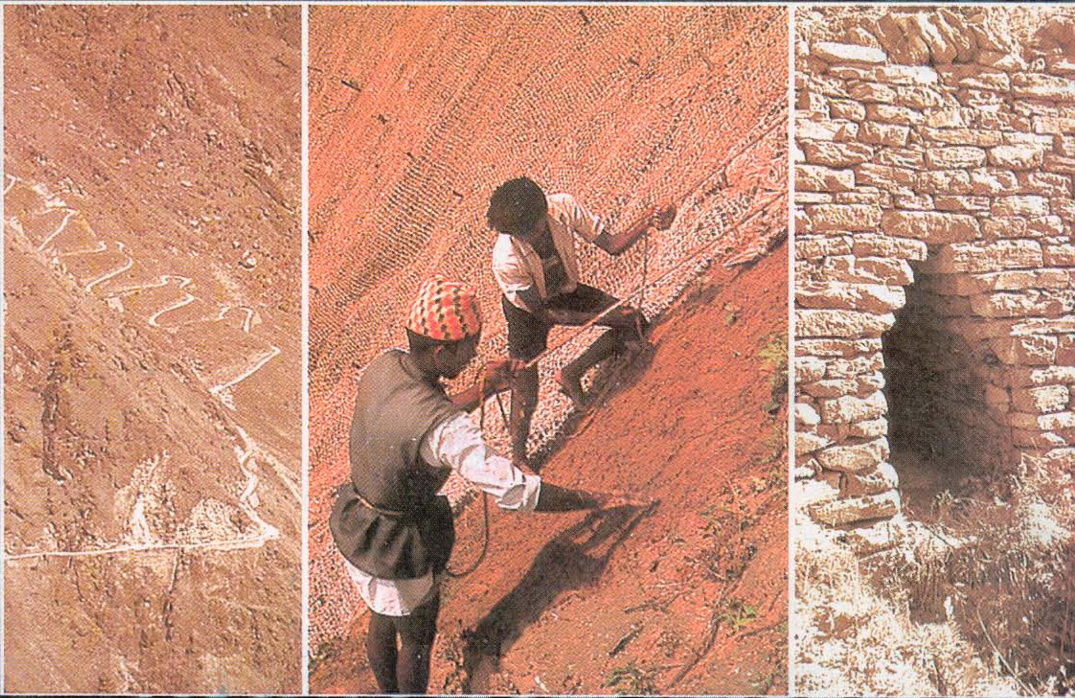
ROADSIDE Bio-engineering



SITE HANDBOOK

Department of Roads
His Majesty's Government of Nepal

ROADSIDE
Bio-engineering

SITE HANDBOOK

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ROADSIDE Bio-engineering

SITE HANDBOOK

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CONTENTS

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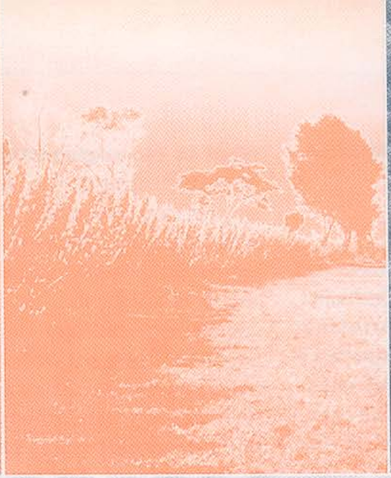



The nature and scope of bio-engineering

USING THE *SITE HANDBOOK*

This handbook provides the information needed to design, plan, implement and maintain roadside bio-engineering works. It also covers the establishment and maintenance of bio-engineering nurseries. It is intended that the handbook cover all subjects that an engineer would need on site. (The companion *Reference Manual* provides background and supporting information and is intended for office use.)

Each subject is covered in a separate section and sections are marked with a vertical coloured bar for easier reference.

THE NATURE AND SCOPE OF ROADSIDE BIO-ENGINEERING

What is this handbook for?

This *Site Handbook* is to inform Engineers and Overseers on the use of bio-engineering in Nepal. It is written specifically for use on roadside slopes. It covers all of the practical aspects of designing, planning, implementing and maintaining bio-engineering site works. The companion *Reference Manual* provides all the supporting information required.

What is bio-engineering?

Bio-engineering is the use of living plants for engineering purposes. Vegetation is carefully selected for the functions it can serve in stabilising roadside slopes and for its suitability to the site. It is usually used in combination with civil engineering structures. Bio-engineering offers the engineer a new set of tools, but does not normally replace the use of civil engineering structures. Incorporating the use of bio-engineering measures usually offers a more effective solution to the problem. The materials and skills are all available in rural areas, however remote.

Placing jute netting on a steep cut slope

What does bio-engineering do?

- Bio-engineering can be used to protect almost all slopes against erosion[1].
- Bio-engineering reduces the instances of shallow planar sliding[2].
- Bio-engineering can be used to improve surface drainage and reduce slumping[3].

Bio-engineering systems work in the same way as civil engineering systems and have the same functions. They are effective at depths of up to 500 mm below the surface. They are not effective for deep-seated landslides or failures.

Designs that incorporate bio-engineering are usually the most effective and the most economic solutions for the shallow-seated problems listed above. Although bio-engineering costs more in the short term than the 'do nothing' approach, in the long term there should be additional benefits from reduced maintenance costs.

How does bio-engineering work?

Bio-engineering structures can provide a range of engineering functions (see below). The civil engineering systems given in the table for comparison are the nearest equivalent, but are not always appropriate for slope stabilisation in Nepal.

Where should bio-engineering be used?

Bio-engineering techniques for stabilising slopes should be used on:

- all areas of bare soil on embankment and cut face slopes;
- wherever there is a risk of gullying;
- all slopes where there is a risk of shallow slumps or planar slips of less than 500 mm depth;
- any slope segment in which civil engineering structures are planned or have been built, and the surface remains bare;
- any area that has failed and needs to be restored, other than rock slopes;
- any area, such as tipping and quarry sites, or camp compounds, that requires rehabilitation.

As with all engineering works, it is most important that the techniques selected are correct for the site to be treated, and that the work is carried out with all due care and attention.

How is bio-engineering done?

In the Department of Roads, executive authority and responsibility for bio-engineering lies with the Division Chief or Project Manager, with assistance from the Regional Office or from the Geo-Environmental Unit.A Supervisor is usually responsible for each nursery (as the naike), and others for specialised bio-engineering labour gangs. Engineers and Overseers are now expected to understand bio-engineering enough to organise programmes under their chief's direction.

Some bio-engineering contractors operate nationally, but most are local, 'D class'contractors.

When is bio-engineering done?

Bio-engineering works are planned in the same way as other works, following the annual pattern of planning, budget estimation and submission, detailed site assessment, estimation and implementation. However, some differences exist: the need to establish and maintain nurseries, for example, and the fact that timing is controlled by seasons.

[1] Erosion is the gradual wearing away of soil (or other material) and its loss, particle by particle.

[2] Planar sliding is a mass slope failure on a slip plane parallel to the surface (*i.e.* not rotational). It is the most common type of landslide and is usually shallow (less than 1.5 metres deep). It is also called a debris slide or a translational landslide.

[3] Slumping is a form of saturated flow of soil or debris. It occurs mostly in weak, poorly drained materials, when a point of liquefaction is reached following heavy rain. It is usually shallow (less than 500 mm deep).

The main engineering functions of structures, with examples of civil and bio-engineering structures

Function*	Civil engineering technique	Bio-engineering technique	Combination of both
Catch	Catch walls	Contour grass lines	Catch wall with bamboos above
Armour	Revetments	Grass carpet	Vegetated stone pitching
Reinforce	Reinforced earth	Densely rooting grasses	Jute netting with planted grass
Anchor	Soil anchors	Deeply rooting trees	Combination of anchors and trees
Support	Retaining walls	Large trees and large bamboos	Retaining wall with bamboos above
Drain	Surface or sub-surface drains	Downslope vegetation lines	French drains and angled grass lines

* The six main engineering functions are defined in Section 1.2 on page 15 and are elaborated in the *Reference Manual*.

SAFETY CODE OF PRACTICE FOR WORKING ON SLOPES

1. This code is designed to promote the safety of all Department and Contract personnel while working on slopes at sites where persons are at risk of falling a distance of more than 2 metres.

2. No-one may gain access to the site unless they are authorised by the Engineer or the Contractor.

3. No person may work unaccompanied unless they are on a very gentle slope (less than 30° slope). All personnel must leave the slope to take refreshments, meals etc.

4. During site works, all fragile slopes shall be clearly marked off and personnel informed of the dangers.

5. Extreme care must be exercised on slopes during adverse weather conditions as wind, rain, fog and darkness create their own hazards in addition to the hazards inherent in slope work. The site in-charge must assess the conditions with great care before allowing access to the slope. Only in emergencies may persons go on to slopes in heavy rain or during the hours of darkness. In such cases, no person shall go on to the slope unaccompanied.

6. All access equipment, ropes and tackle must be regularly inspected and adequately maintained in a sound condition.

7. Where persons could fall over the edge of a slope, temporary guard rails or ropes are to be installed where practicable. All persons exposed to a risk of falling must be provided with a secure and well-anchored safety line. Such a rope must be of sufficient strength to provide them with safe arrest in the event of a fall.

8. Care must be taken to prevent tools and loose objects falling from the slope. Loose articles should be raised or lowered in a safe manner. They should not be carried up or down ladders, unless in the case of small items, which may be carried in a suitable shoulder bag.

9. Any scaffolding that is used must be composed of good quality materials. Bamboos should be freshly cut, of strong and flexible nature. Scaffolding must be of appropriate capacity and correctly erected by competent persons.

10. Ladders must be in good condition and adequate for the job. Ladders should extend one metre beyond the landing point and must be on a firm base, correctly pitched and lashed as soon as is possible. Unlashed ladders must be 'footed'.

11. If there is any potential hazard to personnel below where the slope work is taking place, adequate temporary warning notices, barriers and a 'look out' person shall be employed. Where appropriate, standard traffic warning and control measures must be taken.

12. Appropriate protective clothing shall be issued, including, where necessary, protective helmets and boots with steel toe caps and slip-resistant soles.

How safe are the working practices in your area?

Site safety

The engineer or contractor is always responsible for the safety of people working on a site. Where a contractor is engaged, then the responsibility is usually delegated to him. Although accidents are often blamed on workers, the fault lies with management alone in more than 60 per cent of cases. The executive authority must ensure that safe practices are followed.

Roads are intrinsically dangerous. They are made even more dangerous by the presence of maintenance gangs and road works. The road safety regulations produced by the Traffic and Engineering Safety Unit (of the Department of Roads) must be followed.

Slopes in mountainous areas are also dangerous by nature. As well as the obvious dangers of falling off steep slopes, there are dangers of falling debris or tools hitting other workers, and of the slope itself giving way.

The Safety Code of Practice for Working on Slopes (see page 10) must always be followed.

Stabilising Slopes with Civil and Bio-engineering

This section provides:

- a brief introduction to the common problems of slope instability, and ways of solving them;
- a straightforward procedure to identify and implement the appropriate treatments for each site, following a series of logical steps summarised in Figure 1.3, on page 14.

1.1 PROBLEMS OF SLOPES AND THEIR SOLUTIONS

Ideally, the causes of slope instability would be well understood and appropriate solutions would be easy to select. However, this is rarely the case and engineers must make assumptions about the causes of slope instability, based on their knowledge and experience of the terrain. This is particularly true in Nepal, where slopes tend to be long and steep, and the climatic variables are as yet poorly understood. Attaining a desired factor of safety may not be feasible.

With such a variety of materials and sites, choosing stabilisation techniques is a complicated process. There are many variables, most of which cannot practicably be measured in the field. Therefore, it is not possible to set quantitative limits on many of the parameters. This section outlines instead a practical analysis to help the engineer to decide on the best course of action.

Bio-engineering is not a substitute for civil engineering. It offers engineers a set of tools to complement those already available in solving a range of shallow slope problems.

Bio-engineering serves two distinct roles: providing additional techniques for stabilising shallow failures and controlling erosion; and enhancing civil engineering structures by protecting them and maximising their effectiveness. In both roles, bio-engineering techniques must be carefully integrated with civil engineering structures.

Every slope has a different variety of erosion and failure processes at work on it; often, there

Shoulder erosion threatening the edge of the road pavement. Even the smallest slope problems must be tackled (Left)

A deep planar slide on the Arniko Highway has removed a portion of the road (Right)

Figure 1.1: Common types of erosion and slope failure

Description	Depth	Mechanism *	Function required
Rills and gullies form in weak, unprotected surfaces. **Erosion** should also be expected on bare or freshly prepared slopes.	Usually in the top 0.5 metre, but can become deeper if not controlled.	**Erosion** on the surface.	Armour, Reinforce Catch
Mass slope failure on a shallow **slip plane** parallel to the surface. This is the most common type of landslide, slip or debris fall. The plane of failure is usually visible but may not be straight, depending on site conditions. It may occur on any scale.	Frequently 0.5 metres or less below surface (or along a local discontinuity).	**Planar sliding (translational landslide or debris slide)**.	Reinforce, Anchor Catch, Drain
Mass slope failure on a deep, curved slip plane. Many small, deep landslides are the result of this process. Large areas of subsidence may also be due to these.	Usually > 1.5 metres deep.	**Shear failure (rotational landslide)**.	Anchor, Support Drain
Slumping or flow where material is poorly drained or has low cohesion between particles and liquefaction is reached. These sometimes look similar to planar slides, but are due to flow rather than sliding. The resulting debris normally has a rounded profile.	Frequently 0.5 metres or less below surface.	**Slumping** or flow of material when very wet.	Drain, Reinforce
Collapse due to failure of the supporting material. This usually takes the form of a rock fall where a weaker band of material has eroded to undermine a harder band above. These are very common in mixed Churia strata.	0.5 to 2 metres in road cuts; deeper in natural cliffs.	**Debris fall** or collapse.	Reinforce, Support

* The mechanisms of failure or erosion are covered in detail in the *Reference Manual*.

Phase	Step	Action to be taken	Location
PLANNING	1	Make an initial plan of the year's works	Office
	2	Prioritise the works	Roadline
	3	Divide the sites into segments for assessment	Sites
	4	Assess the site	Sites
	5	Determine civil engineering works	Sites
	6	Choose the right bio-engineering techniques	Sites
DESIGN	7	Design the civil and bio-engineering works	Office
	8	Select the species to use	Office
	9	Calculate the required quantities and rates	Office
	10	Finalise priority against available budget	Office
	11	Plan plant needs	Office
	12	Arrange implementation and prepare documents	Office
IMPLEMENTATION	13	Prepare for plant propagation	Nursery
	14	Make the necessary site arrangements	Office/sites
	15	Prepare the site for work	Sites
	16	Implement the civil engineering works	Sites
	17	Implement the bio-engineering works	Sites
	18	Monitor the works	Sites
MAINTENANCE	19	Maintain the works	Roadline/sites

Figure 1.2: The main engineering functions of structures, with examples of techniques

FUNCTION*	CIVIL ENGINEERING TECHNIQUE	BIO-ENGINEERING TECHNIQUE	COMBINATION OF BOTH
Catch	Catch walls	Contour grass lines or brush layers	Catch wall with densely planted shrubs
	Catch fences	Shrubs and large bamboo clumps	Catch wall with bamboo clumps planted above
Armour	Revetments	Mixed plant storeys giving complete cover	Vegetated stone pitching
	Surface rendering	Grass carpet	Jute netting with planted grass
Reinforce	Reinforced earth	Densely rooting grasses, shrubs and trees	Wire bolster cylinders and planted shrubs or trees
	Soil nailing	Most vegetation structures	Jute netting with planted grass
Anchor	Rock anchors	Deeply rooting trees	Combination of soil anchors and deeply rooting trees
	Soil anchors		
Support	Retaining walls	Large trees and large bamboo clumps	Retaining wall with a line of large bamboo clumps planted above
	Prop walls		
Drain	Masonry surface drains	Downslope and diagonal vegetation lines	Herringbone-pattern wire bolster cylinders and angled grass lines
	Gabion and french drains	Angled fascines or brush layers	French drains and angled grass lines

* The six main engineering functions are defined in Section 1.2 below and are elaborated in the *Reference Manual.*

will be more than one process affecting each part of a slope. Freshly prepared slopes (*i.e.* those just cut or filled) are usually subject to erosion, and so ***all*** slopes need to be stabilised. These erosion and failure processes must be identified before remedial work can be started. Examples of the most common problems are given in Figure 1.1[1].

Figure 1.2 shows examples of civil and bio-engineering techniques that have been devised to overcome these common problems

1.2 STEPS FOR THE STABILISATION OF SLOPES

In the steps outlined below and shown schematically by the flow chart in Figure 1.3 on page 14, the engineer follows a logical procedure to plan and implement the works.

These steps initially use as their basis the six main functions of both civil engineering and bio-engineering techniques of slope stabilisation, given in Figures 1.2. In more detail, engineering structures serve to:.

Catch eroded material moving down the slope. Movement may occur as a result of gravity alone, or with the aid of water as well. Material is caught by a physical barrier such as a wall or the stems of vegetation;

Armour the slope against erosion from runoff and rain splash. This is most effectively done using a continuous cover of low vegetation (inert coverings such as stone pitching tend to be expensive over large areas). Partial armouring is often provided, for example by using lines of grasses, brush layers or gabion wire bolsters;

Reinforce the soil by physically stiffening it to increase its resistance to shear. Plant roots are effective at reinforcing soil;.

Anchor surface material to deeper layers by soil pinning. This helps to reduce mass movements at depths greater than provided by general reinforcement. The roots of large plants emulate soil anchors or rock bolts;

Support a soil mass by buttressing. On a large scale, a retaining wall or the roots of large plants (and their stems once they have caught some debris) such as big bamboo clumps can buttress a soil mass. On a micro scale individual large stones or smaller vegetation, perform this function.

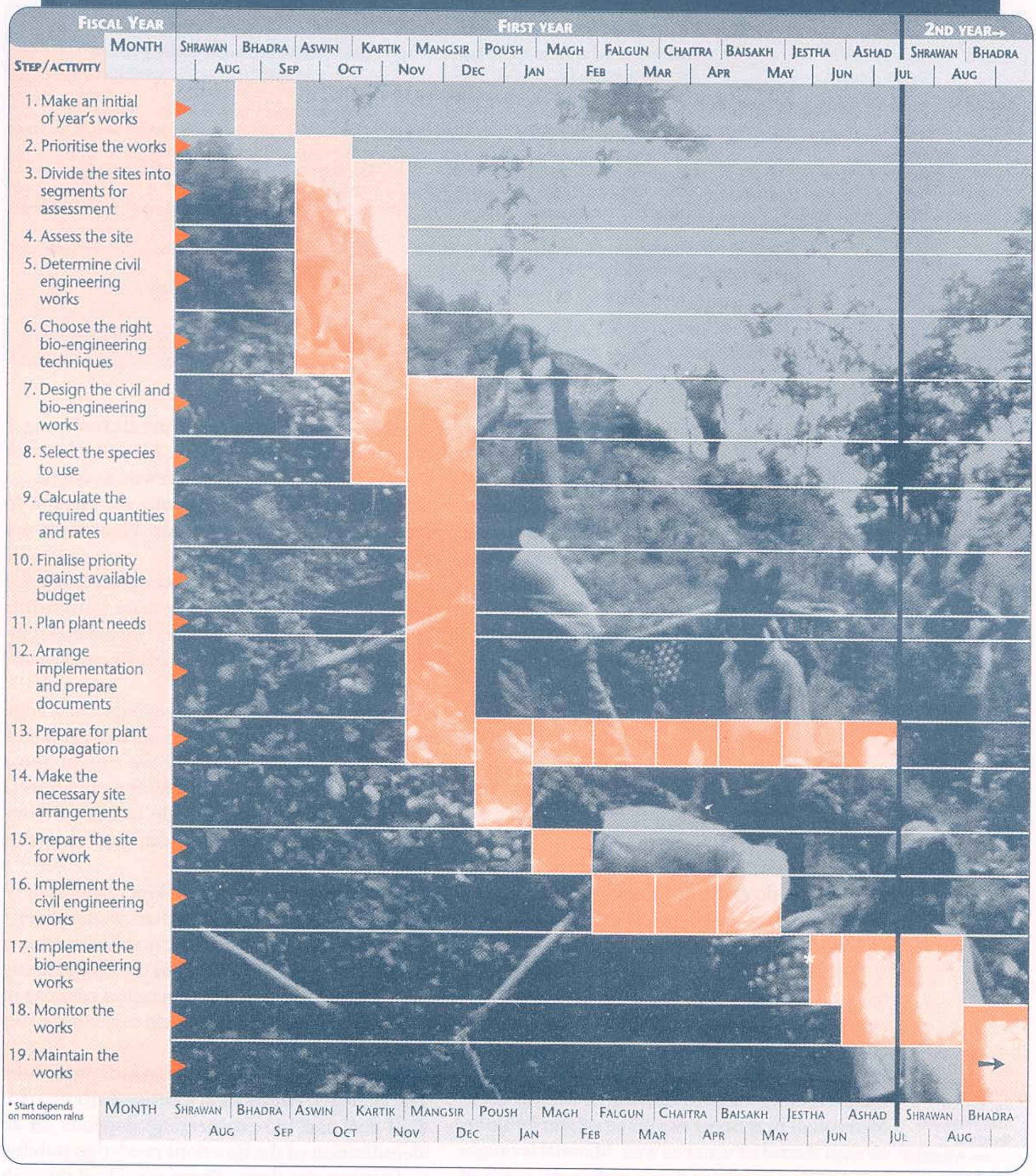
Drain excess water from the slope. Drier materials tend to be more stable than wetter ones - many failures occur when the material reaches a point of liquefaction. Standard civil engineering drains can be provided; vegetation planted in lines angled down the slope help to drain the surface layers.

Sites are assessed using a standard procedure. The choice of stabilisation techniques (both standard civil and bio-engineering) depends on an identification of the functions needed to stabilise and protect the slope. These steps lead through the process to give a logical application of the techniques available.

To implement slope stabilisation works including both civil and bio-engineering, follow these steps.

[1] For a more comprehensive list of the common forms of failure and erosion, refer to pages 12 and 13 of TRL Overseas Road Note 16, *Principles of low cost engineering in mountainous regions.*

Figure 1.4. Summary calendar of civil and bio-engineering works



STEP 1: MAKE AN INITIAL PLAN

Early in the fiscal year, you must prepare for the process of checking all slopes along the road and planning the year's work. The calendar in Figure 1.4 shows how the various steps involved, as described above, will be scheduled through the year.

Note that there are three critical points on this calendar; all are governed by seasons. These are:

- seed collection, which starts in Mangsir for many species;
- civil engineering works, which must be complete before the rains start in Jestha; and
- site planting, which usually starts in late Jestha or Ashad, as soon as the rains are reliable.

All of the other activities must be completed on schedule for these to be carried out in the right season. This accounts for the heavy planning and design load early in the fiscal year.

STEP 2: PRIORITISE THE WORKS

Inspect the road and make a list of the sites that require treatment. Prioritise them according to the importance of stabilisation.

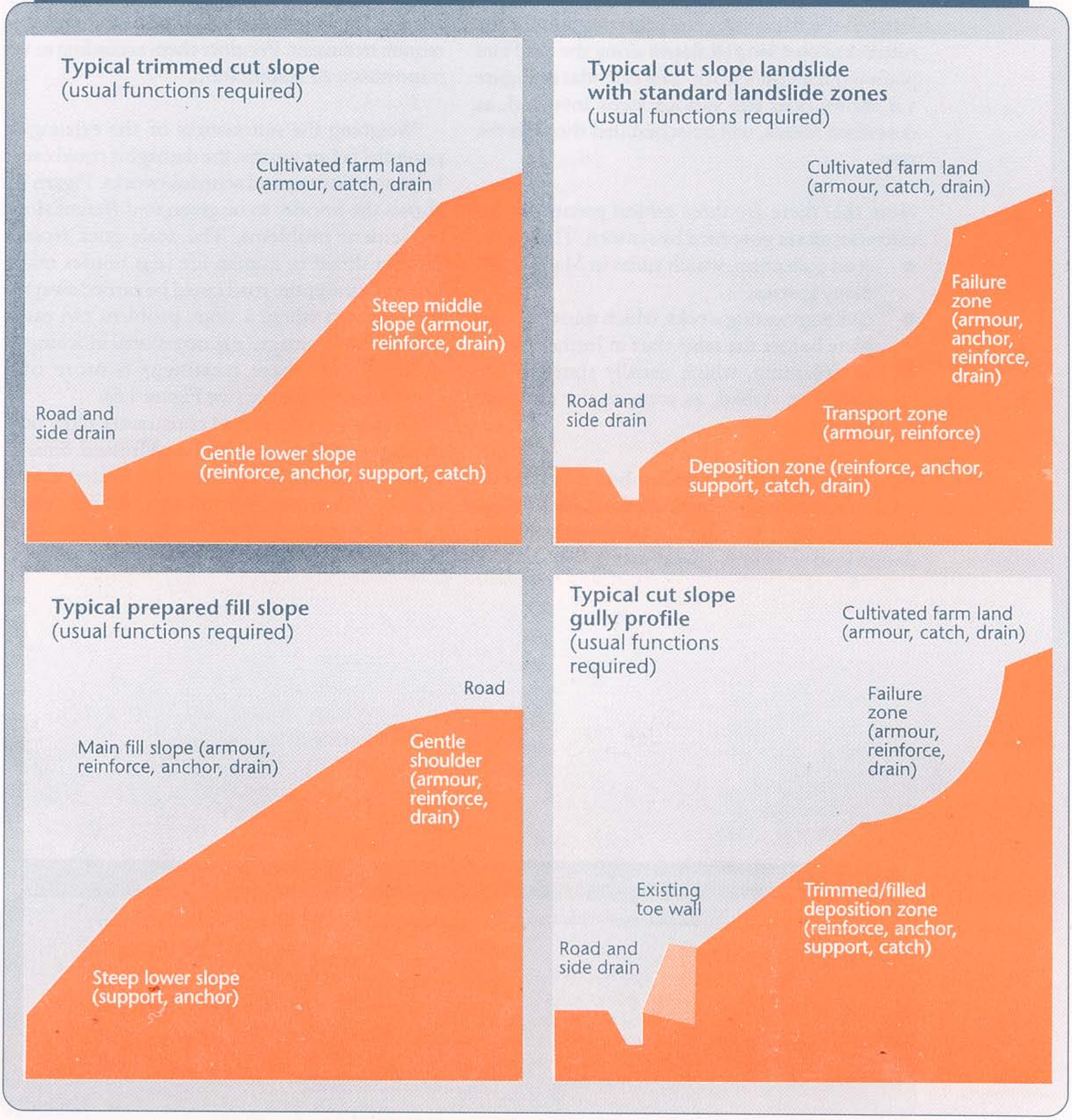
Weighing the seriousness of the existing or potential failure against the damage it could cause helps to prioritise and schedule works. Figure 1.5 shows the priority to be given to different slope movement problems. The scale goes from a distinct threat to human life (*e.g.* houses might be lost or the entire road could be carried away) to the situation where a slope problem can cause only limited damage (*e.g.* occasional blocking of drains), and where treatment is more of a preventative measure (see Figure 1.5).

In many cases, budget constraints allow only the higher priority sites to be addressed. Sites up to priority 3 should always be treated if at all possible. However, the aim should be to move towards treatment of all sites under a regular maintenance programme.

Figure 1.5: Prioritisation of repair work (from the perspective of the Department of Roads)

Expected consequence if the site is not treated	Priority rating
Slope movement threatens houses	Priority 1 (*i.e.* very high priority)
Slope movement threatens complete loss of road	Priority 2
Slope movement threatens partial loss of road	Priority 3
Slope movement threatens complete road blockage	Priority 3
Debris may fall on top of pedestrians or vehicles and cause injury	Priority 3
Slope movement threatens loss of productive farmland	Priority 4
Slope movement threatens blockage of drains	Priority 4

Figure 1.6. Typical slope segments, showing patterns of material movement



STEP 3: DIVIDE THE SITE OR SLOPE INTO SEGMENTS

A slope segment can be defined as a length of slope with a uniform angle and homogeneous material that is likely to erode or fail in a uniform manner.

The mechanical, hydrological and biological processes at work in a slope are many and complex. Nevertheless, before any remedial work can begin, it is necessary to identify the major factors contributing to instability in order to decide on appropriate action. The assessment and treatment of each site is based on the use of one or more techniques for each segment. So it is necessary to divide the slope into its component segments. Some common examples of slopes are given in Figure 1.6.

While carrying out this step on site, it is useful to sketch the site on the pro forma given in Annex A.

Before proceeding to Step 4, you should have a good knowledge of the site. You should know how many segments make up the slope, and have an idea of how the main processes at work within each segment contribute to the overall instability of the site.

From now on, each segment of slope must be considered a separate entity for treatment: both civil engineering and bio-engineering techniques should be planned for each segment rather than for an entire site.

Careful site inspection is essential for successful stabilisation

Figure 1.7: Common types of erosion and slope failure

Mechanism *	Description	Depth
Erosion on the surface.	**Rills** and gullies form in weak, unprotected surfaces. **Erosion** should also be expected on bare or freshly prepared slopes.	Usually in the top 0.1 metre, but can become deeper if not controlled.
Gully erosion	Gullies that are established in the slope continue to develop and grow bigger. Large gullies often have small landslides along the sides.	Usually in the top 0.5 metre, but can become deeper if not controlled.
Planar sliding (translational landslide or debris slide).	Mass slope failure on a shallow **slip plane** parallel to the surface. This is the most common type of landslide, slip or debris fall. The plane of failure is usually visible but may not be straight, depending on site conditions. It may occur on any scale.	Frequently 0.5 metre or less below surface (or along a local discontinuity).
Shear failure (rotational landslide).	Mass slope failure on a deep, curved slip plane. Many small, deep landslides are the result of this process. Large areas of subsidence may also be due to these.	Usually > 1.5 metres deep.
Slumping or flow of material when very wet.	**Slumping** or flow where material is poorly drained or has low cohesion between particles and liquefaction is reached. These sometimes appear afterwards like planar slides, but are due to flow rather than sliding. The resulting debris normally has a rounded profile.	Frequently 0.5 metre or less below surface.
Debris fall or collapse.	Collapse due to failure of the supporting material. This normally takes the form of a rock fall where a weaker band of material has eroded to undermine a harder band above. These are very common in mixed Churia strata.	0.5 to 2 metres in road cuts; deeper in natural cliffs.
Debris flow	In gullies and small, steep river channels (bed gradient usually more than 15°), debris flows can occur following intensive rain storms. This takes the form of a rapid but viscous flow of liquefied mud and debris.	The flow depth is usually 1 to 2 metres deep.

* The mechanisms of failure or erosion are covered in detail in the *Reference Manual* .

STEP 4: ASSESS THE SITE

This is the most important step, and the one on which you must spend the most time. You must make a site visit, and you will need:

- either some copies of the pro forma in Annex A or a notebook;
- a 30-metre tape measure;
- a clinometer or an Abney level (if you do not have one of these, take this handbook with you and use the angled slope lines in Annex A to estimate slope angle in profile); and
- an altimeter, or maps or site drawings of the roadline that show the altitude.

Carefully assessing a site, through an investigation on the ground, is the key to applying good engineering practice. Without proper investigation and assessment, both civil and bio-engineering techniques are likely to fail. This section gives only a very brief guide; more details on site assessment are provided in Section 2 of the *Reference Manual*.

The objective of Step 4 is to arrive at a more detailed appreciation of the factors contributing to instability within each slope segment. In order to achieve this, you will need to look carefully at each segment of the site and note down the following facts (more details are given in the paragraphs below).

Erosion and failure processes	***List***
Other factors	***List***
Slope angle(s)	***3 classes: < 30°, 30 – 45°, or > 45°***
Slope length	***2 classes: < 15 metres or > 15 metres***
Material drainage	***2 classes: good or poor***
Site moisture	***4 classes: wet, moist, dry or very dry***
Altitude	***Determine: use an altimeter, map or site drawing***

Figure 1.8: The main physical factors affecting slopes

Potential factor	Description
Fault lines	Small fault lines may cause differential erosion in parts of the site.
Springs	There may be seasonal springs within the site, which cause localised problems of drainage or slumping.
Slip planes	The main plane of failure may not be the only one. Many sites have secondary, smaller slip planes additional to the main failure mechanism
Large gullies	Large gullies nearby may erode backwards and damage the site. Alternatively, they may discharge, causing deposition on the site.
Landslides	Nearby landslides may extend headwards or sideways, or may supply debris on to the site.
River flooding	A large river below the site may flood badly, damaging the site by either erosion or deposition, or a combination of both.
River cutting	Rivers below the site may move in floods, undercutting the toe of the site.
Catchments	If there is an extended catchment area above the site, it could lead to a large discharge, which causes bad damage by erosion or deposition.
Drain discharge	The discharge of drainage water must be safeguarded to avoid causing erosion or mass failures. Poorly sited or inadequately protected discharge points can cause severe problems.
Khet and kulo	Khet (rice paddy) land or a kulo (irrigation channel) above a site usually means a large volume of water infiltrating into the slope, with a greater potential for failure or large-scale erosion.
Construction activities	Construction activities on or near the site may lead to undermining through excavations, or surcharging through spoil disposal in the wrong places.

[1] For a more comprehensive list of the common forms of failure and erosion, refer to pages 12 and 13 of TRL Overseas Road Note 16, *Principles of low cost engineering in mountainous regions.*

Erosion and failure processes

Each site has a different variety of erosion processes at work, which must be identified before remedial work can be started; often, there will be more than one process affecting each slope segment. A list of the erosion and failure problems is given in Figure 1.7. But remember that most sites, however small, are the result of a combination of these processes. It is assumed that freshly prepared slopes (*i.e.* those just cut or filled) are subject to erosion, and so ***all*** slopes need to be treated.[1]

List the erosion and failure processes at work in each segment of slope and mentally cross-check it against the functions required of the stabilisation measures. Sketch these on paper for your later reference and to help with the design of structures. If you need more details on any aspect of site assessment, refer to Section 2 of the *Reference Manual.*

Other factors

You must identify and note down all of the physical factors affecting a site. Those additional to the basic features of slope segments are listed in Figure 1.8. Some are internal (*e.g.* springs) while others are external (*e.g.* river undercutting).

Slope angle(s)

Record the slope angles and assign each segment to one of three classes: <30°, 30 – 45°, or > 45° Slopes of less than 30° will need only mild treatment;) those falling in the other two classes will require more substantial stabilisation.

Figure 1.9: Common characteristics of well-drained and poorly drained soils

Material drainage characteristics	Tendency towards GOOD drainage	Tendency towards POOR drainage
Overall drainage	Freely draining material; dries quickly after rain storms	Slowly draining material; tends to remain wet for long periods after rain; behaves like firm dahi (curd)
Soil particle size	Coarse textures; loams and sandy soils	Fine textures; clays and silts
Porosity	Large inter-connecting pores	Small pores
Material types	Stony colluvial debris; fragmented rock; sandy and gravelly river deposits	Residual soils of fine texture; debris from mud flows, slumps, *etc*; rato mato (red clay loam soil)
Slope types	Fill slopes; cut slopes in stony debris (**colluvium**)	Cut slopes in original consolidated ground

Slope length

Record the length of each segment of the site as < 15 metres or > 15 metres. A slope length of 15 metres represents a practical dividing line between 'big' and 'small' site segments. Slope segments longer than 15 metres are prone to greater risks, for example of gullying. Also, cost constraints may lead to a compromise over the desired intensity of work. Segments with very long slopes (greater than 30 metres) are singled out for special consideration in step 5 (see Figure 1.11).

Material drainage

This relates to the internal porosity of soils and the likelihood of their reaching saturation, losing cohesion and starting to flow. Materials with poor internal drainage tend to have more clay than sand. They are prone to slumping at a shallow depth (*e.g.* < 500 mm) if they accumulate too much moisture. In such a case, stabilisation requires some kind of drainage in addition to other functions.

For convenience, materials need to be classed only into 'good' or 'poor' drainage. Figure 1.9 provides a guide.

Segment moisture

The moisture regime of the entire site must be considered although, in the field, this can only be estimated. In assessing sites, it is necessary to determine into which of four categories each segment falls.

- Wet: permanently damp sites (*e.g.* north-facing gully sites).
- Moist: sites that are reasonably well shaded or moist for some other reason.
- Dry: generally dry sites.
- Very dry: sites that are very dry; these are usually quite hot as well (*e.g.* south-facing cut slopes at low altitudes).

Figure 1.10 summarises the main factors and how they can be identified.

Altitude

Altitude is the main determinant of temperature in Nepal and therefore regulates the local climate to a large extent. It is necessary to know the altitude to a reasonable degree of accuracy (ideally ± 100 metres) when the actual species are selected for bio-engineering works.

Figure 1.10: Environmental factors indicating site moisture characteristics

Site moisture factor	Tendency towards DAMP sites	Tendency towards DRY sites
Aspect	Facing N, NW, NE and E	Facing S, SW, SE and W
Altitude	Above 1500 metres; particularly above 1800 metres	Below 1500 metres; deep river valleys surrounded by ridges
Topographical location	Gullies; lower slopes; moisture accumulation and seepage areas	Upper slopes; spurs and ridges; steep rocky slopes
Regional rain effects	Eastern Nepal in general; the southern flanks of the Annapurna Himal	Most of Mid Western and Far Western Nepal
Rain shadow effect	Sides of major ridges exposed to the monsoon rain-bearing wind	Deep inner valleys; slopes sheltered from the monsoon by higher ridges to the south
Stoniness and soil moisture holding capacity	Few stones; deep loamy* and silty soils	Materials with a high percentage volume of stones; sandy soils and gravels
Winds	Sites not exposed to winds	Large river valleys and the Terai
Dominant vegetation	*e.g.* amliso, nigalo, bans, chilaune, katus, lali gurans, utis	*e.g.* babiyo, khar, dhanyero, imili, kettuke, khayer, salla

* Loam is the name given to a soil with moderate amounts of sand, silt and clay, and which is therefore intermediate in texture and best for plant growth.

Figure 1.11: Assessing the requirements for civil engineering treatments

Question	Functional implication	Action if the answer is "yes"	Use of bio-engineering
Is the slope segment or the whole site subject to a deep-seated (>1 metre depth) shear (rotational) failure?	Major reinforcing, anchoring or physical support required.	If the failure plane can be identified, use conventional civil retaining walls to support the toe. Alternatively, it may be possible to remove weight from higher up on the slope by heavy trimming.	Bio-engineering measures will mainly be used to armour backfill and foundation areas. If trimming is carried out, bio-engineering measures will be needed to armour the new bare surfaces.
Is the slope segment very long (greater than about 30 metres), steep and in danger of a mass failure below the surface?	Reinforcing or physical support is required. Armouring is also required. Bio-engineering measures alone may be adequate, but where a large volume of surface runoff is possible, physical structures are also necessary.	If suitable foundations are available, use retaining walls to break the slope into smaller, more stable lengths. Some other kind of physical scour check should be used, such as wire bolster cylinders.	Bio-engineering measures must be designed to reinforce and armour the slope between the physical structures.
Is the foot of the slope undermined, threatening higher segments or the whole slope above?	Strong physical support is required. Bio-engineering measures will enhance civil structures.	Investigate the necessity of building revetment, toe or prop walls.	Bio-engineering measures will mainly be used to armour backfill and foundation areas.
Is there a distinct overhang or are there large boulders poorly supported by a soft, eroding band?	Localised physical support or anchoring are required. Support can be given using a civil structure.	Consider prop walls or **dentition** to support the overhang.	The direct seeding of shrubs on fragmented rocky slopes can provide anchorage.
Does the slope segment have a rough surface; or is it covered in loose debris; or is it a fractured rocky slope; or does it have any very steep or overhanging sections, however small?	Armouring is required, but only after the slope has been altered to stop it shedding loose material.	Trim the slope as far as possible to attain a smooth, clean surface with a straight profile in cross-section.	The trimmed slope will need to be armoured afterwards by the appropriate bio-engineering measure.
Is there water seepage, a spring or groundwater on the site, or a danger of mass slumping after heavy rain?	Deep drainage is required.	Investigate the need for a drainage system involving french or other sub-surface drains, depending on site conditions.	Deep drains can be enhanced by surface bio-engineering systems (*e.g.* downslope planted grass lines).
Is the slope made up of poorly drained material, with a high clay content?	Techniques used on this sort of material must be designed to drain rather than accumulate moisture.	There is a danger of shallow slumping. Investigate the need for a surface drainage system.	An appropriate bio-engineering system (*e.g.* downslope planted grass lines) is often adequate on its own.
Is the site a major gully, subject to occasional erosive torrents of water?	Major drainage is already present; heavy armouring is required.	Use masonry check dams to reduce the **scouring** effect.	Between the check dams, use large bamboo planting, live check dams or vegetated stone pitching.

STEP 5: DETERMINE CIVIL ENGINEERING WORKS

At this stage, standard civil engineering structures (*e.g.* gabion and other types of retaining structures, breast walls, prop walls and revetments; check dams; masonry drainage systems) should be considered. In later stages, small-scale civil engineering structures used only for surface protection (*i.e.* stone pitching and jute netting) are considered as options where appropriate.

Some sites will not require the building of structures, but will instead be stabilised using only bio-engineering techniques. In most cases, however, bio-engineering techniques will also be employed to enhance the effectiveness of civil engineering structures. The series of questions in Figure 1.11 helps to simplify the process of assessing the requirements for major civil engineering treatments. These must be integrated with bio-engineering measures, but normally need to be implemented first.

If civil engineering structures are to be used, they must be designed and constructed according to normal practice. Apart from the key design details referred to in Section 2, these are beyond the scope of this manual. A useful reference work is TRL Overseas Road Note 16, *Principles of low cost road engineering in mountainous terrain.*

The next step concentrates on shallow (< 500 mm depth) stabilisation and surface protection using bio-engineering techniques, and on areas around civil engineering structures.

How to use the flow chart in Figure 1:12
There are two methods: either

1. Use it as a prescriptive system to determine the treatments required, based on the site assessment described in step 4; or
2. If you have already determined a treatment, use it to check that your choice is suitable against normal practice.

STEP 6: CHOOSE THE RIGHT BIO-ENGINEERING TECHNIQUES

Having completed step 5, any deeper-seated problems will have been addressed by conventional civil engineering measures, such as retaining walls and drainage systems. This step gives details of bio-engineering and other related techniques for protecting the surface, stabilising the upper 500 mm, and improving surface drainage; and for enhancing and protecting large civil engineering structures. These are required as part of the whole stabilisation package; bio-engineering must be fully integrated with any civil engineering structures.

The flowchart in Figure 1.12 suggests appropriate techniques for different slope segments. It is assumed that these are combined with appropriate civil engineering structures where necessary to enhance slope stability. Many factors determine the optimum technique or combination of techniques, but only the most important have been included here.

The seven columns in Figure 1.12, (a) to (g), are summarised below.

(a) Slope angle(s)
3 classes: <30°, 30 – 45°, or >45° (measured in step 4).

(b) Slope length
2 classes: <15 metres or >15 metres (measured in step 4).

(c) Material drainage
2 classes: good or poor (estimated in step 4).

(d) Site moisture
2 classes: wet/moist or dry/very dry (combined from the four estimated in step 4).[1]

(e) Potential problems
The potential problems to be encountered on each slope segment have been identified in step 4.

(f) Function required
Once you have assessed the most likely potential problems on a slope segment you can select the most appropriate engineering functions required (*i.e.* catch, armour, reinforce, anchor, support or drain) for each segment. . In bio-engineering, the functions required by the treatment determine

[1] The four classes determined in step 4 (as well as the altitude of the site) are required to establish the actual species to be used for bio-engineering, in step 8.

