, according to specification?**
- **Are the lines even, with no gaps or poor plants in them?**
- **Are they straight, according to specification?**

Quality Checking of Bio-engineering Works (4)

Brush layers and live check dams

- **Are the works complete, with the right number of cuttings per running metre?**
- **Is the distance right between the lines, according to specification?**
- **Are the works even, with no gaps or dead cuttings?**
- **Are they straight, according to specification?**

Quality Checking of Bio-engineering Works (5)

10.5 Slope Maintenance Strategies

Principles (1)

- The poor predictability of vegetation growth means that it cannot be guaranteed to provide an immediate solution. We do not yet know how to ensure good growth on all sites.
- Trees should not be allowed to grow to more than 10 metres in height, or large bamboo clumps permitted to grow, on steep or fragile slope areas. This means that these big plants are appropriate in the following locations: (a) on slopes of less than 1V:1.5H; (b) in the bottom 2 metres of slopes steeper than 1V:1.5H; or (c) more than 5 metres from the top of slopes steeper than 1V:1.5H.
- Maintaining a line of large trees or bamboo clumps at the base of a slope can help to buttress the slope and reduce undercutting by small streams.

Principles (2)

- Grasses that form large, dense clumps generally provide the most robust slope protection in tropical areas where rainfall can be particularly intense. This type of plant is usually best for erosion control. However, most grasses will not grow under the shade of a tree canopy.
- Shrubs (i.e. woody plants with multiple stems) and small trees (i.e. woody plants with single stems) can often be grown from cuttings taken from their branches. Plants propagated by this method tend to produce a mass of fine, strong roots. These are often better for soil reinforcement than the natural rooting systems developed from a seedling of the same plant.
- In most cases the establishment of a full vegetation cover on *unconsolidated fill slopes* can be achieved in one to two wet seasons.

Principles (3)

- In most cases the establishment of a full vegetation cover on *undisturbed cut slopes* in residual soil may take 3 to 5 wet seasons. Less stony and more permeable soils will have faster plant growth rates, and drier locations will lead to slower rates.
- There is no single species or technique that can resolve all slope protection problems.
- Plant roots cannot be guaranteed to contribute to soil reinforcement below a depth of 500 mm (although tree, shrub and bamboo roots may eventually strengthen the soil to at least 1 metre depth).
- Plants cannot be expected to reduce soil moisture significantly at the critical periods of intense and prolonged rainfall when slopes are most likely to fail.

Principles (4)

- Grazing by large numbers of domestic animals can devastate a planted site if it occurs before the plants are properly established.
- Once established, plants are flexible and robust. They can recover from significant levels of damage (e.g. flooding and debris deposition) although this may not occur fully until the wet season following the year in which they were planted.
- In the long term, the aim is to create a strong and sustainable surface protection.

Practice (1)

Why is it necessary to manage vegetation?

- **Roadside slopes are mainly covered in vegetation, which helps to control erosion on soil slopes**
- **Plants grow rapidly and need to be controlled regularly to stop them from extending out into the road**
- **They become dangerous to traffic when they hide pedestrians, cause vehicles to be driven in the middle of the road or reduce drivers' sight lines**

Practice (2)

How should vegetation be controlled?

- **Plants should be cut back several times a year, according to need**
- **Smaller plants can be cut with a machete**
- **Plants must never be pulled or dug out by the roots, and must never be burnt**

Practice (3)

Where should the cut plant material be placed?

- **Ensure that the cut plant material is placed in locations where it won't be washed into the drainage system during heavy rain (for example on a flat area on the opposite side of the road)**
- **The removed material should be left in tidy piles but not burnt**

Practice (4)

What are the biggest hazards in slope protection?

- **Tipping of debris on roadside slopes**

- **Uncontrolled drainage discharge**

Grass Planting

Grass Planting

Grass Planting

Grass Planting

Grass Planting

Grass Planting

Grass Planting: The Same Site, 15 Months Apart

Direct Seeding of Shrubs

Brush Layers during Planting

Brush Layers a few Days after Planting

Brush Layers about one Month after Planting

Brush Layers after 2 Growing Seasons

Brush Layers with Grass Lines

Palisades

Truncheon Cuttings

Truncheon Cuttings

Live Check Dams

Mixed Techniques

Grass lines on upper soil slopes

Direct seeding on rocky band

Brush layers on backfill

Revetment wall

Road 13N, km 316.6 Before Treatment

Road 13N, km 316.6 After Treatment