Figure 1.12: Choosing a bio-engineering technique

START (a) SLOPE ANGLE	→ (b) SLOPE LENGTH	→ (c) MATERIAL DRAINAGE	→ (d) SITE MOISTURE	→ (e) PREVIOUS/POTENTIAL PROBLEMS‡	→ (f) FUNCTIONS REQUIRED	→ (g) TECHNIQUE(S)
> 45°	> 15 metres	Good	Damp	Erosion, slumping	Armour, reinforce, drain	**Diagonal grass lines**
			Dry	Erosion	Armour, reinforce	**Contour grass lines**
		Poor	Damp	Slumping, erosion	Drain, armour, reinforce	1 **Downslope grass lines and vegetated stone pitched rills** or 2 Chevron grass lines and vegetated stone pitched rills
			Dry	Erosion, slumping	Armour, reinforce, drain	**Diagonal grass lines**
	< 15 metres	Good	Any	Erosion	Armour, reinforce	1 **Diagonal grass lines** or 2 Jute netting and randomly planted grass
		Poor	Damp	Slumping, erosion	Drain, armour, reinforce	1 **Downslope grass lines** or 2 Diagonal grass lines
			Dry	Erosion, slumping	Armour, reinforce, drain	1 **Jute netting and randomly planted grass** or 2 Contour grass lines or 3 Diagonal grass lines
30° – 45°	> 15 metres	Good	Any	Erosion	Armour, reinforce, catch	1 **Horizontal bolster cylinders and shrub/tree planting** or 2 Downslope grass lines and vegetated stone pitched rills or 3 Site grass seeding, mulch and wide mesh jute netting
		Poor	Any	Slumping, erosion	Drain, armour, reinforce	1 **Herringbone bolster cylinders & shrub/tree planting** or 2 Another drainage system and shrub/tree planting
	< 15 metres	Good	Any	Erosion	Armour, reinforce, catch	1 **Brush layers of woody cuttings** or 2 Contour grass lines or 3 Contour fascines or 4 Palisades of woody cuttings or 5 Site grass seeding, mulch and wide mesh jute netting
		Poor	Any	Slumping, erosion	Drain, armour, reinforce	1 **Diagonal grass lines** or 2 Diagonal brush layers or 3 Herringbone fascines and shrub/tree planting or 4 Herringbone bolster cylinders & shrub/tree planting or 5 Another drainage system and shrub/tree planting
< 30°	Any	Good	Any	Erosion	Armour, catch	1 **Site seeding of grass and shrub/tree planting** or 2 Shrub/tree planting
		Poor	Any	Slumping, erosion	Drain, armour, catch	1 **Diagonal lines of grass and shrubs/trees** or 2 Shrub/tree planting
	< 15 metres	Any		Erosion	Armour, catch	**Turfing and shrub/tree planting**
	Base of any slope			Planar sliding or shear failure	Support, anchor, catch	1 **Large bamboo planting** or 2 Large tree planting
Special conditions						
Any *	Any *	Any *	Any *	Planar sliding, shear failure	Reinforce, anchor	**Site seeding of shrubs/small trees** †
> 30°	Any	**Any rocky material**		Debris fall	Reinforce, anchor	**Site seeding of shrubs/small trees**
Any loose sand		Good	Any	Erosion	Armour	**Jute netting and randomly planted grass**
Any rato mato		Poor	Any	Erosion, slumping	Armour, drain	**Diagonal lines of grass and shrubs/trees**
Gullies ≤ 45°		**Any gully**		Erosion (major)	Armour, reinforce, catch	1 **Large bamboo planting** or 2 Live check dams or 3 Vegetated stone pitching

* Possible overlap with parameters described in the rows above. † May be required in combination with other techniques listed on the rows above. ‡ Only the common potential problems listed in Figure 1.7 are given here. 'Any rocky material' is defined as material into which rooted plants cannot be planted, but seeds can be inserted in holes made with a steel bar. 'Any loose sand' is defined as any slope in a weak, unconsolidated sandy material. Such materials are normally river deposits of recent geological origin. 'Any rato mato' is defined as a red soil with a high clay content. It is normally of clay loam texture, and formed from prolonged weathering. It can be considered semi-lateritic. Techniques in **bold type** are preferred. Chevron pattern: <<<<< (like a sergeant's stripes). Herringbone pattern: <<<<<< (like the bones of a fish).

the plant types used and the way they are propagated. This is given in detail in step 8.

(g) Techniques

One or more techniques that are known to be successful on sites for each category are given. However, the general picture may not cover every case and so this flowchart cannot be considered to be fully comprehensive: some local variation may be needed and this, of course, is the reason for having an engineer on site.

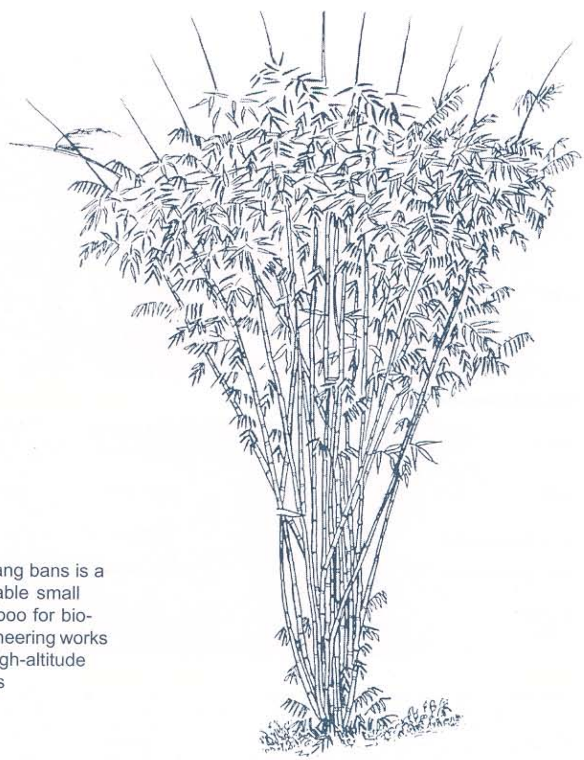
Once this step has been completed, it is possible to move on to the detailed design of the works for each site

STEP 7: DESIGN THE CIVIL AND BIO-ENGINEERING WORKS

Design the civil and bio-engineering works using normal procedures. It is more cost effective to design the works so that they are carried out in a fully integrated way. As usual, you should bear in mind the resources and budget available for the work. Make the designs as detailed as you can at this stage.

Practical design considerations for the most common civil engineering structures are given in Section 2.

Details of the design of bio-engineering works are given in Section 3.



Padang bans is a valuable small bamboo for bio-engineering works on high-altitude roads

STEP 8: SELECT THE SPECIES TO USE

It is important to select the right species for use in each bio-engineering technique. To do this there are three factors to consider: **function/technique**, **propagation** and **site suitability**.

Function/technique

Having worked through the previous steps, you will have determined the functions required for each slope segment and will now have identified the techniques you need to use. The most appropriate class of plant to use depends on the techniques. These are summarised in Figure 1.13, but are also shown in the table listing the main bio-engineering species (Figure 1.14).

Propagation

There are various methods of propagation appropriate for the main plant classes, but individual species can be propagated only by certain of these methods. The method of propagation to be used is often determined by the function required and the bio-engineering technique being used. For example, if grass lines are to be planted, the species chosen must be capable of propagation from slip cuttings; if brush layering, palisades or fascines are to be used, the shrubs or small trees must be capable of growing from hardwood cuttings.

Site suitability

Whatever the function and propagation method required of the plants by the bio-engineering technique, the plants selected must be able to grow in the site being treated. The suitability of each species to their growing sites is complex, but there are some straightforward rules that simplify the matter. The three main aspects of the environment affecting plant growth are as follows.

- Temperature. This is very closely related to altitude for most of Nepal. In choosing the species, therefore, the site altitude measured in step 4 is used.
- Moisture. This is very difficult to quantify. It was assessed in step 4 for the site and classed as one of wet, moist, dry or very dry. This is now used to choose the species.
- Nutrients. The main species used in bio-engineering are all tolerant of very poor soils. Therefore the nutrition factor can be ignored at this stage.

The final choice of species according the technique for which it is to be used, and the site characteristics of altitude and moisture, is made by reference to Figure 1.14.

Figure 1.13: Bio-engineering techniques and appropriate plant classes

Techniques	Plant class to use	Page reference to Figure 1.14	
Planted grass lines (all configurations) and vegetated stone pitching gully beds	Grasses grown from slip/rhizome cuttings	page	28
Brush layers, palisades, live check dams, fascines and vegetated stone pitching walls	**Shrubs***/small trees grown from hardwood cuttings	Page	30
Large bamboo planting	Large bamboos	Page	33
Site seeding with grass	Grasses grown from seed	Page	29
Turfing	Small **sward** grasses	Page	29
Site seeding with shrubs/small trees	Robust shrubs/small trees grown from seeds	Page	32
Shrub/small tree planting	Shrubs/small trees (grown from seeds/polypots)	Page	31
Large tree planting	Large trees (grown from seeds/polypots)	Page	31

* A shrub is a woody plant with multiple stems growing up from the ground; a tree has usually one stem growing up from the ground. For bio-engineering purposes, shrubs and small stature trees have the same functions, since the rooting patterns tend to be similar.

Figure 1.14: Selection of species for bio-engineering by groups of techniques

Planted grass lines (all configurations) and Vegetated stone pitching gully beds

These grasses are grown from slip or rhizome cuttings

MOISTURE / ALTITUDE	WET	MOIST	DRY	VERY DRY
		Grasses		
2500 – 2000 m	Padang bans Tite nigalo bans	Padang bans Phurke Tite nigalo bans	Tite nigalo bans	
2000 –1500 m	Amliso Kans Katara khar Padang bans Phurke Tite nigalo bans	Amliso Babiyo Kans Katara khar Khar Padang bans Phurke Tite nigalo bans	Amliso Babiyo Kans Katara khar Khar Phurke Tite nigalo bans	Babiyo Kans Khar
1500 – 1000 m	Amliso Kans Katara khar Khus Phurke Sito Tite nigalo bans	Amliso Babiyo Dhonde Kans Katara khar Khar Khus Narkat Phurke Sito Tite nigalo bans	Amliso Babiyo Dhonde Kans Katara khar Khar Khus Narkat Phurke Sito	Babiyo Dhonde Kans Khar Narkat
1000 – 500 m	Amliso Kans Katara khar Khus Phurke Sito	Amliso Babiyo Dhonde Kans Katara khar Khar Khus Narkat Phurke Sito	Amliso Babiyo Dhonde Kans Katara khar Khar Khus Narkat Phurke Sito	Babiyo Dhonde Kans Khar Narkat
500 m –Terai	Amliso Kans Katara khar Khus Sito	Amliso Babiyo Dhonde Kans Katara khar Khar Khus Narkat Sito	Amliso Babiyo Dhonde Kans Katara khar Khar Khus Narkat Sito	Babiyo Dhonde Kans Khar Narkat

This table gives the main species used for bio-engineering in Nepal. A range of plants is available for each particular location.A list of all tested bio-engineering species is given in Annex B. Full details of the main bio-engineering species are given in the *Reference Manual*

Figure 1.14: Selection of species for bio-engineering by groups of techniques

Species for grass seeding and turfing

Moisture / Altitude	Wet		Moist		Dry		Very dry	
	Clump grasses(for seeding)	Small sward grass(for turfing)	Clump grasses(for seeding)	Small sward grass(for turfing)	Clump grasses(for seeding)	Small sward grass(for turfing)	Clump grasses(for seeding)	Small sward grass(for turfing)
2500 – 2000 m								
2000 – 1500 m	Kans Katara khar Phurke	Dubo	Babiyo Kans Katara khar Khar Phurke	Dubo	Babiyo Kans Katara khar Khar Phurke	Dubo	Babiyo Kans Khar	
1500 – 1000 m	Kans Katara khar Phurke Sito	Dubo	Babiyo Dhonde Kans Katara khar Khar Phurke Sito	Dubo	Babiyo Dhonde Kans Katara khar Khar Phurke Sito	Dubo	Babiyo Dhonde Kans Khar	
1000 – 500 m	Kans Katara khar Phurke Sito	Dubo	Babiyo Dhonde Kans Katara khar Khar Phurke Sito	Dubo	Babiyo Dhonde Kans Katara khar Khar Phurke Sito	Dubo	Babiyo Dhonde Kans Khar	
500 m – Terai	Kans Katara khar Sito	Dubo	Babiyo Dhonde Kans Katara khar Khar Sito	Dubo	Babiyo Dhonde Kans Katara khar Khar Sito	Dubo	Babiyo Dhonde Kans Khar	

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STEP 9: CALCULATE THE REQUIRED QUANTITIES AND RATES

Calculate the quantities and rates required for the works. This is a standard procedure and, for work by the Department of Roads, must follow the schedules established by the government for this purpose.

Rate analysis norms for bio-engineering are given in the *Reference Manual.*

STEP 10: FINALISE PRIORITY AGAINST AVAILABLE BUDGET

You can now finalise the work to be undertaken in the year's programme. This entails determining the right balance between the resources available and the seriousness of the failures on the sites that need to be stabilised.

The prioritisation made in step 2 showed how important it is to stabilise each site. This should be re-examined to check that the higher priority sites can all be covered. In certain cases it may be necessary to return to steps 7 and 8, to reconsider the design of the civil and bio-engineering works with a view to reducing costs and covering more sites.

Figure 1.14: Selection of species for bio-engineering by groups of techniques

Species for brush layers, palisades, live check dams, fascines and vegetated stone pitching walls

Shrubs/small trees grown from hardwood cuttings

Moisture	Wet		Moist		Dry		Very dry	
Altitude	**Shrubs/ small trees**	**Large trees ***	**Shrubs/ small trees**	**Large trees ***	**Shrubs/ small trees**	**Large trees ***	**Shrubs/ small trees**	**Large trees ***
2500 – 2000 m	Bainsh	Phaledo	Bainsh	Phaledo		Phaledo		
2000 – 1500 m	Bainsh Namdi phul	Phaledo	Bainsh Namdi phul	Phaledo	Namdi phul	Phaledo		
1500 – 1000 m	Bainsh Namdi phul Saruwa/ bihaya	Dabdabe Phaledo	Bainsh Kanda phul Namdi phul Saruwa/ bihaya Simali	Dabdabe Phaledo	Kanda phul Namdi phul Saruwa/ bihaya Simali	Phaledo		
1000 – 500 m	Assuro Bainsh Kanda phul Saruwa/ bihaya Simali	Dabdabe	Assuro Bainsh Kanda phul Saruwa/ bihaya Simali	Dabdabe	Assuro Kanda phul Saruwa/ bihaya Simali	Dabdabe	Assuro Kanda phul	
500 m – Terai	Assuro Bainsh Kanda phul Saruwa/ bihaya Simali	Dabdabe	Assuro Bainsh Kanda phul Saruwa/ bihaya Simali	Dabdabe	Assuro Kanda phul Saruwa/ bihaya Simali	Dabdabe	Kanda phul	

* Required for live check dams only

This table gives the main species used for bio-engineering in Nepal. A range of plants is available for each particular location. A list of all tested bio-engineering species is given in Annex B. Full details of the main bio-engineering species are given in the *Reference Manual.*

STEP 11: PLAN PLANT NEEDS

Calculate the exact need for plants for the bio-engineering works. This can be done with reference to Section 3, which gives the plant spacings for each of the bio-engineering techniques. This will allow you to list the precise plant requirements for the programme. In turn, this is what must be produced by your nurseries, provided by the contractors or obtained from elsewhere.

It is standard practice when planning the growing of plants in a nursery to allow for losses during production. This is covered in Section 4. Therefore at this stage you should calculate the exact site needs, and you do not need to add an allowance for losses before the plants reach site. It may, however, be useful to add a contingency quantity of plants in case site conditions vary from those expected, and more plants are required.

Figure 1.14: Selection of species for bio-engineering by groups of techniques

Species for shrub/small tree planting and large tree planting

Shrubs/trees grown from seeds/polypots

Moisture Altitude	Wet		Moist		Dry		Very dry	
	Shrubs/ small trees	Large trees	Shrubs/ small trees	Large trees	Shrubs/ small trees	Large trees	Shrubs/ small trees	Large trees
2500 – 2000 m		Lankuri Painyu Rato siris Utis		Gobre salla Lankuri Rato siris Utis		Gobre salla Lankuri Rato siris Utis		Gobre salla
2000 – 1500 m		Chilaune Khanyu Lankuri Painyu Rato siris Utis	Keraukose	Bakaino Chilaune Gobre salla Khanyu Lankuri Painyu Rani salla Rato siris Utis	Keraukose	Bakaino Chilaune Gobre salla Khanyu Painyu Rani salla Rato siris Utis	Keraukose	Bakaino Gobre salla Khanyu Rani salla
1500 – 1000 m	Keraukose	Chilaune Khanyu Lankuri Painyu Rato siris Seto siris Utis	Areri Dhanyero Kanda phul Keraukose Tilka	Bakaino Chilaune Khanyu Painyu Rani salla Rato siris Seto siris Sisau Utis	Areri Dhanyero Kanda phul Keraukose Tilka	Bakaino Chilaune Khanyu Painyu Rani salla Rato siris	Areri Dhanyero Kanda phul Keraukose Tilka	Bakaino Khanyu Rani salla
1000 – 500 m	Dhanyero Dhusun Keraukose Tilka	Khanyu Painyu Rato siris Seto siris Sisau Utis	Areri Dhanyero Dhusun Kanda phul Keraukose Tilka	Bakaino Kalo siris Khanyu Painyu Rani salla Seto siris Sisau	Areri Dhanyero Dhusun Kanda phul Keraukose Tilka	Bakaino Kalo siris Khanyu Khayer Painyu Rani salla Sisau	Areri Dhanyero Dhusun Keraukose Tilka	Bakaino Kalo siris Khanyu Khayer Rani salla Sisau
500 m-Terai	Dhanyero Dhusun Keraukose Tilka	Khanyu Seto siris Sisau	Dhanyero Dhusun Kanda phul Keraukose Tilka	Bakaino Kalo siris Khanyu Seto siris Sisau	Dhanyero Dhusun Kanda phul Keraukose Tilka	Bakaino Kalo siris Khanyu Khayer Sisau	Dhanyero Dhusun Keraukose Tilka	Bakaino Kalo siris Khanyu Khayer

This table gives the main species used for bio-engineering in Nepal. A range of plants is available for each particular location. A list of all tested bio-engineering species is given in Annex B. Full details of the main bio-engineering species are given in the *Reference Manual*.

STEP 12: ARRANGE IMPLEMENTATION AND PREPARE DOCUMENTS

In this step, the question as to whether the works are to be carried out by contract or through a direct labour force is considered. Both have advantages in different situations. Small-scale works are normally best done through daily-rated labour. Both the government regulations and the private sector in Nepal provide considerable flexibility for either system.

Whichever method of implementation is chosen, it is necessary at this stage to prepare the appropriate documentation for the works to be undertaken. For contracting, standard specifications for bio-engineering are given in the *Reference Manual.* Standard specifications for civil engineering structures are also available from the Department of Roads.

Figure 1.14: Selection of species for bio-engineering by groups of techniques

Species for seeding (on site) with shrubs/small trees or large trees

Robust plants grown from seeds

Moisture	Wet		Moist		Dry		Very dry	
Altitude	Shrubs/ small trees	Large trees	Shrubs/ small trees	Large trees	Shrubs/ small trees	Large trees	Shrubs/ small trees	Large trees
2500 – 2000 m		Utis *		Gobre salla Utis *		Gobre salla Utis *		Gobre salla
2000 – 1500 m		Khanyu * Utis *	Keraukose	Bakaino Gobre salla Khanyu * Rani salla Utis *	Keraukose	Bakaino Gobre salla Khanyu * Rani salla Utis *	Keraukose	Bakaino Gobre salla Khanyu * Rani salla
1500 – 1000 m	Bhujetro Keraukose	Khanyu * Utis *	Areri Bhujetro Keraukose	Bakaino Khanyu * Rani salla Sisau Utis *	Areri Bhujetro Keraukose	Bakaino Khanyu * Rani salla	Areri Bhujetro Keraukose	Bakaino Khanyu * Rani salla
1000 – 500 m	Bhujetro Keraukose	Khanyu * Sisau Utis *	Areri Bhujetro Keraukose	Bakaino Kalo siris Khanyu * Rani salla Sisau	Areri Bhujetro Keraukose	Bakaino Khanyu * Khayer Rani salla Sisau	Areri Bhujetro Keraukose	Bakaino Khanyu * Khayer Rani salla Sisau
500 m – Terai	Keraukose	Khanyu * Sisau	Keraukose	Bakaino Khanyu * Sisau	Keraukose	Bakaino Khanyu * Khayer Sisau	Keraukose	Bakaino Khanyu * Khayer

* Utis and khanyu should be seeded by broadcasting (Broadcasting is where seed is thrown over the surface in as even a way as possible, but forming a totally random, loose cover) only. The other species have larger seeds and can be direct seeded (direct seeding is where seeds are sown carefully by hand into specific locations in a slope, such as in gaps between fragmented rock).

This table gives the main species used for bio-engineering in Nepal. A range of plants is available for each particular location. A list of all tested bio-engineering species is given in Annex B. Full details of the main bio-engineering species are given in the *Reference Manual*.

STEP 13: PREPARE FOR PLANT PROPAGATION

There are three main considerations in producing plants.

- Seeds must be collected for the grasses, shrubs and trees that are needed for the programme (step 11). Seed collection times for bio-engineering plants are given in Annex B. The timing of this operation is critical (for obvious biological reasons) and orders must be placed in time. The calculation of the required seed quantities is given in Section 4.
- Fill grass slip beds with stock to give sufficient of the right species of plants. Section 4 gives all the details of grass bed preparation and production in nurseries.
- Nurseries must be checked to make sure that they have all the resources necessary for the production season. Below about 1200 metres, nurseries should be prepared in Mangsir and Poush (mid November to mid January) for growth and production to start in Falgun (February). Section 4 provides the details for nursery preparation and production.

Higher altitude nurseries need a longer phase of production. Above about 1500 metres, and certainly above 1800 metres, most plants need to grow for a year in the nursery. Plants raised from seeds sown in Shrawan (July-August) of one year will be planted out on site in Ashad (June-July) of the following year. Nurseries between 1200 and 1800 metres must be planned on an individual basis depending on the particular local micro-climate. Some nurseries in this zone take six months and some take a year to produce usable plants.

Figure 1.14: Selection of species for bio-engineering by groups of techniques

Species for large bamboo planting

Moisture / Altitude	Wet	Moist	Dry	Very dry
		Large bamboos		
2500 – 2000 m	Kalo bans	Kalo bans	Kalo bans	
2000 –1500 m	Choya bans Kalo bans Nibha bans	Choya bans Kalo bans Nibha bans	Kalo bans Nibha bans	
1500 – 1000 m	Choya bans Dhanu bans Kalo bans Mal bans Nibha bans Tharu bans	Choya bans Dhanu bans Kalo bans Mal bans Nibha bans Tharu bans	Mal bans Nibha bans Tharu bans	
1000 – 500 m	Choya bans Dhanu bans Mal bans Tharu bans	Choya bans Dhanu bans Mal bans Tharu bans	Mal bans Tharu bans	
500 m –Terai	Dhanu bans Mal bans Tharu bans	Dhanu bans Mal bans Tharu bans	Mal bans Tharu bans	

This table gives the main species used for bio-engineering in Nepal. A range of plants is available for each particular location. A list of all tested bio-engineering species is given in Annex B. Full details of the main bio-engineering species are given in the *Reference Manual*

STEP 14: MAKE THE NECESSARY SITE ARRANGEMENTS

The final part of the design phase involves issuing the necessary instructions for site responsibilities and quality control. Check that all staff understand the designs for every part of the site works, and that they know the implementation programme and where their responsibilities lie.

If contractors are being employed, it is also necessary to finalise the liability for defect repair if this has not already been established in the contract. It may be necessary to make special arrangements if different civil engineering works and bio-engineering contractors are being used on the same sites.

At this stage it is also necessary to check that safety measures are understood and will be complied with. See page 10 for a *Safety Code of Practice for Working on Slopes.*

Kanda phul can be grown from hardwood cuttings and prefers dry sites between 500m and 1500m altitude

STEP 15: PREPARE THE SITE

Before civil engineering structures can be put in place and bio-engineering treatments applied, the site must be properly prepared. The surface should be clean and firm, with no loose debris. It must be trimmed to a smooth profile, with no vertical or overhanging areas. The object of trimming is to create a semi-stable slope with an even surface, as a suitable foundation for subsequent works.

Trim slopes to a straight profile, with a slope angle of between 30° and 60°. (In certain cases the angle will be steeper, but review this carefully in each case.) Never produce a pronounced convex or concave profile; these are prone to failure starting at a steep point. Trim off steep sections of slope, whether at the top or bottom. In particular, avoid convex profiles with 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. If removing indentations would cause an unacceptably large amount of work, excavate them carefully and build a prop wall.

In plan, a trimmed slope does not need to be straight. An irregular plan view is acceptable and, in most cases, reduces costs because protrusions do not need to be removed.

Remove all debris and loose material from the slope surface and toe to an approved tipping site. If there is no toe wall, the entire finished slope must consist of undisturbed material.

Where toe walls form the lower extreme of the slopes to be trimmed, you can use the debris for backfilling. Where backfilling is practised, compact the material in layers, 100 to 150 mm thick and sloping back at about 5°, by ramming it thoroughly with tamping irons. This must be done while the material is moist.

Dispose of excess spoil carefully, in an approved tipping site. Just throwing it over the nearest valley side wall is not good enough. Much slope instability and erosion is caused in this way. Always include adequate provision in your estimates for haulage to an approved safe tipping area.

Trimming slopes

To trim slopes effectively, follow these steps.

1 Check that all prior construction work has been completed and that the site is clear of equipment.

A carefully prepared site has more chance of reaching stability

2 Define the type of site. Possibilities are as follows: minor trimming required only on part of site; keeping rill or gully pattern in plan section; trimming to a new designed plan section; new retaining wall to be backfilled.

3 Make a site visit and explain to the site staff and workers exactly what the finished site should look like. Draw sketches to ensure their understanding.

4 Ensure that there is safe access to the site. On very steep slopes, make new paths if necessary. Make sure that ropes or ladders are provided. When trimming a site, always work from the top of the site, moving down the slope. Check that all safety requirements have been fulfilled (refer to the section on safety in the Introduction, pages 10 and 11).

5 Carry out a trimming survey. Put in pegs and lines as necessary.

6 Cut notches through the mass to be trimmed to give the final cut lines.

7 Trim in steps from the top, using the steps as ledges for the labourers to stand on during trimming.

8 If backfilling is required behind a retaining structure below, compact the trimmed material as you go. This will require halting the trimming, redistributing and compacting the debris as backfill. Compact in level layers approximately 100 – 150 mm thick, laid back into the slope at about 5°. If possible, add water while compacting the material.

Trimming should be done logically, to remove as much or as little as necessary. On this slope, the weaker material has been trimmed ready for glass planting, while a hard rock outcrop has been left intact

9 Complete the main trim. Then go back to the top of the slope and work down again, carrying out the final trim. This should give a clean, smooth surface, good enough for vegetation to be planted on.

10 Check the final trim line. If protrusions or indentations remain, go back and re-do those parts; if the profile is satisfactory, clean all debris off the slope finally and tidy up.

11 Dispose of excess spoil safely (see below).

Spoil disposal

However much care is taken to minimise quantities of spoil, it cannot be eliminated altogether. Controlling the disposal of spoil is very important, because it can give rise to a variety of problems, including:

- erosion of the spoil tip itself;
- the smothering or removal of natural vegetation. Once stripped of plant and soil cover, slopes usually take three to five years to re-vegetate, and as many as 10 years on steeper and more sterile slopes;
- instability within the spoil material itself, especially when infiltrated by water;
- overloading and resultant failure of the slope;

Even on valley alignments, spoil tipping must be carefully controlled. This debris should have been pushed down to the river; left like this, it surcharged the slope and contributed to a slide

- disruption of existing runoff patterns and siltation of water courses and drainage channels;
- disruption to agricultural practices.

You can minimise spoil problems by taking two steps. The first is to identify those operations that will generate spoil, the places where it will be generated and the quantities involved, no matter how small. The second is to plan for its disposal by designating safe tipping sites.

You are responsible for designating suitable sites, and your criteria for their selection should aim to avoid the problems listed above. When construction is being undertaken through a conventional construction contract, you should ensure that both the contractor and the construction workforce are aware of the restrictions on the disposal of spoil, the location of approved spoil disposal sites and specific requirements for the management of these sites. Strictly enforce contract specifications regarding spoil disposal.

You may choose either to discard spoil, or to turn it into landfill. Observe the following guidelines:

- when you are creating a landfill site, make maximum use of terraces, level ground and spurs;
- if spoil tipping has to be done on steep slopes, select areas formed in resistant bedrock. Tipping should result in no more than the removal of vegetation and shallow soil, with negligible slope incision thereafter. Bitumen drum disposal chutes can be used to convey the spoil down a short slope to a safe site below;
- build many small spoil benches rather than a few large ones, to avoid slope overloading;
- provide a drainage blanket beneath a spoil bench where there is any indication of a spring seepage at or near the spoil site;
- compact spoil benches during construction. While benches cannot be compacted in the formal sense, you can construct them in definite lifts normally not more than 0.5 m thick, with the top surface of each lift approximately horizontal. This will allow machines involved in spreading the spoil to track the surface and provide some degree of compaction;
- where spoil benches are constructed on agricultural land, form the tip into a benched profile so that it can eventually be returned

to agricultural production. In the meantime, the risers between levels must be protected against erosion by applying vegetation or constructing dry stone walls;

- where the top surface of the bench is large, reduce runoff by providing regular shallow interceptor drains. The slope of these drains should be constant as far as is practicable and should not be so steep as to induce erosion;
- on completion, leave spoil benches in their required shape and plant them with grasses, shrubs and trees to encourage maximum stability and resistance to erosion.

Careless spoil disposal on long, steep slopes can cause very extensive damage

Do not permit the following:

- tipping of spoil into stream channels other than major rivers, as the increased sediment load will lead to scour and siltation downstream;
- tipping of spoil on to slopes where road alignments, housing areas or farmland downslope might be affected;
- use of areas of past or active instability and erosion as tip sites, unless they are at least 50 metres from the road;
- the discharge of runoff over the loose front edge of a tip bench during or after construction;
- tipping of spoil in front of road retaining walls, where impeded drainage could soften the wall foundation.

Figure 1.15. Checklist to assess the quality of bio-engineering site works

Type of works	Signs of good works
Individual plants	A bright, healthy colour. Showing no signs of wilting. Well proportioned (*i.e.* not stunted or very tall and thin). Growing fast, with a number of long new shoots. Without signs of discoloration on the leaves. Without signs of insect attack on the leaves or shoots (*e.g.* holes eaten in the leaves). Without any obvious signs of disease. Undamaged. Not yellowed, except in the later part of the dry season.
Whole sites	Completely treated, with no gaps or areas missed out. Evenly covered. Fully tidied up, with no loose debris on the slope. Showing no signs of instability. Stable enough to survive the early rains while plants get established. Generally looking good, complete and healthy throughout.
Grass lines	Complete, with plants at the spacing specified within the rows. The right distance between the rows, according to specification. Even, with no gaps or poor plants in them. Straight, according to specification.
Brush layers and palisades	Complete, with the right number of cuttings per running metre. The right distance between the lines, according to specification. Even, with no gaps or dead cuttings. Straight, according to specification.
Fascines (minor excavations needed to check)	Complete, with the right number of cuttings per running metre. The right distance between lines, according to specification. Straight, according to specification.

STEP 16: IMPLEMENT THE CIVIL ENGINEERING WORKS

Civil engineering works must be completed before the start of the rainy season. This usually disrupts work seriously from Jestha (May-June) onwards. Hence the calendar in Figure 1.4 (step 15) suggests carrying out site preparation works in Magh (January-February), and implementing the civil engineering works between Falgun and Baisakh (mid February to mid May).

All works must be carried out to a high standard. For this it is necessary to ensure that adequate site supervision and monitoring are provided.

Dressing stone during the construction of dry stone dentition

STEP 17: IMPLEMENT THE BIO-ENGINEERING WORKS

The actual implementation of bio-engineering site works normally begins in Ashad (late June). However, this depends on the onset of reliable monsoon rains. In the east of Nepal it may be slightly earlier, perhaps even in Jestha; and in the far west a little later, perhaps not until the second half of Ashad. The start should usually coincide with the time when farmers start to plant rice on non-irrigated khet land in the local area.

As usual, it is necessary to provide adequate site supervision to ensure that the works are carried out to the highest possible standard. Section 3 gives the construction steps for all bio-engineering techniques.

STEP 18: MONITOR THE WORKS

Check that the works have been completed to a high standard on the site. Figure 1.15 gives a simple checklist for assessing the quality of bio-engineering works. It is not fully comprehensive, but gives the main indicators to look for.

If the plants are being attacked by animals, or are likely to be, provide protection. Move on to step 19 to plan the maintenance inputs required by each site.

Grass planting on an eroded landslide scar. The supervisor is monitoring the works closely

STEP 19: MAINTAIN THE WORKS

The maintenance of bio-engineering sites is part of *roadside support maintenance*. This is split between *routine* and *preventative* maintenance activities.

The maintenance of roadside vegetation should be planned to ensure that maximum benefit is attained from the existing infrastructure. Most maintenance activities have to be carried out at a specific time of year. You should consider each site independently because maintenance interventions are site-specific for each slope in each roadside area.

In order to plan roadside support maintenance carefully, it is necessary to follow these steps.

(a) Devise a schedule of checks for all roadside support maintenance activities (i.e. list the maintenance tasks and the intervention times).

(b) Devise a schedule of sites for each check.

(c) Carry out the checks punctually at the allotted times for every selected area.

(d) Monitor the programme to ensure that the maintenance takes place as required.

The calendar in Figure 1.16 summarises the timing for the recommended bio-engineering maintenance operations.(Full details of bio-engineering maintenance are given in Section 5.)

WHERE TO FIND MORE INFORMATION

In this site handbook, more information is given on each step. However, because of the large amount of information, the handbook is split up into a series of technical sections from this point on. The main sections are as follows.

Section 2 Civil engineering techniques: design features of the main civil engineering works and construction details of the smaller scale techniques not covered by other manuals.

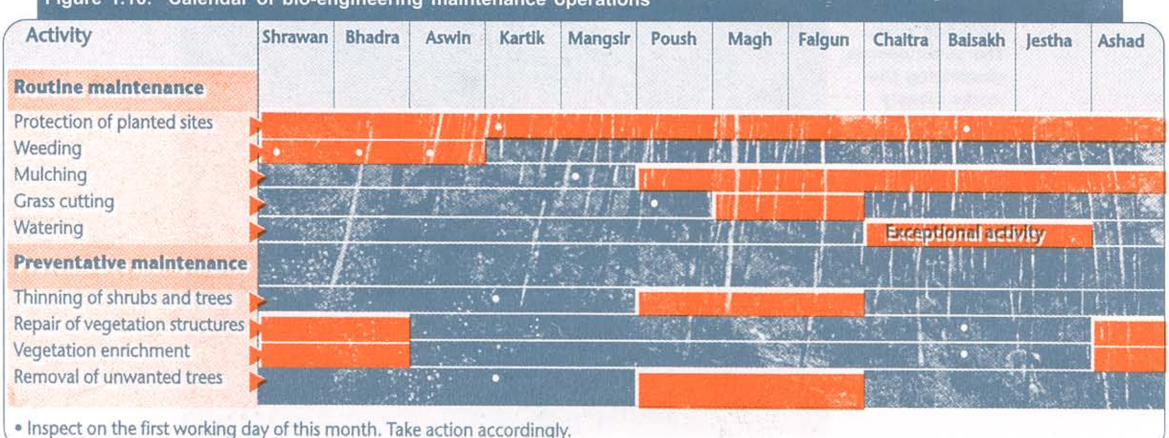
Section 3 Bio-engineering techniques: construction details of all the bio-engineering techniques used by the Department of Roads.

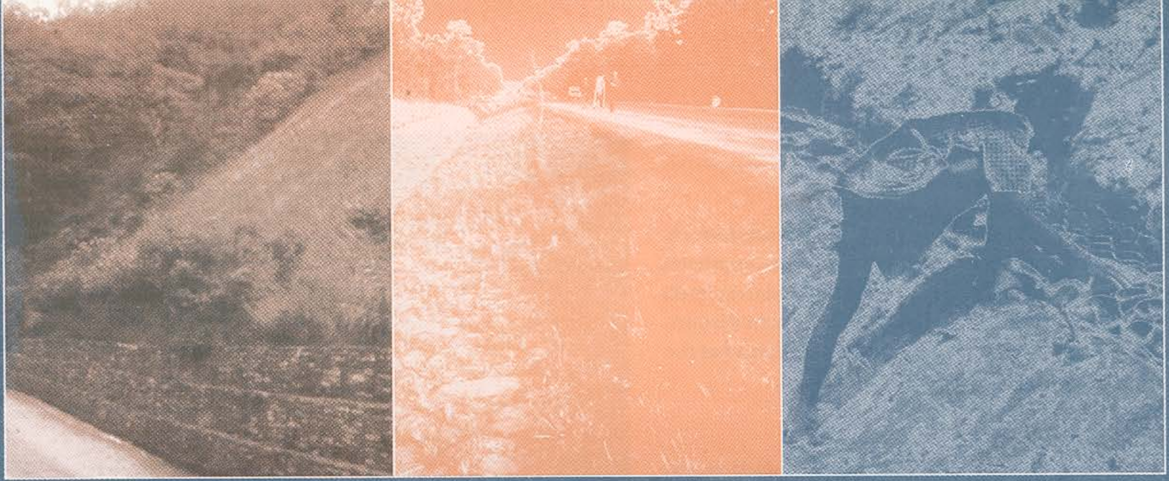
Section 4 Plant production and nurseries: full practical information about the propagation of plants for bio-engineering and the management of nurseries.

Section 5 Maintenance of bio-engineering sites: practical guidelines on every maintenance task under routine and preventative off-road (or roadside support) maintenance related to vegetation.

In addition, the *Reference Manual* contains a great deal of supporting information.

Figure 1.16: Calendar of bio-engineering maintenance operations





Civil engineering techniques

This section outlines the main civil engineering structures used for slope stabilisation and erosion control in conjunction with bio-engineering:

- retaining walls (Section 2.1);
- revetments (Section 2.2);
- prop walls/dentition (Section 2.3);
- check dams (Section 2.4);
- drains (Section 2.5);
- stone pitching (Section 2.6);
- wire bolster cylinders (Section 2.7);
- other civil engineering techniques: notes on their use (Section 2.8).

This section describes the main features of civil engineering structures and the ways in which they may be integrated with bio-engineering techniques. It does not give full design details of structures such as retaining walls and check dams but provides references to sources of further information.

Techniques that have been tried extensively in the Nepal road sector but rejected by the Department of Roads (e.g. waterproof slope covers and non-living wattle fences) are not included in this section. The reasons for their rejection are given in the *Reference Manual.*

2.1 RETAINING WALLS

Functions

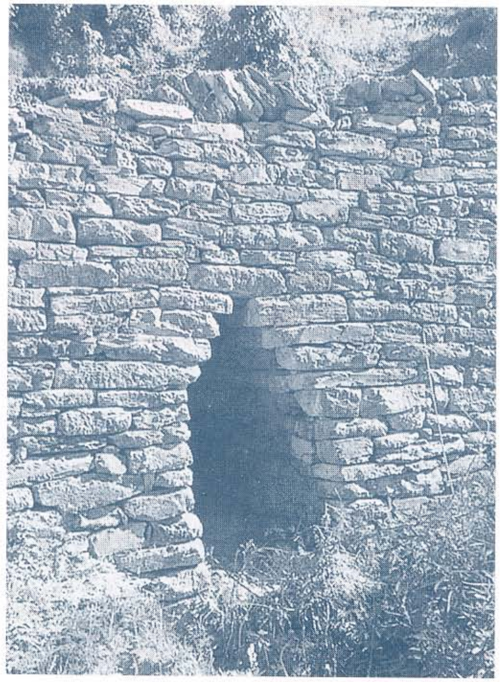
Retaining walls help to support mountainside slopes, or support the road or slope segments from the valley side. They are designed to stop an active earth pressure. Toe walls are normally considered to be a type of retaining wall found at the base of a slope or segment of slope.

Sites

Any slope where there is a problem of deep-seated (> 500 mm) instability, or where the steepness of the slope makes benching impractical.

Practical features

- Use dry masonry in every case where it is applicable (see *special features of dry masonry walls* below). Only use other types of wall when you are certain you need greater strength and can justify the additional cost.
- Careful design and supervision of foundations are of paramount importance.
- While excavating foundations, remove debris to a safe location. Do not allow it to be thrown down the slope.
- In most locations, solving the drainage problem is a major difficulty. Therefore consideration should always be given to using the best-drained of structures.
- In bound masonry and reinforced concrete walls, weep holes of a minimum width of 75 mm, sloping downwards, should be given every one metre along and up the wall. There should be a line of weep holes along the wall at the lowest level at which it can be drained.



A dry masonry retaining wall with a scupper culvert

- Backfilling is critical: many walls are not backfilled and so retain nothing but air! Always ensure that retaining walls are properly backfilled and compacted in layers. Place a drainage blanket of aggregate with a porous membrane of filter fabric (geotextile if possible; but otherwise hessian) over weep holes or drainage areas.

Figure 2.1: Comparison of retaining wall types*

Wall type	Maximum safe height	Width:height ratio	Advantages/limitations
Dry masonry	4 metres	1:1 to 0.6:1	Well drained; flexible; relatively low cost; low strength threshold
Composite masonry	8 metres	0.75:1 to 0.5:1	Better drained than mortared masonry, but with reduced strength
Mortared masonry	10 metres	0.75:1 to 0.5:1	Relatively easy to construct on steep terrain; cannot tolerate settlement; poor drainage
Gabion	10 metres	Width = ½ h + 0.5	Flexible without rupturing; tolerates poor foundations; well drained; relatively low cost for strength
Reinforced earth	8 metres	Depends on design	Reinforcing expensive or difficult to obtain; difficult to achieve tension
Reinforced concrete	10 metres	Depends on design	Relatively costly; requires advanced technical skills to build; poor drainage

* Despite these general criteria, design must always be site specific rather than based on a "typical" design.

- Once construction is complete, ensure that the slopes around the structure are tidied up and treated using appropriate bio-engineering measures. All surplus debris must be removed, or it will encourage the development of erosion.

Figure 2.1 compares the main types of retaining wall.

Integration with bio-engineering

Bio-engineering techniques should be used in conjunction with retaining walls, according to site characteristics, as follows:

- Protection of backfill.
- Protection from scour and undercutting of the foundations and sides.
- Flexible extension to the wall by planting large bamboos, shrubs or trees above the wall, increasing the catch function (refer to Sections 3.9 and 3.7 for details of these techniques).

Further information

There is an entire chapter on road retaining walls in TRL Overseas Road Note 16, *Principles of low cost road engineering in mountainous terrain* (chapter 11, *Road retaining walls*, pages 116 to 126). The design of retaining walls is also covered in most geotechnical engineering text books.

2.2 Revetment walls

Function

Revetment walls are constructed to protect the base of a slope from undermining or other damage, such as grazing by animals. They give only protection, not support, and are not used on large, unstable slopes, where substantial retaining structures may be required. Breast walls are normally considered to be types of revetment.

Sites

Along the base of inherently stable cut slopes where seepage erosion can destabilise the base of large slopes; along the foot of abandoned spoil tips which have reached their angle of repose; along the foot of large fill sites.

Practical features

- Excavate a foundation at the foot of the slope until you find a sound layer to build on.
- Construct walls of freely drained materials wherever possible, such as dry stone masonry or gabions.
- If using cement-bound masonry, include weep holes to drain water from behind the wall and reduce hydrostatic pressure. Weep holes should have a minimum width of 75 mm, slope downwards, and be constructed every one metre along and up the wall. There

Figure 2.2 : A guide to the dimensions of dry masonry retaining walls on different slopes

Slope	Wall height	Base width	Top width
30 – 35° (58 – 70%)	1.5 – 2.0 m	1.25 – 1.5 m	0.75 m
35 – 40° (70 – 84%)	2.0 – 2.5 m	1.5 – 2.0 m	0.75 – 1.0 m
40 – 45° (84 – 100%)	2.5 – 3.0 m	2.0 – 2.3 m	1.0 m

SPECIAL FEATURES OF DRY MASONRY RETAINING WALLS

- Careful design of dry masonry retaining walls can make them highly effective.
- Lay the foundations back into the slope at 1v:3h.
- Dress all stone (if it is rounded) into rectangular blocks.
- Lay stones so that they are tied into the slope, so that only the small ends, not long sides, are at the face of the wall.
- Overlap all joints.
- Use stones as large as possible. If mainly small stones are available, use large ones at least every one metre to improve the tying.
- Keep the angle of the foundations (1v:3h) with each layer of stone. The outer face of the wall will automatically come to 1h:3v if this is done.
- Use flatter stones for the top layer. Cover the top of the retaining wall with soil or build a bound masonry band along the top to stop it unravelling.
- Dry walls co-exist with, and are strengthened by plant roots. Encourage or plant vegetation.
- Use the dimensions in Figure 2.2 for dry stone retaining walls, dependings on slope angle.

SPECIAL FEATURES OF GABION CONSTRUCTION

Gabions have many possible functions, including their use in toe walls, revetments and retaining walls. They have special properties of strength, flexibility and free drainage.

Practical features

- The normal width to height ratio is: width = ½ height + 0.5.
- Ensure drainage is provided from the lowest point of the foundations.
- Use heavily galvanised high-grade steel wire complying with the latest Nepal Standard.
- Mesh should be either a heavily galvanised mild steel or a triple-twist hexagonal mesh (i.e. 1.5 complete turns), nominally of 100 mm width and 120 mm length.
- Panel frames should be made using 8 SWG wire, and mesh should be of 10 SWG wire.
- Special attention must be paid to binding the boxes together along the seams (selvedging).
- Wire all gabion boxes together using 12 SWG wire, allowing an additional 5% of wire for binding and tying.
- During construction, add four or five cross-trusses (of 10 SWG wire) per square metre in each horizontal direction.
- Ensure that the minimum dimension of all stones is larger than the wire mesh size.
- Stones should be tabular and angular.
- All stones should be carefully and densely packed, not just the facings.
- Wire the lids down with additional wire of 12 SWG.
- Backfill behind the gabion structure with a filter blanket to improve drainage.

should be a line of weep holes along the wall at the lowest point at which it can be drained. .

- The back face should be vertical; the front face should slope back at the rate of 330 mm horizontally per metre of height (a gradient of 3:1);
- The ends of the wall should turn in to meet the slope, and should be raised about 250 mm: water falling on them will then run down over the wall and not scour the ends.
- If there is a risk of people or animals damaging the top of a dry stone wall, provide a capping beam of cement-bound masonry.
- Once the wall is complete, finish backfilling behind it and compact the fill thoroughly at a steep angle (at least 30°) to rejoin the original slope as high up as possible; plant into the fill as soon as you can.

A revetment toe wall is protected by grasses planted on the slope above

Integration with bio-engineering

Bio-engineering techniques should be used in connection with revetment and toe walls as follows:

- Protection of backfill.
- Protection from scour and undercutting of the foundations and sides.
- Flexible extension above the wall by the use of large bamboo or shrub and tree planting, increasing the catch function: refer to Sections 3.9 and 3.7 for details of these techniques.

Further information

Revetments are covered in TRL Overseas Road Note 16, *Principles of low cost road engineering in mountainous terrain* (page 136), with typical design diagrams given on page 137.

2.3 PROP WALLS/DENTITION

Function

The term 'prop wall' also covers support walls and dentition. On very steep cut slopes, prop walls are used to support blocks of harder rock where they are underlain by softer rock bands. Where differential weathering occurs due to variations in adjacent strata, large segments of slope can become destabilised by a soft rock band eroding away underneath it. This presents two options: either remove all the material above or support it with a prop wall.

Prop walls do not usually offer total support to the full weight of all slope material above. Rather, they stop the erosion of softer bands below harder bands supported on them.

Sites

Only on steep cut slopes. Anywhere that a large slope-trimming job can be avoided by installing a relatively small wall. This technique is particularly useful in bands of alternating hard and soft rocks, such as are common in the Churia ranges.

Practical features

- Excavate a foundation on a band of rock that is as hard as possible: this must be underneath the band that is being replaced by the prop wall and must show evidence of much greater resistance to erosion.
- Using dressed stones and a cement:sand mixture of 1:4 or 1:3, build a cement masonry wall following the line of the slope.
- For sections less than 2 metres high only, use dry stone masonry built with well-dressed stones.
- In cement-bound masonry, weep holes should be at least 75 mm in diameter, sloping downwards and should be installed every 500 mm (horizontally as well as vertically); they must also be included in the lowest level of masonry.
- Normally, the bound masonry wall should be no more than 50 mm thick; if support deeper than this is required, it can be provided by careful dry stone packing behind the masonry wall. There must be no cavities allowing collapse of even very small areas behind the wall.
- When the lower surface of the material to be supported is reached, it is important to pack in the stones and mortar very tightly; the whole wall is useless if the last millimetre is not solidly completed.

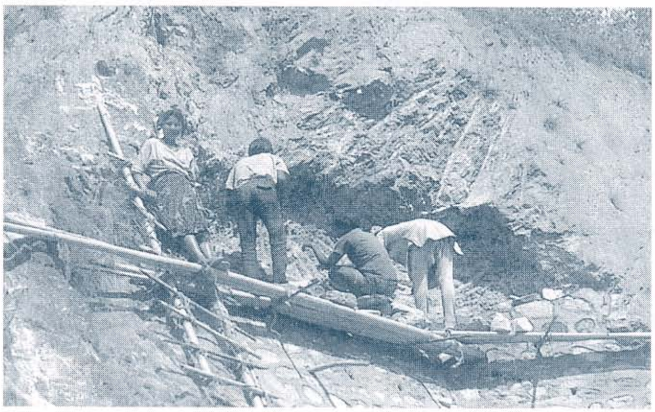
Integration with bio-engineering

Prop walls are usually used to support bands of harder strata and so there is usually a limited scope for close integration with bio-engineering techniques. However, where conditions give rise to a need for additional protection, bio-engineering techniques should be used as follows:

- Protection from scour and undercutting of the foundations and sides.

Further information

Prop walls are covered in TRL Overseas Road Note 16, *Principles of low cost road engineering in mountainous terrain* under retaining structures (chapter 11, pages 116 to 126 and revetments (pages 136 and 137).



Constructing a cement masonry dentition wall to prevent undercutting of the upper part of a steep cut slope in differentially weathered gneiss

2.4 CHECK DAMS

Function

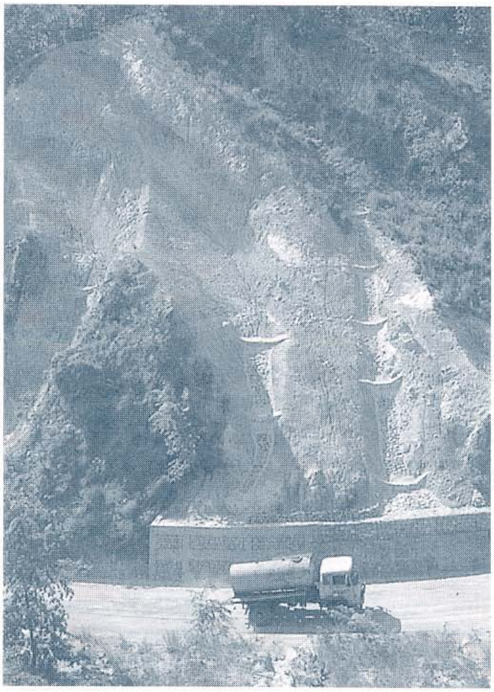
Check dams are simple physical constructions to prevent the downcutting of runoff water in gullies. They ease the gradient of the gully bed by providing periodic steps of fully strengthened material. Check dams are designed to accept an active pressure if it applied in the future, while permitting a safe discharge of water (and perhaps debris) via a spillway.

Sites

Any loose or active gully. In any rill that threatens to enlarge. In general, anywhere on a slope where there is a danger of scour from running water.

Practical features

- Choose locations for the check dams so that the maximum effect can be achieved using the minimum possible volume of construction. Refer to the box on the spacing of check dams.
- Excavate a foundation in the gully bed until you find a sound layer to build on . The base of the dam should be at least 660 mm thick if it is one metre high; for every additional metre of height, add a further 330 mm to the width.
- Construct the check dam using the best-drained and most cost-effective materials. If possible, use dry stone masonry or gabions to improve drainage. If this will not work, use concrete-bound mortar.



Small check dams at frequent intervals are effective, even in very steep gullies

- If using concrete-bound masonry, include weep holes to drain water from behind the check dam and reduce hydrostatic pressure.
- The ends of the dam should be keyed right into the gully sides and should be raised at least 250 mm to form a central spillway or notch: this ensures that water coming over the dam will then run down the middle and not scour the ends.

SPACING OF CHECK DAMS

Check dams should normally be placed where:

- they protect weak parts of a gully from scour;
- they maximise effective gully protection for the smallest possible quantities, such as at natural nick points and the foot of debris heaps;
- adequate foundations are available.

In most cases, gullies are so irregular that the spacing of check dams will be determined by ground conditions. However, if the gully is sufficiently uniform, the spacing of check dams can be determined using the relationship devised in 1973 by Heede and Mufich.

This states that

$$X = \frac{H_E}{K \tan S \cos S}$$

where X = check dam spacing in metres,
H_E = effective dam height in metres as measured from the gully bottom to the spillway crest,
S = slope of the gully floor
and K is a constant, $K = 0.3$ when $\tan S \leq 0.2$ and $K = 0.5$ when $\tan S > 0.2$.

The effective height (H_E) has to be estimated by the engineer on site. It is a function of the foundation conditions and the construction material used. The height should normally be maximised to reduce the number of check dams required.

- An apron must be provided below the dam to ensure that energy is dissipated and that flow continues in the centre of the gully below the check dam.
- If there is a risk of people or animals damaging the top of the dam, or if it is in a gully likely to take a large flow of water, point the top layer with cement mortar.
- Once the construction of the check dam is completed, backfill behind the wings and sides and compact the fill thoroughly.

Integration with bio-engineering

Bio-engineering techniques should be used in connection with check dams as follows:

- Protection of backfill and gully floor above check dam.
- Protection from scour and undercutting of the foundations and sides.
- Construct live check dams between civil check dams, to reduce water velocity in the gully and improve stability (refer to Section 3.12); or line the gully bed with vegetated stone pitching (refer to Section 3.14 for details of this technique).

Further information

Check dams are discussed in TRL Overseas Road Note 16, *Principles of low cost road engineering in mountainous terrain* (page 108), with typical design diagrams given on pages 110 and 111.

2.5 SURFACE AND SUB-SURFACE DRAINS

Function

Surface drains are installed in the surface of a slope to remove surface water quickly and efficiently. Surface-water drains often use a combination of bio-engineering and civil engineering structures.

Cascades are surface drains designed to bring water down steep sections of slope.

Sub-surface drains are installed in the slope to remove ground water quickly and efficiently. In practice they can be installed to a maximum of 1.0 to 1.5 metres (although the design depends on site conditions). Sub-surface drains are usually restricted to civil engineering structures, and do not normally use bio-engineering measures. However, bio-engineering techniques can be used to strengthen the slope around the drain.

Sites

Any site less than 35°. Certain drain types can be used on slopes up to 45° (e.g. drains constructed using gabion wire or concrete-bound masonry). Cascades are normally used on slopes steeper than 45°.

Stone-pitched surface drains on a wet landslide scar

The same site, two years later, following establishment of the protective grass cover between the drains

Figure 2.3: Surface drains and cascades, and sub-surface drains: design and integration with bio-engineering (all drainage systems are assumed to be dendritic)

Drain type Structure	Bio-engineering	Main sites	Advantages	Limitations
Surface drains				
Unlined natural drainage system (rills and gullies already developed on bare surfaces).	Grasses in the rills and gullies, and grasses and other plants on the sides.	Existing landslide scars and debris masses.	By far the cheapest form of surface drain. Rapid drainage is assured.	There is a risk of renewed erosion in exceptionally heavy rain in weak materials.
Unlined earth ditch system.	Grasses and other plants on sides and between feeder arms.	Slumping debris masses on slopes up to 45°, where the continued loss of material is not a problem (*e.g.* in debris masses well below a road, draining straight into large rivers)	By far the cheapest form of surface drain.	There is a serious erosion hazard, especially on steep main drains, so this type should be used only where further erosion is not a problem. Leakage into the ground may also occur.
Unbound dry stone system of ditches.	Grasses between stones (as vegetated stone pitching), and grasses and other plants on sides and between feeder arms.	Almost any site, however unstable, where the ground is firm enough to hold stone pitching and the flow of water is not too excessive for this construction technique.	A low-cost drain type. Strong and very flexible. These two features make it good on unstable slopes.	A membrane of thick, black polythene may be required to stop leakage back into the ground.
Bound cement masonry ditch system.	Grasses and other plants on sides and between feeder arms.	Only on stable slopes with suitable material for good foundations.	A strong structure for heavy discharges.	Relatively high cost. Very inflexible, so there is a high risk of cracking and failure due to subsidence and undermining.
Wire bolster cylinders (herringbone pattern).	Grasses and other plants on sides and between feeder arms.	Almost any site, however unstable, without excessive amounts of stone, but where the ground is firm enough to hold the structure. The drainage discharge should not be excessive.	A medium-cost shallow type of drain. Very strong and flexible, which makes it good for unstable slopes.	A membrane of thick, black polythene may be required to stop leakage back into the ground.
Open gabion ditch system.	Grasses and other plants on sides and between feeder arms.	Almost any site, however unstable, where the ground is firm enough to hold a relatively big structure, and where a large volume of discharge is possible.	A large and high-cost type of drain. Very strong and flexible, which makes it good for unstable slopes.	A membrane of thick, black polythene may be required to stop leakage back into the ground.
Cascades				
Dry stone cascade.	Grasses and other plants along the sides.	Any slope section steeper than 50°, where foundations are adequate and discharge is relatively low.	A low-cost form of cascade with a degree of flexibility.	A membrane of thick, black polythene may be required to stop leakage back into the ground.
Mortared masonry cascade.	Grasses and other plants along the sides.	Very stable slope sections steeper than 45°, where foundations are very good.	A strong structure for heavy discharges.	Relatively high-cost and inflexible cascade type, so there is a high risk of cracking and failure due to subsidence and undermining.
Gabion cascade.	Grasses and other plants along the sides.	Any slope section steeper than 45°, where foundations are adequate and discharge is likely to be high.	Very strong and flexible, which makes it good for unstable slopes.	A relatively large and high cost cascade type. A membrane of thick, black polythene is required to stop leakage back into the ground.
Concrete cascade.	Grasses and other plants along the sides.	Very stable slope sections steeper than 45°, where foundations are very good.	A very strong structure for the heaviest discharges.	Very high cost and inflexible cascade type. The risk of cracking and failure due to subsidence and undermining is partly offset by the innate strength of the construction.

Figure 2.3: Surface drains and cascades, and sub-surface drains: design and integration with bio-engineering (all drainage systems are assumed to be dendritic) *continued*

Drain type — Structure	Bio-engineering	Main sites	Advantages	Limitations
Sub-Surface drains				
French drain system (perforated pipe of durable, high grade black polythene, 150 mm diameter with approximately 40 holes of 5 mm per metre) in a drainage medium of aggregates). Drain can be made more resistant to disruption by building it in a casing of gabion.	Grasses and other plants along the sides and between feeder arms.	Almost any site, however unstable, where the ground is firm enough to hold the structure and the flow of water is not too excessive for this construction technique.	A relatively low-cost and common sub-surface type of drain. Very flexible, which makes it good for unstable slopes.	A membrane of permeable geotextile should be used. If the flow is too great, piping may occur underground. The outfall must be monitored to check that the drain is functioning, but the hidden nature of the drain means that this cannot always be fully ascertained.
Site-specific design of drain to pick up seepage water. An open ditch or a drain with a flexible gabion lining is preferred.	Plant grasses and other species along the sides.	Any slope with obvious seepage lines.	Specific drains can be designed for any site, leading to the optimum collection of water.	Great care is needed to ensure all seepage water is trapped by the drain. Movement in the slope may affect this.
Deep surface drain types (deeper versions of the surface drains described above, designed to catch shallow ground water seepage).	As for each surface drain type described above.	As for each surface drain type described above.	Open drains allow easy cleaning and repair, as well as monitoring of effectiveness.	The usual practical maximum depth is about 1.5 metres. Special care must be used to allow water to seep into the drains.

Practical features

- Always design drainage systems to run along natural drainage lines. Choose locations for the drains so that the maximum effect can be achieved using the minimum possible volume of construction.
- Always ensure that drain outfalls are protected against erosion.
- Only use a rigid geometrical pattern of drains on newly formed fill slopes where there are no clear natural drainage lines.
- Excavate a foundation until a sound layer to build on is located. Drains must be well founded like all other civil structures.
- Run main drains straight down the slope. Feed side drains in on a herringbone pattern.
- Never use contour drains: these block very easily and are also highly susceptible to subsidence. A blocked or cracked drain can create terrible damage as a result of concentrated water flow.
- Design and construct the drains in such a way that water can enter them easily on the higher side but not seep out on the lower side. Use weep holes and thick (^{3} 20 gauge), black polythene membranes carefully to achieve this.
- A flexible design is usually an advantage. Concrete masonry can be easily cracked by the slightest movement in the slope, and then leakage problems result.
- If there is a risk of people or animals damaging the drain, make sure that the construction is strong enough (*e.g.* use gabion rather than dry stone construction).
- Once the drain is completed, backfill around it and compact the fill thoroughly.

A gabion cascade in heavy rain. This type of structure can transport large volumes of water down steep slopes without damage

- Apply appropriate bio-engineering measures to enhance the effectiveness of the drain.
- Where the site requires deeper drainage and the machinery is available, drains can be drilled into the slope.
- Figure 2.3 gives comparison details of the main drain and cascade types.

Further information

Surface drainage on slopes is covered on pages 136 to 139 of TRL Overseas Road Note 16, *Principles of low cost road engineering in mountainous terrain.*

Sub-surface drainage on slopes is covered on pages 139 to 140 of TRL Overseas Road Note 16, *Principles of low cost road engineering in mountainous terrain.*

2.6 STONE PITCHING

Functions

A slope is armoured with stone pitching. This gives a strong covering. It is freely drained and will withstand considerable water velocities.

Note that in Section 3.14, among the bio-engineering techniques, full details are given of *vegetated stone pitching*: that is a stronger form of stone pitching, with greater emphasis given to its strengthening by vegetation.

Sites

Any slope up to 35°. This technique is particularly useful on slopes with a heavy seepage problem, in flood-prone areas or where vegetation is difficult to establish, such as in urban areas. It is also useful on gully floors between check dams and for scour protection by rivers.

Materials

- Boulders;
- Tools for digging and for dressing stones.

The largest available stones should be used which permits pitching to be done effectively on the site. The stones used should have one large flat side, and should be of equal size and angularity.

Spacing

Stone pitching effectively gives a complete surface cover.

Construction steps

1. Prepare a sound slope before constructing the stone pitching; it must be free of loose debris and topsoil, and trimmed to an even surface.
2. Bed the stones down well into the slope surface. Excavate as necessary to ensure an even upper surface to the stone pitching.
3. Build the stone pitching carefully, with the stones fitted together firmly, as if it is a dry masonry wall. Stones should be perpendicular to the slope, with the main point or narrow side down.
4. In drains and gullies, a rough surface can be left to retard water flow.
5. For further strengthening it is best to plant grasses or the hardwood cuttings of shrubs through the stone pitching (see below and Section 3.14).
6. Other options for strengthening are either to use a gabion mattress (of 0.3 to 0.5 metre

WHY YOU SHOULD AVOID USING CUT-OFF DITCHES OR CATCH DRAINS ABOVE CUT SLOPES

Cut-off ditches, otherwise known as cut-off drains or catch drains are:

- almost certain to become blocked;
- very likely to suffer from settlement of the foundations and crack as a result;
- often difficult to maintain because they are above the road and out of sight

A cut-off ditch becoming blocked or cracked is a common cause of a landslide or the severe erosion of a cut slope in Nepal. Damage to a cut slope can be considered the usual outcome of the installation of a cut-off ditch.

This warning applies to all surface ditches that are out of sight of the road, and therefore they are best avoided unless there is no alternative.

Water should be brought down the slope along its natural course, protected with vegetation and civil structures as required, and if necessary carried into the nearest roadside ditch by a cascade. Localised damage can then be seen and repaired as soon as it occurs.

thickness) instead of dry stone pitching; or to use cement mortar (but this can impede drainage).

Integration with bio-engineering

For the best effects, bio-engineering techniques should be used in connection with stone pitching as follows.

- Strengthening of stone pitching: plant grass slips in the gaps between stones: see Section 3.14.
- Increased strengthening of stone pitching: insert live cuttings of shrubs into the gaps between stones: see Section 3.14.

Maintenance

If stones are displaced, the pitching should be repaired as soon as possible. Otherwise the maintenance depends on the type of bio-engineering used (refer to the relevant part of Section 5 for details).

Main advantages

Stone pitching forms a strong and long-lasting method of reinforcing a slope surface and stopping gully development.

Main limitations

Stone pitching is relatively expensive in comparison with bio-engineering measures such as brush layers.

2.7 WIRE BOLSTER CYLINDERS

Function

Wire bolster cylinders (in cross-section, a tube of 300 mm diameter filled with stone) are laid in shallow trenches across the slope. They prevent surface scour and gullying (by reinforcing and fulfilling an intermittent armouring function), and provide shallow support. Bolsters can be laid in two ways: (1) along the contour; or (2) in a herringbone pattern (←←←←←) to double as a surface drainage system.

Sites

On most long, exposed slopes between 35° and 50° where there is a danger of scour or gullying on the surface. Contour bolsters are used on well drained materials; slanted (herringbone pattern) bolsters are used on poorly drained material where there is a risk of slumping.

Constructing a wire bolster (see *construction step 5*, overleaf)

Completed wire bolster cylinders on a steep colluvial slope

Materials

- Woven gabion panels;
- 16 mm rebar or high yield steel rod cut into 2 m lengths;
- Boulders: for contour bolsters, angular, smallest dimension > 100 mm; for herringbone bolsters, rounded, smallest dimension > 100 mm;
- Tools for digging trenches and for working with gabion wire;
- Sledge hammers.
- For herringbone bolsters, thick (³ 20 gauge), black polythene sheet to line the trenches.

Gabion bolster panels are normally 5 m × 1 m. Where larger bolsters are required 5 m × 2 m panels can be woven. They are made on a conventional gabion weaving frame but with a smaller mesh than usual: this is normally 70 × 100 mm, triple twist. Heavy coated 10 SWG wire is used for the border and 12 SWG for the mesh.

Spacing

Contour bolsters are normally spaced as follows.

slope < 30°: 2000 mm centres;

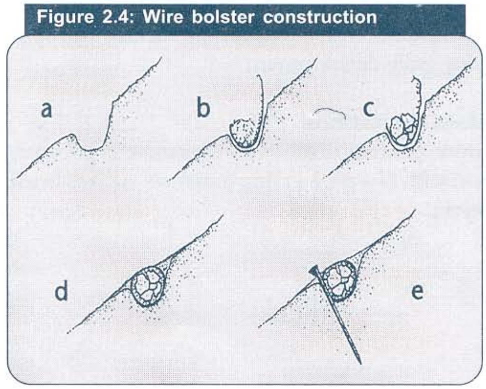
slope 30 - 45°: 1500 mm centres.

Herringbone bolsters are placed at 1500 mm centres.

Construction steps (contour bolsters)

1. Trim the area to be treated to an even slope with no small protrusions or depressions which will interfere with the bolsters.
2. Starting about 2 metres from the bottom of the slope, mark out a contour line across the slope with the aid of a spirit level.
3. Dig a trench along the line: the trench should be about 300 mm wide and 300 mm deep (Figure 2.4;a).
4. Lay a gabion bolster panel lengthways along the trench: make sure the edge of the panel on the lower side is flush with the edge of the trench.
5. Fill the bolster with stones larger than the mesh size (Figure 2.4; b,c).
6. Fold the upper edge of panel over the stones and join it to the lower panel edge. Leave a 100 mm flap from the upper edge extending over the lower edge (Figure 2.4;d).
7. Join abutting bolsters: form the bolsters into a continuous line across the slope and close the extreme ends with wire.
8. Backfill the material around the bolsters, compact it and clean away surplus debris.
9. Drive steel bars into the ground at right angles to the slope every 2 metres along the bolsters. Position them immediately below and touching the bolsters, and drive them in far enough so that they cannot be pulled out by hand (Figure 2.4; e).
10. Cover remaining site: repeat steps (2) to (9) up the slope at the spacing required until the area is covered.
11. Starting from the top of the slope, clean away surplus debris and make sure that backfill is complete and firm.
12. Implement bio-engineering works throughout the site.

Figure 2.4: Wire bolster construction



Construction steps (herringbone bolsters)

1 The site to be treated should first be trimmed to an even slope: there should be no protrusions or depressions that will interfere with the bolsters; loose rocks should be removed if possible;
2 Starting about 2 metres from the bottom of the slope, mark out the lines for the bolsters; they should be at 45° to the line of the slope and each slanting piece should normally be 5 metres long (although the design must be flexible to take individual site conditions into account).
3 Dig trenches along the lines, about 300 mm wide and 300 mm deep.
4 Lay a sheet of black polythene along the bottom and lower side, but not the higher side, of the trench.
5 Lay gabion bolster panels lengthways along the trenches. The edge of the panel on the lower side should be flush with the lower edge of the trench.
6 Fill the bolster with stones larger than the mesh size. Stones must not be packed carefully on top of each other as this reduces water flow: instead, they must be poured in from above and packed firmly but at random within the mesh.
7 Fold the upper edge of the panel over the stones and join it to the lower panel edge; at the end of the pattern, where the slanting lines meet, the bolster ends should be closed over with wire but not joined to adjacent patterns: this is so that each stack of V patterns can fail without affecting the pattern next to it.
8 Repeat steps 3 to 7 at 1.5 metre intervals, installing a series of bolsters up the slope.
9 Once the slanting lines are complete, dig a trench straight down the slope and install a 'vertical' bolster in it to collect water from the bottoms of each V, and run it to the base of the slope. Tie the herringbones or ribs to the spine.
10 Backfill the material around the bolsters, compact it and clean away surplus debris as necessary.
11 Drive mild steel bars into the ground at right angles to the slope every 2 metres along the bolsters: they should be positioned immediately below and touching the bolsters, and should be driven in far enough that they cannot be pulled out by hand.
12 Implement bio-engineering works throughout the site.

Integration with bio-engineering

The spaces between the bolsters should be treated with appropriate bio-engineering as soon as the subsequent rains have broken, as follows:

- Between wire bolster cylinders: plant shrub and small tree seedlings at 1000 mm centres throughout the slope treated, according to site characteristics and as determined by the instructions in Section 1.2.
- If a more complete surface protection is required, the surface can be planted or seeded with grass between the wire bolster cylinders, using the techniques described in Sections 3.1 to 3.5, according to the site requirements described in Section 1.2.

Maintenance

Maintain the bio-engineering works according to the needs of the particular treatment used.

If rills develop between the bolsters and threaten to undercut them, small-scale stone dentition should be used to support undermined places and stop scour erosion. In extreme cases, fully stone-lined gullies can be made between bolsters in order to shed large amounts of accumulated runoff without damaging the slope.

Main advantages

Bolsters form the strongest and longest-lasting method of armouring a slope surface and preventing gully development.

Main limitations

Bolsters are relatively expensive in comparison with bio-engineering measures such as brush layers.

2.8 OTHER CIVIL ENGINEERING TECHNIQUES

Wire netting

Function

Wire netting (usually gabion wire mesh) is spread over the surface of a rocky slope. This can be carried out to reduce the shedding of rock debris and slow the degradation of the surface.

Sites

Slopes composed of hard rock with a degree of fragmentation leading to the occasional shedding of debris particles larger than about 100 mm.

Comments

The main difficulty with this technique is fixing the wire mesh to the face of the slope. This is normally done by hammering steel pegs into rock cracks or by cementing them into depressions. If this is done satisfactorily, then it can be a very robust measure.

If the slope has not been trimmed well in advance, the accumulation of loose boulders behind weakening wire netting could release a bigger and more dangerous load in one go, rather than a gradual shedding of individual boulders. But with a good maintenance regime this technique could be used to advantage.

Gunite (shotcrete)

Function

Gunite is a cement-stabilised aggregate sprayed on to a wire mesh slope covering. It can be used for surface armouring and to bind together the surface of weathered and fractured rock slopes.

Sites

This technique has potential on steep (> 50°) cut slopes less than about 30 metres in height.

Comments

This technique has been used successfully in Hong Kong and Malaysia. The main limitation is the difficulty of ensuring slope drainage through the covering, even when numerous weep holes are provided: it is generally considered to be inappropriate on slopes with high groundwater seepage rates, such as are common in Nepal. The expense is also a limiting factor.

Chunam

Function

Chunam is a lime-based plaster applied as a slurry across the surface of a slope. It waterproofs and supports the immediate surface, armouring against scour of the surface and weathering of the material below. It can be reinforced using wire mesh already attached to the surface.

Sites

This technique has potential on (>50°) cut slopes less than about 30 metres in height.

Comments

This technique has been successful in limited areas only. It is essential to install drainage or weep holes, sloping towards the outside of the material. Even with these, many surfaces have failed when treated with chunam because too much water has percolated behind the surfacing from higher up the slope and it has flaked away from the less weathered material behind. The best successes might be achieved in naturally dry sites, where hard chunam facings can stop surface erosion during heavy rains.

Cement slurry

Function

A watery cement slurry is poured into the ground. It percolates along pores and gaps in the material. When it sets, it binds the material together and increases the cohesive strength. The main engineering function is to reinforce.

Sites

This technique has potential in highly permeable debris materials, such as colluvium with a low proportion of fines.

Comments

There are no records of the widespread use of this technique in Nepal, but it has been used occasionally on colluvial slopes above roads. It is probably only worth using on the very porous materials described above, where there is adequate void space to absorb a critical quantity of slurry. Its best application is to reinforce material immediately upslope from a retaining structure which is considered too weak, such as a gabion wall which has bulged: in this situation, it may avoid the necessity of replacing one threatened structure with a stronger one. It could also be used in a purpose-designed situation, where there is inadequate space to construct a wall of the desired thickness, and where cement stabilisation of the retained debris can increase the factor of safety satisfactorily. In emergencies, it might be used shortly before the start of the monsoon rains, when there is not enough time to build a normal structure.

Reinforced earth

Function

A proprietary or purpose-designed material is laid at intervals into debris, which is built up in layers to form a slope of earth strengthened with the reinforcing material. The result is intermediate in strength between a straightforward fill slope and a retaining structure. The main engineering function is to reinforce.

Sites

This technique is best used on fill slopes, where the design angle is relatively low and the major disturbance involved in construction can be accomplished more easily.

Comments

There are various proprietary systems of reinforced earth, but there are no records of them being tried for slope stabilisation in Nepal. A form of earth reinforcement could be undertaken using a material such as gabion mesh laid into the slope at intervals as it is backfilled. However, reinforced earth systems present complex slope stability calculations, and the standard retaining structures are preferable in most cases.

Further information

Reinforced earth structures are covered in TRL Overseas Road Note 16; *Principles of low cost road engineering in mountainous terrain* (page 122), with typical design diagrams given on page 120.

Soil nailing

Function

Tensile strengthening is added to the slope in the form of steel bars inserted into the soil (or surface layers). Insertion is possible to a maximum depth of about 5 metres.

Sites

Any slope that is liable to creeping planar mass failures and where access for machinery is feasible. It is not effective against erosion or many shear failures.

Comments

There are two main methods. One uses a procedure of drilling and grouting, and the other hammers the nails in, normally using a mechanical percussion device. Both have advantages in certain situations, but both require machinery to gain access to the slope. The high cost of the technique makes its usefulness in Nepal dubious compared with the established systems of slope stabilisation.

Further information

Information is available from the companies offering proprietary systems of soil nailing, and their agents. No proven examples of this technique are known in Nepal.



Bio-engineering techniques

This section gives details of the design and construction of the main bio-engineering systems used for stabilising slopes and controlling erosion. These are:

- grass planting, seeding and turfing (Section 3.1 to 3.6);
- shrub and tree planting and seeding (Sections 3.7 and 3.8);
- large bamboo planting (Section 3.9);
- brush layering (Section 3.10);
- palisades (Section 3.11);
- live check dams (Section 3.12);
- fascine constructions (Section 3.13);
- vegetated stone pitching (Section 3.14);
- jute netting: detailed information on its use and construction: standard mesh (Section 3.15) and wide mesh (Section 3.16);
- mulching: detailed information on the use of mulch as an aid to bio-engineering (Section 3.17);
- vegetated gabions (Section 3.18);
- live wattle fences (Section 3.19);
- hydro-seeding (Section 3.20).

Details of all of the civil engineering measures used in combination with these bio-engineering systems are given in Section 2.

3.1 PLANTED GRASS LINES: CONTOUR/HORIZONTAL

Function

Grass slips (rooted cuttings), rooted stem cuttings or clumps grown from seed are planted in lines across the slope. They protect the slope with their roots and, by providing a surface cover, reduce the speed of runoff and catch debris, thereby armouring the slope. The main engineering functions are to catch, armour and reinforce.

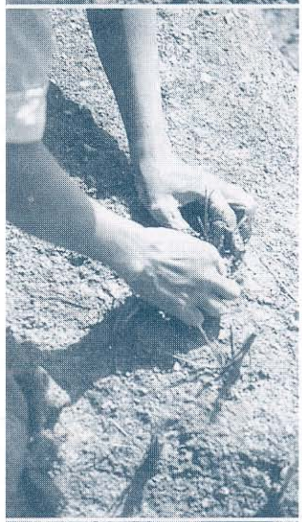
Sites

Almost any slope less than 65°. This technique is mostly used on dry sites, where moisture needs to be conserved. It is most widely used on well-drained materials where increased infiltration is unlikely to cause problems. On cultivated slopes less than 35°, horizontal lines planted at intervals across the field can be used to avoid loss of soil and to help conserve moisture, as a standard soil conservation measure. Planted grass lines at intervals are essential if cultivation has to be carried out on slopes greater than 35°.

Materials

- Grass plants raised in a nursery or cuttings obtained elsewhere;
- Short planting bars;
- Line string;
- Spirit level;
- Tape measure (30 metres);
- A means of transporting plants to site;

Planting grass lines. Use a planting bar to make holes just big enough for the roots



Place the grass into the hole, taking care not to tangle the roots or have them curved back to the surface

Fill the soil in around them, firming it gently with your fingers

SPECIES SUITABLE FOR PLANTED GRASS LINES: COUNTOUR/HORIZONTAL

Local name	Botanical name	Altitude range	Sites summary
Amliso	*Thysanolaena maxima*	Terai - 2000 m	Varied
Babiyo	*Eulaliopsis binata*	Terai - 1500 m	Hot and dry
Dhonde	*Neyraudia reynaudiana*	Terai - 1500 m	Hot and dry
Kans	*Saccharum spontaneum*	Terai - 2000 m	Hot and dry; moist
Katara khar	*Themeda* species	Terai - 2000 m	Varied
Khar	*Cymbopogon microtheca*	Terai - 2000 m	Hot and dry; varied
Khus	*Vetiveria lawsoni*	Terai - 1500 m	Varied
Narkat	*Arundo clonax*	Terai - 1500 m	Hot and dry; varied
Padang bans	*Himalayacalamus hookerianus*	1500 - 2500 m	Moist
Phurke	*Arunduella nepalensis*	700 - 2000 m	Varied; stony
Sito	*Neyraudia arundinacea*	Terai - 1500 m	Varied
Tite nigalo bans	*Drepanostachyum intermedium*	1000 - 2500 m	Varied

- Hessian and water to keep the roots moist;
- (*Optional*) Manure or compost.

Spacing

Line spacing depends largely on the steepness of the slope.

Within rows: plants at 100mm centres (except padang and tite nigalo bans, which should be spaced at 500 mm centres)

Row spacings: slope < 30°: 1000 mm;
slope 30-45°: 500 mm;
slope > 45°: 300 mm.

Where this technique is used on agricultural land, a compromise must be reached between ease of cultivation and reduction of soil and water movement. A vertical interval of 2 metres or more is generally adequate.

Construction steps

1. Prepare the site well in advance of planting. Remove all debris and either remove or fill in surface irregularities so that there is nowhere for erosion to start. If the site is on backfill material, it should be thoroughly compacted, preferably when wet.
2. Always start grass planting at the top of the slope and work downwards.
3. Mark out the lines with string, using a tape measure and spirit level. Make sure the lines run exactly as required by the specification, along the contour.
4. Split the grass plants out to give the maximum planting material. Trim off long roots and cut the shoots off at about 100 mm above ground level. Wrap the plants in damp hessian to keep them moist until they are planted. Remember that you will need two slip cuttings per drill (planting hole) if the grass is a fibrous rooting type (*e.g.* babiyo, kans, khar, phurke, *etc.*) but only one if it is rhizomatous (*e.g.* amliso, padang bans, *etc.*), and only one rooted stem cutting or seedling.
5. With a planting bar, make a hole just big enough for the roots. Place the grass into the hole, taking care not to tangle the roots or have them curved back to the surface. Fill the soil in around them, firming it gently with your fingers. Take care to avoid leaving an air pocket by the roots.
6. If compost or manure are available, scatter a few handfuls around the grasses. This is especially important on very stony sites, where compost or manure can help to improve early growth. You may have to incorporate it into the surface material to prevent it being washed off.
7. If it looks rather dry and there is no prospect of rain for a day or two, consider watering the plants by hand.

Maintenance

This normally involves:

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Grass cutting (check on Poush 1).

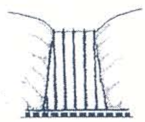
Main functions

Contour grass lines catch material moving downslope. They also armour slopes on highly impermeable materials by retarding runoff and reinforcing slope materials.

Main limitations

Contour grass lines can increase the infiltration rate to the point of liquefaction on poorly drained materials, particularly on steeply sloping, fine-textured debris.

3.2 PLANTED GRASS LINES: DOWNSLOPE/VERTICAL



Function

Grass slips (rooted cuttings), rooted stem cuttings or seedlings are planted in lines running down the slope. They protect the slope with their roots, provide a surface cover and help to drain surface water. They do not catch debris. The main engineering functions are to armour, reinforce and drain. Using this technique, a slope is allowed to develop a semi-natural drainage system, gullying in a controlled way.

Sites

Almost any slope less than 65°. It is mostly used on damp sites, where moisture needs to be shed. It is also most widely used on poorly drained materials where an increase in infiltration can lead to liquefaction of the soil.

Materials

- Grass plants raised in a nursery or cuttings obtained elsewhere;
- Line string;

Vertical grass lines allow a slope to develop a semi-natural drainage system, reducing infiltration and the likelihood of liquefaction of the soil

- Triangular set square or frame with a plumb line;
- Spirit level;
- Tape measure (30 metres);
- A means of transporting plants to site;
- Hessian and water to keep the roots moist;
- (*Optional*) Manure or compost.

Spacing

If the site is a newly cut slope, then a simple geometrical pattern can be used. The normal spacing is as follows:

Within rows: plants at 100 mm centres (except padang and tite nigalo bans, which should be spaced at 500 mm centres)

Row spacings: 500 mm.

SPECIES SUITABLE FOR PLANTED GRASS LINES: DOWNSLOPE/VERTICAL

Local name	Botanical name	Altitude range	Sites summary
Amliso	*Thysanolaena maxima*	Terai - 2000 m	Varied
Babiyo	*Eulaliopsis binata*	Terai - 1500 m	Hot and dry
Dhonde	*Neyraudia reynaudiana*	Terai - 1500 m	Hot and dry
Kans	*Saccharum spontaneum*	Terai - 2000 m	Hot and dry; moist
Katara khar	*Themeda* species	Terai - 2000 m	Varied
Khar	*Cymbopogon microtheca*	Terai - 2000 m	Hot and dry; varied
Khus	*Vetiveria lawsoni*	Terai - 1500 m	Varied
Narkat	*Arundo clonax*	Terai - 1500 m	Hot and dry; varied
Padang bans	*Himalayacalamus hookerianus*	1500 - 2500 m	Moist
Phurke	*Arunduella nepalensis*	700 - 2000 m	Varied; stony
Sito	*Neyraudia arundinacea*	Terai - 1500 m	Varied
Tite nigalo bans	*Drepanostachyum intermedium*	1000 - 2500 m	Varied

However, if a gully system has already partly developed, then the spacing is defined naturally. Lines of grass should not be more than 500 mm apart if possible and, if ridges are bigger, a series of small lines in a chevron pattern (<<<<<) is required to protect gaps. Careful supervision is required on site to ensure that all planted lines follow the direction of natural fall.

Construction steps

1. Prepare the site well in advance of planting. Remove all debris and either remove or fill in surface irregularities so that there is nowhere for erosion to start.
2. Always start grass planting at the top of the slope and work downwards.
3. Mark out the lines with string, using a tape measure. Use the spirit level, string and set square, or the frame to check the maximum line of fall. Make sure the lines run exactly as required by the specification, down the slope or drainage line.
4. Split the grass plants out to give the maximum planting material. Trim off long roots and cut the shoots off at about 100 mm above ground level. Wrap the plants in damp hessian to keep them moist until they are planted. Remember that you will need two slip cuttings per drill (planting hole) if the grass is a fibrous rooting type (*e.g.* babiyo, kans, khar, phurke, *etc.*) but only one if it is rhizomatous (*e.g.* amliso, padang bans, *etc.*), and only one rooted stem cutting or seedling.
5. With a planting bar, make a hole just big enough for the roots. Place the grass into the hole, taking care not to tangle the roots or have them curved back to the surface. Fill the soil in around them, firming it gently with your fingers. Take care to avoid leaving an air pocket by the roots. Mound the soil along the grass line, to encourage water to run mid way between the lines rather than close to the plant stems.
6. If compost or manure is available, scatter a few handfuls around the grasses. This is important on very stony sites, where it can help to improve early growth. You may have to incorporate it into the surface material to prevent it being washed off.
7. If it looks rather dry and there is no prospect of rain for a day or two, consider watering the plants by hand.

Maintenance

This normally involves:

Protection (check on Kartik 1);

Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);

Grass cutting (check on Poush 1).

If gullies develop, they must be controlled. If they become large enough to endanger the site, they must be checked with dry stone pitching and small **check dams**. If caught early enough, a few stones may be all that is required to create an armoured **rill** in which the runoff can safely pass. If allowed to grow too big, much more work will be required.

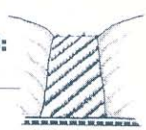
Main functions

Downslope grass lines provide the maximum amount of surface drainage by channeling run-off and minimising infiltration. They still armour against **erosion** and reinforce the slope.

Main limitations

On impermeable materials, runoff can become damaging. In drier sites, grass plants can suffer from drought due to the increased drainage. On some weak materials, rills can develop down the side of the plant line, damaging the grass slips and reducing their growth.

3.3 PLANTED GRASS LINES: DIAGONAL



Function

Grass slips (rooted cuttings), rooted stem cuttings or seedlings are planted in lines running diagonally across the slope. They armour the slope with their roots and by providing a surface cover. They have limited functions of catching debris and draining surface water. The main engineering functions are to armour and reinforce, with secondary functions to catch and drain. This technique offers the best compromise of the grass line planting systems in many situations.

Sites

Almost any slope less than 65°. It is mostly used on poorly drained materials where an increase in infiltration can lead to liquefaction of the soil. It is also useful on damp sites, where moisture needs to be shed. It should be used whenever there is doubt as to which grass line planting system should be used, as a result of uncertainties over site environmental characteristics or material properties.

Materials

- Grass plants raised in a nursery or cuttings obtained elsewhere;
- Line string;
- Tape measure (30 metres);
- Triangular set square or frame with a plumb line (optional);
- Spirit level (optional);
- A means of transporting plants to site;
- Hessian and water to keep the roots moist;
- (Optional) Manure or compost.

Spacing

If the site is a newly cut slope, then a simple geometrical pattern can be used. The normal spacing is as follows:

Within rows: plants at 100 mm centres (except padang and tite nigalo bans, which should be spaced at 500 mm centres)

Row spacings: 500 mm.

However, if a gully system has already partly developed, then the spacing is defined naturally. Lines of grass should not be more than 500 mm apart if possible and, if ridges are bigger, a series of small lines in a chevron (<<<<<) or herringbone (←←←←←) formation is required to protect gaps.

Construction steps

1. Prepare the site well in advance of planting. Remove all debris and either remove or fill in surface irregularities so that there is nowhere for erosion to start.
2. Always start grass planting at the top of the slope and work downwards.
3. Mark out the lines with string using a tape measure. Make sure they run exactly as required by the specification, diagonally across the slope or towards drainage lines. It may help to use a spirit level and set square or frame to check the maximum line of fall.
4. Split the grass plants out to give the maximum planting material. Trim off long roots and cut the shoots off at about 100 mm above ground level. Wrap the plants in damp hessian to keep them moist until they are planted. Remember that you will need two slip cuttings per drill (planting hole) if the grass is a fibrous rooting

SPECIES SUITABLE FOR PLANTED GRASS LINES: DIAGONAL

Local name	Botanical name	Altitude range	Sites summary
Amliso	*Thysanolaena maxima*	Terai - 2000 m	Varied
Babiyo	*Eulaliopsis binata*	Terai - 1500 m	Hot and dry
Dhonde	*Neyraudia reynaudiana*	Terai - 1500 m	Hot and dry
Kans	*Saccharum spontaneum*	Terai - 2000 m	Hot and dry; moist
Katara khar	*Themeda* species	Terai - 2000 m	Varied
Khar	*Cymbopogon microtheca*	Terai - 2000 m	Hot and dry; varied
Khus	*Vetiveria lawsoni*	Terai - 1500 m	Varied
Narkat	*Arundo clonax*	Terai - 1500 m	Hot and dry; varied
Padang bans	*Himalayacalamus hookerianus*	1500 - 2500 m	Moist
Phurke	*Arunduella nepalensis*	700 - 2000 m	Varied; stony
Sito	*Neyraudia arundinacea*	Terai - 1500 m	Varied
Tite nigalo bans	*Drepanostachyum intermedium*	1000 - 2500 m	Varied

type (*e.g.* babiyo, kans, khar, phurke, *etc.*) but only one if it is rhizomatous (*e.g.* amliso, padang bans, *etc.*), and only one rooted stem cutting or seedling.

5 With a planting bar, make a hole just big enough for the roots. Place the grass into the hole, taking care not to tangle the roots or have them curved back to the surface. Fill the soil in around them, firming it gently with your fingers. Take care to avoid leaving an air pocket by the roots.

6 If compost or manure is available, scatter a few handfuls around the grasses. If the site is very stony, this is important for improving early growth. You may have to incorporate it into the surface material to prevent it being washed off.

7 If it looks rather dry and there is no prospect of rain for a day or two, consider watering the plants by hand.

Maintenance

This normally involves:

- Protection (check on Kartik 1);
- Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
- Grass cutting (check on Poush 1).

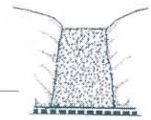
Main functions

Diagonal grass lines armour and reinforce slopes effectively, and can also drain and catch material moving down the slope. This system appears to combine the best features of both horizontal and vertical planting in the majority of sites.

Main limitations

Where the specific advantages of contour or downslope planting patterns are critical, diagonal planting should not be used. On certain very weak materials, small rills can develop down the slope.

3.4 PLANTED GRASSES: RANDOM PLANTING



Function

Grass slips (rooted cuttings), rooted stem cuttings or seedlings are planted at random on a slope, to an approximate specified density. They armour and reinforce the slope with their roots and by providing a surface cover. They also have a limited function of catching debris. This technique is most commonly used in conjunction with standard mesh jute netting, where complete surface protection is needed on very steep, harsh slopes. In most other cases, however, the advantages of one of the grass line planting systems (*i.e.* contour, downslope or diagonal) offer better protection to the slope.

Sites

Almost any slope less than 60° that allows grass planting. Normally used only on sites where jute netting (standard mesh) has already been applied. This implies slopes steeper than 45° and less than 15 metres in length, where moisture is not a serious problem.

Materials

- Grass plants raised in a nursery or cuttings obtained elsewhere;
- Short planting bars;
- A means of transporting plants to site;
- Hessian and water to keep the roots moist;
- (*Optional*) Manure or compost.

Spacing

Plants should be at an average of 100 mm centres (*i.e.* 100 plants per square metre). No gap should exceed 200 mm.

Construction steps

1 Apply the jute netting (standard mesh) well in advance of the monsoon, as described in Section 3.15. Start the grass planting as soon as the rains allow. If the site has not been

treated with jute netting, prepare it well in advance of planting: remove all debris and either remove or fill in surface irregularities so that there is nowhere for erosion to start.

2 Always start grass planting at the top of the slope and work downwards. Workers should stand on the pegs holding the netting, not on the netting itself.
3 Split the grass plants out to give the maximum planting material. Trim off long roots and cut the shoots off at about 100 mm above ground level. Wrap the plants in damp hessian to keep them moist until they are planted. Remember that you will need two slip cuttings per drill (planting hole) if the grass is a fibrous rooting type (*e.g.* babiyo, kans, khar, phurke, *etc.*) but only one if it is rhizomatous (*e.g.* amliso, padang bans, *etc.*), and only one rooted stem cutting or seedling.
4 With a planting bar, make a hole just big enough for the roots. Place the grass into the hole, taking care not to tangle the roots or have them curved back to the surface. Fill the soil in around them, firming it gently with your fingers.
5 Plant grasses at random over the surface, but aim for an average spacing of 100 mm centres (*i.e.* 100 plants per square metre). No gap should be greater than 200 mm.
6 If compost or manure is available, scatter a few handfuls around the grasses.
7 If it looks rather dry and there is no prospect of rain for a day or two, consider watering the plants by hand.

Maintenance

This normally involves:

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Grass cutting (check on Poush 1).

Main functions

Random grass planting armours and reinforces slopes effectively. This is particularly the case when it is used in conjunction with standard mesh jute netting.

Main functions and limitations

Where the specific advantages of contour, downslope or diagonal planting patterns are critical, random planting should not be used.

SPECIES SUITABLE FOR PLANTED GRASSES: RANDOM PLANTING

Local name	Botanical name	Altitude range	Sites summary
Amliso	*Thysanolaena maxima*	Terai - 2000 m	Varied
Babiyo	*Eulaliopsis binata*	Terai - 1500 m	Hot and dry
Dhonde	*Neyraudia reynaudiana*	Terai - 1500 m	Hot and dry
Kans	*Saccharum spontaneum*	Terai - 2000 m	Hot and dry; moist
Katara khar	*Themeda* species	Terai - 2000 m	Varied
Khar	*Cymbopogon microtheca*	Terai - 2000 m	Hot and dry; varied
Khus	*Vetiveria lawsoni*	Terai - 1500 m	Varied
Narkat	*Arundo clonax*	Terai - 1500 m	Hot and dry; varied
Phurke	*Arunduella nepalensis*	700 - 2000 m	Varied; stony
Sito	*Neyraudia arundinacea*	Terai - 1500 m	Varied

3.5 GRASS SEEDING

Function

Grass is sown directly on to the site. It allows easy vegetation coverage of large areas. This technique is often used in conjunction with mulching and jute netting to aid establishment. The main engineering functions are to armour and, later, to reinforce.

Sites

Almost any bare site with slopes up to 45°. Grass seeding is mostly used on well-drained materials, where increased infiltration does not give rise to problems.

Materials

- A supply of a carefully chosen grass seed;
- Tools to **scarify** the surface to be sown;
- Mulch (cut plant material) or hessian sheeting to cover the seed once sown (see Section 3.17).

SPECIES SUITABLE FOR GRASS SEEDING

Local name	Botanical name	Altitude range	Sites summary
Babiyo	*Eulaliopsis binata*	Terai - 1500 m	Hot and dry
Dhonde	*Neyraudia reynaudiana*	Terai - 1500 m	Hot and dry
Kans	*Saccharum spontaneum*	Terai - 2000 m	Hot and dry; moist
Katara khar	*Themeda* species	Terai - 2000 m	Varied
Khar	*Cymbopogon microtheca*	500 - 2000 m	Hot and dry; varied
Phurke	*Arunduella nepalensis*	700 - 2000 m	Varied; stony
Sito	*Neyraudia arundinacea*	Terai - 1500 m	Varied

In grass seeding, spread the seeds or grass seed heads liberally over the slope. Ideally, the whole surface should be very lightly covered in seed material

- On slopes of 30° to 45°, wide mesh jute netting will be required to hold the mulch in place on the slope (see Section 3.16).

Construction steps

1 Well in advance of the date of sowing, prepare the site. Remove all irregularities likely to allow slumps or gullies and clean loose debris away.
2 Immediately before sowing, scarify the surface of the slope. This means scratching the surface or carrying out basic cultivation to give a loose surface into which the germinating grass seeds can send their roots.
3 Start sowing from the top of the slope and work downwards. Spread the seeds or grass seed heads liberally over the slope. Ideally, the whole surface should be very lightly covered in seed material. An application rate of 25 grammes per square metre is normal.
4 Cover the seeds completely with a layer of mulch, made from cut herbs such as ban mara (*Eupatorium adenophorum*), or with hessian sheeting. A vegetation mulch is preferable. Wide mesh jute netting (150 mm × 500 mm mesh size) should be used to hold mulch on to the surface if the slope is greater than 30°.

Maintenance

This normally involves:

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Grass cutting (check on Poush 1).

Main functions

Grass seeding armours surfaces effectively: it can be used to create an even cover over all surfaces. It reinforces slopes after a few years of growth.

Main limitations

This technique gives none of the structural advantages of grass slip planting. Plants take longer to develop from seeds than from slips. Very heavy rain in the days immediately after sowing can lead to seeds being washed off the slope, or to damage to the very small seedlings.

3.6 TURFING

Function

Turf, consisting of a shallow rooting grass and the soil it is growing in, is placed on the slope. A technique commonly used on gentle embankment slopes. Its only engineering function is to armour.

Sites

This technique can be used on any gently sloping site (less than 30°). It is normally used on well-drained materials, where there is a minimal risk of **slumping.**

Materials

- Flat shovel with a sharp edge to cut the turf;
- Old khukuri to cut the turf to shape;
- Water to keep the turf moist;
- Wooden rammer (mungro);
- If the slope to be turfed is greater than about 25°, wooden pegs about 300 mm long and 30 mm in diameter will be required.

SPECIES SUITABLE FOR TURFING

Local name	Botanical name	Altitude range	Sites summary
Dubo	*Cynodon dactylon*	Terai - 1800 m	Varied

Construction steps (making turf)

Turf should be cut the same day as it is to be placed; if this is not possible, it should be kept very moist in a shady place. To cut the turf:

1 Mark out with lines the size and shape to be cut (300 mm square is easy to manage but 300 × 600 mm is better);
2 Cut the sides of the shapes with a khukuri, to at least 50-mm depth;
3 Using a broad, flat shovel with a sharp edge, cut horizontally under the shapes and lift them out.

If the ground where the turf is to be taken

Turfing provides instant surface protection, as used on this road shoulder (the embankment has been treated with grass lines and brush layering)

from is hard and dry, it may be helpful to water it thoroughly the day before cutting.

Construction steps (placing the turf)

1 Well in advance of the turfing operation, thoroughly smooth the surface to be covered. It is most important to obliterate all irregularities;
2 If the slope to be turfed is a gravel-fill embankment, then a 50-mm layer of topsoil should be laid and compacted by hand;
3 Immediately before placing the turf, scarify the ground surface slightly and water it well if it is not already moist;
4 Place the turf, taking care to fit the pieces together with no gaps between. Use the khukuri to cut the pieces to shape;
5 If the slope is steeper than about 25°, wooden pegs should be hammered through the turf to stop it sliding;
6 Once the slope has been satisfactorily covered, compact the turf with the wooden rammer.
7 Finally, water the fresh turf thoroughly.

Maintenance

This normally involves:

Protection (check on Kartik 1);
Grass cutting (check on Poush 1).

Main functions

Turfing armours slopes: it gives a complete instant surface cover.

Main limitations

Turfing is relatively costly, and creates equal bare areas at the source of the turf, where erosion can start. For this reason its use needs to be restricted in hill areas. In addition, there is a discontinuity between the turf and the underlying material which, in extreme conditions, can give rise to gradual creep or a shallow planar failure. Because turfing has to be carried out using the small grass dubo, there are no higher plants to discourage animal tramping, so damage can be caused by this means.

3.7 SHRUB AND TREE PLANTING

Function

Shrubs or trees are planted at regular intervals on the slope. As they grow, they create a dense network of roots in the soil. The main engineering functions are to reinforce and, later, to anchor. In the long term, large trees can also be used for slope support.

Sites

This method can be used without adverse effects on almost any slope up to 30°. With care, it can be used on slopes between 30° and 45°. It can be used on any material and in any site.

Materials

- Plants raised in a nursery, usually as polypot seedlings;
- Tools to dig holes and a means of transporting the plants to site;
- (*Optional*) Compost.

Spacing

The spacing of plants is important. The main considerations are cost and the speed with which a full cover is required. In most bio-engineering sites a spacing of 1 × 1 metre is necessary, requiring 10,000 plants per hectare. Plants should be planted in off-set rows unless a different pattern is needed for specific bio-engineering requirements.

Construction steps

1 Prepare the site well in advance of planting. Remove all debris and remove or fill surface irregularities. If the site is on backfill material, thoroughly compact it, preferably when it is wet. Cut all weeds.

2 If possible, dig pits for the shrubs or trees well in advance of the planting programme, but refill them the same day. Pits should be 300 mm deep and 300 mm in diameter if this is possible without causing excessive damage to the slope.

3 When the ground is wet enough to support reasonable growth, plant out the seedlings. The bigger the hole made, the better it is for the plant; but there must be a compromise between helping the plant and avoiding excessive disturbance to the slope.

4 Carefully remove the polypot by slicing it down the side with a razor blade or tear it carefully along the fold. Take care not to cut the roots.

5 Plant the seedling in the pit, filling the soil carefully around the cylinder of roots and soil from the polypot. Ensure there are no cavities. Firm the soil all around the seedling with gentle foot pressure.

6 If available, mix a few handfuls of well-rotted compost with the soil around the roots when you are backfilling the hole.

7 Remove any weeds around the plant. Add mulch around the seedling, but with a slight gap so that it does not touch the stem.

SPECIES SUITABLE FOR SHRUB AND TREE PLANTING

Local name	Botanical name	Altitude range	Sites summary
Shrubs			
Areri	*Acacia pennata*	500 - 1500 m	Hot and dry; harsh
Dhanyero	*Woodfordia fruticosa*	Terai - 1500 m	Hot and dry; harsh
Dhusun	*Colebrookea oppositifolia*	Terai - 1000 m	Hot and dry; harsh
Kanda phul	*Lantana camara*	Terai - 1750 m	Hot and dry
Keraukose	*Indigofera atroturpurea*	Terai - 2000 m	Hot and dry; harsh
Tilka	*Wendlandia puberula*	Terai - 1500 m	Hot and dry; harsh
Trees			
Bakaino	*Melia azedarach*	Terai - 1800 m	Hot and dry; harsh
Chilaune	*Schima wallichii*	900 - 2000 m	Varied; dry - moist
Gobre salla	*Pinus wallichiana*	1800 - 3000 m	Dry; varied
Kalo siris	*Albizia lebbeck*	Terai - 1200 m	Hot and dry; harsh
Khanyu (khosro)	*Ficus semicordata*	Terai - 2000 m	Hot and dry; varied
Khayer	*Acacia catechu*	Terai - 1000 m	Hot and dry; harsh
Lankuri	*Fraxinus floribunda*	1200 - 2700 m	Varied; moist best
Painyu	*Prunus cerasoides*	500 - 2400 m	Varied/dry; stony
Rani (khote) salla	*Pinus roxburghii*	500 - 1950 m	Hot and dry; varied
Rato siris	*Albizia julibrissin*	800 - 3000 m	Varied and moist
Seto siris	*Albizia procera*	Terai - 1350 m	Moist
Sisau	*Dalbergia sissoo*	Terai - 1400 m	Varied
Utis	*Alnus nepalensis*	900 - 2700 m	Varied and moist

This eight-year old utis plantation, raised from polypot seedlings, is established enough to reinforce and anchor the roadside slope

Maintenance

This normally involves:

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

Main functions

Planting shrubs and trees reinforces and anchors the slope by establishing a community of larger plants.

Main limitations

Seedlings take about five years to contribute significantly to slope strengthening. Care and protection are required in the first three years.

3.8 SHRUB AND TREE SEEDING

Function

Shrub (or **tree**) seeds are applied directly to the site. This technique allows very steep, rocky and unstable slopes to be revegetated where cuttings and seedlings cannot be planted. There are two methods: (1) direct sowing and (2) **broadcasting**. In the first, seeds are placed individually, whereas the second involves throwing the seed all over the site. The main engineering functions are to reinforce and, later, to anchor.

Sites

Any steep, rocky or unstable sites. This technique is particularly useful on fractured rock slopes where normal planting cannot be done. Direct sowing can be practised on very steep slopes (**i**.*e*. up to about 60°) and it is rarely necessary to use this technique on slopes more gentle than 45°. Broadcasting seeds can be carried out on any slopes up to 45°, but is usually less successful on slopes steeper than 30°.

Materials

- A supply of the seeds to be sown;
- Small planting bars (if direct seeding).

Construction steps: direct seeding

The sowing of shrub seeds directly into the material of the site. Choose larger seeds such as areri or bhujetro.

1. In advance of the sowing programme, clear all very loose debris from the site.
2. Start seeding from the top of the slope and move downwards. Make a small hole, a little bigger than the seed, using a planting bar.
3. Push the seed right into the hole and cover it with soil; or, if it is in a rocky crevice, check that it is right out of direct sunlight. Make sure that the seed coat is not damaged in this process.

Construction steps: broadcasting

The sowing of tree and shrub seeds by throwing them over the site. It is normal to choose small seeds such as khanyu or utis, although larger seeds can be used as well.

1. In advance of the sowing programme, clear all very loose debris from the site.
2. Any smooth surfaces should be scarified to give a rough, looser surface for the seed to be held on and put roots into.
3. Throw the seeds on to the surface of the slope, ensuring that they do not blow away or slide down into concentrated masses in crevices and rills.

Spacing

Seeds are normally sown or broadcast to give a coverage of one plant every 250 mm, centre to centre. The actual seeding rate should be increased to three seeds for every plant required to give a reasonable survival rate.

Maintenance

This normally involves:

Protection (check on Kartik 1);

Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);

SPECIES SUITABLE FOR SHRUB AND THEE SEEDING

Main species used for **direct seeding**

Local name	Botanical name	Altitude range	Sites summary
Shrubs			
Areri	*Acacia pennata*	500 - 1500 m	Hot and dry; harsh
Bhujetro	*Butea minor*	500 - 1500 m	Hot and dry; harsh
Keraukose	*Indigofera atroturpurea*	Terai - 2000 m	Hot and dry; harsh

Main species used for **broadcasting**.

Local name	Botanical name	Altitude range	Sites summary
Shrubs			
Areri	*Acacia pennata*	500 - 1500 m	Hot and dry; harsh
Bhujetro	*Butea minor*	500 - 1500 m	Hot and dry; harsh
Keraukose	*Indigofera atroturpurea*	Terai - 2000 m	Hot and dry; harsh
Trees			
Bakaino	*Melia azedarach*	Terai - 1800 m	Hot and dry; harsh
Gobre salla	*Pinus wallichiana*	1800 - 3000 m	Dry; varied
Khanyu (khosro)	*Ficus semicordata*	Terai - 2000 m	Hot and dry; varied
Khayer	*Acacia catechu*	Terai - 1000 m	Hot and dry; harsh
Rani (khote) Salla	*Pinus roxburghii*	500 - 1950 m	Hot and dry; varied
Sisau	*Dalbergia sissoo*	Terai - 1400 m	Varied
Utis	*Alnus nepalensis*	900 - 2700 m	Varied and moist

Thinning (check on Kartik 1, starting three years after site works).

Main functions

Seeding shrubs and trees reinforces and anchors any slope, however rocky, by establishing a community of larger plants.

Main limitations

Seedlings take about five years to contribute significantly to slope strengthening. Protection is required in the first few years.

3.9 LARGE BAMBOO PLANTING

Function

Large **bamboos** can reduce movement of material and stabilise slopes. Large bamboos are usually planted by one of two methods: (1) the traditional planting method or (2) to plant rooted **culm cuttings** from a nursery. Large clumps of the larger stature bamboos are one of the most substantial vegetation structures available to reinforce and support a slope. However, they do not have deeply penetrating roots and so do not have an anchoring function; also, they can surcharge upper slope areas.

Sites

Mostly used at the base of slopes and in gullies, where the slope segment has an angle of less than 30°. Any fill site can be planted. Bamboos do not thrive on very dry or excessively stony sites.

Materials

- For the traditional method; one-year-old rhizomes and 2-2.5 metres of culm, removed from the clump carefully with minimal damage to the roots;
- For the rooted culm cutting method, rooted single-node culm cuttings from a nursery;
- Hessian and water to wrap around the root ball to keep it moist;
- A means of transporting the cutting to the planting site;
- Tools to dig a hole for planting;
- Material for mulching after planting;
- For the traditional method, the upper sections of the culm should be kept to support the cutting once it has been planted.

Spacing

Planting large bamboos is so much bigger a job than with other plants that it is almost impossible to plant too many. However, they should never be planted closer than 2 metres apart across a slope and perhaps 5 metres up and down the slope.

Construction steps: traditional method

The traditional planting method for bamboos is well known throughout the hills and Terai. It involves taking a very large rhizome and culm cutting. Source clumps should be identified well in advance and an agreement reached with the owners. This method can be used for any bamboo species.

1 Remove all loose debris from the site and prepare the surface well in advance of the planting day;

SPECIES SUITABLE FOR LARGE BAMBOO PLANTING

Local name	Botanical name	Altitude range	Sites summary
Traditional planting method only			
Mal bans	*Bambusa nutans*	Terai - 1500 m	Dry/varied
Nibha/ ghopi/ lyas bans	*Ampelocalamus patellaris*	1200 - 2000 m	Varied
Tharu bans	*Bambusa nutans*	Terai - 1500 m	Varied
Either traditional planting method or rooted single-node culm cutting method			
Choya/ tama bans	*Dendrocalamus hamiltonii*	300 - 2000 m	Moist
Dhanu bans	*Bambusa balcooa*	Terai - 1600 m	Varied
Kalo bans	*Dendrocalamus hookeri*	1200 - 2500 m	Varied

A stand of large bamboos can catch debris and support the base of a slope

2 Select a suitable culm near the edge of the parent clump and dig out the rhizome carefully. Cut off the culm about 2 metres above ground level. Cut the rhizome where it branches from the main plant, taking great care not to damage the buds and small roots;
3 Wrap the root ball in damp hessian and transport the big cutting to site for planting on the same day;
4 Dig a large hole (at least five times the size of the cutting's rhizome) and plant the rhizome either upright or at right angles to the slope. Carefully backfill the hole and firm the soil as much as possible;
5 Mulch well the disturbed and surrounding soil.
6 Form a depression around the roots to act as a water collection area. If possible, water it thoroughly;
7 (*Optional*) If available, use two pieces from the higher part of the culm to make a tripod structure with the planted piece. Lash them together with jute string (not wire) as high as possible. This holds the plant much more firmly when disturbed by grazing animals.

Construction steps: rooted culm cutting method

This is suitable for many large bamboos that have heavy branching. It can be used for choya/tama bans, dhanu bans and kalo bans. It requires a rooted culm cutting brought from a nursery (see Section 4.6 for details on this).

1 Keep the root ball wrapped in wet hessian until you are ready to plant it, so that it does not dry out.
2 Remove all the loose debris from the site and carry out any other site preparation well in advance of the planting day.
3 Dig a sufficiently large hole and plant the cutting in it.
4 Carefully backfill the hole, making sure that you do not damage buds at the base of the cutting. Firm the soil.
5 Place a layer of mulch over the disturbed soil and the surrounding area.
6 Form a depression around the roots to act as a water collection area;
7 Water thoroughly.

Maintenance

This normally involves:

Protection (check on Kartik 1);
Watering in the first year (check weekly in Chaitra, Baisakh and Jestha);
Mulching in the first two years (check on Mangsir 1).

Main functions

Large bamboos support the base of a slope by establishing a very strong line of plants. With their multiple stems, they catch debris moving down the slope.

Main limitations

Bamboos take about five years to contribute significantly to slope strengthening. Protection is required in the early years. This technique cannot be used in most in hot, dry sites, since bamboos generally require cool, moist sites. Bamboos planted in steep upper slope situations are prone to slumping some years (seven or more) after planting.

3.10 BRUSH LAYERING

Function

Woody cuttings (or **hardwood cuttings**) are laid in lines across the slope, usually following the contour. These form a strong barrier, preventing the development of **rills**, and trap material moving down the slope. In the long term, a small terrace will develop. The main engineering functions are to catch debris, and to armour and reinforce the slope. In certain locations, brush layers can be angled to provide a drainage function.

SPECIES SUITABLE FOR BRUSH LAYERING

Local name	Botanical name	Altitude range	Sites summary
Assuro	*Adhatoda vasica*	Terai - 1000 m	Varied
Bainsh	*Salix tetrasperma*	Terai - 2700 m	Moist
Dabdabe	*Garuga pinnata*	Terai - 1300 m	Varied and dry
Kanda phul	*Lantana camara*	Terai - 1750 m	Hot and dry
Namdi phul	*Colquhounia coccinea*	1000 - 2000 m	Varied
Phaledo	*Erythrina* species	900 - 3000 m	Varied
Saruwa/ bihaya	*Ipomoea fistulosa*	Terai - 1500 m	Varied; hot or wet
Simali	*Vitex negundo*	Terai - 1750 m	Hot and dry; varied


Brush layering. Lay the first layer of cuttings along the terrace, with a 50 mm interval between the cuttings (Far left, see also step 4); a second layer of cuttings is placed on top (above left, step 6); layers are positioned at 1 to 2 metre intervals up the slope (above middle, step 8); in the long term, small terraces develop (above right)

Sites

This technique can be used on a wide range of sites up to about 45°. It is particularly effective on debris sites, fill slopes and high embankments. Avoid using the technique on materials that are poorly drained and are subject to high rates of small-scale slumping (see Section 3.13, Fascines, which may be more appropriate for poorly drained sites).

Materials

- Cuttings made from woody material that is 6 to 18 months old. They should be 20 to 40 mm in diameter and 450 to 600 mm long. When taking the cuttings, cut the top at right angles to the stem and the bottom at 45° to make it clear as to which way it should be inserted. If possible, take the cuttings the same day that they are to be planted.
- Hessian and water to keep the cuttings moist until planting.
- Shovels and pick axes to make the trenches for planting.
- Line string.
- Tape measure (30 metres).
- For brush layering on gravel fill embankments, a supply of forest topsoil at the rate of 1 cu. m per 20 metres of layering.

Spacing

Spacing between brush layers depends on the steepness of the slope. The following spaces should be used.

Slope less than 30°	2 m interval;
Slope 30 to 45°	1 m interval.

Within the brush layers, cuttings should be at 50 mm centres, in the double layer described above. A wider gap than this is acceptable on gentle slopes, but on steep slopes this spacing is required to give adequate protection.

Construction steps

1 Using string, mark the lines to be planted, starting 500 mm from the base of the slope.
2 Always install brush layers from the bottom of the slope, and work upwards.
3 Form a small terrace, with a 20 percent fall back into the slope. The terrace should be 400 mm wide. If you are brush layering a gravel-filled road embankment you should lay a 50 mm thick layer of soil along this terrace to improve rooting conditions.
4 Lay the first layer of cuttings along the terrace, with a 50 mm interval between the cuttings. Leave at least one bud and up to one-third of the cuttings sticking beyond the terrace edge and the rest inside. The branch growing tips should point towards the outside of the terrace.
5 Lay a 20 mm-thick layer of soil in between the cuttings to provide a loose cushion.
6 Lay a second layer of cuttings on top of this, staggered with the first layer. On a gravel-filled embankment slope lay an 80 mm layer of soil over the cuttings before you do any backfilling.
7 Partly backfill the terrace with the excavated materials. This should not be more than 50 mm thick.
8 Mark a line 1 metre above the first brush layer and set the string for the next layer.
9 Follow steps 3 to 7. As the next terrace is cut, always fill the lower bench with the material excavated from above and compact it reasonably well by gentle foot pressure.

Good site supervision is essential to ensure that lines run along the contours and do not concentrate runoff; also to make sure that cuttings are not allowed to dry in the sun. Well-buried cuttings have a higher survival rate.

Maintenance

Since the spacing of plants recommended here is very dense, there is unlikely to be a need for replacing failures, but some thinning of the trees or shrubs may be required after a few years. The main maintenance checks should be as follows.

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

Main functions

Brush layering armours and reinforces the slope; it catches debris; and, if angled, it helps to drain the slope. Brush layers provide a very strong and low-cost barrier, especially on debris slopes, however loose.

Main limitations

The main limitation is that construction gives rise to a considerable level of disturbance to the slope.

3.11 PALISADES

Function

Woody (or **hardwood**) **cuttings** are planted in lines across the slope, usually following the contour. These form a strong barrier and trap material moving down the slope. In the long term, a small terrace will develop. The main engineering functions are to catch debris, and to armour and reinforce the slope. In certain locations, palisades can be angled to give a drainage function.

Sites

This technique can be used on a wide range of sites up to about 60°. It is particularly effective on steep landslide debris slopes. Materials that are poorly drained and are subject to high rates of small-scale slumping should be avoided (see Section 3.13, Fascines, which may be more appropriate for poorly drained sites of up to 45°).

Materials

- Cuttings made from woody material that is 6 to 18 months old. They should be 20 to 40 mm in diameter and 300 to 500 mm long. Cut the tops at right angles to the stems and cut the bottom at 45°: it is then clear as to which way each cutting should be inserted. If possible, take the cuttings the same day that they are to be planted.
- Hessian and water to keep the cuttings moist until planting.
- Pointed planting bars or crowbars to make the holes for planting.

A completed palisade (left)
A simali palisade excavated after one growing season to show the development of roots (right)

Spacing

Spacing between palisades depends on the steepness of the slope. The following spaces should be used.

Slope less than 30° 2 m interval;
Slope 30 to 60° 1 m intervals.

Within the palisade lines, cuttings should be at centres of between 30 and 50 mm. A wider gap than this is acceptable on gentle slopes, but on

SPECIES SUITABLE FOR PALISADES

Local name	Botanical name	Altitude range	Sites summary
Assuro	*Adhatoda vasica*	Terai - 1000 m	Varied
Bainsh	*Salix tetrasperma*	Terai - 2700 m	Moist
Dabdabe	*Garuga pinnata*	Terai - 1300 m	Varied and dry
Kanda phul	*Lantana camara*	Terai - 1750 m	Hot and dry
Namdi phul	*Colquhounia coccinea*	1000 - 2000 m	Varied
Phaledo	*Erythrina* species	900 - 3000 m	Varied
Saruwa bihaya	*Ipomoea fistulosa*	Terai - 1500 m	Varied; hot or wet
Simali	*Vitex negundo*	Terai - 1750 m	Hot and dry; varied

steep slopes this spacing is required to give adequate protection.

Construction steps

1 Trim and clean the site well in advance of the planting operation. Remove irregularities and loose debris.
2 With string, mark out the lines to be planted.
3 Always start at the top of the slope and work downwards.
4 Using a pointed bar, make a hole in the slope that is bigger than the cutting and deep enough to take at least two-thirds of its length.
5 Carefully place the cutting in the hole, so that at least two-thirds is buried. Firm the soil around it, taking care not to damage the bark. Ideally, only one node of the cutting or about the top 100 mm should protrude from the soil. On steep, unstable sites, however, a greater protrusion helps to raise the delicate new shoots above the zone of moving debris, and to catch more debris.

Good site supervision is essential to ensure that lines run along the contours and do not concentrate runoff; also to make sure that cuttings are not allowed to dry in the sun. Cuttings buried completely have a higher success rate than those planted with the tops partially exposed. Under extreme conditions, cuttings can be hammered into the slope. However, this is likely to cause physical damage and reduce the chances of success.

Maintenance

Since the spacing of plants recommended here is very dense, there is unlikely to be a need for replacing failures, but some thinning of the trees or shrubs may be required after a few years. The main maintenance checks should be as follows.

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

Main functions

Palisades armour and reinforce the slope, catch debris and, if angled, provide drainage. They form a strong and low-cost barrier built with the minimum disturbance to the slope.

Main limitations

Palisades are not as strong as brush layering.

3.12 LIVE CHECK DAMS

Function

Large woody (or **hardwood**) **cuttings** are planted across a gully, usually following the contour. These form a strong barrier and trap material moving downwards. In the longer term, a small step will develop in the floor of the gully. The main engineering functions are to catch debris, and to armour and reinforce the gully floor.

Sites

This technique can be used on a wide range of gully sites, on slopes of up to 45°. However, materials subject to high rates of small scale slumping should be avoided.

Materials

- Large cuttings (2 metres long and 20 to 50 mm in diameter) made from woody material that is 6 to 30 months old. Cut the tops at right angles to the stem and the bottom at 45°; it is then clear as to which way it should be inserted. If possible, take the cuttings on the same day that they are to be planted.
- Truncheon cuttings 2 metres long and 30 to 80 mm in diameter, preferably of simali, dabdabe or phaledo.
- Hessian and water to keep the cuttings moist until planting.
- Pointed planting bars or crowbars to make the holes for planting.

Spacing

Spacing between check dams depends on the steepness of the gully slope and the profile of the

Backfill around the check dam and compact the soil with foot pressure

Live check dams form a strong barrier on a wide range of gully site, on slopes up to 45°

gully floor. Live check dams should normally be at intervals of between 3 and 5 metres. Within the check dams, cuttings should be about 30 to 50 mm apart. A wider gap than this is acceptable on gentle slopes, but on steep slopes this spacing is required to give adequate protection. If a double, offset line is planted, it will give a much stronger check dam.

Construction steps

1 Choose a location for the live check dam so that the maximum effect can be achieved in terms of gully stabilisation.

2 Make a hole deep and big enough to insert vertical hardwood cuttings of the largest size available (truncheon cuttings up to 2 metres in length of species such as dabdabe and phaledo are best). Use a crowbar if necessary to extend the hole.

3 Insert the vertical cuttings by carefully pushing them into the hole and firming the soil around them. Try not to damage the bark. They should protrude about 300 mm above the ground surface.

4 Place fascines or long hardwood cuttings on the uphill side of the vertical stakes.

5 Key these horizontal members into the wall of the gully.

6 Backfill around the check dam and compact the soil with foot pressure.

Maintenance

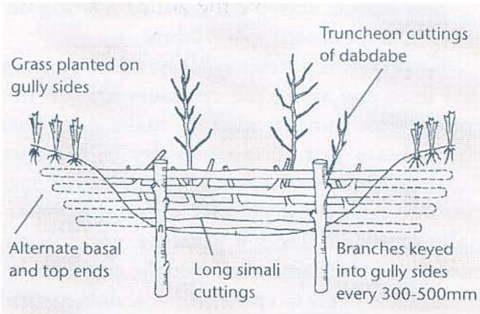
Since the spacing of plants recommended here is very dense, there is unlikely to be a need for replacing failures, but some thinning of the trees or shrubs may be required after a few years. The main maintenance checks should be as follows.

Protection (check on Kartik 1);

SPECIES SUITABLE FOR LIVE CHECK DAMS

Local name	Botanical name	Altitude range	Sites summary
Horizontal cuttings			
Assuro	*Adhatoda vasica*	Terai - 1000 m	Varied
Bainsh	*Salix tetrasperma*	Terai - 2700 m	Moist
Kanda phul	*Lantana camara*	Terai - 1750 m	Hot and dry
Namdi phul	*Colquhounia coccinea*	1000 - 2000 m	Varied
Saruwa/bihaya	*Ipomoea fistulosa*	Terai - 1500 m	Varied; hot or wet
Simali	*Vitex negundo*	Terai - 1750 m	Hot and dry; varied
Main vertical support member cuttings			
Dabdabe	*Garuga pinnata*	Terai - 1300 m	Varied and dry
Phaledo	*Erythrina* species	900 - 3000 m	Varied

The cuttings to provide vertical support should be of the biggest and strongest materials, in the form of truncheon cuttings (2 metres long and 30 to 80 mm in diameter). Dabdabe and phaledo are excellent for this. Other possible species are chuletro (*Brassaiopsis hainla*), kavro (*Ficus lacor*) and gliricidia (*Gliricidia sepium*).



Components of a live check dam

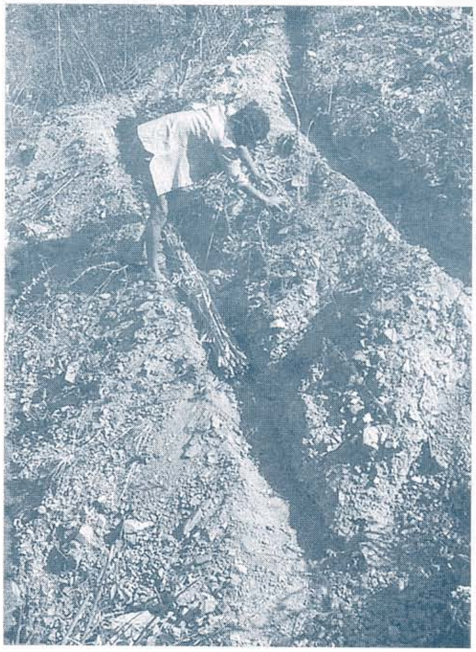
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

Main functions

Live check dams catch debris and to a lesser extent, also armour and reinforce gully floors. They are an effective low-cost structure in smaller gullies, or can be used in between masonry check dams. Their flexibility and the relative lack of site disturbance during construction make them very suitable for use on weak materials, where civil engineering can easily be scoured around.

Main limitations

Large and very active gullies require stronger measures than can be provided by vegetation alone.



Fascines are effective on consolidated debris. They put out roots and shoots which develop into a strong line of vegetation, catching falling debris as well as armouring and reinforcing the slope

3.13 FASCINES

Function

The word 'fascine' means a bundle of sticks. In this technique, bundles of live branches are laid in shallow trenches. After burial in the trenches, they put out roots and shoots, forming a strong line of vegetation. It is sometimes called live contour wattling. The main engineering functions are to catch debris, and to armour and reinforce the slope. In certain locations, fascines can be angled to provide drainage. Where time is at a premium, brush layers may be more appropriate as these are quicker to establish than fascines (see Section 3.10, Brush layering).

SPECIES SUITABLE FOR FASCINES

Local name	Botanical name	Altitude range	Sites summary
Assuro	*Adhatoda vasica*	Terai - 1000 m	Varied
Bainsh	*Salix tetrasperma*	Terai - 2700 m	Moist
Dabdabe	*Garuga pinnata*	Terai - 1300 m	Varied and dry
Kanda phul	*Lantana camara*	Terai - 1750 m	Hot and dry
Namdi phul	*Colquhounia coccinea*	1000 - 2000 m	Varied
Phaledo	*Erythrina* species	900 - 3000 m	Varied
Saruwa/ bihaya	*Ipomoea fistulosa*	Terai - 1500 m	Varied; hot or wet
Simali	*Vitex negundo*	Terai - 1750 m	Hot and dry; varied

Sites

Fascines are best used on consolidated debris or soft cut slopes. If the material is too hard, growth will be unacceptably slow. The maximum slope is about 45°. On well-drained materials, contour fascines are used; on poorly drained materials, a herringbone pattern (←←←←←) of fascines is used to improve drainage.

Materials

- Woody cuttings of suitable species, at least one metre long and 20 to 40 mm diameter;
- Hessian and water to keep the cuttings moist until planting;
- Tools to dig trenches;
- *(Optional)* Jute or coir string or wire to bind the fascine as it is laid.

Spacing

Spacing between fascines depends on the steepness of the slope.

Less than 30°	4 m interval;
30 to 45°	2 m interval.

Within the fascines, there should be at least four but no more than eight cuttings.

Construction steps

1 Prepare the site well in advance of planting. Clear all loose material and protrusions and firmly infill depressions.

2 Mark on the slope the lines where fascines are to be installed. Supervise workers carefully to

ensure that the lines follow the contour or desired angle precisely.

3 Always construct fascines from the bottom of the slope, and work upwards.

4 Dig about five metres of trench at a time, carrying out Step 5 at the same time. This ensures that the soil in the trench is exposed only for a short period, thereby minimising the loss of residual soil moisture. The trench should be about 100 mm deep and 200 mm wide.

5 Lay the cuttings together, filling the trench and with their ends overlapping so that they form a single cable right across the slope. Four cuttings per bundle is normal, but use eight per bundle if there is a lot of material available or if the site is very critical.

6 The fascines can be bound as they are installed by first laying strings across the trench and then tying it when the cuttings are in place. This helps to keep the cuttings together during backfilling but is not essential.

7 Backfill the trench as soon as possible, lightly covering the cuttings, and tamp the soil down firmly around it.

8 If the slope angle is more than 25°, you should peg the fascine. This can be done by placing a large cutting at right angles into the slope immediately below the fascine. Use one peg per 500-mm run of fascines.

Maintenance

Since the spacing of plants resulting from fascines is very dense, there is unlikely to be a need for replacing failures, but some thinning of the shrubs may be required after a few years. The main maintenance checks should be as follows.

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

Main functions

Fascines armour and reinforce the slope, catch debris and, if angled, provide drainage. They form a very strong and low-cost barrier, useful on a variety of sites.

Main limitations

Fascines do not form a physical barrier immediately as do brush layers, but require a period of growth to become effective. Construction causes disturbance to the slope.

3.14 VEGETATED STONE PITCHING

Function

Slopes are strengthened by a combination of dry stone walling or cobbling, and vegetation planted in the gaps between the stones. There are two distinct uses: (1) reinforced toe walls; and (2) protected gully beds. This technique provides a very strong form of armouring. Because it specifically uses vegetation to strengthen a simple civil engineering technique, it represents a stronger form of normal stone pitching (see Section 2.6).

Sites

Steep, low slope toe walls of up to 2 metres in height, and gully floors with a maximum slope of 45°.

Vegetated stone-pitched toe walls

These provide strong armouring at the base of a slope and prevent undermining. Where major support is needed, gabion or masonry toe walls may be required. Dry stone toe walls can only be used in limited applications. Walls using this technique should not be more than 2 metres high and should be laid back at an angle of about 60°.

Cobbling with vegetation planted between the stones provides strong armouring

Vegetated stone-pitched gully floors

Gully beds are cobbled to prevent downcutting, and then plants are established between the cobbles to stop them being pulled out by running water.

Materials

- Stones for construction.
- Hardwood cuttings or seeds of suitable shrubs (but not of large trees) for walls.
- Grass slips for gully floors.

Spacing

Plants should be established at 250 mm centres initially, on a random pattern.

Construction steps

Walls

1 Construct the wall normally, but make sure that there is plenty of soil in the backfill mixture.

2 once the wall is ready, wait until the monsoon rains are imminent. Then place the cuttings or seeds carefully between the stones, taking care not to damage the bark or seed coat.

Gullies

1 Clean the gully floor completely of all debris and excavate as necessary until a firm base is exposed;

2 lay the stones carefully together, always keeping the flattest sides on the surface. Reduce gaps to a minimum and pack all voids with soil. The stone pitching should have a U-shaped cross-section to prevent scour at the sides;

3 once the monsoon rains have started, plant grass slips between the stones. Ideally, smaller grasses should be planted in the main channel, with larger grasses along the sides.

Maintenance

Since the spacing of plants in vegetated stone pitching is very dense, there is unlikely to be a need for replacing failures, but some thinning of shrubs may be required after a few years. The main maintenance checks should be as follows.

Protection (check on Kartik 1);
Weeding in the first few years (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

Jute netting is a temporary measure, designed to enhance the establishment of vegetation

Main functions

Vegetated stone pitching provides a very strong form of armouring. This is particularly useful for gully floors carrying large flood discharges.

Main limitations

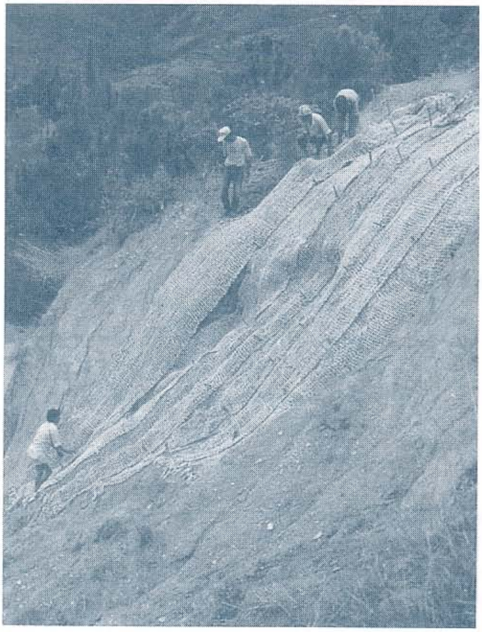
The main limitation is that over a large area it becomes costly; although relative to many toe walls or other forms of gully control, this may not in fact be limiting.

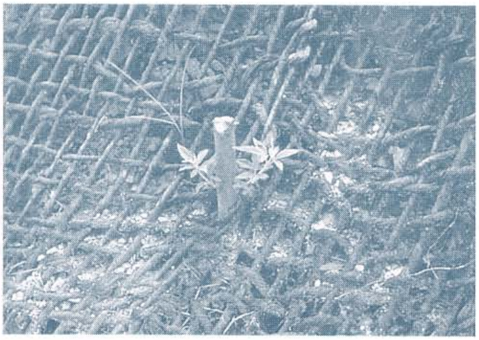
3.15 JUTE NETTING (STANDARD MESH)

Function

A locally made geotextile of woven jute netting is placed on the slope. Standard mesh jute netting (mesh size about 40 × 40 mm) has four main functions:

- Protection of the surface, armouring against erosion and catching small debris;
- Allowing seeds to hold and germinate;
- Improvement of the microclimate on the slope surface by holding moisture and increasing infiltration;
- As it decays, it acts as a mulch for the vegetation established.





Ensure that the jute netting is loose enough to be held against the surface over the whole slope (left). Live pegs will grow to add more strength to the slope

Any use of jute netting is a temporary measure designed to enhance vegetation establishment. It does not protect a surface in itself for more than one or two seasons of monsoon rains.

Sites

Standard netting is used on steep, hard slopes where the existing conditions are too harsh for vegetation to establish itself without assistance. Slope angles of 45 to 60° are normal. It is best on well-drained materials that are too hard for vegetation to grow in unaided, or on slopes exposed to hot sun and where extreme drought would otherwise be a problem. It should not be used on soft or poorly drained materials. It should never be used on materials with a high rate of shallow slumping. Drainage is so important in sites treated with jute netting that slopes less than 45° should not normally be covered. This excludes all debris materials.

Materials

- Woven jute netting.
- Hardwood cuttings from shrubs or trees, 20 to 50 mm in diameter and 300 to 400 mm long, or other pegs, such as split bamboos.
- Tools for cutting wood and jute; an iron bar for making holes, and a wooden mallet.

Standard jute netting rolls are normally 10.0 to 11.5 metres long by 1.0 to 1.2 metres wide. The yarn is of 5 to 8 mm diameter. Across the net there should be an average of 27 **warp** ends (length-ways threads) per metre; along the length of the net, there should be 20 to 24 **weft** strands (cross threads) per metre. The average mesh size should be 40 mm square holes. The weight should be 1.0 to 1.2 kg per square metre. These specifications are higher than those used in the Indian road sector (where 0.5 and 0.75 kg/sq. m are recommended). Experience has shown that the heavier grade material hangs better on the slope, catches more material, retains more moisture and has remains effective for longer.

The life of jute netting can be extended by soaking in a bath of bitumen diluted with kerosene. However, this has the effect of reducing the water retention capacity of the material, which is a desirable attribute on many sites.

Spacing

Completely cover the affected area with netting, anchoring pegs spaced at 500 to 1000 mm centres.

Construction steps (standard netting)

1. Trim the site to an even slope, ensuring that there are no small protrusions or depressions that will interfere with the netting.
2. Starting at one end of site, peg the end of one roll of netting 300 mm above the slope to be covered.
3. Slowly unroll the netting down the slope.
4. Allowing some slack in the netting, begin to peg it from the bottom of the slope. Hammer hardwood cuttings or pegs through it at intervals of 500 to 1000 mm, leaving the cuttings protruding about 80 mm.

5 Repeat the process, making sure that the vertical edges of the net meet, until the whole slope is covered in netting.
6 Place a series of pegs down each side of the net so that there is no gap between the strips.
7 Adjust the netting in order to reduce the tension and let it hug the surface closely. If it remains tight it will not lie right against the slope surface.
8 Add further pegs as necessary to ensure complete contact with the surface.
9 Trim the netting strips to the length required.
10 As soon as the monsoon rains permit, plant grass slips randomly through the netting over the entire area (see Section 3.4).

Integration with bio-engineering

Standard mesh jute netting should only be used in conjunction with bio-engineering techniques as follows:

- Through the netting: plant grass slips in a random pattern, at an average spacing of about 100 mm centres, according to site characteristics and as determined by the instructions in Section 3.4.
- If a deeper reinforcing is required, the surface can be seeded with shrubs or small trees (direct seeding is best, but broadcasting is also possible), using species appropriate to the site and following the techniques described in Section 3.8.

It is important to ensure that the netted area becomes protected with vegetation during the first two planting seasons, because it has to take over the role of surface protection from the jute in that time.

Maintenance

The jute netting itself is not normally maintained, but simply allowed to rot away. Maintenance is carried out only for the bio-engineering measures.

Main advantages

A very effective aid to the establishment of a permanent grass cover on hard, dry materials on steep cut slopes.

Main limitations

Since jute netting forms a **mulch**, it raises the moisture content of the soil: if the material has poor internal drainage, this can lead to liquefaction following intense rainfall.

3.16 JUTE NETTING (WIDE MESH)

Function

A locally made geotextile of woven jute netting is placed on the slope. Wide mesh jute netting (mesh size about 150 × 450 mm) is used to hold mulch on slopes that have been seeded.

Any use of jute netting is a temporary measure designed to enhance vegetation establishment. It does not protect a surface in itself.

Sites

Wide-mesh netting is normally used on any site where plant seeds have been covered in **mulch**, where the slope angle is between 30° and 45°. Sites less than 30° do not normally need netting to hold the mulch in place.

Materials

- Woven jute netting.
- Hardwood cuttings from shrubs or trees, 20 to 50 mm in diameter and 300 to 400 mm long, or other pegs.
- Tools for cutting wood and jute; an iron bar for making holes, and a wooden mallet.

Rolls of wide-mesh jute netting are usually 10.0 to 11.5 metres long by 1.0 to 1.5 metres wide. The yarn is of 3 to 5 mm diameter. Across the net there should be an average of seven warp ends (length-ways threads) per metre; along the length of the net, there should be an average of three weft strands (cross threads) per metre. The average mesh size should be 150 × 450 mm rectangular holes. The weight should be 0.2 kg ±10% per square metre.

Spacing

Mulch (placed over seeds) is covered with netting. Anchoring pegs are normally placed at 500-mm centres.

Construction steps (wide mesh netting)

1 Place the netting only on to sites which have been seeded and covered in mulch: for details of these, refer to grass seeding (Section 3.5) and mulching (Section 3.17).
2 Open the net to its full length and place it carefully on the slope.
3 Allowing some slack in the netting, begin to peg it from the bottom of the slope. Hammer hardwood cuttings or pegs through it at intervals of 500 mm, leaving the cuttings protruding about 80 mm.

4 Repeat the process, making sure that the vertical edges of the net meet, until the whole slope is covered in netting.
5 Place a series of pegs down each side of the join between strips and bind the strips of net together, so that the jute is held together as a continuous net.
6 Adjust the netting to ensure that it holds the mulch firmly on to the slope surface throughout the site.
7 Add further pegs as necessary to ensure complete contact with the surface.
8 Trim the netting strips to the length required.

Integration with bio-engineering

Wide mesh jute netting should only be used in conjunction with bio-engineering techniques as follows:

- Before the netting is applied, the slope is seeded with grass (see Section 3.5) and covered in mulch (see Section 3.17).
- If a deeper reinforcing is required, the surface can be seeded with shrubs or small trees (direct seeding is best, but broadcasting is also possible if done before the mulch is applied), using species appropriate to the site and following the techniques described in Section 3.8.

Maintenance

The jute netting itself is not normally maintained, but simply allowed to rot away. Maintenance is therefore that of the vegetation, and the relevant part of Section 5 should be consulted for details.

Main advantages

A useful way of ensuring that mulch stays in position on a slope, while the seeds underneath germinate and establish a complete vegetation cover.

Main limitations

Like the mulch underneath, the jute netting is only a very temporary aid to vegetation establishment. Mulch cannot normally be held on slopes steeper than 45°.

Mulching helps to keep the soil cool and moist close to young seedlings

3.17 MULCHING

Function

Mulch is used only as a temporary measure to aid the establishment or growth of vegetation. Alone it will not protect a slope or establish a vegetation cover. There are two main ways of applying mulch: either it is placed around individual plants or it is applied over a whole slope.

In the first, it is to help keep the soil cool and moist, to enhance the growth and early establishment of shrub and tree seedlings, and particularly of large bamboos.

Where mulch is to treat the entire site, chopped plant material or brushwood is laid across the slope to form a surface cover. This is an extremely temporary measure useful only to help other plants establish. It is normally used to aid the establishment of grass seed, and therefore is a temporary form of surface armouring.

Sites

Any site suitable for grass seeding. This is almost any bare site with slopes up to 45°; mostly on well-drained materials, where increased infiltration does not give rise to problems. Also anywhere that large bamboos, or shrub or tree seedlings, have been planted.

Materials

- Cut stems and leaves of any plants. It is important not to use plant parts carrying seeds, as this will lead to a big weeding problem. Annual herbs such as ban mara (*Eupatorium adenophorum*) and tite pate (*Artemesia vulgaris*) are best if they are allowed to wilt before use. This is the only use of these plant species in bio-engineering..
- On slopes greater than 30°, wide mesh jute netting (150 mm × 500 mm mesh size) is needed to hold mulch on to the surface (see Section 3.16).

Spacing

A complete cover of mulch to the depth described in the construction steps.

Construction steps

1 Collected material should be chopped to a maximum size of 150 mm. It can be stored until required if necessary.
2 When mulching grass seeded areas, the mulch is evenly spread over the surface to give a cover of 50-mm thickness.
3 When mulching individual seedlings, the mulch is spread around the plant being treated in a layer between 50 and 100 mm thick. A circle of radius 150 mm should be left by the plant itself. Outside this, the mulch should form a circle of about 750 mm radius.

Integration with bio-engineering

Bio-engineering techniques should be used in connection with mulching as follows.

- Large areas: before the mulch is applied, the slope is seeded with grass (see Section 3.5); if the slope is greater than 30°, then the mulch should in turn be covered by wide mesh jute netting (see Section 3.16).
- Where large bamboos have been planted, mulch is always applied around the new plant during the first two years.
- If the mulch is being used around other existing plants, then it is normally applied to aid the growth of planted shrubs or trees by keeping the soil cooler and more moist at the hot, dry time of the year.

Maintenance

This is a temporary technique, requiring no maintenance. Future maintenance is for the bio-engineering technique for which the mulch is an aid.

Main advantages

A cheap aid to the establishment of different kinds of vegetation, particularly important on hot and dry slopes, and where lack of soil moisture can limit growth.

Main limitations

Mulch is only very temporary in nature. Freshly cut ban mara and tite pate used in the monsoon may root and start to grow. It must be allowed to wilt in the sun before being applied to the site. Mulch carrying seeds can cause a massive problem from weeds.

3.18 VEGETATED GABIONS

Function

Gabion walls are strengthened by trees growing on them. There are two distinct types: (1) normal stone gabions; and (2) earth-filled gabions. This technique provides a form of slope support.

Sites

Any slope where gabion walls are suitable for slope retention. Stone gabions require damp sites for trees to establish on them.

Vegetated stone gabions

These tend to come about naturally where trees have seeded existing gabion walls, although they could be seeded artificially. There is no distortion of the gabion boxes. The benefit is that the trees will provide flexible binding to the structure once the wire has corroded.

Vegetated earth-filled gabions

These have been tried in some locations as a lower-cost alternative to stone gabions. A fill of *in situ* earth is placed behind a single layer of dry stone within the gabion basket (the stone layer prevents the washing out of the earth fill). Tree seedlings are planted on the gabion.

Materials

- Stones wire and tools for gabion construction. In earth-filled gabions, the material from the excavation is used as a fill.
- For stone gabions, seeds of suitable trees: utis (*Alnus nepalensis*) and dar (*Boehmeria rugulosa*) colonise existing walls most often. Alternatively, if holes can be made right through the gabion wall, long hardwood cuttings can be used of species such as dabdabe (*Garuga pinnata*) or phaledo (*Erythrina* species).
- For earth-filled gabions, polypot seedlings of tree species appropriate to the site.

Spacing

Plants should be established at 500 mm centres initially, on a random pattern.

Construction steps

1 Construct the gabion normally, depending on the fill type.
2 For stone gabions, sow the seeds directly into the gaps between the stones. A rate of 25 seeds

per cu. m of gabions allows for the high rate of failure, which should be expected.

3 If hardwood cuttings are to be used, a hole must be made right through the gabion into the original ground below. This is normally practical only for gabion mattresses or revetments of 1-metre thickness.
4 For earth-filled gabions, plant four polypot tree seedlings per cu. m of gabion at an equal spacing in the top panel of each box.

Maintenance

Since the spacing of plants in vegetated gabions is very dense, there is unlikely to be a need for replacing failures, but some thinning of trees may be required after a few years. The main maintenance checks should be as follows:

Protection (check on Kartik 1);
Weeding in the first few years (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

Main functions

Vegetated gabions may offer a lower cost option for supporting certain slope types.

Main limitations

For stone-filled gabions, trees are unlikely to contribute much to the strength of the structure until the wire has corroded seriously. The stability of a gabion wall with serious corrosion problems, with or without trees, is not well researched in Nepal, and remains uncertain at present. Numerous observations demonstrate that tree roots do not distort gabion structures, as is sometimes claimed.

The use of vegetated earth-filled gabions may well have great potential in Nepal. Experiments have been limited in scope and the results have consequently not been conclusive. At the time of writing this manual, the Geo-Environmental Unit of the Department of Roads had not recommended them for use on the strategic road network; but nor had it ruled them out as a future possibility.

Live wattle fences can be effective at catching falling debris on gentle slopes

3.19 LIVE WATTLE FENCES

Function

Fences made out of live cuttings are placed across the slope. Debris moving down the slope is trapped behind them. This is a relatively poor technique used to catch material on gentle slopes.

Sites

Slopes up to a maximum of 30°.

Materials

The following will be required:

- Hardwood cuttings, as for fascines, at least 1 metre long and 20 to 40 mm in diameter.
- Hessian and water to keep the cuttings moist.
- Tools for digging grooves in the slope.

Spacing

Wattle fences should be placed about every 4 to 5 metres down the slope.

Construction steps

1 Prepare the site well in advance of planting. All loose material and protrusions should be cleared away, and depressions firmly infilled.
2 Mark on the slope the lines where wattle fences are to be installed. Careful supervision will be required to ensure that the lines follow the contour precisely.

3 Place pegs at intervals of about 250 mm along the lines: this is done by placing large cuttings into the ground. Pegs should protrude about 300 mm.
4 Dig out a groove along the contour between the pegs: it should be at least 100 mm deep.
5 Place the cuttings with their lower ends in the groove, bending them down along the line of the fence. Weave them in and out between the pegs. Firm the soil back into the groove.
6 The end result should have the cuttings almost horizontally above each other, but with the ends firmly planted in the soil.

Maintenance

Because the spacing of plants in wattle fences is very dense, there is unlikely to be a need for replacing failures, but some thinning of shrubs may be required after a few years. The main maintenance checks should be as follows:

Protection (check on Kartik 1);
Weeding in the first few years (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

Main functions

Live wattle fences catch debris moving down the slope, and have limited functions of armouring and reinforcement.

Main limitations

Often the structure is too weak to support the volume of debris that is caught. They have not been found to be as effective as techniques such as brush layering and fascines; or, on more critical slopes, as reliable as wire bolster cylinders.

3.20 HYDRO-SEEDING

Function

'Hydro-seeding' covers a range of possible options, which use high pressure pumps to spray a mixture of seed and mulch, and sometimes other materials, directly on to a slope. These techniques provide a random cover of vegetation and do not have the structural benefits of manual bio-engineering systems. The main functions are to armour and reinforce the slope.

Sites

Hydro-seeding is reputed to be capable of use on almost any site. However, pumps and their hoses tend to limit reach to a maximum of 100 metres or less from the nearest road point. This technique should not be used on poorly drained materials, where there is any risk of slumping or shallow mass movement.

Experience in Nepal

At the time of writing this handbook, there had never been any widespread use of hydro-seeding in Nepal. The Department of Roads, through several donor-assisted projects, had conducted experiments on a number of different technical systems. There appears to be scope for these techniques on well-funded road construction projects, but a number of limitations affect its routine use in maintenance activities. These limitations are chiefly as follows: (1) high cost, complex machinery is required to spray the mixtures; (2) a large number of inputs (such as seed, mulch, and fertiliser) are required; (3) a number of special skills are required for the team implementing the work; (4) the unit cost is extremely

Manual methods of bio-engineering are cheaper and easier to implement than mechanical techniques such as hydro-seeding

high for small areas, but diminishes with increased scale.

For routine works, the experience of the Department of Roads, and of most projects, is that the manual methods of bio-engineering described in this handbook are cheaper and more straightforward to implement. They also allow very precise treatment of slope surfaces.

Materials

- High pressure solids pump, with mixing tanks, agitators, hoses and spray nozzles.
- A lorry with a mounted crane to carry the pump, tanks and other equipment.
- A water tanker.
- For steep slopes greater than 15 metres above or below the road, scaffolding is required.
- A mix (between 1 and 30 litres per sq.m) of seeds (usually grasses and shrubs), fertiliser, mulch, soil improver, binding agent and water. Some methods also add a mixture of forest topsoil and clay loam to improve surface rooting conditions, bringing the mix to about 100 litres per sq. m (*i.e.* 0.1 cu. m/sq. m).

Construction steps

1. Prepare the site well in advance of planting. Remove all debris and either remove or fill in surface irregularities so that there is nowhere for erosion to start. If the site is on backfill material, it should be thoroughly compacted, preferably when wet.
2. Collect together the various materials needed for the operation. It is normal to have a training session with the hydro-seeding team in a suitable off-site location.
3. Mix the ingredients together in the tank and spray them on to the site immediately. Delays cannot be allowed because of the need to keep all parts of the mixture agitated in suspension, and because the binding agent will start to act.
4. The thickness of the surface cover depends on the technique being used and the nature of the sprayed mixture. A minimum of 5 to 20 mm is normal. Techniques adding a soil base are usually 50 to 100 mm thick, often requiring two sprayings.

Maintenance

Since the spacing of plants resulting from hydro-seeding is very dense, there is unlikely to be a need for replacing failures, but some thinning of the shrubs may be required after a few years. The main maintenance checks should be as follows:

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

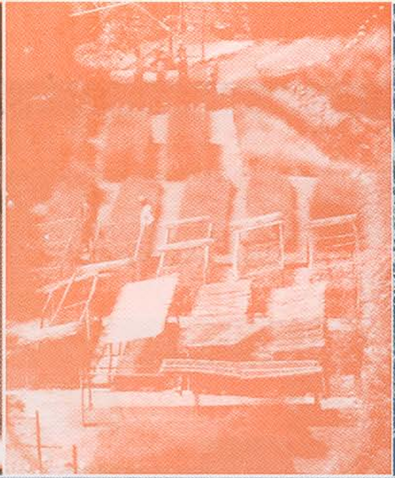
hydro-seeding can yield spectacular results for surface covering, but this example was estimated to cost about thirty times more than the manual method

Main functions

Hydro-seeding is used in many countries to armour and reinforce slopes. The vegetation also has a limited catching effect. In appearance, the overall results often appear spectacular.

Main limitations

Hydro-seeding has none of the structural advantages of the planted grass lines, or techniques such as **brush layering** and **fascines**. It lacks the detailed treatment of site conditions offered by all the manually applied techniques. However, the greatest limitations lie in the relatively high cost, and its reliance on a wide range of complex inputs, of which the high-pressure pump is only one.

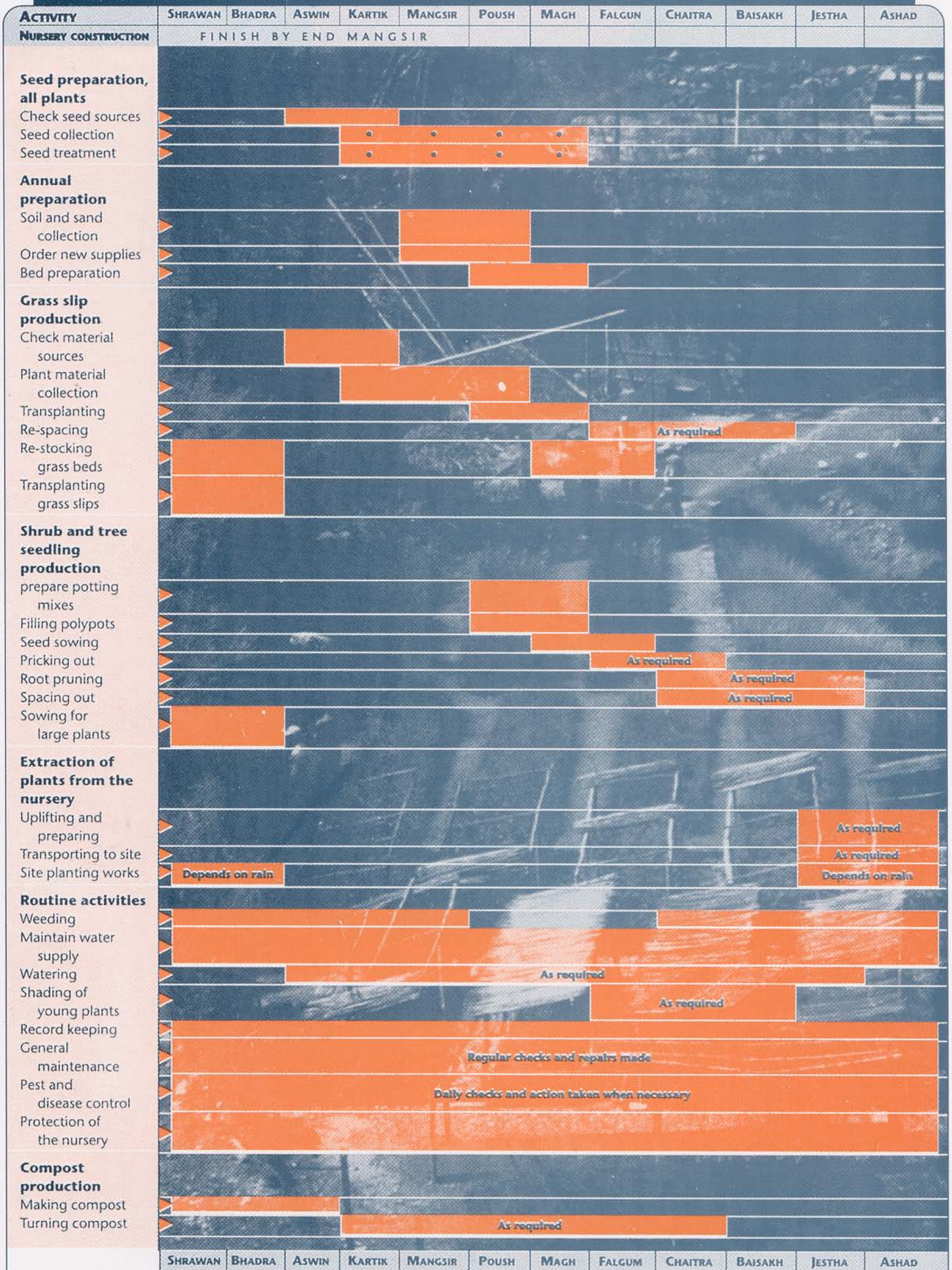




Production of bio-engineering plants

This section gives the following information:

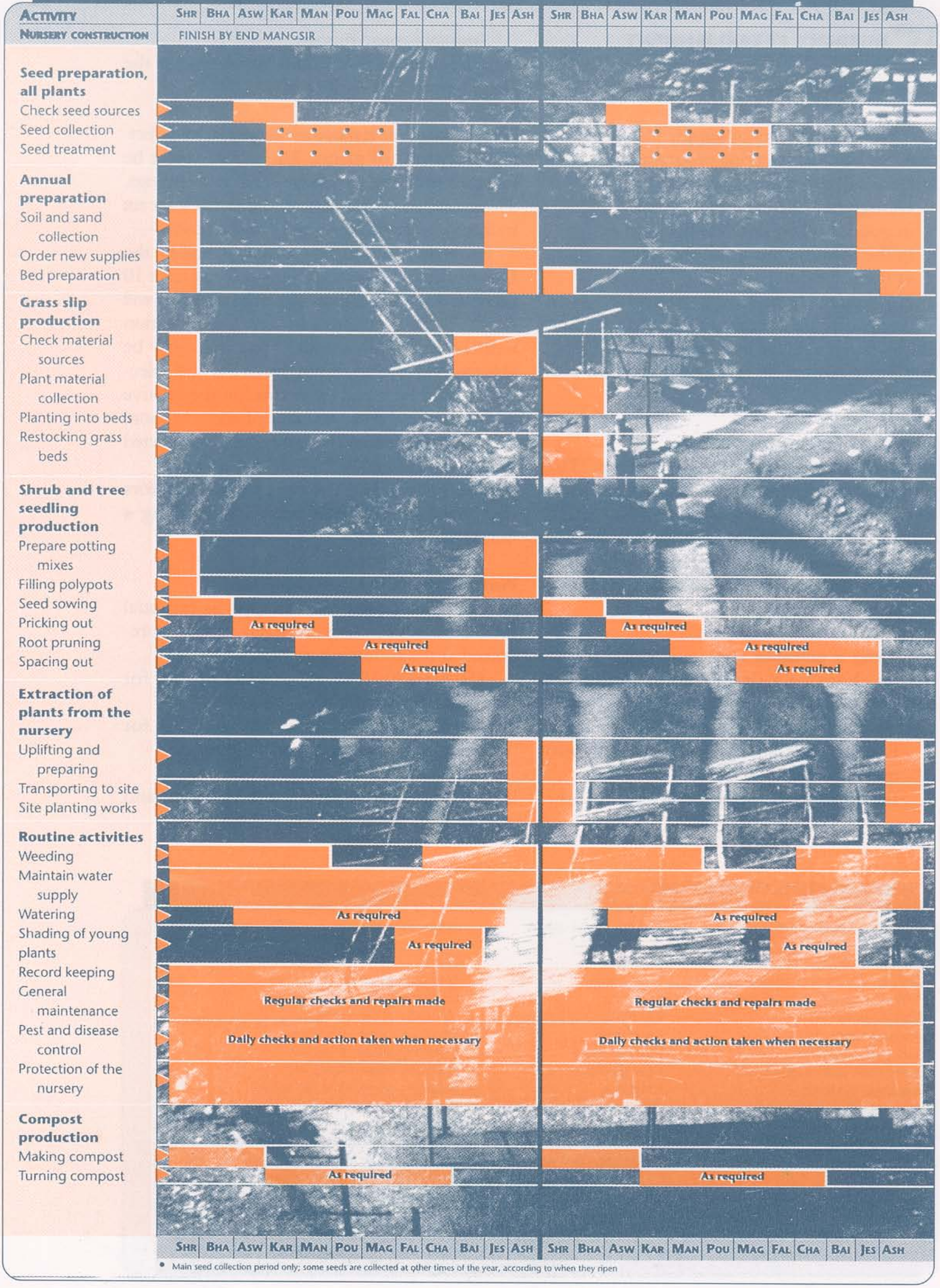
- where to establish a nursery (Section 4.1);
- the components, layout and materials of a nursery (Section 4.2);
- propagation of grasses (Section 4.3);
- propagation of shrubs and trees (Section 4.4);
- propagation of bamboos (Section 4.5);
- nursery management (Section 4.6);
- seed collection and storage (Section 4.7);
- assessing the quality of bio-engineering nurseries (Section 4.8).

Figure SH4.1. Nursery activity calendar: low-altitude nurseries. For nurseries below about 1200 to 1500 metres above sea



• Main seed collection period only; some seeds are collected at other times of the year, according to when they ripen.

Figure SH4.1. Nursery activity calendar: High-altitude nurseries. For nurseries above about 1200 to 1500 metres above sea



4.1 NURSERY ESTABLISHMENT

What are nurseries for?

A nursery is a factory to supply plants, in this case, for a bio-engineering programme. A good nursery will supply:

- 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 organisms and their production is a skilled business. For this reason, nurseries require careful organisation and operation.

When are nurseries used?

Nurseries are a permanent feature. The production of plants is seasonal at lower altitudes (below about 1200 or 1500 metres, depending on the warmth of each individual nursery location) but continues throughout the year above this altitude. The calendars in Figures 4.1 show the variations.

Selecting a suitable site

Before choosing a site, carefully define the objectives of the nursery, including:

- the approximate number of plants of each type (*i.e.* grass, shrubs/trees and bamboos) to be produced each year;
- the location of the planting sites that the nursery must supply;
- the availability of land belonging to the Department of Roads.

The choice of site is the single largest factor affecting the quality of plants. The nursery must be carefully prepared to receive seeds and cuttings. Therefore, you must choose the site at least six months before the first seed is to be sown.

Nurseries need to be on land owned by the Department of Roads (or leased for at least 10 years) and as close as possible to the sites they will serve. At the same time, however, the location must be technically suitable. You will rarely be able to get everything just right, so the final selection should be based on evaluating the relative advantages and disadvantages of three or more possible sites after you have thoroughly inspected them

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

Water supply

A reliable, adequate water supply is essential for all nurseries. A guaranteed supply is required at the following rates:

- 150 litres (0.15 cu. m) of water per day for every 10 sq. m of grass beds;
- 500 litres (0.5 cu. m) of water per day for every 10,000 polypot seedlings;

if watering is done with a watering can, and

Figure 4.2. Calculating the nursery size

NURSERY COMPONENT	CALCULATION BASIS	AREA ALLOWED
Office/Store/Chowkidar's hut	Estimate	Normally allow 15 sq. m
Vehicle access and turning area	Estimate	Normally allow 50 to 100 sq. m
Pathways to all parts of the nursery	Estimate	Normally allow 50 to 100 sq. m
Working area	Estimate	Normally allow 25 sq. m
Soil and sand stores	Estimate	Normally allow 20 sq. m
Compost bays	Standard size	Normally allow 10 sq. m
Water tank and accessories	Standard size	Normally allow 10 sq. m
Drainage systems	Estimate	Normally allow 25 to 50 sq. m
Grass beds: see Figure 4.4	100 cuttings per sq. m	Depends on requirement: see below
Seed beds		Normal requirement Normally allow 5 sq. m
Standout beds for polypot seedlings	128 polypots per sq. m	Number of seedlings required x 1.25 ÷ 128
Beds for hardwood cuttings	40 cuttings per sq. m	Above 1500 m: number required x 2 ÷ 40 Below 1500 m: number required ÷ 40
Bamboo beds	4 cuttings per sq. m	Above 1500 m: number required x 3 ÷ 4 Below 1500 m: number required x 2 ÷ 4
Space between beds	Estimate	Total area of beds x 0.75
Space for terracing on slopes	Estimate	Total area of nursery x 0.5

rather more for watering with hose pipes. Whatever the source of the water, check that it is available throughout the year; especially check the flow in the driest months: March, April and May (Chaitra to Jestha).

General location

The site should be near to the road and as close as possible to the centre of the area to which plants will be supplied.

Physical features

Aspect is very important. North-facing slopes are cooler and more humid and are better for nurseries at lower elevations, whereas nurseries above 1200 metres are better on warmer southern slopes.

Drainage is important to avoid waterlogging of the beds. In the Terai, a slope of 2 - 3 percent is best if possible. In the hills, terracing is usually necessary.

Avoid areas threatened by landslides, flooding or strong winds, and at higher elevations avoid sites which are particularly liable to frost (e.g. small valley bottoms).

Availability of materials and labour

You should select a location with the best quality soil available. If possible, it should be an old forest soil, loamy and with a good content of organic matter, and on a well-drained site.

Additional soil will be required for the production of polypot seedlings. This should be a sandy loam forest topsoil; if the available soil is too heavy (i.e. contains too much clay), sand will also be required.

Easy access to stone for building the nursery wall and beds as well as other items, such as a water tank, a shed and a compost bin, is also an advantage. Otherwise stone or bricks have to be brought in.

A lot of labour is required for constructing the nursery and later on for tasks like transplanting grasses, carrying soil and filling pots. You should locate the nursery where it is possible to obtain labour without difficulty at most times of the year.

Calculating the appropriate size

The amount of space required for a nursery depends upon the number of plants to be produced, the time they will spend in the nursery and the density at which they will stand in the beds. The slope and the quality of the site will also influence the decision on how much space to allocate.

Before you start to calculate the area needed, list the various components of the nursery that you require and calculate the area required for each. Figure 4.2 summarises this.

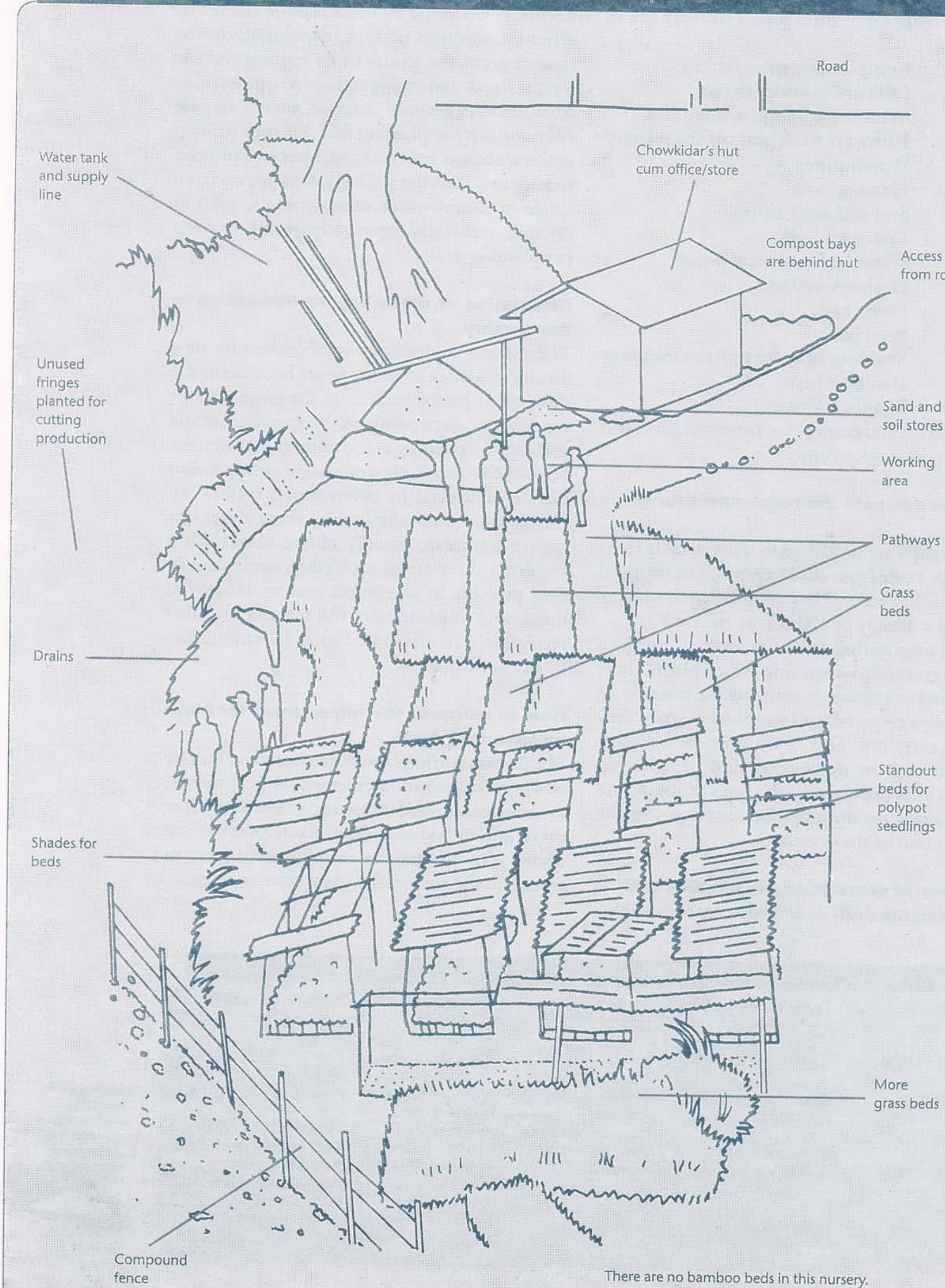
Figure 4.2: Calculating the nursery size (continued): **worked examples**

Nursery component	Terai nursery**	Nursery at 1400 metres	Nursery at 2000 metres
Fixed elements (Office/Store/ Chowkidar's hut, vehicle access, pathways, working area, soil and sand stores, compost bays, water tank and drainage)	**265 sq. m**	**265 sq. m**	**265 sq. m**
Grass beds	290	633	633
Seed beds	5	5	5
Standout beds for polypot seedlings	98	98	195
Beds for hardwood cuttings	25	25	25
Bamboo beds	50	50	75
Sub-total: beds	**468 sq. m**	**811 sq. m**	**958 sq. m**
Space between beds	351	608	718
Sub-total: all above components	**1,084 sq. m**	**1,684 sq. m**	**1,941 sq. m**
Space for terracing on slopes	0	842	970
Total area required *	**1,084 sq. m or 2.1 ropani or 0.2 bigha**	**2,526 sq. m or 4.8 ropani**	**2,912 sq. m or 5.6 ropani**

*1 ropani = 0.052 hectare.

**Assume that each nursery is expected to produce, per year: 100,000 grass slips, of which 10,000 are amliso; 10,000 polypot shrub and tree seedlings; 1,000 rooted hardwood cuttings; and 100 rooted bamboo culm cuttings.

Figure 4.3: Typical low-altitude nursery that has been well laid out



The main components of a nursery are as follows:

General: Compound wall or fence
Office/Chowkidar's hut
Vehicle access and turning area
Pathways to all parts of the nursery
Working area

Storage: Nursery store
Soil and sand stores
Compost bays

Water: Water tank and accessories
Drainage systems

Beds: Grass beds
Seed beds
Standout beds for polypot seedlings
Bamboo beds
Shades for beds

Other areas and corners for perennial grass and hardwood stock plants

How to estimate the requirement for grass beds

Grass slips are produced in nursery beds from cuttings made from either a portion of root and stem, or just stem. They are planted in nursery beds at a density of 100 per sq. m.

Bio-engineering nurseries have to produce more grass slips than any other plants. It is therefore important to estimate the quantity of grass slips required, and the nursery space they need, early on. This is done in two stages: determining the number of slips per planting drill, which depends on the type of grass; and then calculating the multiplication factor for the production of the grass.

Number of grass slips per planting drill

The **planting drills** described in the rate analysis norms, given in the *Reference Manual*, consist of different numbers of slips, depending on the type of grass, the nature of its rooting and the parts used for vegetative propagation. Rhizomatous grasses[1], such as amliso, require only one slip per planting drill. Fibrous rooting grasses, such as babiyo, kans, khar and phurke, require two slips per drill. Grasses grown from single or double-node stem cuttings, such as dhonde, narkat and napier, require only one slip per planting drill.

Calculation of grass slip multiplication in the nursery

The nursery multiplication of grasses by slips produces a three to seven times increase in the number of plants each time the grass clumps are split out, depending on the species, altitude and time of planting in the nursery. At altitudes below 1200 metres, slips of grasses except amliso can be multiplied by seven times; amliso can usually only be multiplied by three times. At higher altitudes, usually above about 1200 metres, a three-times multiplication is usually only possible in one warm season. However, the timing of planting in the nursery bed also regulates the productivity. Figure 4.4 summarises all this information.

How to estimate the requirement for hardwood cutting beds

Hardwood cuttings can be propagated at the rate of 40 cuttings per square metre of bed. However, in nurseries above 1500 metres, you need to allow two complete bed areas. The reason for this is that above 1500 metres the cuttings often have to remain in the nursery for 16 months or more.

Figure 4.4: Calculation of grass slips numbers

Nursery altitude	Propagation method	Species	Cuttings planted in nursery	Number to plant
Above 1800 m	Rooted slip cuttings	Amliso	Previous August	Final site number ¸ 3
		Any other grasses	Previous August	Final site number x 2 ¸ 3
	Stem cuttings	Dhonde, narkat	Previous August	Final site number x 0.25
1200 to 1800 m	Rooted slip cuttings	Amliso	February/March	Final site number ¸ 3
		Any other grasses	February/March	Final site number x 2 ¸ 3
	Stem cuttings	Dhonde, narkat	February/March	Final site number ´ 0.25
Terai to 1200 m	Rooted slip cuttings	Amliso	February	Final site number ¸ 3
		Any other grasses	February	Final site number ´ 2 ¸ 7
			April/May	Final site number ´ 2 ¸ 3
	Stem cuttings	Dhonde, narkat	March	Final site number ´ 0.25

[1] Some grasses, especially bamboos, grow with a form of underground stem called a rhizome. Roots and shoots form from nodes on the rhizome.

Figure 4.5: Main construction features of nursery beds

BED TYPE	GRASS BEDS	SEED BEDS	STAND OUT BEDS	BAMBOO CUTTING BEDS
Purpose	Beds for grass seeds, grass slips, hardwood and stump cuttings of shrubs and trees	Very finely prepared beds for germinating small shrub and tree seeds	Frames in which to stand polypot seedlings	Beds for the propagation of bamboo culm cuttings
Bed size *	1000 mm wide × 250 mm high	1000 mm wide × 170 mm high	1000 mm wide × 150 mm high	1000 mm wide × 300 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.	Ground below the bed is dug to a depth of 300 mm. Bed is made with 100 mm of unsieved soil (lower) and 200 mm of sieved soil (upper). A bund 100 mm high is formed around the edge.
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	Top shade of thick thatch; side shades of hessian sheet

* Beds may be constructed to any length.

How to estimate the requirement for bamboo beds

Bamboo **culm** cuttings can be propagated at the rate of four cuttings per square metre of bed. However, in nurseries below 1500 metres, you need to allow two complete bed areas, and in nurseries above 1500 metres, three complete bed areas.The reason for this is that below 1500 metres the cuttings remain in the nursery for 16 months and, above 1500 metres, for 28 months.

Layout and construction of the nursery

Nurseries are essentially a form of factory and need to be laid out with the production process in mind. Some aspects are usually pre-set. For example, the point of road access is usually fixed. The office/store/chowkidar's hut is normally placed near this gate. In the hills, the water tank has to be at the highest point of the nursery in order to allow gravity feed by hose pipe; in the Terai it should be located in the centre, as water is needed equally throughout the nursery (see Figure 4.3).

Other considerations are as follows.

- Place the soil and sand store beside the vehicle access and turning area.
- Locate the working area beside the soil and sand store.
- Locate the seed beds close to the chowkidar's hut, since these require more attention.
- If it is a remote area, make the chowkidar's hut big enough for his family as well.
- Ensure easy access to all parts of the nursery. Do not put the beds too close together. Remember that when shades are erected, they will reduce the space between the beds.
- Make sure that the whole nursery is well drained. In particular, check that there is no risk of any of the plant beds being flooded.
- Use any remaining corners and rough areas for long-term production of grass and hardwood cuttings.

All construction must be done to a high standard, as per the norms and specifications. Nurseries are usually permanent fixtures, and therefore must be designed and built to last.

Figure 4.5 summarises the main features of nursery bed construction.

4.2 COMPONENTS OF A NURSERY

Nursery equipment

Main permanent equipment

The main equipment required is as follows.

Pate kuto	Chuche kuto
Hasiya	Shovel
Kodalo	Kodali
Chuppi	Khukuri
Dante	Axe
Hammer	Doko

Crowbar/khanti	Watering can with roses
Hose pipe	Scissors/secateurs
Tin trunks with padlocks	Flit gun sprayer
	Leather or paper punch
Soil and sand sieves	First aid kit
Tape measure	

Plant carrying trays (metal or wood, ideally 400 × 2009 mm, with sides 100 to 200 mm high)

Seed trays (optional; make by cutting oil tins in half).

Tools and equipment must be kept in good working order. Replace defective items before they are needed, and keep blades sharp.

Expendable materials

The main expendable materials required are as follows:

Soil	Sand
Compost	Seeds
Grass slips	Bamboo cuttings
Hardwood cuttings	Fungicide and insecticide
Fertiliser	Polypots: 4" ´ 7", 200 gauge black polythene
Heavy gauge polybags for storage	polythene sheeting
Shade material (bamboo, thatch, hessian)	String
	Wire mesh
	Soap
Wire	Waterproof marker pens
Nails	Registers: grass slip/ hardwood cutting, seedling
Seedbed labels	
Pens/pencils	

Expendable materials need to be re-supplied each year and you should order them well in advance, normally by the end of Mangsir, after discussion with the naike.

Most of these materials are simple and easily obtainable.Some technical details about the more complex items are given below.

Soil

For polypot seedlings especially, you will need to bring in large quantities of sandy loam or loam forest topsoil. If only heavy soils such as clays are available, they will have to be mixed with sand.

SOIL TEXTURE TEST

You can tell when the soil texture is right by trying to roll a little moist soil to pencil thickness between your fingers. If this is not possible, there is too much sand. If the roll can be bent in a semi-circle without breaking, there is too much clay.

Certain species of trees have special requirements for micro-biological soil constituents. To satisfy these, you need to try to collect soil from under existing stands of the trees concerned. The species in this category are given below; of all of them, it is most important that soil for pine seedlings comes from under pine trees (the other species usually grow reasonably well without the relevant microbes).

Pines (salla) require special **mycorrhizal** soil[1].

The legume genera *Acacia* (*e.g.* khayer), *Albizia* (siris) and *Dalbergia* (sisau) require soil containing ***Rhizobium*** bacteria[2].

The genus *Alnus* (utis) requires soil containing ***Frankia***[3].

The quantity of soil required is often underestimated. A nursery with a target of 10,000 usable plants would fill 12,500 pots. For 100 × 175 mm (4" × 7" inch) pots, this would require 6.1 cu. m of potting mixture. For a 2:1:1 soil:sand:compost mixture you would need about 3.1 cu. m of soil and 1.6 cu. m of sand, which would weigh about 4.5 and 2.7 tonnes. If sieving was done in the nursery you need 15 percent more soil and 5 percent more sand.

Compost

Details of the making and use of compost are given in Section 4.6. Compost is used to enrich the soil in the nursery beds.

Seeds

Seed collection and storage is covered in Section 4.7.

Grass slips

The collection and propagation of grasses from slips are covered in Section 4.3.

Hardwood cuttings

The propagation of shrubs and trees from hardwood cuttings is covered in Section 4.4.

Bamboo cuttings

The propagation of bamboos in nurseries from single node culm cuttings is described in Section 4.5.

[1] Mycorrhizae are a living arrangement produced between special fungi and the roots of a plant, which increase the growth of the plant considerably. This is a form of symbiosis, where two organisms live together for mutual benefit. Soils from pine forests contain the necessary fungi to bring this about.

[2] *Rhizobia* are the nitrogen-fixing bacteria that form nodules on the roots of many leguminous species, including those listed here.

[3] *Frankia* are actinomycetes that form a symbiotic relationship with the roots of certain species, and which also fix nitrogen.

Registers

The use of nursery registers is described in Section 4.6. The register forms are given in Annex C.

Nursery staff

Each nursery normally requires a staff of one **naike**, one watchman and two labourers. During the peak nursery season of February to June (Magh to Ashad), the number of labourers may need to be increased to five.

The staff of bio-engineering nurseries should be drawn from rural areas, to ensure that they have a good understanding of how to handle delicate plants. Only naikes and specialist seed collectors are considered to be skilled workers. The abilities and roles of the various staff are given below.

Nursery naikes

Naikes (or nursery foremen) are each responsible for the operation of one nursery. They must understand all aspects of nursery work and be able to motivate labourers and keep them busy. Training is usually necessary, but this can either be done within the Division (perhaps by the Supervisor), by attachment to another Division with a well-established nursery, or with help from the Geo-Environmental Unit. Literacy (in Nepali) is required for record keeping. The Naike should work full time in his nursery and manage his team of labourers. Duties include:

1 Daily operation of the nursery and attendance to all matters concerned with keeping a clean and healthy environment for seedlings and plants to thrive in.
2 Carrying out with due care all nursery operations.
3 Reporting to the local and senior road line supervisors any problems of plant health or growth.
4 In general, the provision of quality planting material for use in roadside planting.
5 Keeping records of all nursery stock.

In summary, nursery naikes should have the following attributes:

- good understanding of local plants;
- experience in nursery work;
- very active in the nursery at all times;
- knowledge of seed collection, treatment and storage;
- know how to motivate others.

Nursery watchmen

Anyone employed as a watchman has to be thoroughly trustworthy. He will be working alone all the time and has to be sufficiently motivated to work long hours in uncomfortable conditions. He should be in the nursery 12 hours a day or night, seven days a week. The best watchmen are usually the most reliable of the labour force and may be non-literate and poorly educated. In summary, nursery watchmen should have the following attributes:

- reliable and trustworthy;
- intelligent approach to work and show initiative;
- self motivated.

Labourers

Whenever possible, employ local farmers as labourers as they have a good understanding of plants. They should be from as close to the nursery or work site as possible. There is no need for literacy, but a good level of intelligence helps a lot. In summary, nursery labourers should have the following attributes:

- local farmers;
- good understanding of local plants;
- reliable.

Seed collectors

Seed collection requires skilled personnel who have been specifically trained for the job. There are three distinct elements: timing of seed collection and selection of good seed trees; ability to climb trees safely and pick the seeds; and knowledge of seed treatment and storage. People selected for this job should, therefore, be experienced, with a sound knowledge of local trees.

Some literacy is useful for reading training information and seed-collection calendars. In summary, seed collectors should have the following attributes:

- good understanding of local plants;
- knowledge of seed collection, treatment and storage;
- specially trained in tree climbing and seed collection.

In practice, each Division or project is unlikely to have specially trained seed collectors. Instead, labourers who are particularly good at this can be retained on the payroll to ensure that they are always available.

Tree climbing equipment can be partly

purchased and partly made in the nursery. The Department of Forests sometimes gives training courses on making equipment.

The following questions can be used when interviewing people who are possible employees as nursery **naikes**, watchmen and labourers.

- Have they worked in the subject area before? For how long? Where?
- Have they ever done anything beyond the normal requirements of their job? What?
- How can you show a previous interest in or commitment to this job?
- What do they know about this job and why do they think they can do it?
- What tasks required in this job have they actually performed before?
- Have they ever worked in a team before? To do what?
- Have they ever organised others to work before?
- Have they ever had a bad accident or injured anyone? How?
- Do they live locally? Where exactly?
- How much land do they have? What do they grow on it? Do they have many private trees?
- Why did they leave their last job?
- How many days per month do they take off?
- Ask them to show you a khukuri or hasiya; if it is sharp and in good condition, the person should know how to look after their tools.

4.3 PROPAGATION OF GRASSES

This section explains how to produce grass plants in simple soil beds in a nursery.

Introduction: the methods of grass production

Perennial grasses usually form the main part of a bio-engineering scheme. Propagating these grasses vegetatively (i.e. from cuttings) is not difficult technically and various vegetative methods of propagation are highly successful. However, the reason for using a particular propagation method in the nursery is often related to the availability of material.

There are three methods for propagating grasses in bio-engineering, as described in Figure 4.6. Some grasses (e.g. dubo and kikiyu) can also be propagated from **stolon** cuttings[1], but these are not normally used in bio-engineering. Seed is a cheap means of propagating grasses, but requires much longer growing in the nursery before the plants can be used on site.

Grasses from cuttings always grow much faster than those produced from seed. Also, they are tougher and do not go through such a delicate stage as seedlings.

Propagation of grasses from slip and rhizome cuttings

All of the bio-engineering grasses can be propagated by this method. It is by far the most widely used method of propagation in bio-engineering.

Grass clumps are split up and trimmed (top) to make slips (middle). Slips are then planted in nursery beds to multiply (bottom)

[1] A stolon is a stem that grows along the ground, producing at its nodes new plants with roots and upright stems.

Take a clump of the grass, cut the shoots off about 100 to 150 mm above the ground and then split the whole clump carefully into sections. Each section should include several old shoots, any new buds that are visible and as much root as possible. You need to balance getting the maximum number of transplants from one clump while making sure each is a viable plant.

When you are planting the slips, bury the root parts carefully into loose, moist soil, trying to keep them as straight as possible and about 20 mm below the surface. If they are more shallow they may dry out. The tops can be either at an angle or vertical. After planting, lay a sheet of hessian over the tops of the cuttings to give shade. Keep it there until the new shoots are about 50 mm long and then remove it in stages, starting by removing the hessian for a few hours a day.

Rhizome cuttings

Some grasses have a **rhizome** system (e.g. amliso and the small bamboos, padang and tite nigalo). The method involves making a slip, which includes part of the rhizome.

Take a clump of the grass and cut off the shoots above the first or second node above the ground. Separate the clump, taking care not to damage the rhizomes and fine roots. Keep at least 50 mm of the rhizome, or horizontal part, per cutting. Each cutting should have some buds at the nodes on the rhizome, but often these are difficult to see. The new growth will come from these buds. When you plant the slip, keep the level of the soil as it was originally, making sure the rhizome is well covered. The method of planting and covering is similar to that of other slip cuttings.

Propagation of grasses from culm or stem cuttings

This is suitable for grasses that have heavy branching, such as dhonde and narkat. Usually, a piece of stem with at least two or three nodes is used, but the most vigorous species, such as napier, can be propagated from single-node cuttings if material is scarce.

Select material that is between one and two years old. Cut the stem horizontally about 30 mm above the higher node and at 45° about 30 mm below the lower node. The different cuts help you to tell at a glance which way up the cutting should be planted.

Insert the cutting into loosened, moist soil, so that it is two-thirds buried. Cuttings can be inserted at an angle of about 45° but vertical insertion is also acceptable. Many plants survive equally well if cuttings are planted horizontally. Often the upper node gives shoots and the lower node gives roots, but a large, strong shoot may also emerge from the lower node.

After planting, lay a sheet of hessian over the tops of the cuttings to give shade. Keep it in place until the new shoots are about 50 mm long, and then remove it in stages, starting by removing the hessian for a few hours a day.

Stolon cuttings

If the grass produces a stolon, it is usually possible to make cuttings from the individual nodes. This is particularly easy with dubo and kikiyu.

Often, roots grow naturally from the nodes on the stolon. This is called 'layering'. If this happens you only have to cut the stolon mid-way between

Figure 4.6: Propagation methods for bio-engineering grasses

Propagation methods	Description	Main species
Slip cuttings	The main method of propagating grasses for bio-engineering. Rooted cuttings are made by splitting out grass clumps grown in the nursery. If the grass is rhizomatous (like amliso or tite nigalo), then the slip consists of a section of the rhizome and some shoots, and must include root buds	All bio-engineering grass species
Stem cuttings	Propagation by planting a section of the stem, usually with two nodes and a section of culm. This is carried out either in the nursery for transplanting as a rooted cutting, or directly on site	Dhonde, napier, narkat
Seeds	Grass plants are grown up from seeds. This is carried out either in the nursery for transplanting as a rooted plant, or directly on site	Babiyo, dhonde, kans, katara khar, khar, phurke, sito

the nodes and carefully transplant it with its roots and shoots intact. It is already a new plant. If roots have not yet appeared, you can cut off a node and plant it not more than 10 mm below the surface. Keep any leaves attached to it and plant the cutting with them above the ground. Avoid damaging any shoots or buds that exist. The node will shoot and root very quickly.

Propagation of grasses from seeds

Most grass seeds will remain viable for several years, but you should use them within one year if possible.

Sow the whole remains of the seed heads on the surface of a recently cultivated bed. Dense sowing is usually the best method (i.e. 25 g of seed per 1 sq. m of bed), so that several thousand seeds germinate per square metre.

Very young grass seedlings can be scorched by the sun and killed if they do not have enough shade. Avoid this problem by covering them with a sheet of dampened hessian. Similarly, spreading a layer of dampened hessian jute over newly sown seeds can protect them from intense heat. Keep the jute damp as much as possible, because very intense sun can dry out the surface even underneath it. Remove the hessian in stages once the seedling stems are about 10 mm long. First remove it for a few hours during the early morning and late afternoon, then for longer, and finally completely. Thin the seedlings heavily from time to time.

Most of the soil conservation grasses require warmth before the seeds will germinate. This may be an in-built survival mechanism, as small seeds do not have very big reserves. In order to overcome this problem, do not sow too early. If you have to sow early, you can use **cloches**[1] to increase the temperature in the seed bed.

A cloche is made by placing bamboo hoops across the bed and covering the bed with polythene, which is kept well clear of the seeds.

Management of grasses in the nursery

Keep grass beds well watered and weeded. Replant any gaps where plants have failed as soon as possible. Grass seedlings will need to be thinned heavily every week or so, to allow clumps to develop. Eventually you should aim to have 100 plants per square metre.

When grasses grown from slips have grown up and completely filled the beds, there are two options. The usual one is to cut the shoots off about 150 mm above the soil, to encourage the development of new shoots. However, if the planting season is a long time off, you can lift the grasses out, split them up and replant them. One bed of large plants ready for splitting usually fills three to seven beds after transplantation.

[1] A temporary tunnel of clear polythene sheeting used in nurseries and horticulture farms during the winter. The tunnel produces a warm, sheltered micro-climate around young plants.

Grass beds in a bio-engineering nursery

4.4 PROPAGATION OF SHRUBS AND TREES

This section explains how to grow shrubs and trees[2] in a nursery, starting from either seed or from hardwood cuttings.

Introduction: methods of shrub and tree production

There are many ways of propagating **shrubs** and **trees**. Although this is a very specialised activity the bio-engineering species have been chosen partly for ease of propagation. In the road sector, two main methods are used: polypot seedlings and hardwood cuttings. A third method (stump cuttings) is particularly useful for sisau and some other species, and is also described here (see Figure 4.7 for a summary of these methods).

Polypot seedlings

There are distinct steps in the production of seedlings in polythene pots ('polypots') (see Figure 4.8). These depend on the size of the seed, and whether they need to be sown into a seed bed, or can be sown directly into the polypots.

[2] A shrub is a woody plant with multiple stems growing up from the ground; a tree has usually one stem growing up from the ground. For bio-engineering purposes, shrubs and small-stature trees have the same functions.

Figure 4.7: Propagation methods for shrubs and trees

Propagation methods	Description	Main species
Polypot seedlings	Plants are raised from seed in a nursery. They are grown on in polythene containers ('polypots'), and also moved in them to site for final transplanting. If the seed is reasonably large (e.g. khayer or sisau), it is sown directly into the prepared polypot. If it is very small, however, like utis seed, it is sown in a seed bed and later is pricked out to the polypot.	Areri, dhanyero, dhusun, keraukose, bakaino, chilaune, gobre salla, kalo siris, khanyu, khayer, lankuri, painyu, khote salla, rato siris, seto siris, sisau, utis
Hardwood cuttings	A section of woody stem (a 'cutting') is cut from a parent plant and inserted into the soil. From the buds on the cutting, shoots and roots develop to form a new plant. This is usually done on site but, in some cases, it is done in the nursery, and the entire rooted plant moved to site later on. Techniques such as brush layering (Section 3.10) and palisades (Section 3.11) use hardwood cuttings.	Assuro, bainsh, kanda phul, namdi phul, saruwa/ bihaya, simali, dabdabe, phaledo
Stump cuttings	'Stumps' are cuttings consisting of sections of the plant that include both root and shoot. They are made from seedlings more than one year old raised in soil beds (e.g. standard nursery grass beds).	Sisau
Direct seeding	Plants are sown directly on site, either by broadcasting small seeds across the surface, or by inserting larger seeds directly into the soil. This technique is described in detail in Section 3.8. It does not involve a nursery stage.	Broadcasting: khanyu, utis; direct seeding: areri, bhujetro
Root suckers	Some plants put out new shoots from the root level: banana trees are a common example. You can propagate new plants by digging around the existing plant and separating off the new shoot or 'sucker' growing from the roots. This technique does not involve a nursery stage.	Kettuke
Budding, grafting and layering	These are specialist techniques used mostly in horticulture and the production of high-yielding fodder trees. Budding and grafting combine different plants for specific properties. For example, one plant may contribute better root stock to fruit or fodder trees. Layering encourages the development of roots from a node on a branch, which is then separated to form a new plant.	Not normally used in bio-engineering

Preparing seed beds.

See Section 4.1.

Polypots

Polypots should have the following attributes.

Material: 200 gauge (0.05 mm thick) black polythene.

Size: 4" × 7" laid flat.

Drainage holes: 8 to 12 holes, about 5 - 6 mm in diameter, in the lower third of the pot; corners may also be cut off.

Potting mixture in polypots

Use only topsoil with the texture of sandy loam or loamy sand (40 to 70per cent sand). You can identify these soils by trying to roll a little moist soil to pencil thickness between your fingers. If this is not possible, there is too much sand. If the roll can be bent in a semi-circle without breaking, there is too much clay. Add washed sand as required to improve the soil texture. Add sieved, well-rotted compost to improve the fertility and moisture retention.

An ideal potting mixture has the following characteristics:

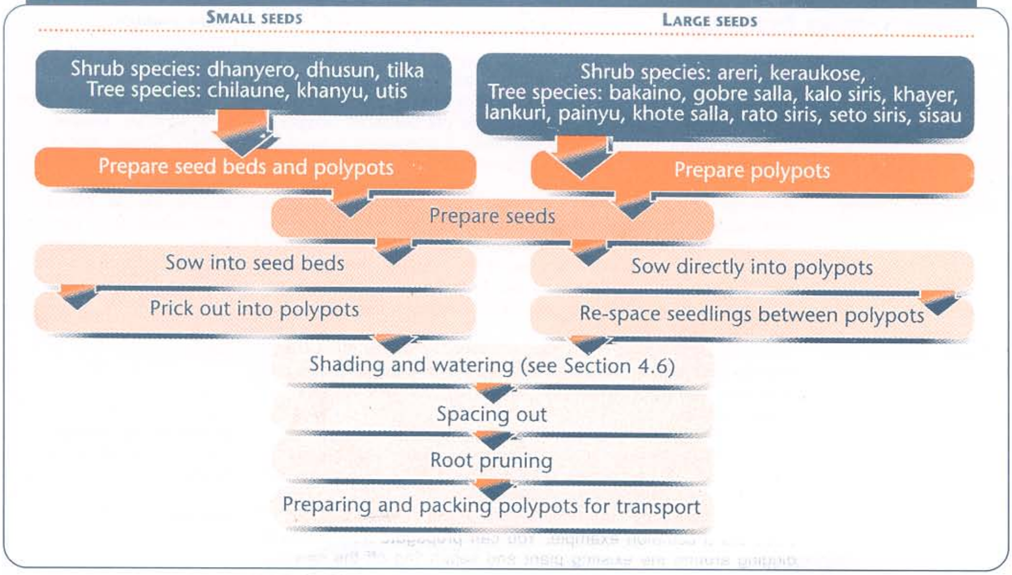
- light weight;
- homogeneous;
- easily available;
- fertile, and retains nutrients well;
- a pH between 4.5 and 6.0;
- well drained, but retains sufficient moisture;
- sufficiently cohesive to maintain the root ball after removal from a polypot.

Soil for growing pines must be collected from a pine forest. Alternatively, add mycorrhizal soil to the potting mixture. If possible, when propagating khayer, siris, sisau or utis, soil should be used from forests of these species; however, this is not as critical as it is for pines.

Filling polypots

When the mixture of soil/sand/compost is ready you can fill the polypots by hand. A scoop made from an old half-litre plastic bottle will help speed

Figure 4.8: The main steps in producing polypot seedlings



up the process. Make the mixture very slightly moist, but keep it loose so that you can easily pour it. Fill the pot in three or four stages, firming down the mixture after each stage. Do not fill the whole pot and then try to firm all the soil at once, because this leaves air pockets. Fill the pot completely. Allow the mixture to settle for about four weeks. Do not allow the pots to dry out during this period. Water them periodically to permit the development of micro-organisms. This is especially important if the soil has been stored dry for some time. The pots are then ready to take seeds or transplants.

Preparing seeds

Most species used for bio-engineering have seeds that will germinate quickly when sown. Others may take several months to germinate unless they are treated properly. Such seeds are said to be dormant. There are several ways to overcome dormancy, depending on the species. These are summarised in Figure 4.9.

Sowing small seeds in seed beds

Estimate the sowing density so there will be about 4,000 seedlings per sq. m. Taking khanyu as an example, there are about 1,500,000 seeds per kg. Assume an effective germination of 25 per cent (the percentage is low because experience has shown that naikes have great difficulty in germinating very small seeds). If 25 percent of 1 g of seed (i.e. about 1,500 seeds) germinates, we can expect 375 seedlings. Dividing the desired seedling density (i.e. 4,000/sq. m) by 375 gives the weight of seed to sow on 1 sq. m as 10.67 g.

Press down the soil with a small block and water it. The surface must be perfectly level. Mix small seed with two or three times its volume of clean, fine, dry sand. Then broadcast the seed/sand mixture over the surface. Distribute the seed/sand evenly by placing it on a flat piece of card, holding this just above the soil and tapping it lightly underneath. The seed bounces off, making it easier to control its distribution.

After sowing, cover the seed evenly with pure washed sand. Use just enough to cover the seed. Make the seed cover firm with a wooden block, cover lightly with a mulch of rice husks, pine needles or straw and water the tray with a watering can fitted with a fine rose. The mulch will prevent the seed from drying out. Protect the bed or tray from heavy rain with a strong shade.

Small seeds must not be allowed to dry out, so you must inspect the beds several times a day and water when necessary. However, too much water will also reduce germination.

When germination is nearly finished, remove the mulch and expose the seedlings to full light for a few hours each day. If the soil becomes too wet, or if damping off becomes a problem, allow

Polypots are filled with a fertile topsoil ofloamy or sandy loam texture (left) and placed in standout beds (above)

them to dry out a little by reducing the amount of shade.

Pricking out

This is the process of transferring seedlings from the seed beds to polypots. It is a very delicate operation that should be done with great care, preferably by experienced workers. Prick out shortly after germination, when the seedlings have only three or four primary leaves in addition to the **cotyledons**[1]. Pine seedlings can be pricked out three or four days after germination, when the seed coat is still attached to the cotyledons giving the appearance of a match-stick. Do the pricking out on a cloudy day or in the late afternoon or evening.

When the seedlings have started to produce new leaves, start to remove the shade as explained in Section 4.6. Generally, after about a week no shade should be given.

Sowing larger seeds directly into polypots

Thoroughly water the pots the evening before sowing, and lightly water again immediately before sowing. Sow two seeds in each pot. Push the seeds into the soil surface in the centre of the pot and cover it with sand. Never sow seed deeper than twice its width and in any case not more than 5 mm deep. Shade the pots and water them again.

Re-spacing seedlings between polypots

After germination, pots will have 0, 1 or 2 seedlings each. When germination is almost finished, prick out plants from pots that have more than one into pots without any. This may still leave some pots with more than one seedling. Remove the extra plants, once germination and pricking out have been successfully completed, by pulling them up or by breaking or cutting the stem near soil level.

Shading and watering

These are covered in Section 4.6.

Figure 4.9: Pre-sowing treatments for the main bio-engineering shrubs and trees

Treatment	Shrub species	Tree species
No treatment required; just sow	Areri, bhujetro, dhanyero, dhusun, keraukose, tilka	Chilaune, gobre salla, khanyu, khote salla, utis
Soak in warm water for 24 hours before sowing	-	Bakaino, painyu, sisau
Chipping: cut off a small piece of the seed coat with nail clippers on the side of the seed opposite the hilum (the scar from which the seedling root emerges	-	Kalo siris, khayer, rato siris, seto siris
Avoid dormancy by sowing immediately	-	Lankuri (green)
Keep over a winter before sowing	-	Lankuri (brown)

[1] Part of the embryo of a seed plant. The cotyledon often becomes the first photosynthetic (green, light-gathering) organ of the young seedling.

Spacing out polypot seedlings

Plants growing close together in the nursery compete for moisture, nutrients and light. Their growth and form is affected and they become tall and thin, with weak, soft stems and poorly developed root systems. Plants grown in 4" × 7" pots to a height of over 300 mm do not have enough growing space.

When plants reach a height of 300 mm, separate the rows of pots across the bed, leaving a space of up to 100 mm between them. You can make the spaces with wooden sticks, bamboo laths, bricks, stones, or old filled polypots without seedlings. Spacing between plants within the rows is not necessary. Spacing requires more bed area in the nursery and you must consider this in planning bed sizes. Where insufficient area is available, spacing only between pairs of rows is a reasonable compromise.

Proper spacing of polypots minimises competition for moisture, nutrients and light

Root-pruning polypot seedlings

Root pruning prevents the formation of very long roots in the nursery, which would have to be cut when the plants are transferred to the field, increasing the shock to the seedling. It also reduces excessive shoot growth, increases the hardening of the stem and increases the development of lateral roots.

Check the need for root pruning by lifting a few pots; if roots are seen protruding from the bases, all the pots in the bed should be checked.

Roots should be trimmed off just below the pot, using a razor blade or a sharp khukuri. If root-pruning causes the plant to wilt slightly, it has been done at the right time.

As with watering, root-pruning cannot be carried out according to a fixed timetable but must be done according to the needs of the plant, as ascertained by frequent checks.

Preparing and packing polypots for transport

These are covered in Section 4.6.

Hardwood cuttings

Rooting hardwood cuttings is the easiest and cheapest way of propagating plants vegetatively. Make cuttings from wood of the previous season's

HOW TO PRICK SEEDLINGS OUT SUCCESSFULLY

Use the following procedure for good survival after pricking out:

1. One day before, thoroughly water the polypots into which the seedlings will be pricked out. Ensure that shades are erected and in good order.
2. Immediately before starting to prick out, lightly water the seedbeds.
3. Remove the seedlings from the seedbeds by inserting a flat stick under them and gently lifting. Take care to do as little damage as possible to the roots. Hold the seedlings by the leaves or cotyledons. Never touch the stem or roots.
4. Take just enough seedlings for about fifteen minutes pricking out, and keep them in a dish of water. Keep this shaded so that the water does not heat up rapidly in the sun and kill the seedlings. Do not let the roots dry out.
5. Make a hole in the soil, in the centre of the polypot, with a pointed wooden stick a little thicker than a pencil. The hole must be deep, and wide enough to contain the seedling's roots without bending them.
6. Hold the seedling's root in the hole with the root collar just below the soil surface. Do not bend the roots into a J or U shape. If any of the roots are too long, cut them to the desired length with your finger nails or a sharp blade. Do not leave the primary leaves in contact with the soil surface.
7. Insert the stick used for making the hole about 10 mm from the roots and close the hole around the root by levering the stick gently back and forth. Be careful to close the hole throughout its depth, and not just at the top.
8. Lightly water the seedlings and ensure that the soil around the roots remains fairly moist but not saturated, as this would lead to rotting, by lightly watering two or three times a day for the next few days. Keep the shades on throughout this period.
9. Three or four days after pricking out, replace any plants that have died, by repeating the above procedure.

growth or sometimes of the one before. Never use older wood because this does not develop roots easily. Use material from branches in the lower part of the tree crown, but not from the main shoots or other outer parts of these branches. Even better, take cuttings from stool shoots produced in the nursery for this purpose (see below).

Prepare cuttings just before the buds open, usually from mid-January to mid-April (Magh to Chaitra), from healthy vigorous stems or branches. Do not use weak stems. The cuttings should be about 150 - 200 mm long, 8 - 20 mm diameter, with at least two, and preferably three or four, nodes. Make a horizontal cut 10 to 30 mm above the upper node and a sloping cut just below the lowest node with secateurs, a sharp khukuri or similar blade. Avoid crushing, splitting or otherwise damaging the ends. Cut off all leaves and side branches.

Prepare the cuttings the same day you collect the shoots and set them immediately into pots or beds that have been prepared in advance. Cuttings that are allowed to dry out will not form roots.

You can root cuttings in large polypots (not less than 4" × 7"), or in previously prepared nursery beds (*e.g.* standard nursery grass beds).

In beds, set the cuttings 300 mm apart, in holes slightly larger than their diameter, placing them so that only one bud, *i.e.* about 30 mm of the cutting, remains above the soil level. Firm the soil up so that there are no air pockets around the cutting. Use the same method for polypots, but finish by rolling the pot between your hands to firm up the soil.

Water the beds or pots and shade them immediately after setting. Keep them constantly moist, but not too wet, until well after root formation. If the soil becomes too wet, remove the shade for a few hours, but not long enough to permit the soil to dry out completely.

New shoots will develop a few weeks after setting, and will cause increased loss of water through transpiration. Maintain shade to minimise this loss until fully functioning roots have formed. Sometimes success is suggested by the development of healthy vigorous shoots, but they dry up and die if there is no equally vigorous development of roots. Remove the shade once the roots are well developed (i.e. when they start to grow from the bottom of the pots and you have to begin root pruning).

In nurseries at lower elevations, and with faster growing species, rooted cuttings reach the required size for planting by the beginning of the monsoon (five months after setting). In other cases it may be necessary to keep them in the nursery until the following monsoon.

You can produce young material ideal for hardwood cuttings in the nursery by establishing stool beds. Plant 20 to 50 plants of each of two or three species in a soil bed (*i.e.* a standard grass bed) and cut them back each year so they produce plants from which cuttings can be made. This makes collecting cutting material easy, saves a lot of time, and ensures that juvenile material is used.

Stump cuttings

Stumps are a form of cutting used in the propagation of certain trees, notably sisau. The advantage of this technique is that the plant leaving the nursery is smaller and easier to transport.

Prepare the ground for the stump beds as for standard nursery grass beds. Sow the seeds directly into the beds, in lines 100 mm apart. Water to keep the soil moist. Shade the seedlings until they are well developed and about 50 to 100 mm tall. Once they have reached this size, thin them out to give a spacing of one plant per 150 mm in the lines. To thin the plants, gently uproot the unwanted seedlings or break them off at the **root collar**[1]. Take care not to disturb the plants that are to be left.

Allow the plants to grow on after the first monsoon. They will not need as much watering during the second dry season.

The stumps will be required for site planting during the second monsoon after sowing, when the plants are about 15 months old. Sisau should be 1.5 to 2.5 metres in height by this time.

To make the stumps, start by uprooting the plants carefully. Cut the tap roots about 300 mm below the surface level. Then make the stump cutting itself, using a sharp khukuri. Cut the stem about 50 mm above the root collar and cut the tap root about 250 mm below the root collar. Trim any side roots about 10 mm from the main root. Cuttings should be within the diameter range of 7 to 15 mm (between the thickness of a pencil and your thumb) at the root collar. Discard any badly misshapen or damaged cuttings. Wrap the cuttings in damp hessian for transporting to site.

[1] The root collar of a seedling is the line below which the roots emerge. It normally corresponds with the surface of the soil and often shows a change of colour or a slight swelling.

4.5 PROPAGATION OF BAMBOOS

Introduction: the methods of bamboo production

Bamboos are large grasses. They are relatively slower growing and harder to establish than the smaller grasses, and tend to grow in damper locations. But once they are established, the big bamboos form huge plants, which are especially useful for catching debris and supporting the slope.

Bamboos do not often seed and so they are normally propagated from big cuttings. To do this, there are two main methods used in Nepal (Figure 4.10 summarises these). The traditional method is commonly known in rural areas but is a big undertaking for large bamboos, and therefore expensive. Some species can be propagated from single-node culm cuttings, but this requires a long period in the nursery.

The traditional method of bamboo propagation does not involve a period in the nursery. This process is described in Section 3.9.

Propagation of bamboos from single-node culm cuttings

Rooted culm cuttings are relatively cheap, easy to transport and survive well after planting.

Equipment required

A sharp tool like a khukuri or hasiya is sufficient, but a handsaw and secateurs, for pruning branches, are useful if they are available.

Selection of materials

Only use choya/tama, dhanu or kalo bans for this method. Take cuttings from culms in their second year of growth. If such culms are not available you can use third-year culms. Culms less than one year old are not strong enough to give cuttings. Choose healthy culms with strong branches. Avoid damaging the dormant buds in the central branches at nodes. Select suitable culms one year in advance and mark them.

Time for taking cuttings

The best months for taking culm cuttings are February and March (mid Magh to mid Chaitra). Take the cuttings when the buds are ready to burst but before new growth starts. In hotter places take them earlier, generally in February (mid Magh to mid Falgun), whereas in cooler places March is best (mid Falgun to mid Chaitra).

Preparation of cuttings

Prepare the cuttings where you obtain the culms. Cut the culms midway between the nodes without splitting them, so that all the cuttings are single-noded. Cut off the leaves and small branches as close as possible to the culm. Reject material less than 40 mm in diameter from the tops of culms. Prune central branches off beyond the first node. You can take cuttings from culms whose buds are completely dormant or with undeveloped central branches. Dip the cuttings into water or sprinkle them with water immediately after preparation.

Transport

After you have prepared cuttings at the bamboo clump bring them to the nursery. Do not allow them to dry out during transport. If they are kept in a doko or any other container, pour water on them. Cover them fully with leaves and grass or wet sacks.

Preparation of beds

The best place to set culm cuttings is the coolest, dampest and shadiest part of the nursery. Prepare the beds as described for bamboo cuttings in Figure 4.5. Water the beds thoroughly before and after setting the cuttings. Good facilities for watering are essential. Provide shades all the year round.

Setting

Plant the cuttings horizontally with the large central branch, or the bud from which it will come, sideways at the soil surface. The main bud at the first node of the central branch should be facing upwards. Ensure that the ends of the culms are well covered with soil because all the water needed for the development of the cutting enters through the cut ends of the culm for at least the first two months. If the ends are allowed to dry out, success rates will be reduced.

If the cuttings obtain enough water from the beds and do not dry out, shoots will develop in 1 to 3 weeks. Most of those shoots will grow to about a metre in height and produce leafy branches before beginning to root after about three months. The cuttings must be watered well and shaded throughout this period and beyond.

Setting a single node bamboo cutting in a saturated bed

Planting out

Below 1500 metres, keep the cuttings in the nursery for 16 months; above 1500 metres, keep them in for 28 months. After 16 or 28 months in the nursery, culm cuttings that have many rhizomes with more than three shoots will be ready for planting. This will be in June or July (Ashad), when the monsoon rain starts. The recommended height of bamboo plants is at least 2 m, but if the planting site is far away you can cut them back to 0.5 metre for ease of transport. Take precautions to ensure that they will not dry out while being transported. Wrap the rhizomes well in a sack full of wet soil. Make sure the rhizomes are not damaged. Cut most of the remaining leaves in half to reduce transpiration.

Dig a large pit and plant the rooted cutting carefully. Add compost to the soil if it is available. Mulch the area around the plant well. If there is no rain, water it during the first few weeks after planting. See Section 5.3(**Mulching**) for more details on mulching.

Survival rates of plants

Grasses propagated by slip should give a survival rate of almost 100 percent in the nursary and about 95 percent on site. If there are sifnificantly more failures than this, then you should investigate the possible reasons. The most common reasons are that the slips were allowed to dry out at some stage drring the transplanting process.

Grasses propagated by rhizome cuttings have a slightly lower survival rate. However, this should still exceed 95 percent in the nursery and 90 percent on site. Failures greater than these should be investigated.

Where grassses are grown from seed, it is almost impossible to estimate the survival rate. However, if the standard application rates are used, there should be a thick, even cover of grasses resulting. If this does not occur, the usual causes are from sowing too early or from seeds being washed off the surface.

Shrubs and trees have to be considered separately. In nurseries it is normal to plant more cuttings or to sow more seeds than are required because, however good the nursery staff, there will inevitably be significant losses. The processes of taking from cuttings or germinating, transplanting and growing on, all take a toll on the young plants.

It is normal practice to allow four times the amount of seed for the final number of seedlings required.

It is normal practice to grow up 25 perrrcent more seedlings than will be required, and to discard the poorer plants when they leave the nursery.

Therefore, for every 100 seedlings used on site, 400 seeds will have been sown and 125 seedlings will have been grown up.

Figure 4.10: Propagation methods for bamboos

Propagation methods	Description	Main species
Traditional method	A section of rooted rhizome and an entire culm is cut out of an established bamboo clump. It is replanted with the culm cut off about 2 metres above the ground, leaving branches emerging from one or two of the nodes.	All bamboos
Rooted single-node culm cuttings	A single node of a bamboo culm is planted in a wet, well-shaded nursery bed and allowed to root over a period of at least one year. It is then transported for planting on site as a newly rooted plant.	Choya/tama, dhanu or kalo bans
Other methods	Bamboos can occasionally be grown from seed, but only if seeds have been obtained (bamboos produce seeds only about once in 20 years). Other cutting methods and advanced techniques such as tissue culture have not proved successful in Nepal on a widespread basis.	

On site, the survival rates for shrubs and trees can vary considerably depending on the biophysical harshness of the site, the quality of the plants and the quality of the planting works. In forestry plantations in Nepal, survival of only 80 percent is considered acceptable, although it should be much more. The same rate should be used for bio-engineering works. If less than 80 percent survive, then a thorough investigation should be made. The usual causes of casualties are from careless handling and planting on site, and subsequent grazing damage.

4.6 NURSERY MANAGEMENT

The management of nurseries, beyond what has already been described in previous sections, consists of:

- environment management (which means controlling shade and water);
- restriction of pests and diseases;
- preparing plants to leave the nursery;
- use of registers; and
- making and using compost.

Shading

Plants in all nurseries in Nepal require shading at some stage. It is needed for a variety of reasons at different stages of growth, but must be done carefully. The wrong use of shades can be damaging to young plants.

However, shading is only required on a very temporary basis. It is usually needed during germination, for protecting recently pricked out seedlings, and for protection against adverse climatic conditions such as excessively hot sun, heavy rain, hail, or frost.

Making shades

Make shades of locally available materials. They should be easy for one person to handle. They must be movable but capable of being fixed to prevent them blowing away in strong winds. The height of the shade depends on its use. It should be about 300 mm above seedbeds and recently pricked out seedlings, and 750 mm above ground level for protecting larger seedlings against hail, hot sun and heavy rain. Construct beds along an east-west line if possible and arrange the shade so that it slopes downwards from north to south. The slope carries water off and the alignment gives maximum protection against the mid-day sun.

Complete shades can be made from woven bamboo matting, hessian cloth or the stalks of maize or wheat. They should be wide enough to overhang the bed slightly and can be up to two metres long. Longer lasting shades can be made from wooden or bamboo slats tied together with spaces between them to allow some light and air to penetrate. They can be rolled up for easy storage and unrolled very quickly when needed. They are heavy enough not to need fixing. Polythene sheets can be spread over them to make them waterproof when necessary.

Shading from hot sun

This is used for seeds and young plants. Shade helps germinating plants because it slows the drying out of the growing medium and the seed. It also prevents damage from rain. Shade over germinating seed should be waterproof. Polypot seedlings also require shade for a few days only after they have been pricked out, to protect them from the sun and to keep the soil moist. The amount of shade needed during germination and after pricking out varies with the weather. If it is used when it is not necessary, for example during spells of cool cloudy weather, the beds may become too moist and this often leads to the development of damping-off disease.

Removing shades from young seedlings.

Remove shades gradually, starting as soon as new leaf development is seen. At first, take the shades off for a short time in the morning and afternoon, keeping them in place at the hottest times.

All plants need shade at some stage of their growth. These shades can easily be removed when necessary

Gradually increase the time they are removed each day until after about a week the shade can be completely removed, without causing any damage to the plants.

Heavy rain

During the monsoon, shade for protection against the rain should only be used when it is actually raining heavily, or at night or during the day when staff are absent.

Hail

Hail usually occurs in the months immediately before the monsoon (Chaitra to Jestha) and during this period shades should be erected at night or when staff are absent from the nursery during the day. When the nursery staff are present they should only erect the shades when a storm is seen to be coming.

Frost

In higher altitude nurseries during the winter, if there is a danger of frost, erect shades each evening and remove them early the following morning. Do not leave them on all day at this season. Frost protection shades are most effective when they are just a few centimetres above the plants.

Shading bamboo beds

Bamboo culm cuttings need complete shade. This can be achieved by hanging sheets of hessian along the sides of the shade structures. The structures should also be higher, giving about 1.5 metres clearance above the soil, as the plants can grow to be quite large.

Cloches provide a warm, sheltered micro-climate for growth early in the season

Cloches

Cloches are tunnels of clear polythene they are placed over nursery beds to raise the temperature during cooler weather. They are constructed by placing semi-circular hoops, made from split bamboo or the branch of a tree, every one to two metres along the bed. The polythene is then stretched over the hoops and weighed down at the sides and ends using stones or soil.

On sunny days the micro-climate inside the cloche can become very warm. The danger is that it can also become very humid and airless. For this reason, cloches must be opened out for at least one hour, twice per day to ensure that fungi do not thrive inside them.

Cloches are often used in horticulture for speeding up the rate of vegetable production. They are extremely useful in higher altitude nurseries, as they can increase the growing season greatly at very little cost.

Watering

Watering in most small nurseries is done with 8-litre watering cans or a hose pipe with a watering rose, fed from a raised tank. These are the most appropriate and efficient methods. Careless watering can severely damage young plants.

There are no rules for watering, as the amount and frequency of watering required varies with weather conditions, species, the stage of development of the plants, soil type, and nursery management such as the use of shade. An inexperienced naike cannot be expected to know how often and how heavily to water. It is far better to teach the naike the basic principles of plant water requirements; a good naike will quickly learn from experience.

Keep seedbeds and recently pricked-out seedlings moist but never allow them to become saturated. This often means frequent, small applications of water, sometimes two or more per day. However, shading and mulching reduce the need for frequent watering. In cool, cloudy weather, water may not be required at all on some days. Check the beds periodically so that decisions can be made on the needs of the seeds or plants. Remember that the object is to keep the seeds or the seedling roots moist but not soaking wet. Always check the soil to the required depth before and after watering, to see if watering is required and if enough has been applied. Too much water can cause just as many problems as too little.

Weed, pest and disease control

Weeds

Weeds compete with plants for moisture, nutrients and light, and must be carefully controlled in the whole of the nursery area. If beds are weeded frequently, weeds will not have the chance to grow and weeding will take much less time. Their removal complete with roots is easy, and damage to the plants is minimised. Water the beds or pots before you start to weed, and pull the weeds out with their roots. If the roots cannot be pulled out, weeding has been started too late.

Keep the fence line, unused areas and paths free of weeds. Never leave weeds to flower and seed in any part of the nursery as this creates more problems and work later on. Weed throughout the year.

Insect and mammal pest control

Serious losses from insect damage are less common than losses from disease, but they are occasionally severe in some nurseries. Once again, prevention is better than cure.

Damage by insect larvae can lead to serious losses, especially just after germination. Some types live in the soil and come out to feed at night. They usually cut the stem of the young plant close to the soil surface, and they may also eat the leaves. Other types just eat the leaves. Where possible, it is best to control larvae by carefully examining the beds each day, picking off any that are found and squashing them. Insecticides containing methyl parathion, such as Metacid and Paramar are effective. Make a 0.05 per cent solution (i.e. mix 1 ml with 2 litres of water) and apply this with a watering can with a fine rose. You need to measure the very small quantities of chemical needed accurately, with a 4 ml hypodermic syringe.

Ants and "white grubs[1]" will occasionally eat seed or attack seedlings. If this is a problem, sprinkle the area lightly with Aldrin dust. In the case of larvae, cultivate the Aldrin into the soil. However, Aldrin is a very hazardous chemical; do not use it unless you have to. When its use is unavoidable, take every possible care to minimise the risk of physical contact with the chemical.

Rodents, cattle, goats, pigs, dogs and chickens must be completely excluded from the nursery by constant maintenance of the fence or wall and use of the normal deterrent and trapping methods.

Fungal diseases control

Two fungal diseases are important in nurseries in Nepal: damping-off and brown needle disease. The latter affects only pines, which are not used very widely in bio-engineering nurseries. Napier and Robbins discuss it in *Forest Seed and Nursery Practice in Nepal.*

'Damping-off' affects young seedlings. It may be caused by many different fungi, which are always present in soils. Good nursery management involves stopping them from killing seedlings. There are three types:

- pre-emergent damping-off, in which the fungus attacks the seed and the newly developing root before the shoot emerges from the soil. It can easily be confused with poor germination that is due to the seed having poor viability;
- post-emergent damping-off, in which the fungus attacks the base of the stem or roots after the seedling has emerged from the soil. The plant falls over and rots quickly. This usually occurs within 2 - 3 weeks of germination, while the stem is still soft. It is easy to recognise, but can be confused with insect damage to roots and the seedling stem-base. It often occurs in patches on the seedbed, with the most recently affected plants at the outside of the patch. It can spread very rapidly unless corrective action is taken as soon as it is noticed; all the plants in a seedbed can be killed within 48 hours;
- root rot affects older seedlings than the other two types. The first signs are yellowish (chlorotic) foliage in the upper leaves. This is followed by the wilting, discoloration and death of the shoot, after which the lower leaves may show signs of secondary fungal attack. Some of the roots will be seen to be soft and rotten or already dead. A good test is to see if the outer root layer can easily be pulled away from the inner core. Also, when healthy roots are broken, a sharp snap should be heard, but this will not happen if they are affected by root rot. Unfortunately, the first visible symptom of root rot, chlorosis, can be caused by many other problems such as a shortage of nutrients, too much or too little watering, or insect or nematode damage.

In bio-engineering nurseries, where soil sterilisation and extensive use of fungicides are not normally practised, prevention and control of

[1] Insect larvae that live in the soil and eat plant roots: they are large, thick, white larvae, usually C-shaped, and may be more than 30 mm long.

Grass slips must be prepared carefully for use on site

damping-off depends on good nursery techniques. Damping-off fungi thrive in warm, moist, shady conditions and the most common cause is excessive moisture. This can be controlled. The naike should prevent damping-off by:

- not over-watering;
- removing shade as soon as it becomes unnecessary;
- not sowing seed too deep;
- where possible, sowing in the dry season;
- ensuring free air circulation over the beds;
- keeping the nursery free of weeds and old unmanaged seedlings;
- not including compost or fertilisers in the sowing medium;
- using a well drained, sandy medium;
- using pure sand as a seed cover;
- avoiding transplanting damage by always handling seedlings carefully, by the cotyledons or leaves and not by the stems or roots and, where possible, by sowing seed directly into polypots or stand-out beds.

If damping-off occurs, reduce watering, remove shade and, if possible, protect the plants from rain by moving the seed trays under cover, or covering the beds with plastic sheets, during heavy showers. Once the disease is established it is very difficult to control. Try to prevent it altogether, but if it does happen, act quickly to prevent it spreading.

If fungicides are available, they can be used to help prevent damping-off spreading to other plants but they will not have much effect once it is well developed. Mix 25 g of Blitox (a blue powder) with 5 litres of water, and apply to the affected plants with a watering can twice a week.

Preparing plants to leave the nursery

Hardening-off

In a nursery we try to produce ideal conditions for plant growth. When the plants are planted out on site, they often face conditions that are far from ideal. They may face strong competition from weeds. They may receive excess rain or suffer from an interruption in the rains. In the nursery we must get them accustomed to, and able to tolerate, more difficult conditions. This is achieved through the process known as 'hardening-off'. Its main features are:

- removal of shade at an early stage;
- spacing;
- reduction of watering.

Culling

There will always be some plants that are not good enough for planting out. Planting out poor seedlings is a waste of money and opportunity. It is perfectly normal to reject as many as 20 percent of the plants in a bio-engineering nursery because they are not suitable for planting and you should have taken this into consideration in planning the annual production (see Section 4.1).

Sort the plants out so that only those suitable for planting, and with a good chance of survival, are used. Cull thoroughly, following a previously planned specification that includes size, health, no distorted growth and lack of any damage. Keep the specification easy to apply. This should make it much easier to introduce the idea to naikes who are unfamiliar with it and may be reluctant to throw apparently sound plants away. Reject all plants that do not meet the specification.

Destroy all shrubs and trees that are not of a good enough standard to be used on site. Do not keep them for next year in the hope that they will be better.

Preparing and packing grass slips for transport

Lift grass clumps carefully, keeping the root ball intact so that the roots are not damaged. Wrap the root ball in wet hessian. Split them out on site. Trim the roots and stems to length, as for nursery planting. Wrap bundles of slips in wet hessian until they are needed for planting by the site labourers. Do not let them get exposed to direct sun because this will dry out the grass slips rapidly. At every stage, encourage labourers to treat the grasses as if they are slips of millet or rice, which are being transplanted.

Preparing and packing polypots for transport

Thoroughly water plants in polypots 2 to 3 days before they are to be transported and, again, lightly water them the evening before planting. Soil that is too wet or too dry tends to break up and this can damage plant roots. Thorough watering in advance is very important because it helps the plant withstand dry periods immediately after planting (one of the major advantages of using polypot plants).

Handle the plants by the container, not by their shoots; the stress caused by the transfer from nursery to plantation is great enough, without adding to it unnecessarily. When you are handling and transporting seedlings, ensure that the soil around the roots is not broken or damaged. Pack them vertically and close together so that they cannot shake about or fall over during transport. However, in packing them closely together do not force them as this will also break the soil cone and damage the roots.

If possible, transport the polypots in trays made of metal or wood. A 400 × 250 mm tray, with sides 100 - 120 mm high, containing about twenty-four 4" × 7" polypots, weighs about 12 kg and can be safely handled by one person. Paint numbers on the trays to make it easy to keep track of them and ensure they all come back to the nursery.

Although not ideal , you can also use dokos for carrying plants. Fill the bottom of the doko with straw or some other light material to form a firm level base for the plants to stand on. Pack the seedlings so that they are vertical and will not shake about. About 40 plants in 4" × 7" polypots can be transported at a time. This makes a normal load of 20 to 25 kg. Place the plants into the doko individually. Never allow the pots to be bundled together and tied with string. It breaks the soil root ball and damages the roots of all the plants on the outside of the bundle.

Preparing and packing other plants for transport

Stumps are easy to transport; which is their major advantage. Wrap them in wet jute cloth, tie the bundles with string and keep them in a cool shady place. Do not let them dry out.

Dig up bare-root plants carefully, shake the soil off their roots, cull and then make up bundles of 100 to 300 with only the roots wrapped in saturated jute cloth. Do this work quickly and in the shade. Bare-root seedlings can also be transported in plastic buckets with their roots submerged in a mixture of 1 kg clay in 1 litre of water.

Never take more planting stock to site than can be planted that day. With a bit of experience staff can judge the requirements and ensure that surplus stock is not kept on site overnight.

Care of planting stock on site

Once the nursery stock is on site, treat it carefully. There will often be a delay before it is planted. Plants treated carelessly can be badly damaged on site and this can make the entire bio-engineering programme useless.

Keep bare-rooted plants and slips in damp hessian. Do not stack them in damp bundles in big heaps, as they will soon start to rot. Assign one person to the task of repeatedly checking the plants and ensuring that they are in good condition. This person can move them as necessary and add water when they start to become dry.

Ensure that all labourers know that they must lift polypot seedlings by the pots, not by the stems. They should be moved in strong trays or a few at a time in the hands.

Always handle plants, slips and cuttings carefully. Always keep them moist and in the shade, and never let them dry out. Destroy plants that have dried out, as they are certain to die.

Use of registers

There are four registers used in bio-engineering nurseries. They are all given in Annex C.

- Grass slip hardwood cutting register.
- Seedling register.
- Seed identification register.
- Seed collection calendar.

The purpose of each of these is described below.

Grass slip/hardwood cutting register

This provides a simple method of keeping track of grass and cutting stocks in a nursery. It allows the Overseer and Engineer to check on the amounts of material available when calculating site requirements. It also permits checking of likely problem areas if plants fail on site.

Seedling register

This does the same for plants produced from seed in the nursery. Their progress is checked from the time of germination onwards. It allows monitoring of technical problems in plant production, since it will be clear if the seedlings have fared particularly badly at any stage of development.

Seed identification register

It is important that seeds are kept in good condition and that they do not stay too long in the nursery. This register provides the information required to track problems resulting from poor germination, and to ensure that seed sources are of adequate quality.

Seed collection calendar

This is not a formal register. Instead, it serves to remind staff of the seeds that must be collected to provide future plants in the nursery. It has to be filled out locally, since it depends both on the particular bio-engineering programme and the availability of seeds in the area. It lists, month by month, the seeds that must be collected and the places from which they can be taken.

Making and using compost

Compost is produced from the breakdown of organic materials by micro-organisms in a warm, moist, aerated environment. The bacteria responsible for this require moisture, oxygen, carbon, nitrogen, and other nutrients. The energy they use is given off as heat.

Compost is added to the beds in nurseries to enrich the soil and help to retain moisture.

Good compost is black and crumbly, and you cannot distinguish the original plant parts. If standard farm 'mull' is used, you must check that it is in this condition, which means that it has decomposed fully.

You can make compost out of almost any organic material that is easily available. This includes weeds, forest litter, crop residues, animal bedding and dung. Weeds such as ban mara are plentiful during the monsoon, which is the best time to start compost making. Crop residues and pine needles take much longer to compost than recent weed growth and litter from the forest floor because they contain too much carbon and not enough nitrogen. When you compost them you can speed up the process by adding liquid manure and larger amounts of recent weed growth. Chop up large material such as maize straw before you compost it.

You can make compost in a compost bay, a simple heap or a pit. Compost bays or heaps are best because pits are easily water-logged in the monsoon. Make the volume between 1 cu. m and 4 cu. m with a maximum height of 1.5 to 2.0 metres. In order to ensure good aeration, start with a layer of brushwood, old branches or rocks. Then pile the compost materials on top, ensuring that there is a good mix of different sizes and types. Apply components that are in short supply, such as farmyard manure, animal bedding and liquid manure (1 part dung mixed with 10 parts water), in thin layers every 200 – 300 mm. Add layers of a good loamy soil every 200 – 300 mm. If the components are dry before starting the heap, wet them for a few days beforehand. Layers of lime at a rate of 0.5 kg/cu. m will help promote the decomposition of acid components such as pine needles.

When the heap is finished, cover it with a large polythene sheet. This will prevent the compost from getting too wet, will conserve heat and, after the monsoon, will prevent it drying out. Two to four weeks later the heap should have heated up to its maximum and will need turning. Check the temperature by pushing a thin metal rod into the middle of the heap; if it becomes too hot to touch, the heap is ready to be turned. Simply dig it up and make a new one alongside it. This serves to aerate the components and to mix in the outer parts of the heap, which do not heat up as much as the inside. Inspect the heap occasionally to ensure that decomposition is taking place. You can find information on poor decomposition in the *Reference Manual.*

Compost making may take only 2 - 3 months in the Terai but may take more than 6 months above 2,000 metres. Other factors, however, are more important than altitude, in particular the attention paid to correct techniques, and the type of material used.

When the compost has been made, pass it through a soil sieve before mixing it into beds or potting mixtures. The larger components, which will not pass through the sieve, can be used for starting up another heap, as they will introduce bacteria to it. Add compost to every bed at least once per year. This is best done when the bed is empty and about to be cultivated. Make sure it is mixed well with the soil.

About 20 dokos (70 litres) of fresh green veg-

Figure 4.11: Nursery troubleshooting chart

Problem	Diagnosis	Action if "yes"	Action if "no"
SEEDS			
Seeds not germinating	Has the weather been cold?	Wait for warmer weather and check again. Alternatively, place cloches over the beds and monitor carefully.	Consider other possibilities.
	Is the bed waterlogged?	Allow the bed to dry until it is just slightly moist; check the seeds are not rotten; be very careful not to over-water.	Consider other possibilities.
	Are the seeds rotten?	Remove the seeds from the seed beds replace the top layer of soil/sand; re-sow the seeds; be very careful not to over-water. Remove cloches if they have been used.	Consider other possibilities.
	Do the seeds seem healthy?	The seed may no longer be viable. Obtain new seeds and re-sow.	The seed may have been stored badly Obtain new seeds and re-sow.
GRASSES			
Grasses are growing abnormally slowly	Has the weather been cool or lacking in sun?	Wait for warmer weather and check again. Alternatively, place cloches over the beds and monitor carefully.	Consider other possibilities.
	Is the soil in the beds mostly dry?	Increase the rate of watering.	The soil in the beds may be poor. If there are still several months before site planting, transplant to a new bed with better soil. If there is little time, add fertiliser.
Grasses are very yellow	Is the soil in the beds very wet?	Reduce the rate of watering.	Add a nitrogen-based fertiliser.
SHRUBS AND TREES			
Poor growth	Has the weather been cool or lacking in sun?	Wait for warmer weather and check again.	Consider other possibilities.
	Does the soil in the polypots feel hard?	The pots may have been over-compacted when filled; or there may be too much clay in the potting mixture. Loosen the soil with a pointed stick, taking care not to damage the plant roots, and water regularly.	Consider other possibilities.
	Is the soil in the polypots mostly dry?	Increase the rate of watering.	The potting mixture may be poor. If the plant is small, transplant it to a new pot with a better mixture. If it is big, water dilute fertiliser on to the plants using a watering can.
Plants become long and thin	Are the plants kept under shade?	Reduce or remove the shades.	Increase the spacing between the plants.
Plants have yellow leaves	Is the soil in the polypots very wet?	Reduce the rate of watering.	Add a nitrogen-based fertiliser.
Plants have wilting leaves	Is the soil in the polypots dry?	Increase the rate of watering.	Consider other possibilities.
	Have the roots just been pruned?	Wait a week and check again.	Consider other possibilities.
	Have there been gusty winds recently?	Wait a week and check again.	Consider other possibilities.
	Are there signs of attack by insects or fungus?	Spray with the most appropriate insecticide.	The potting mixture may be poor. If the plant is small, transplant it to a new pot with a better mixture. If it is big, add fertiliser.
Small plants suddenly start to die off	Does it look like damping off, described in Section 4.6 (p104)?	Reduce watering and shading.	Consider other possibilities.
	Is there evidence of other fungal attacks (white hairs growing on the plants)?	Reduce watering and shading.	Consider other possibilities.
	Is the soil very wet?	Reduce watering.	Consider other possibilities.
	Do the plants look rotten?	There may not have been enough ventilation, leading to excessive humidity on hot days. Ensure that air can flow under the sides of the shades. Remove the shades more.	Look for signs of insect damage to the roots and treat the plants accordingly.
Excessive growth	Are roots growing into the ground below the bed?	Prune the roots level with the bottom of the pots.	Reduce the amount of water and increase the amount of shade.
BAMBOOS			
More than 25 percent of cuttings fail to grow	Is the soil moist and shady all the time?	Look at other possibilities.	Increase the amounts of water and shade.
	Are there signs of insects, especially termites, attacking the cuttings?	Re-plant with new cuttings, flood the beds again and check carefully every day for the next week. If the termites or other insects persist, excavate the cuttings carefully and sprinkle Aldrin dust around the cutting. Reduce the watering and observe carefully over the next week. If all is well, then increase the watering again. Take care: Aldrin is highly poisonous.	The nutrient status of the bed may be poor. Improve the depth and quality of soil in the bed and re-plant the failures.
Poor growth	Is the soil deep and stone free?	The nutrient status of the bed may be poor. Add fertiliser.	Improve the depth and quality of soil in the bed and re-plant the cuttings.

etation, such as ban mara, each weighing 20 - 30 kg with the material piled up above the rim of the doko, are needed to make one doko of compost, weighing 35 kg with the compost level with the rim.

Troubleshooting

All nurseries, however well run, experience difficulties at some stage. To assist in detecting problems, a troubleshooting chart is given in Figure 4.11. While this covers the most common problems, always bear in mind that there are exceptional circumstances. If you cannot resolve a problem, call the Geo Environmental Unit for specialist advice.

4.7 SEED COLLECTION, TREATMENT AND STORAGE

Seed collection, treatment and storage are a skilled business. Care has to be taken in order to ensure that you get material of good quality as a basis for a bio-engineering programme.

Seed collection: basic considerations

Start by choosing carefully the location and actual plants from which you collect seeds.

- Collect seeds from plants growing in sites similar to the ones you are going to plant the seedlings on.
- Collect seeds from plants with the characteristics you want (e.g. good rooting): seedlings grow like their parents.
- All seed plants should be healthy and growing vigorously.
- Always collect seed from at least 10 plants, to increase the genetic diversity.

If you have to order seed from elsewhere, give as many details as possible about the planting site (altitude, rainfall, soil) and also how many seedlings will be needed. Ask the supplier to match these considerations as closely as possible.

Keep a register of all sources of seed within your working area, with details of the species, area of the stand (or number of plants), and location. This register will help you plan seed collections. A form for this is given in Annex C.

Keep seed from very different sources separate, *i.e.* sources that are several kilometres apart. Never mix new collections with seed from previous years. Label every seed lot properly with species name, date of collection, location, and the number of seed plants.

Calculating how much seed to collect

Because of natural uncertainties, you need to obtain and sow many more seeds than the actual number of seedlings required. If the seed collectors manage to collect more seed than is needed, do not waste it by sowing too much in the nursery, or storing it carelessly. Seed supplies are always difficult and there may be other nurseries that could use it. Tell the Geo-Environmental Unit, the Regional Director's Office, and other Divisions and Projects. Someone else may well be able to use it.

Calculation of grass seed requirements

It is normal in bio-engineering to sow grass seeds at the rate of 25 g per sq. m. This covers all expected natural losses. However, in case the first seeding fails, it is normal to ensure adequate supplies for a separate complete seeding. Therefore aim to collect seed according to this equation:

Seed required (kg) = area to be seeded (sq. m)/20.

Calculation of shrub and tree seed requirements

It is normal practice to grow 25 per cent extra seedlings and discard the poorer plants when they leave the nursery. It is also normal to allow four times the amount of seed for the total number of seedlings to be grown. Therefore, for every one seedling to be used on site, five seeds should be obtained and sown.

Figure 4.12 shows as an example the quantity of seeds required to grow 5,000 each of utis and khote salla trees.

The tables in Annex B give the average numbers of seeds per kilogramme for all the bio-engineering species. Once you know the number of seeds required, you can easily calculate the weight of dry seeds to be collected.

Collecting and treating grass seeds

In bio-engineering it is normal to collect and use the whole seed head of grasses. The procedure is as follows:

- Collect the seed heads when they are ripe. Bring them back to the camp or nursery in dokos or hessian sacks. If you use polythene bags, empty them out as soon as possible so that they do not go mouldy.
- Spread the seed heads out to dry in sheltered, sunny places, on a clean concrete or hard earth floor.
- Separate them from stems and other unwanted parts in the ways normally used for grains. Since the seeds of bio-engineering grasses are mostly very fine, take great care when winnowing.
- Store them in hessian or polythene bags in a dry, well ventilated place. If you use polythene bags, make sure that the heads are completely dry or they will go mouldy.
- Most grass seeds will remain **viable**[1] for several years, but you should use them within one year if possible.

Collecting shrub and tree seeds

Tree climbing

Climbing trees to collect seeds is dangerous and must be done carefully, so as to avoid accidents. Falling from trees is a common accident and your collectors should be especially cautious while collecting seeds. Local methods can be safe if properly supervised. Follow these guidelines for safety:

- only employ seed collectors if they like climbing;
- only use strong and healthy collectors;
- collectors should work in twos; then if one needs help, the other can go and get it;
- only healthy trees with strong branches should be climbed;
- while picking fruits, the climber should be tied to the tree whenever possible ;
- proper fruit cutting tools with long handles (see below) should be used, so that there is no need to cut off large branches.

If seed must be collected from very large trees that are dangerous or difficult to climb by local methods, contact the Geo-Environmental Unit or the local Department of Forests office for advice. Special equipment (spurs, safety belts and ropes) and trained seed collectors may be available. It may be useful for someone in your area to receive such equipment and training, which is sometimes given by the Department of Forests.

What fruits to harvest

Collect only ripe fruits. If fruits are collected too early, the seed may be immature and weak. If you delay collection too long, the seed may be eaten by birds, or attacked by insects or fungi. Pick fleshy fruits just as they turn from green to their ripe colour. Pick dry fruits that open just before they open. Test the ripeness of seed by cutting the fruit open and looking at the inside of the seeds. They should be firm and white, and completely fill the seed coat. The seed coat should usually be dark and hard.

Do not collect fruits that are unhealthy or attacked by insects. For this reason avoid fruits that have fallen to the ground.

How to harvest the fruits

Harvest the fruits without damaging the tree, so that it can produce again in the following years. Whenever possible, take only the fruits or the small twigs bearing them. Try not to tear them off, but cut or break them cleanly. Unless it is absolutely necessary, do not allow seed collectors to cut whole branches with a khukuri or hasiya.

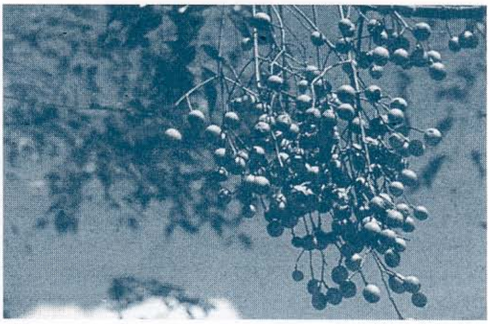
Good seed-collection tools include:

- A hook for bending branches towards the collector. Fix a metal hook to a wooden handle 2 m long. Provide a 2 m length of rope so that the climber can tie the hook and the branch to himself, so that he has both hands free to pick the fruits and put them in the collecting bag. A strongly made hook can

[1] Viability is the length of time that the majority of seeds remain able to germinate. After a certain period of storage, seeds will not germinate once sown. This varies for each species, and approximate viability periods are given in the tables in Annex B.

Figure 4.12: Example of tree seed calculations

S No	Detail	Utis	Khote salla
[1]	Number of plants needed	5,000	5,000
[2]	Number of plants to be produced: [1] × 1.25	6,250	6,250
[3]	Number of seeds needed: [2] × 4	25,000	25,000
[4]	Seeds/kg	1,350,000	10,000
[5]	Seeds/g	1,350	10
[6]	Grammes of seed required: [3] / [5]	18.5	2,500
[7]	Seed order	20 g	2.5 kg



Wait for seed to ripen properly before picking it from the tree

also help in climbing the tree.

- If it is necessary to break off the ends of branches with the fruits attached, a 'wedge knife' will work well. This can be made in any large bazaar. It should be bolted or tied with wire to a light, long wooden or bamboo pole (up to 4 m). The collector places the tool over the branch end and pulls it. The branch may slice off easily, but if it is woody, the knife may have to be twisted to snap the branch.
- A collecting bag can be made from a strong hessian sack, which has been made shorter and has a draw string to close the mouth easily. When full, the bag is closed and thrown to the ground.

The best material for long handles is one-inch aluminium tube with thick walls, which can be purchased in large bazaars. Otherwise, use well dried wooden or bamboo poles.

If it is difficult to gather the fruits by hand in the tree, they can be allowed to fall to the ground and be gathered by an assistant. Clearing the ground of vegetation may help. The assistant should wear a strong hat as protection from falling fruit and twigs. It is safer to wait until the climber has finished his work.

Transport and storage of fruits

Store and transport fruits in cloth or hessian sacks. Do not put them in polythene bags, as they will get warm and mouldy very quickly, spoiling the seeds inside. Always store the sacks in the shade. Keep them cool, dry and off the ground by placing them on planks of wood, or hanging them .

When to collect seeds

You need to know the dates for seed collection in order to get good results. Details are given in the tables in Annex B, as far as they are known, for all of the bio-engineering species. Remember that these give an approximate guide only, and there is always some local variation. Every month, you should check which species are due to ripen, so that you do not forget to arrange for their collection.

As part of the routine planning of a bio-engineering programme, you should establish a seed collection calendar for your Division or Project. A form for this purpose is given in Annex C.

Before the collecting season of a species starts, the person responsible should keep a regular check on how the fruits are ripening. In some years, fruits will ripen earlier than usual, and in other years they may ripen later. As a general rule, fruits tend to ripen later in the west than in the east, and are also later at higher altitudes.

Processing and storing shrub and tree seeds

Seed processing following collection

Most seeds need to be removed from their fruits before sowing or storage. Separate them carefully to avoid damaging the seeds. Although they may look inert and tough, heat, moisture, physical breakage, fungi, insects, etc can easily damage them. Try to extract the seeds as soon as possible after collection, unless recommended otherwise.

The pods of many leguminous species (*e.g.* sisau, khayer, areri and the siris species) are brittle and split easily once they have been dried in the sun. The seeds must be carefully separated from all the pod fragments that result.

Some species (*e.g.* bakaino) have a stone inside a fleshy fruit. The flesh must be removed before storage. This is best done by soaking in water and then rubbing the soft fruits together so that the flesh comes away. Once cleaned, the seeds must be properly dried in the sun.

Fleshy fruits containing many small seeds (*e.g.* khanyu) are separated in the same way, but much more care has to be taken because the seeds are much smaller and more delicate. Again, once cleaned, the seeds must be properly dried in the sun.

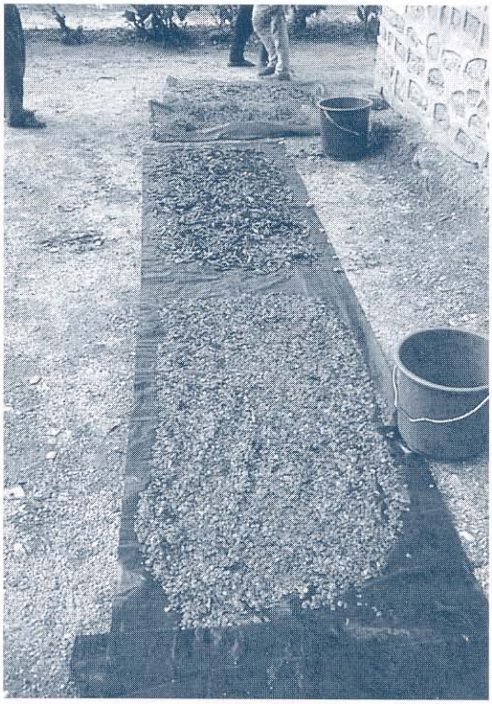
Storing seed

If you are sowing the seeds immediately after processing (within a few days), put them in a cloth bag and keep them cool. Never use a sealed container such as a polythene bag, glass jar or tin, as the seed will be too moist and will quickly get warm and mouldy.

If you are keeping the seeds for more than a week (often several months or even a year may be required), store them properly to avoid loss of viability. When the seeds have dried sufficiently, leave them in the sun until the afternoon, and then put them immediately into a container that can be properly sealed, thus keeping them dry. Do not leave packing until the morning, as the seeds will absorb moisture overnight.

The simplest container is a thick polythene bag, or two thin ones, one inside the other. Squeeze out the excess air, and then tie the neck tightly with string or wire. It is often a good idea to put the bag in a tin box to protect it from being punctured and from rodents that may try to eat the seed. Label and number the containers of seed.

Keep the containers in a cool, dry room. The best place is a well-ventilated ground-floor room on the north side of a two-storey building. Keep the containers off the ground, preferably on shelves half way up the wall. Do not put them in the eaves of a roof, as this will become warm during the day; or directly on a ground floor as this may be damp.



Dry seeds thoroughly before storing them in a container that can be properly sealed

Recalcitrant seeds

Most seeds have to be dried before storage and are called 'orthodox'. But some species have seeds that must be kept moist if they are to remain viable. They are called 'recalcitrant'. If they are dried they will quickly die. These seeds are often found in species that have fleshy fruits which do not dry out on the tree, and which are dispersed just before or during the rains. The species used for bio-engineering which fall into this category are badahar (*Artocarpus lakoocha*), champ (*Michelia champaca*), chiuri (*Aesandra butyracea*), dhale katus (*Castanopsis indica*), chuletro (*Brassaiopsis hainla*), khasru (*Quercus semecarpifolia*), kutmero (*Litsea monopetala*), musure katus (*Castanopsis tribuloides*), okhar (*Juglans regia*), patle katus (*Castanopsis hystrix*) and phalant (*Quercus lamellosa*).

Always sow this type of seed as soon as possible. If it has to be stored for more than a week, use the following method. Extract the seed from the flesh, do not dry it, but mix it with twice its volume of damp sand. Put this mixture in a tin with a lid, whose sides and bottom have at least 20 small holes (2 mm diameter), made with a nail. After putting in the sand/seed mixture, fill it to the top with damp sand. Dig a hole 1 m deep in a sheltered and well-drained place. Cover the bottom with a layer of damp sand, and put the seed containers on it. Then cover with more damp sand, and fill the rest of the hole with the excavated soil. Mark the spot with a stick. When you require the seed, dig it out. Remove the seed from the sand carefully, as some of it may have started to germinate.

4.8 ASSESSING THE QUALITY OF BIO-ENGINEERING NURSERIES

The following are some simple indicators for assessing the quality of bio-engineering nurseries. They are not comprehensive.

Grass beds (slip and rhizome cutting, and grass seeds) and **hardwood cutting beds** should be:

- composed of good, fertile, well aerated soil;
- kept moist at all times;
- showing even growth;
- well weeded;
- kept with a porous, uncapped soil surface.

Grass plants should be:

- a healthy green colour;
- growing vigorously, with long new shoots;
- showing no signs of wilting;
- attack.

Shrub and tree seed beds should be:

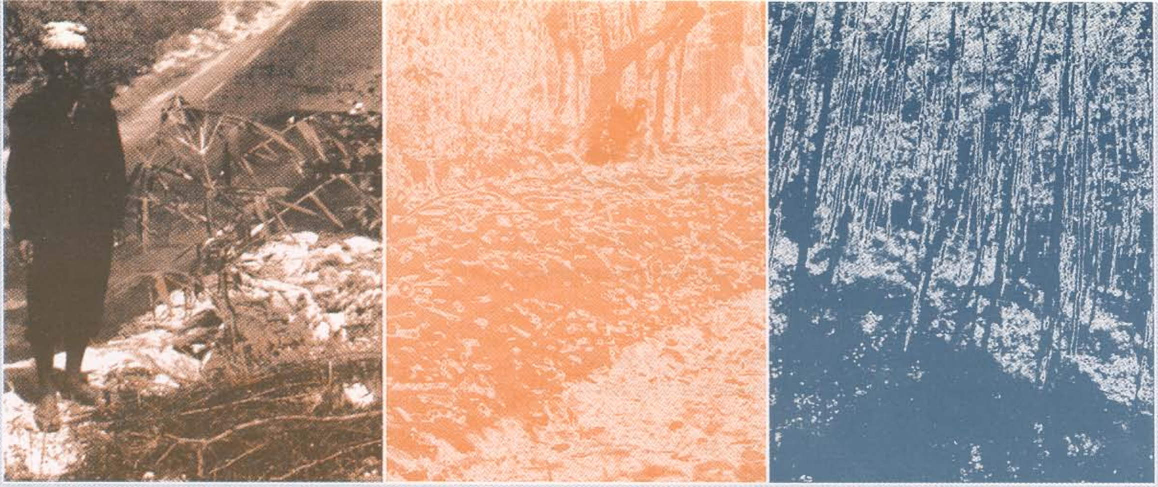
- composed of good, fertile, well-aerated soil and fine, clean sand;
- kept moist at all times;
- well shaded;
- showing even growth;
- well weeded.

Polypot seedings should be:

- a bright, healthy colour;
- showing no signs of wilting;
- growing fast, with long new shoots;
- kept with roots pruned;
- kept moist throughout the soil cylinder;
- well weeded;
- without signs of discoloration on the leaves;
- without signs of insect attack on the leaves or shoots (e.g. holes eaten in the leaves);
- without any obvious signs of disease;
- undamaged.

Whole nurseries should be:

- kept tidy and clean ;
- weeded throughout;
- well maintained;
- protected properly at all times.



Maintenance of Bio-engineering

This section:

- defines bio-engineering maintenance and the principles behind it and lists the requirements (Section 5.1);
- gives guidelines on how to plan for the maintenance of bio-engineering and other roadside vegetation (Section 5.2);
- describes routine bio-engineering maintenance activities (Section 5.3), including site protection, weeding, mulching, grass cutting and watering;
- describes preventative maintenance activities (Section 5.4), including the thinning and pruning of trees and shrubs, the repair of bio-engineering structures, vegetation enrichment and the removal of unwanted shrubs and trees: these are long-term management activities;
- includes a code of practice for working with rural road neighbours (Section 5.5); full guidelines on this subject are given in the *Reference Manual*.

Detailed technical guidelines on the management of shrubs and trees for the principal purpose of slope stabilisation, are given in the *Reference Manual*.

A guide to the law, as it applies to all roadside vegetation, is also given in the *Reference Manual*.

5.1 INTRODUCTION

What is the maintenance of bio-engineering?

Vegetation must be managed for the maximum advantage to be gained from it in order to realise the long-term benefits of bio-engineering in slope stabilisation. Sound management will also maximise productivity and improve appearance. In the road reserve, this work becomes part of *road-side support maintenance* [1].

Routine maintenance involves simple protection and care of plants, such as weeding, mulching and grass cutting.

Preventative maintenance is more complex. Larger plants (shrubs and trees) require treatments such as pruning and thinning. Pruning is the removal of the lower branches of large plants. Thinning is the careful removal of whole shrubs and trees to allow more light to penetrate. All forest areas must be thinned on a recurrent basis. Under this long-term management of vegetation comes the repair and replacement of vegetation structures, and the removal of unwanted large plants.

[1] Definition of Maintenance and Maintenance Activities. Department of Roads, Mangsir 2051 (November 1994).

For some activities, legal questions may arise. A Guide to the Law regarding roadside vegetation is given in the companion *Reference Manual*

In rural areas, the **road neighbours** ('local people') must be taken into consideration. The Department of Roads may be able to collaborate with them for mutual benefit. Section 5.5 gives a code of practice for collaboration with road neighbours and more detailed guidelines are given in the *Reference Manual.*

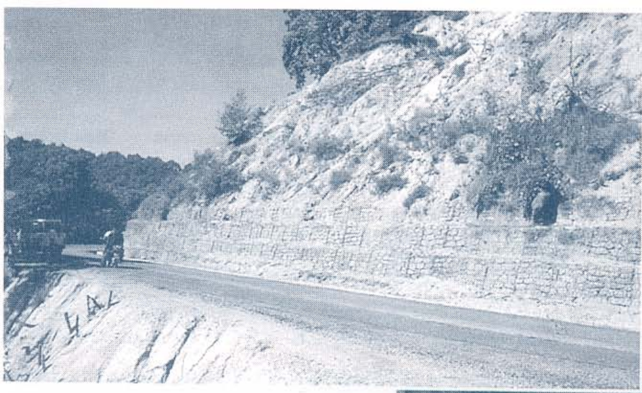
'Maintenance' of vegetation in engineering is equivalent to 'management' in forestry, horticulture and agriculture. Vegetation on roadsides must be maintained on a long-term basis in order to maximise their engineering contribution, productivity and appearance. Most operations are similar to normal forestry practices. However, there are some particular needs for bio-engineering which are specific to the road sector.

In general, routine maintenance activities can carried out by lengthmen and gangs should carry out preventative maintenance. However, the mode of operation depends on the scale of each site and should be kept flexible.

The timing of checking and intervention for each activity is given in Section 5.2.

General principles of vegetation maintenance

In bio-engineering, the aim is to stop all forms of erosion and shallow mass movement. It is usually necessary to manage vegetation in order to achieve this since a semi-natural (or unmanaged) community of vegetation does not always provide the functions required for engineering. Often, unmanaged vegetation leads to a dense



A recently rehabilitated road pavement (above): its longevity depends on the protection and maintenance of the adjoining slopes. Well-maintained roadside slopes(right). The vegetation is managed and cut on a regular basis canopy of trees with relatively little vegetation underneath. Although the trees have deep roots, they do not stop erosion on the surface. That is why soil erosion often takes place under natural or protected forests.

Mixed structure

You should aim to manage the vegetation to produce a mixed vegetation community[1] with a variety of trees, shrubs and grasses on a single site. Single species, or vegetation communities dominated by one or a few species, are unlikely to have either an irregular structure or variety of ages.

Mixed age

Try to achieve a collection of plants of mixed ages for each site (an uneven-aged structure). This means that all plants do not need to be replaced at the same time and there will always be some strong, healthy plants protecting the slope.

Low maintenance

Aim to establish a vegetation community that does not need too much intervention from outside to maintain it. For example, choose species that can regenerate naturally (without planting); species that do not grow too fast or too tall (need cutting and removal less frequently); species that live longer, *etc.*

Managed progression

In bio-engineering it is often necessary to start with **pioneer species**[2] and move towards a **climax community**[3]. Examples of this include:

- tilka/dhanyero scrubland → mixed sal forest (eventually → mixed tropical hardwoods);
- khayer/sisau plantation → mixed sal forest (eventually → mixed tropical hardwoods);
- khote salla plantation → mixed broad-leaved forest (tooni; chilaune; katus);
- utis plantation →chilaune/ katus forest;
- gobre salla plantation → khasru/gurans forest.

5.2 PLANNING THE MAINTENANCE OF BIO-ENGINEERING AND OTHER ROADSIDE VEGETATION

Vegetation and bio-engineering maintenance activities

It is important to plan the maintenance of roadside vegetation in order to ensure that the necessary work is carried out at the best time of year, and to avoid future problems resulting from lack of maintenance. Since each site requires its own maintenance budget, planning ensures that budgets are allocated in good time and priority work can be carried out.

Consider each site separately, because maintenance interventions are extremely site-specific for each slope. Consider the history and future plans for each site independently.

Each site has a different combination of conditions, which affects its maintenance, including:

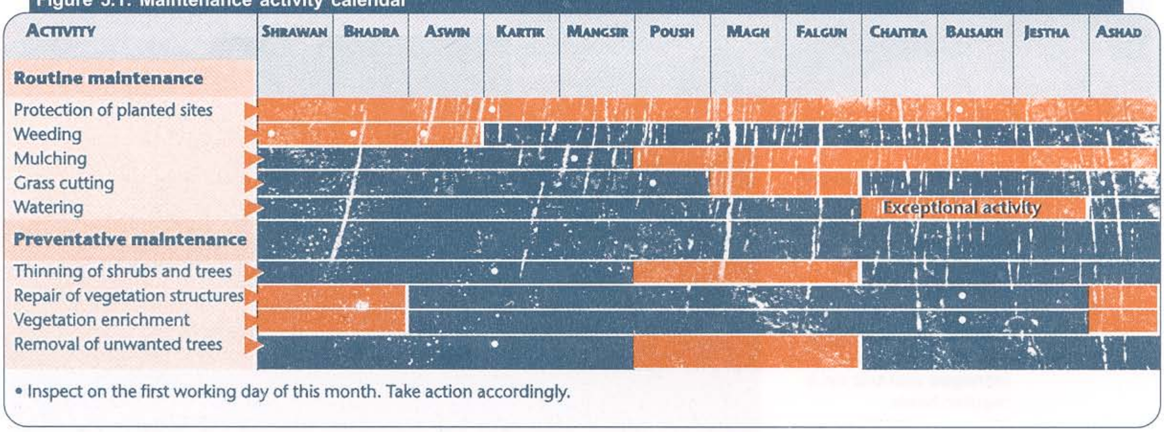
- physical conditions (*e.g.* slopes, materials, local climate, existing vegetation, extent of site);
- legal position (*e.g.* land ownership, existence of disputes, distance from road, type of road);

[1] A vegetation community can be defined as "an established group of plants living more-or-less in balance with each other and their environment; the group can be either natural or managed".

[2] Pioneer or colonising species are the first plants to appear on bare ground and are naturally adapted to living on sites with harsh conditions. Examples are: grasses: babiyo, dhonde, kans, khar; shrubs: areri, bhujetro, keraukose, saruwa; trees: bakaino, khayer, salla, sisau, utis.

[3] Climax community species are plants that can form permanent natural forest or natural vegetation. They tend to require better sites to grow, and grow more slowly. Examples are: grasses: amliso, dangre khar, padang bans; shrubs: bainsh, simali, sajiwan; trees: chilaune, katus, lankuri, sal.

Figure 5.1: Maintenance activity calendar



populations, level of interest and previous involvement in road maintenance, existing local groups such as forest user groups, NGOs, societies).

Before starting to plan, assemble as much information as you can on these three categories. A plan can then be prepared (and budgeted, if necessary) before starting the work.

Most maintenance operations are seasonal. The calendar in Figure 5.1 summarises the recommended timing for the operations described in these guidelines.

Planning the maintenance programme

Follow these steps to plan the maintenance of roadside support carefully.

Step 1
Identify the maintenance needs of vegetation on the roadside slopes. This should cover both vegetation planted under a bio-engineering programme, and other existing vegetation. This will entail a detailed survey of all slopes adjacent to your road section.

Step 2
Quantify the work that must be done regularly, as part of a yearly programme.

Step 3
Devise a programme of regular checks. This must state which sites are to be checked, when they are to be checked, what they are to be checked for, and who will do the checking.

Step 4
Implement the maintenance programme.

Step 5
Monitor the maintenance programme and evaluate its effectiveness. Improve it as necessary.

The table in Figure 5.2 specifies precisely the timing of interventions to maintain roadside support. These should be followed in every case.

Figure 5.2: Detailed timing of the maintenance activities for vegetation on roadside slopes

Activity	Category	Sites to check	Timing of checks	Timing of action
Protection of planted sites	Routine	All roadside slopes.	Carry out checks on 1 Baisakh and 1 Kartik.* If protection is given, make weekly inspections.	Protect immediately, if necessary.
Weeding	Routine	Sites where bio-engineering has been used in the past three years.	Check on 1 Shrawan, 1 Bhadra and 1 Aswin.*	Weed immediately, if necessary
Mulching	Routine	Sites where bio-engineering has been used in the past three years.	Check on 1 Mangsir. *	If mulching is necessary, start work on 1 Poush.*
Grass cutting	Routine	All roadside slopes.	Check on 1 Poush.*	If grass cutting is necessary, start work on 1 Magh.*
Watering	Routine	Only those sites where bio-engineering has been used within the past 12 months.	Check weekly in Chaitra, Baisakh and Jestha.	Water immediately, if necessary.
Thinning of shrubs and trees	Preventative	All roadside slopes with forest cover and all sites where bio-engineering was used more than two years ago.	Check on 1 Kartik.*	If thinning is necessary, start work on 1 Poush.*
Repair of vegetation structures	Preventative	All sites where bio-engineering has been used.	Check on 1 Baisakh. *	If repairs are necessary, start work on 1 Ashad.*
Vegetation enrichment	Preventative	All roadside slopes.	Check on 1 Baisakh. *	If enrichment is necessary, start work on 1 Ashad.*
Removal of unwanted trees	Preventative	All roadside slopes.	Check on 1 Kartik.*	If removal is necessary, start work on 1 Poush.*

* Or on the first working day after this date.

5.3 ROUTINE BIO-ENGINEERING MAINTENANCE ACTIVITIES

Protection of planted sites

Why protect?

People may cut grasses, shrubs or trees too much, or at the wrong time of year. This can stunt growth and prevent plants from fulfilling their functions. If plants are cut before the seeds fall, there will be less natural regeneration, especially from grasses. However, at certain times, local people can be very helpful.

Animals may eat small plants and damage the slope with their hooves. Animals are very difficult to control if they are allowed on to a site.

How to protect slopes

Planted sites can be protected in one of four main ways.

- A warden[1] can be employed to watch the site. If this is done, he or she should be told also to do weeding, mulching and other work, rather than just to walk around watching the site. This would need encouragement from the Engineer, Overseer and Supervisor.
- Protection after planting can be made a compulsory part of a contract package. However, this can be used for only 6 to 12 months.
- The protection of roadside sites can be made part of a road lengthman's duty. In certain cases it may be necessary to reduce the length of road covered by the lengthman.
- An arrangement can be made with local people to protect the area. This is often the most long-lasting, but is also the hardest to achieve. It can be done only if there is a clear incentive for the people involved, such as providing large quantities of fodder from the road reserve. This is considered in more detail in the *Reference Manual.*

Whatever system is used, it is very important that both the areas to be protected and the duties to be performed are clearly defined. The Division staff must ensure that the people doing the protection really understand what is expected of them. The box below gives an example of the duties that a site warden should be expected to perform.

How to check that sites are adequately protected

Basic checks can be made easily by walking through a site that is being protected and looking for signs of damage. Do not just walk along a main path but also go into some other corners of the site. The signs to look for are:

- regular spacing and growth of plants;
- plants are carefully weeded and mulched;

The following signs suggest poor protection:

- physical damage to plants (*e.g.* growing shoots or leaves eaten off);
- animals or signs of animals (*e.g.* dung) in the area.

[1] The function of a warden is more than that of a chowkidar or heralu. He or she has to carry out a number of maintenance activities.

DUTIES OF WARDENS TO PROTECTING PLANTED SITES IN ROADSIDE AREAS (EXAMPLE)

Site wardens should be active in a range of duties, including:

- watching all sites (in their road section) and ensuring that no domestic or wild animals graze the areas;
- explaining to local people the importance of protecting the areas; asking them to graze animals and to cut fodder and firewood well away from the road, and enforcing this as necessary;
- tending the plants, weeding and mulching the site carefully to promote and improve growth;
- cutting weeds (mainly annuals) in the adjoining road reserve and forest areas to make mulch for the plants on the site;
- alerting the Engineer, Overseer or Supervisor to any untoward events, such as damage to any of the site structures, blocking of drains, etc;
- helping to replace and enrich the bio-engineering planting during the rains;
- at other times, carrying out minor repairs of up to 0.25 cu.m to physical structures on the slopes.

The warden should be given the best possible support from the Division. This should be as for lengthmen.

Local wardens are often the most effective in reducing damage. This seems to be partly because they know personally all the people who use the area.

See also *Standard Specifications for Bio-engineering*, item 2881, 'provision and role of site watchmen' (given in the *Reference Manual*).

Weeding

What is weeding?

Weeding is the removal of unwanted vegetation that is competing with the growth of the desired plants.

Why do weeding?

- To improve the growth of the desired species by removing competing vegetation. In some dry forest types, it may also be necessary to reduce the risk of fires.
- To remove dense vegetation (especially invasive weeds such as ban mara and tite pate) in order to allow more desirable plants to regenerate naturally.
- To improve drivers' sight lines and the visibility of pedestrians, where these have been reduced.

When should weeding be done?

When the plantation age is young, and also in older sites when there is a need to encourage better growth or natural regeneration.

Weeding is normally required only during the monsoon rains, once unwanted plants have grown up. The most important time is from Shrawan to Aswin.

How to weed a site

Select individual sites according to their situation and treat them at one time.

Carefully cut and remove only undesirable species, but take care to retain plants of the desired species. Always avoid deep soil working, which can damage plant roots.

Small plants with weak, shallow roots, such as ban mara (*Eupatorium adenophorum*) and tite pate (*Artemisia vulgaris*) can simply be pulled up if this will not damage the remaining plants. Unwanted plants with stronger roots should be cut about 50 mm above ground level using a hasiya (sickle).

Products from weeding

Weeding can produce material for mulching or composting, and sometimes for fodder.

Materials and tools for weeding

Most weeding operations will only require a hasiya (sickle).

Mulching

What is mulching?

Mulching is the positioning of inert dead vegetation around seedlings to keep the soil cool and moist. Mulch is usually made by cutting up the stems and leaves of unwanted plants

Why do mulching?

Mulching is required to improve the growth of plants less than three years old.

By keeping the soil cool and moist, mulching increases the rate of growth. Plants become big more quickly and their roots help to strengthen the slope .

Where grass seeding has been done, mulching also protects delicate new grass plants from both scorch by hot sun and damage by rain splash.

When should you mulch?

Mulching is most needed when there is too much sun and too little water. This means any time during the dry season and early rains, from Poush to Ashad.

All new shrub and tree seedlings should be mulched directly after planting.

How to mulch

Mulch can be made from the stems and leaves of any plants. It is important not to use plant parts carrying seeds, as this will lead to a big weeding problem.

If possible, make mulch from annual and perennial weeds with poor rooting characteristics, such as ban mara (*Eupatorium adenophorum*) and tite pate (*Artemesia vulgaris*). The greenery should be collected when there is most material available, but before it forms seeds. This is most often in Shrawan and Bhadra. However, requirements always have to be assessed specifically and local sources checked.

Straw and thatch grasses can also be used.

Collected material should be chopped: the maximum size is 150 mm. It can be stored until required if necessary.

Spread the mulch around the plant being treated in a layer 50 mm to 100 mm thick. A circle of radius 150 mm should be left next to the plant itself. Outside this, the mulch should form a circle of about 750 mm radius.

Materials and tools for mulching

Most mulching operations will require:

a hasiya (sickle) for cutting the plants;
a khukuri for chopping the weeds into small pieces;
a doko and namlo for transporting the mulch.

Grass cutting

Why cut grasses?

- Cutting grasses encourages them to remain vigorous and to put out new shoots. It also allows better inspection of slopes and provides useful products.
- To improve drivers' sight lines and the visibility of pedestrians, where these have been reduced.

When should grasses be cut?

Grasses are cut once a year, after the seeds have fallen. This means that cutting must not take place before the beginning of Magh. Grasses should be cut on all accessible bio-engineering sites and other roadside slopes with grass cover.

Grass cutting can take place any time during Magh and Falgun. If the grasses impede road traffic at other times, they should be cut immediately.

Fodder grasses (but not tree fodder or dale ghans), which are not commonly planted in roadside areas, should be cut every one to two months during the wet season. Cutting should be done whenever a good crop can be taken.

How to cut grasses

Cut grasses about 150 mm above the ground, using a karauti or hasiya (sickle). Care must be taken not to pull out the roots of the grass clump. Also, other plants must not be damaged; especial care must be taken of small shrub and tree seedlings.

Products from grass cutting

Any cut grass can be used for mulching the plants on the site.

Otherwise, the cut grass can be used for thatching, fodder, fibres, kuchos or other uses, according to the species. Government regulations must be followed for the disposal of products grown on road reserve land. Products from other land should normally be given to the land owner or community group responsible for the land.

Materials and tools for grass cutting

Most grass cutting operations will only require a karauti or hasiya (sickle).

Watering

Why do watering?

Watering[1] can help enormously to improve the growth of plants on harsh sites during the later dry season (Chaitra to Jestha). If watering is done, mulching is normally done as well.

When should you water?

Watering is done only in these situations:

- on all bamboos planted in dry sites;
- on critical sites, where good plant cover must be established before the start of the monsoon rains; or
- when water is easily available on site, such as from a nearby khola or a spring; or
- when a dry period occurs soon after planting in the early monsoon, and resources allow; or
- where a warden has no other duties and water is available close to the site.

Watering is done on days without rain, normally in Chaitra, Baisakh and Jestha. It is done in the morning or evening. It is not done during the middle of the day when it is sunny (because too much would evaporate).

How to water

Water must be applied slowly and allowed to infiltrate, preferably using a sprinkler. It must not run off. If necessary, the ground can be lightly cultivated to increase infiltration. For shrub and tree seedlings, the water can be poured into a small trench just up the slope.

Watering rates:

grass plants:	0.25 litres per plant per day;
shrub and tree seedlings:	5 litres per plant per day;
bamboo plants:	10 litres per plant per day.

Materials and tools for watering

If possible, water should be brought by pipe. Otherwise, it can be carried in buckets or watering cans.

[1] Note: watering of plants is only required in special cases. It is most commonly used on critical sites where planting is carried out well before the monsoon, such as in Baisakh or Jestha.

5.4 PREVENTATIVE MAINTENANCE OF ROADSIDE VEGETATION

Pruning and thinning of shrubs and trees

A detailed technical appraisal of pruning and thinning is given in the *Reference Manual*: that should be followed for large sites and in special cases. However, this section gives guidelines applicable to most sites, and most maintenance requirements.

What are pruning and thinning?

Pruning is the removal of the lower branches of a tree or large shrub.

Thinning means removing selected shrubs or trees to decrease the density of the plants. In practice, this usually means removing about half the number of trees on the site.

There are three forms of thinning:

- pollarding: a tree is cut 2 to 3 metres above the ground and new shoots grow up;
- coppicing: a tree is felled and new shoots come from the stump;
- selection thinning: a tree is felled and the stump allowed to die.

Most thinning operations involve selection thinning: *i.e.* the removal of whole trees.

Why do pruning and thinning?

- To increase the light penetrating through the canopy. This will improve the plants growing on the ground underneath, especially grasses, and reduce surface erosion.
- To remove trees of species that are no longer required in the final, mature site.
- To improve drivers' sight lines and the visibility of pedestrians, where these have been reduced.

When should you prune and thin?

When a plantation is dense and shrubs or trees have crowns that are touching. This may be about every five years, but every site should be inspected annually.

Shrubs and trees are best removed during the winter (Poush to Falgun) when disturbance is least likely to hinder the growth of the remaining plants.

How to prune and thin

- Start by pruning. First cut off the bottom branches, up to half the total height of the shrub or tree. For large mature trees only, cut branches up to two-thirds the total height of the tree.
- Cut branches cleanly and as close to the trunk as possible without causing damage. Cut the branches nearest the ground first and move upwards.
- Use sharp tools to cut branches. Where the branch is more than 50 mm in diameter, make a small cut underneath the branch first. The bark should never be torn: this can damage the plant badly.

Now ask this question:

Has the canopy been opened enough just by pruning, so that there is now enough light penetrating to allow grasses to grow under the trees?

If 'yes', then the operation is complete.

If 'no', then thin the trees.

Thinning is carried out by following this procedure.

- Inspect the site carefully and decide which trees should be kept and which trees should be removed.
- Choose to keep vigorous, healthy trees that

An open canopy with grasses growing underneath (left). Too little light is penetrating this canopy (right) to allow grasses to grow; pruning or thinning is required

A plantation of utis (*Alnus nepalensis*) where the trees are thin and weak due to dense planting and intense competition for light. Pruning and thinning are required to improve the spacing, as well as to allow better understorey vegetation to develop

will continue to grow well if they are given more space.

- As you choose the trees to be felled, select them in this order:

1. All dead, dying or seriously damaged trees.
2. Trees of unwanted species.
3. Trees of bad shape and large crown.
4. Next, select trees to leave a variety of sizes and ages.

- Mark with paint the trees that **should not** be felled.
- Fell the **unmarked trees**.
- Thin a site according to its requirements, to achieve 50 to 67per cent open space and only 33 to 50 per cent canopy.

Products from pruning and thinning

Firewood is the main product from pruning operations, but very little will be produced from plants that have been regularly pruned for several years.

A range of sizes of poles will be produced from thinning, suitable for many uses (building, fences, *etc*). However, much of the cut material will be suitable only for firewood if plants are not straight, or if they are unsuitable for timber.

Government regulations must be followed for the disposal of products grown on road reserve land. Products from other land should normally be given to the land owner or community group responsible for the land.

The Department of Roads can heat bitumen with firewood from trees grown in the road reserve.

Materials and tools for pruning and thinning

Most pruning operations require a khukuri, secateurs or small saw.

Most thinning operations require a saw or axe.

Paint for marking trees that will not be thinned or pruned.

Use very sharp tools; working with blunt tools can damage trees.

Repair of vegetation structures

What is the repair of vegetation structures?

The repair of any form of bio-engineering treatment: mainly palisades, fascines and brush layering, and re-turfing. This should be done as and when required.

Why repair vegetation structures?

To maintain the effectiveness of the treatments and to ensure that they become stronger over time.

When should vegetation structures be repaired?

Bio-engineering sites should be checked regularly. This should normally be once every six months or less.

Repairs should be programmed as part of the Division's work plan.

Repairs to living structures should be done during the monsoon rains (*i.e.* Ashad to Bhadra).

How to repair vegetation structures

Employ a small specialist gang to repair bio-engineering treatments.

The minimum amount of disturbance should be made to the site.

The work to be done depends on the particular bio-engineering treatment and the type of damage.

A suitable lengthman or site warden can undertake very small repairs.

Materials and tools for repairing vegetation structures

These are normally the same as for the original construction of the structure being repaired. The materials and tools required are given in the appropriate rate analysis norms.

Vegetation enrichment

What is vegetation enrichment?

Vegetation enrichment means planting more grasses, shrubs or trees within the site area or in gaps within the existing vegetation.

It can also involve the planting of shrubs and trees to replace those removed for certain reasons (see below).

Why enrich vegetation?

To establish more plants in places where there are gaps.

To introduce or change the species composition on a site: for example to increase the range of species or to move away from a single species (*e.g.* utis), by planting seedlings of other species.

When should vegetation be enriched?

- Whenever there are gaps in the vegetation in which erosion might start.
- When it is necessary to change the mixture of species. This might be to move from pioneer to climax community species (following the principles described in the *Reference Manual*.
- When trees that have had to be removed need replacing. This is when the other remaining vegetation is not adequate to protect the slope.
- Actual enrichment planting should be done during the monsoon rains (*i.e.* Ashad to Bhadra).

How to enrich vegetation

Carefully select plants that are desired on the site and should grow well, and raise them in the nursery.

Plant only in gaps, not under a dense forest canopy. Follow this with regular weeding.

Spread the planting over several years and concentrate on successful establishment in a small area each year, if the total area available for planting is large.

Vegetation enrichment is best combined with other operations that increase the amount of light penetrating the canopy (such as thinning and tree removal). In this case, enrichment should be concentrated in gaps or open areas in the canopy.

Materials and tools for vegetation enrichment

These are normally the same as for the original planting of the vegetation being enriched. The

Thinning roadside plantations can yield significant volumes of firewood

materials and tools required are given in the appropriate rate analysis norms.

Removal of unwanted shrubs and trees

Why remove unwanted shrubs and trees?

A tree may be removed for any of the following reasons:

- The tree is dead and may fall down.
- The tree is obstructing traffic or drivers' sight lines.
- The tree is surcharging a steep slope, or is too big and unstable for the slope on which it is growing.
- The tree needs to be cut as part of a thinning programme. This will allow more light to penetrate and help the understorey grow.
- The tree needs to be cut to allow coppice shoots to come from the stump.
- The tree needs to be cut to allow widening of the road.

When should unwanted shrubs and trees be removed?

Whenever a problem occurs where a tree needs to be removed.

If possible, shrubs and trees are best removed during the winter (Poush to Falgun) when the disturbance is least likely to hinder the growth of the remaining plants.

How to remove unwanted shrubs and trees

Follow the legal guidelines shown in the *Reference Manual*.

Organise labourers or a contractor to fell the shrub or tree and dispose of the produce according to regulations.

Large trees should be felled so that they do not damage young trees and shrubs unduly. If a tree with a very large crown has to be felled, it should be pruned first to remove the crown branches. It should also be felled across the slope to avoid excessive damage.

Materials and tools for the removal of unwanted shrubs and trees

Most removal operations require the same tools as for thinning. These are: a saw, or an axe, and paint for marking trees to be left. All tools used should be very sharp. This is to avoid damage to trees from bad working with blunt tools.

A positive relationship with road neighbours is advantageous for all concerned

A CODE OF PRACTICE CONCERNING ROADS AND OTHER LAND USES

1. This is a practical guide which, if followed by Departmental staff, will help to ensure that roads do not conflict with other land uses. It will also help to improve relationships with rural road neighbours ('local people').
2. The impact of every operation on the surrounding land must be considered before it is undertaken. A full site investigation must be made. Consideration must be given to the potential for damage to surrounding farmland.
3. No operation should be permitted (without due compensation) that gives rise to damage to farmland, water supply lines, irrigation systems, or other forms of local infrastructure.
4. Where there is likely to be any adverse impact or conflict, then contact should be made with the people concerned. Adequate time must be allowed for discussion and agreement. Possible alternatives should be considered.
5. In every case, the requirements of the law should be followed where compensation may be due.
6. On every road section, a number of safe tipping sites must be designated. All staff must be instructed to use them. Such sites must be away from houses and farmland; they must be on stable slopes; and they must be well marked on the lower side.
7. No tipping of material should be permitted anywhere except in designated tipping sites.
8. The discharge of all drains should be checked on a recurrent basis. Any damage resulting from excess flows should be rectified.
9. Any changes (*e.g.* small landslides) to roadside slopes that might affect either the road or adjoining land should be investigated promptly. Repairs, if necessary, should be undertaken at the earliest opportunity.
10. Any complaint by a road neighbour should be investigated promptly and action taken as necessary.
11. Where a road neighbour is undertaking activities causing damage to the road, a thorough investigation should be made. This should start from a sympathetic approach, but where the Department's interests are affected, reference should be made to the laws. The legal standing of the Department of Roads should be ascertained as early as possible in each particular instance.
12. Where there is a conflict, a compromise solution that suits both parties should be sought wherever possible.

5.5 LIAISON WITH RURAL ROAD NEIGHBOURS

Roads should blend with the landscape through which they pass. They should not be permitted to show a negative impact on other land uses. In rural areas, they must enhance agriculture, and not have a damaging effect on the activities of farmers. A positive relationship between road maintenance offices and the people who live beside their roads is advantageous for everyone.

To move in this direction, the code of practice given above should be followed for reasons of good technical working, good professionalism and good ethics. It applies specifically to roadside maintenance, rather than to the construction of new roads.

SITE ASSESSMENT PRO FORMA

Complete one pro forma per site. Use additional forms if there are more than three segments on the site

Site location and chainage:

Date of assessment: **Assessor's name:**

Sketch of site [Label segments]

Scale: Orientation:

Segment number	**(1)**	**(2)**	**(3)**
(a) Erosion and failure processes			
(b) Other factors			
(c) Slope angle(s)			
(d) Slope length			
(e) Material drainage			
(f) Segment moisture			
(g) Altitude			

Assessment criteria. See *Roadside Bio-engineering Site Handbook*, Annex A, pages 127-129 for details

(a)	Erosion and failure processes.	List the erosion or failure processes. State their size and severity.
(b)	Other factors.	List any physical factors that might affect the site. State their size and severity.
(c)	Slope angle(s).	Measure and place in one of 3 classes: < 30°, 30 – 45°, or > 45°.
(d)	Slope length.	Measure and place in one of 2 classes: <15 metres or > 15 metres.
(e)	Material drainage.	Assess and place in one of 2 classes: good or poor.
(f)	Segment moisture.	Assess and place in one of 4 classes: wet, moist, dry or very dry.
(g)	Altitude.	Determine: ± 100 metres. Use an altimeter, map or site drawing.

Figure A1: The main erosion and failure processes

MECHANISM	DESCRIPTION
Erosion on the surface.	Rills and small gullies form in weak, unprotected surfaces. Erosion should also be expected on bare or freshly prepared slopes.
Gully erosion	Gullies that are established in the slope continue to develop and grow bigger. Large gullies often have small landslides along the sides.
Planar sliding (translational landslide or debris slide).	Mass slope failure on a shallow slip plane parallel to the surface. This is the most common type of landslide, slip or debris fall. The plane of failure is usually visible but may not be straight, depending on site conditions. It may occur on any scale.
Shear failure (rotational landslide).	Mass slope failure on a deep, curved slip plane. Many small, deep landslides are the result of this process. Large areas of subsidence may also be due to these.
Slumping or flow of material when very wet.	Slumping or flow where material is poorly drained or has low cohesion between particles and liquefaction is reached. These sometimes appear afterwards like planar slides, but are due to flow rather than sliding. The resulting debris normally has a rounded profile.
Debris fall or collapse.	Collapse due to failure of the supporting material. This normally takes the form of a rock fall where a weaker band of material has eroded to undermine a harder band above. These are very common in mixed Churia strata.
Debris flow	In gullies and small, steep river channels (bed gradient usually more than 15°), debris flows can occur following intensive rain storms. This takes the form of a rapid but viscous flow of liquefied mud and debris.

(a) Erosion and failure processes

A number of erosion and failure processes are to be found. The types of erosion and slope failure found in Nepal are given in Figure A1. All sites have a combination of these mechanisms at work on them. During site assessment, you should check for these.

Figure A2: The main physical factors affecting slopes

POTENTIAL FACTOR	DESCRIPTION
Fault lines	Small fault lines may cause differential erosion in parts of the site.
Springs	There may be seasonal springs within the site, which cause localised problems of drainage or slumping.
Slip planes	The main plane of failure may not be the only one. Many sites have secondary, smaller slip planes additional to the main failure mechanism
Large gullies	Large gullies nearby may erode backwards and damage the site. Alternatively, they may discharge on to the site, causing deposition there.
Landslides	Nearby landslides may extend headwards or sideways, or may supply debris on to the site.
River flooding	A large river below the site may flood badly, damaging the site by either erosion or deposition, or a combination of both.
River cutting	Rivers below the site may move in floods, undercutting the toe of the site.
Catchments	If there is an extended catchment area above the site, it could lead to a large discharge which causes bad damage by erosion or deposition.
Drain discharge	The discharge of drainage water must be safeguarded to avoid causing erosion or mass failures. Poorly sited or inadequately protected discharge points can cause severe problems.
Khet and kulos	Khet (rice paddy) land or a kulo (irrigation leat) above a site usually means a large volume of water infiltrating into the slope, with a greater potential for failure or large scale erosion.
Construction activities	Construction activities on or near the site may lead to undermining through excavations, or surcharging through spoil disposal in the wrong places.

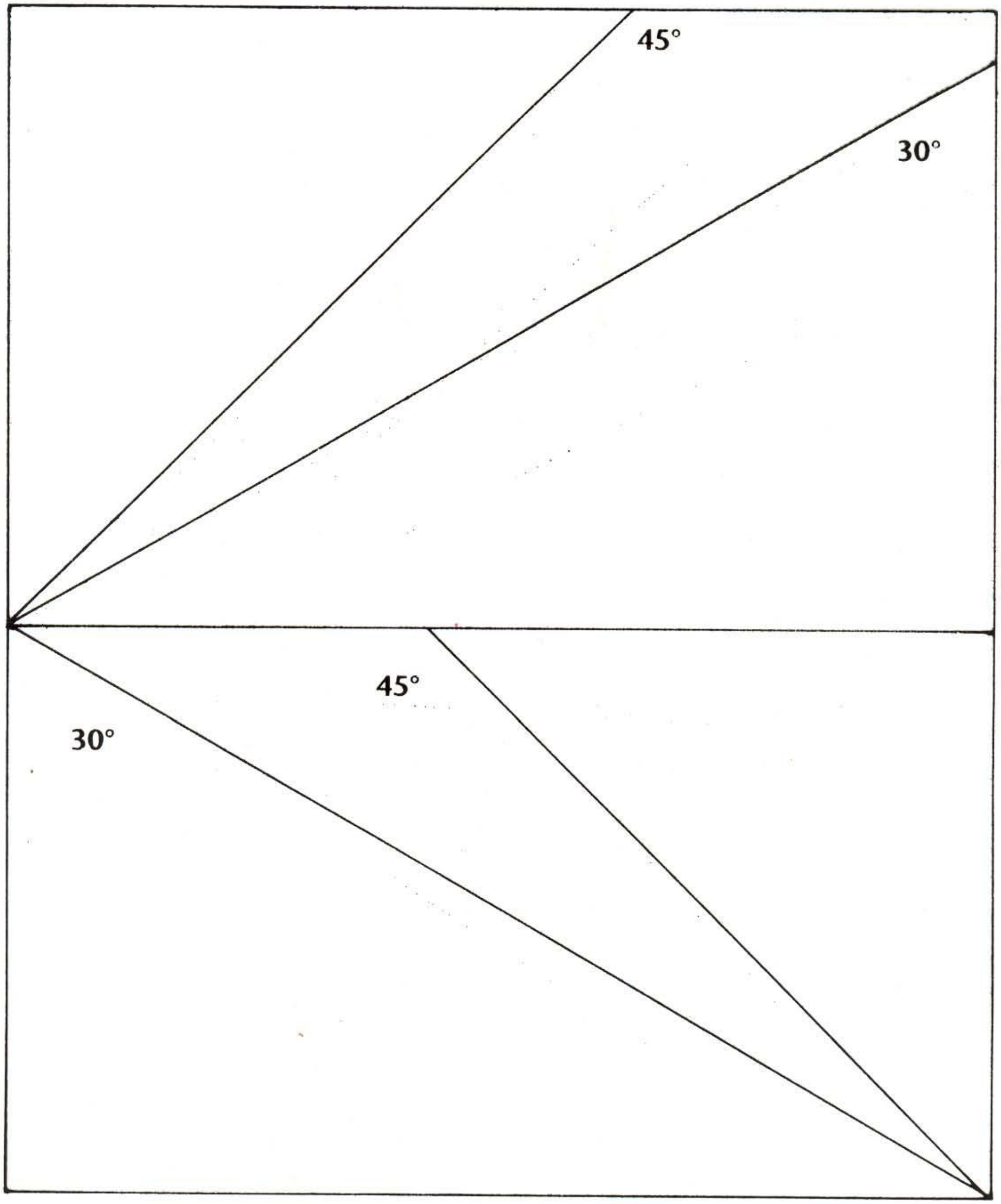
(b) Other factors

In addition to erosion and failure mechanisms, other factors may affect the site. Some are internal (*e.g.* springs) while others are external (*e.g.* river undercutting). During site assessment, you must check for signs off any of the potential damaging factors listed in Figure A2.

(c) Slope angle(s)
Measure the average slope angle of the slope segment and place it in one of 3 classes:

- **< 30°,**
- **30 – 45°, or**
- **> 45°.**

If there is more than one dominant slope, record all main slope angles.



(d) Slope length

Measure the average length of the slope segment and place it in one of two classes:

<15 metres or

> 15 metres.

Figure A3: Common features indicating soil drainage characteristics

Material drainage characteristics	Tendency towards GOOD drainage	Tendency towards POOR drainage
Overall drainage	Freely draining material; dries quickly after rain storms	Slowly draining material; tends to remain wet for long periods after rain; behaves like dahi
Soil particle size	Coarse textures; loams and sandy soils	Fine textures; clays and silts
Porosity	Large inter-connecting pores	Small pores
Material types	Stony colluvial debris; fragmented rock; sandy and gravelly river deposits	Residual soils of fine texture; debris from mud flows, slumps, *etc*; rato mato
Slope types	Fill slopes; cut slopes in stony debris (colluvium)	Cut slopes in original consolidated ground

(e) Material drainage

Assess and place in one of two classes: good or poor (see Figure A3).

Figure A4: Environmental factors determining site moisture

Site moisture factor	Tendency towards DAMP sites	Tendency towards DRY sites
Aspect	Facing N, NW, NE and E	Facing S, SW, SE and W
Altitude	Above 1500 metres; particularly above 1800 metres	Below 1500 metres; deep river valleys surrounded by ridges
Topographical location	Gullies; lower slopes; moisture accumulation and seepage areas	Upper slopes; spurs and ridges; steep rocky slopes
Regional rain effects	Eastern Nepal in general; the southern flanks of the Annapurna Himal	Most of Mid Western and Far Western Nepal
Rain shadow effect	Sides of major ridges exposed to the monsoon rain-bearing wind	Deep inner valleys; slopes sheltered from the monsoon by higher ridges to the south
Stoniness and soil moisture holding capacity	Few stones; deep loamy* and silty soils	Materials with a high percentage volume of stones; sandy soils and gravels
Winds	Sites not exposed to winds	Large river valleys and the Terai
Dominant vegetation	*e.g.* utis, katus, chilaune, amliso, nigalo, bans, lali gurans	*e.g.* khayer, babiyo, khar, dhanyero, salla, imili, kettuke

* Loam is the name given to a soil with moderate amounts of sand, silt and clay, and which is therefore intermediate in texture and best for plant growth.

(f) Segment moisture

Assess and place in one of four classes:

Wet: permanently damp sites (*e.g.* north-facing gully sites).

Moist: sites that are reasonably well shaded or moist for some other reason.

Dry: generally dry sites.

Very dry: sites that are very dry; these are usually quite hot as well (*e.g.* south-facing cut slopes at low altitudes).

See Figure A4

(g) Altitude

Determine: ± 100 metres. Use an altimeter, map or site drawing.

B1: FULL LISTS OF SPECIES FOR BIO-ENGINEERING IN THE ROAD SECTOR

GRASSES FOR BIO-ENGINEERING IN THE ROAD SECTOR (including small legumes)

Local name	स्थानिय नाम	Botanical name	Rec	Character	Altitude
Amliso	अमलिसो	***Thysanolaena maxima***	✓	**Large clumping**	**Terai-2000m**
Babiyo	बाबियो	***Eulaliopsis binata***	✓	**Medium-sized clumping**	**Terai-1500m**
Bansko ghans	बंसो घांस	*Eragrostis tenella*		Large spreading	500-1800 m
Blue panic grass	ब्लु पेनिक घांस	*Panicum antidotate*		Medium-sized spreading	500-1800 m
Buffalo grass	भैसी घांस	*Cenchrus ciliaria*		Medium-sized spreading (exotic)	500-1800 m
Clover	क्लोभर	*Trifolium* species		Small spreading legume (exotic)	Terai-2000 m
Dangre khar	डंग्री खर	*Cymbopogon pendulus*		Large clumping	Terai-1200 m
Desmodium	डेसमोडियम	*Desmodium distortum*		Spreading legume (exotic)	Terai-1800 m
Desmodium greenleaf	डेसमोडियम हरियोपात	*Desmodium intortum*		Spreading legume (exotic)	Terai-2000 m
Dhonde	ढोन्डे	***Neyraudia reynaudiana***	✓	**Large clumping**	**Terai-1500m**
Dubo	दुवो	*Cynodon dactylon*		Small creeping	Terai-1800 m
Dhungre	ढुंग्री	Unknown		Large clumping	1500-2500 m
Dhus	धुस	Unknown		Large clumping	1500-2500 m
Jaughans	जौघांस	Unknown		Medium-large spreading	1600-3000 m
Kagati ghans	कागती घांस	*Cymbopogon citratus*		Medium-large clumping	Terai-1500 m
Kans	कांस	***Saccharum pontaneum***	✓	**Large clumping and spreading**	**Terai-2000m**
Katara khar	कटरा खर	***Themeda* species**	✓	**Large clumping**	**Terai-2000m**
Khar	खर	***Cymbopogon microtheca***	✓	**Medium-large clumping**	**500-2000 m**
Khus	खस	***Vetiveria lawsoni***	✓	**Medium-large clumping**	**Terai-1500m**
Kikiyu, thulo dubo	किकियु, ठूलो दुवो	*Pennisetum clandestinum*		Small creeping (exotic)	Terai-1800 m
Kudzu	कूडजू	*Pueraria lobata*		Spreading legume (exotic)	500-1500 m
Molasses	मोलासेस	*Melinis minutiflora*		Medium-large spreading (exotic)	Terai-1800 m
Musekharuki	मुसेखरुकी	*Pogonatherum paniceum* (?)		Small spreading	Terai-2500 m
Napier	नेपियर	*Pennisetum purpureum*		Large semi clumping (exotic)	Terai-1750 m
Narkat	नरकट	***Arundo clonax***	✓	**Large clumping and spreading**	**Terai-1500m**
NB21	एनबी२१	*P. Purpureum × typhoides*		Spreading (exotic)	Terai-1750 m
Padang bans	पन्याङ्ग वांस	***Himalayacalamus hookerianus***	✓	**Large clumping (small stature bamboo)**	**1500-2500 m**
Phurke	फुर्के घाँस	***Arunduella nepalensis***	✓	**Medium-sized clumping**	**700-2000 m**
Rato kans	रातो कांस	*Frianthus rufipilus*		Medium-sized clumping	900-2200 m
Salimo khar	सालिमे खर	*Chrysopogon gryllus*		Medium-large clumping	800-2000 m
Setaria	सेतारया	*Setaria anceps*		Medium-large spreading (exotic)	500-2500 m
Sito	सिटो	***Neyraudia arundinacea***	✓	**Large clumping**	**Terai-1500m**
Stylo	स्टायलो	*Stylosanthes guianensis*		Spreading legume (exotic)	500-1500 m
Thulo kharuki	ठूलो खरुकी	*Capipedium assimile* (?)		Medium-large clumping	600-2000 m
Tite nigalo bans	तिते निगाले बांस	***Drepanostachyum intermedium***	✓	**Large clumping (small stature bamboo)**	**1000-2500 m**

Rec: ✓ = particularly recommended for roadside areas.

Local name	Sites	Best propagation	Seed collection	Comments
Amliso	**Varied**	**Slip cuttings**	Mar-Apr	**Best in damper areas**
Babiyo	**Hot and dry**	**Slip cuttings/seeds**	Jan-Feb	
Bansko ghans	Varied	Slip cuttings/seeds	Dec-Jan	
Blue panic grass	Varied and dry	Slip cuttings	Use cuttings	High grazing risk
Buffalo grass	Varied and dry	Slip cuttings	Use cuttings	High grazing risk
Clover	Varied; moist	Stem cuttings/seeds	Use cuttings	High grazing risk
Dangre khar	Varied	Seeds	Dec-Jan	Best in damper areas
Desmodium	Varied	Stem/slip cuttings	Use cuttings	High grazing risk
Desmodium greenleaf	Varied and dry	Stem/slip cuttings	Use cuttings	High grazing risk
Dhonde	**Hot and dry**	**Stem/slip cuttings/ seeds**	Dec-Jan	**15,520,000 seeds/kg**
Dubo	Varied	Stem cuttings	Use cuttings	
Dhungre	Damp or shady	Large slip cuttings	Dec-Jan	
Dhus	Varied, dry to moist	Slip/stem cuttings	Dec-Jan	
Jaughans	Varied	Slip cuttings/seeds	May-Jun	
Kagati ghans	Varied	Slip cuttings/seeds	Nov-Dec	
Kans	**Hot and dry to moist**	**Slip cuttings**	Nov-Dec	**Very tough on all sites**
Katara khar	**Varied**	**Slip cuttings/seeds**	Oct-Nov	
Khar	**Hot and dry; varied**	**Slip cuttings/seeds**	Dec-Jan	**1,681,000 seeds/kg**
Khus	**Varied**	**Slip cuttings**	Sep-Nov	**Fill slopes only; 1,712,000 seeds/kg**
Kikiyu, thulo dubo	Varied	Stem/slip cuttings	Use cuttings	High grazing risk
Kudzu	Varied	Stem/slip cuttings	Use cuttings	High grazing risk
Molasses	Varied to dry	Slip cuttings/seeds	Use cuttings	High grazing risk
Musekharuki	Varied	Slip cuttings	Use cuttings	
Napier	Varied;needs fertile soil	Stem cuttings	Use cuttings	High grazing risk
Narkat	**Hot and dry; varied**	**Stem/slip cuttings**	Nov-Jan	
NB21	Varied	Stem cuttings	Use cuttings	High grazing risk
Padang bans	**Moist**	**Large slip cuttings**	Use cuttings	**High grazing risk**
Phurke	**Varied; stony**	**Slip cuttings/seeds**	Dec-Jan	**1,809,000 seeds/kg**
Rato kans	Varied	Slip cuttings/seeds	Dec-Jan	
Salimo khar	Varied	Slip cuttings/seeds	Dec-Jan	
Setaria	Varied to dry	Slip cuttings/seeds	Jul-Aug	High grazing risk
Sito	**Varied**	**Slip cuttings/seeds**	Dec-Jan	**Higher rainfall areas; 16,390,000 seeds/kg**
Stylo	Varied	Stem/slip cuttings	Use cuttings	High grazing risk
Thulo kharuki	Varied	Slip cuttings/seeds	Dec-Jan	Higher rainfall areas
Tite nigalo bans	**Varied**	**Large slip cuttings**	Use cuttings	**Drier sites than padang**

B2: FULL LISTS OF SPECIES FOR BIO-ENGINEERING IN THE ROAD SECTOR

SHRUBS/SMALL TREES FOR BIO-ENGINEERING IN THE ROAD SECTOR

Local name	स्थानिय नाम	Botanical name	Rec	Character	Altitude
Aak	आँक	*Calatropha giganteum*		Small shrub, large fleshy leaves	Terai-1000 m
Ainselu	ऐंसेलु	*Rubus ellipticus*		Thorny shrub up to 2 m high	1000-2500 m
Alainchi	अलैंची	*Elettaria cardomomum*		Herb up to 2 m high	1000-2000 m
Amala	अमला	*Phyllanthus emblica*		Small tree	Terai-1500 m
Amba/ambak	अम्वा	*Psidium guajava*		Small tree, up to 5 m	Terai-2000 m
Aparajita	अपराजिता	*Clitoria ternatea*		Climbing shrub (exotic)	Terai-1500 m
Areri	अरेरी	***Acacia pennata***	✓	**Small thorny tree, up to 5 m**	**500-1500 m**
Argali	अर्गली	Unknown		Shrub up to 3 m high	1500-2500 m
Arile kanda	अरिले कांडा	*Caesalpinia decapetala*		Thorny climber (exotic)	Terai-1500 m
Armalito, seabuckthorn	अर्मालितो	*Hippophae salicifolia*		Small thorny tree	1000-2500 m
Assuro	अस्सुरो	***Adhatoda vasica***	✓	**Shrub up to 3 m high**	**Terai-1000m**
Bains	वैंस	***Salix tetrasperma***	✓	**Tree up to 15 m high**	**Terai-2700m**
Bains	वैंस	Unknown; not *Salix*		Shrub up to 5 m high	1300-2000 m
Baganbeli/ baramase phul	बगनबेली बाह्रमासे फुल	*Bougainvillea spectabilis*		Thorny climber (exotic)	Terai-1500 m
Ban chutro	बन चुत्रो	*Berberis aristata*		Thorny shrub up to 2 m high	1500-3000 m
Ban silam	बन सिलाम	*Elsholtzia blanda*		Shrub	Terai-1500 m
Bayer	बयर	*Zizyphus mauritiana*		Thorny shrub up to 4 m high	Terai-1200 m
Bhimsenpati	भिमसेन पाती	*Buddleja asiatica*		Shrub up to 4 m high	600-1800 m
Bhui katahar	भुईंकटहर	*Ananas comosus*		Thorny herb up to 1 m high	Terai-1600 m
Bhujetro	भुजेत्रो	***Butea minor***	✓	**Shrub up to 4 m high**	**500-1500 m**
Bilaune	बिलाउनी	*Maesa chisia*		Shrub	Terai-2000 m
Bokshi ghans	वोक्सी घांस	*Mimosa rubicaulis*		Shrub up to 3 m high	500-1700 m
Chiya	चिया	*Camellia sinensis* (and other species)		Shrub up to 4 m high	Terai-2000 m
Chutro	चुत्रो	*Berberis asiatica*		Thorny shrub up to 2 m high	1000-2500 m
Coffee	कफि	*Coffea arabica*		Shrub up to 2 m high	Terai-2000 m
Dhanyero	धंएरो	***Woodfordia fruticosa***	✓	**Shrub up to 3 m high**	**Terai-1500m**
Dhusun	धुसुन	***Colebrookea oppositifolia***	✓	**Shrub up to 3 m high**	**Terai-1000m**
Gahate	गहते	*Desmodium* species		Shrub up to 4 m high	400-1500 m
Ghangaru	घंगारु	*Pyracantha crenulata*		Shrub up to 2 m high	1500-2500 m
Ghurmiso	घुर्मिसो / घुर्बिस	*Leucosceptrum canum*		Tree up to 8 m high	1000-2500 m
Hasna/hasua	हसना / हासु	*Cestrum nocturnum*		Shrub	Terai-1500 m
Imali	इमलि	*Rumex hastatus*		Herb up to 1 m high	600-2000 m
Kanda phul	कांडा फुल	***Lantana camara***	✓	**Shrub up to 2 m high**	**Terai-1750m**
Kera	केरा	*Musa paradisiaca*		Tree up to 5 m high	Terai-1300 m
Kettuke	केतुके	***Agave americana***	✓	**Large cactus; sub-species with and without thorns**	**Terai-2400m**
Keraukose	केराउकोशे	***Indigofera atroturpurea***	✓	**Tree up to 8 m high**	**Terai-2000m**
Khirro	खिरो	*Sepium insegne*		Small tree	800-1500 m
Kimbu	किम्वु	*Morus alba*		Small tree	Terai-2000 m
Kunyelo	कुन्यलो	*Trema orientalis*		Small tree, up to 6 m high	Terai-1500 m
Lalupate	लालुपाते	*Poinsettia pulcherrima*		Shrub up to 5 m high	Terai-1500 m
Mesquite	मेसक्युते	*Prosopis juliflora*		Small thorny tree (exotic)	Terai-1000 m
Namdi phul	नाम्दी फुल	***Colquhounia coccinea***	✓	**Shrub up to 3 m high**	**1000-2000 m**
Nil kanda	निलकांडा	*Duranta repens*		Thorny shrub	Terai-1500 m
Pate siuli	पाते सिउली	*Opuntia ficus indica*		Large thorny cactus,up to 4 m high	Terai-1800 m

Local name	Sites	Best propagation	Seed collection	Seeds/kg (months)	Viability	Comments
Aak	Hot and dry; harsh	Seeds/polypots	Feb-Mar	About 500,000	6	
Ainselu	Varied	Seeds/root cuttings	Nov-Dec	About 50,000	6	
Alainchi	Moist	Seeds/polypots	?	-	-	Bears heavy shade
Amala	Hot and dry; harsh	Seeds/polypots	Sep-Jan	-	-	Coppices well
Amba/ambak	Varied and dry	Seeds/polypots	Aug-Oct	About 10,000	12	
Aparajita	Varied and dry	Seeds	?	-	-	Legume; high grazing risk
Areri	**Hot and dry; harsh**	**Seeds/polypots**	Nov-Dec	36,000	12	**36,000 seeds/kg**
Argali	Varied, dry to moist	Hardwood cuttings	Use cuttings	-	-	Not used as a fodder
Arile kanda	Varied	Seeds/stem cuttings	?	-	-	
Armalito, seabuckthorn	Varied and dry	Seeds/polypots	Aug-Nov	130,000	12	Strongly promoted for bio-engineering in China
Assuro	**Varied**	**Hardwood cuttings**	Use cuttings	-	-	
Bainsh	**Moist**	**Hardwood cuttings**	Use cuttings	-	-	**High grazing risk; coppices well**
Bains	Varied to moist; bears shade	Hardwood cuttings	Use cuttings	-	-	
Baganbeli/ baramase phul	Varied and dry	Stem cuttings	Use cuttings	-	-	
Ban chutro	Varied and dry	Seeds/polypots	?	-	-	
Ban silam	Varied	?	?	-	-	
Bayer	Hot and dry; harsh	Seeds/polypots	Dec-Mar	1,000	24	
Bhimsenpati	Hot and dry; harsh	Seeds/hardwood cuttings	Use cuttings	-	-	
Bhui katahar	Hot and dry; harsh	Stem cuttings	Use cuttings	-	-	
Bhujetro	**Hot and dry; harsh**	**Direct seeding**	Nov-Jan	450	18	**450 seeds/kg, including separated pod segments**
Bilaune	Varied	?	?	-	-	
Bokshi ghans	Varied	Hardwood cuttings/ seeds	Use cuttings	-	-	
Chiya	Varied and moist	Hardwood cuttings	Use cuttings	-	-	
Chutro	Varied and dry	Seeds/polypots	Mar-Apr	-	-	
Coffee	Varied	Seeds/polypots	Aug	About 500	3	
Dhanyero	**Hot and dry; harsh**	**Seeds/polypots**	Mar-Apr	About 1,000,000	12	
Dhusun	**Hot and dry; harsh**	**Seeds/polypots**	Mar	About 1,000,000	12	
Gahate	Varied	Seeds/polypots	?	-	-	Eastern Nepal; different from gahate in Far West
Ghangaru	Varied	Hardwood cuttings (?)	Use cuttings	-	-	
Ghurmiso	Varied	Hardwood cuttings/ seeds	Use cuttings	-	-	Coppices well
Hasna/hasua	Varied	?	?	-	-	
Imili	Hot and dry; harsh	Seeds	Mar-Apr	About 250,000	6	
Kanda phul	**Hot and dry**	**Hardwood cuttings**	Use cuttings	-	-	**Not hard cut slopes**
Kera	Varied and dry	Root suckers	Use root suckers	-	-	
Kettuke	**Hot and dry**	**Root suckers**	Use cuttings	-	-	**Grows well on south-facing slopes;shallow rooting**
Keraukose	**Hot and dry; harsh**	**Seeds/polypots**	Nov-Jan	94,000	12	
Khirro	Varied and dry	Hardwood cuttings/ seeds	Use cuttings	-	-	
Kimbu	Varied and dry	Hardwood cuttings/ seeds	Use cuttings	-	-	High grazing risk
Kunyelo	Stony and dry	Hardwood cuttings/ seeds	Use cuttings	-	-	Best on dry sites in higher rainfall areas
Lalupate	Varied	Hardwood cuttings/ seeds	Use cuttings	-	-	
Mesquite	Hot and dry; harsh	Seeds/polypots	May-Jun	-	-	Tolerates calcareous soils
Namdi phul	**Varied**	**Hardwood cuttings**	Use cuttings	-	-	
Nil kanda	Varied and dry	Hardwood cuttings/ seeds	Use cuttings	-	-	
Pate siuli	Varied and dry	Stem cuttings	?	-	-	

SHRUBS; SMALL TREES FOR BIO-ENGINEERING IN THE ROAD SECTOR (continued)

Local name	स्थानिय नाम	Botanical name	Rec	Character	Altitude
Rahar	रहर	*Cajanus cajan*		Shrub up to 4 m high (exotic)	Terai-1500 m
Rato chulsi	रातो चूल्सी	*Osbeckia stellata*		Shrub	Terai-1500 m
Saruwa / bihaya	सरुवा / विहाय	***Ipomoea fistulosa***	✓	**Recumbent shrub**	**Terai-1500m**
Sajiwan (kadam in the Terai)	सजिवन / कदम	*Jatropha curcas*		Shrub up to 4 m high	Terai-1000 m
Simali	सिमाली	***Vitex negundo***	✓	**Small tree, up to 6 m high**	**Terai-1750m**
Sisal	सिसाल	*Agava sisalana*		Cactus	Terai-1000 m
Siuli/sihundi	सिउँली / सिहुँदी	*Euphorbia royleana*		Shrub	900-1800 m
Tara phul/kochu	तारा फुल / कोचु	*Helianthus tuberosus*		Spreading herb	800-1500 m
Thakal	थाकल	*Phoenix humilis*		Small stature palm tree	Terai-1000 m
Tilka	तिल्का	***Wendlandia puberula***	✓	**Tree up to 10 m high**	**Terai-1500m**
Udalo	उडालो	*Hypericum cordifolium*		Shrub up to 1.5 metres high	1200-2500 m

Rec: ✓ = particularly recommended for roadside areas.

Local name	Sites	Best propagation	Seed collection	Seeds/kg (months)	Viability	Comments
Rahar	Varied and dry	Seeds	?	-	-	Fast-growing legume; high risk of grazing
Rato chulsi	Varied	?	?	-	-	
Saruwa / bihaya	**Varied; sunny sites; stands waterlogging**	**Hardwood cuttings**	Use cuttings	-	-	**Fill slopes only**
Sajiwan (kadam in the Terai)	Varied	Hardwood cuttings	Use cuttings	-	-	
Simali	**Hot and dry; varied**	**Hardwood cuttings**	Use cuttings	-	-	**Very versatile; pollards well**
Sisal	Hot and dry; varied	Root cuttings (?)	Use cuttings	-	-	
Siuli/sihundi	Varied	?	?	-	-	
Tara phul/kochu	Varied	Root cuttings	Use cuttings	-	-	
Thakal	Hot and dry; needs shade	Direct seeding on site	Feb	About 1,000	6	Often slow growing; not a pioneer
Tilka	**Hot and dry; harsh**	**Seeds/polypots**	Feb-Mar	About 1,000,000	12	**Pollards well**
Udalo	Varied ; dry to moist	Seeds/polypots	May-Jun	-	-	

B3: FULL LISTS OF SPECIES FOR BIO-ENGINEERING IN THE ROAD SECTOR

LARGE CLUMPING BAMBOOS FOR BIO-ENGINEERING IN THE ROAD SECTOR				
Local name	स्थानिय नाम	**Botanical name**	**Character**	**Altitude**
Choya/tama bans	चोया / तामा बांस	*Dendrocalamus hamiltonii*	Thin culm, heavy branching	300-2000 m
Dhanu bans	धनु बांस	*Bambusa balcooa*	Thick culm, heavy branching	Terai-1600 m
Kalo bans	कालो बांस	*Dendrocalamus hookeri*	Heavy branching, brown hairs	1200-2500 m
Mal bans	माल बांस	*Bambusa nutans*	Strong, straight culms	Terai-1500 m
Nibha/ghopi/lyas bans	निभा बांस	*Ampelocalamus patellaris*	Smaller, bluish culms	1200-2000 m
Tharu bans	थारु बांस	*Bambusa nutans*	Strong, straight culms	Terai-1500 m

Rec: ✓ = particularly recommended for roadside areas.

Local name	Sites	Best propagation	Comments
Choya/tama bans	Moist	Culm cuttings	
Dhanu bans	Varied	Culm cuttings	
Kalo bans	Varied	Culm cuttings	
Mal bans	Dry/varied	Traditional method	Subspecies *cupulata*
Nibha/ghopi/lyas bans	Varied	Traditional method	
Tharu bans	Varied	Traditional method	Subspecies *nutans*

B4: FULL LISTS OF SPECIES FOR BIO-ENGINEERING IN THE ROAD SECTOR

LARGE TREES FOR BIO-ENGINEERING IN THE ROAD SECTOR

Local name	स्थानिय नाम	Botanical name	Rec	Character	Altitude	Sites	Light
Acacia	अष्ट्रेलियन खयर	*Acacia auriculiformis*		Small non-thorny tree (exotic)	Terai-1000 m	Hot and dry; harsh	Full light
Amp/aap	आंप	*Mangifera indica*		Medium-sized fruit tree	Terai-1200 m	Hot and dry but not stony	Full light
Ashare phul	असारे फुल	*Lagerstroemia parviflora*		Medium to large tree	Terai-1200 m	Varied to dry	?
Babul/kikar	बबुल / किकार	*Acacia nilotica*		Medium-sized thorny tree (exotic)	Terai-1000 m	Hot and dry; harsh	Full light
Badahar	बडहर	*Artocarpus lakoocha*		Medium to large deciduous tree	Terai-1300 m	Varied and moist	Bears shade
Bakaino	**बकाइनु/बकाइनो**	***Melia azedarach***	✓	**Medium to large deciduous tree**	**Terai-1800m**	**Hot and dry; harsh**	**Demands light**
Bange kath	बांगे काठ	*Populus ciliata*		Large deciduous tree	2000-3000 m	Dry to moist	Full light
Banghi	बांधी	*Anogeissus latifolia*		Large deciduous tree, drooping branches	Terai-1700 m	Hot and dry	Full light
Birendra phul	विरेन्द्र फुल	*Jacaranda mimosifolia*		Medium-sized exotic, deciduous ornamental	Terai-1600 m	Varied to dry	Light
Champ	चांप	*Michelia champaca*		Large evergreen tree	500-1500 m	Varied to moist	Light or shade
Chilaune	**चिलाउने**	***Schima wallichii***	✓	**Large evergreen tree**	**900-2000 m**	**Varied; dry to moist**	**Bears shade**
Chiuri	चिउरी	*Aesandra butyracea*		Large tree	Terai-1700 m	Varied and poor	Demands light
Chuletro	चुलेत्रो	*Brassaiopsis hainla*		Small prickly evergreen tree	800-2000 m	Varied	?
Dabdabe	**दवदवे**	***Garuga pinnata***	✓	**Large deciduous tree**	**Terai-1300m**	**Varied and dry**	**Full light**
Dar/githi	दार र गिथी	*Boehmeria rugulosa*		Small to medium tree	300-1700 m	Varied	Light or shade
Deshi katus	देशी कटुस	*Castanea sativa*		Large tree (exotic)	1000-2000 m	Varied	Light or shade
Dhale katus	ढाले कटुस	*Castanopsis indica*		Large tree	900-2900 m	Varied	Light or shade
Dhupi salla	धुपी सल्ला	*Cryptomeria japonica*		Large evergreen tree (exotic)	1200-2500 m	Varied but not hot or dry	Bears shade
Dudhilo	दुधिलो	*Ficus neriifolia*		Small deciduous fodder tree	900-2200 m	Varied and dry	Bears shade
Gobre salla	**गोब्रे सल्ला**	***Pinus wallichiana***	✓	**Large coniferous tree**	**1800-3000 m**	**Dry; varied**	**Full light**
Gliricidia	ग्लीरीसिडिया	*Gliricidia sepium*		Small leguminous tree (exotic)	Terai-500 m	Hot, not too dry; free draining	Full light
Gogan	गोगन	*Saurauia nepaulensis*		Medium-sized fodder tree	750-2100 m	Varied	Bears shade
Golainchi/ goila	गोलैंची / गोइला	*Plumeria acuminata*		Ornamental tree	500-1500 m	Varied and dry	Bears shade
Gulmohar	गुलमोहर	*Delonix regia*		Medium-sized ornamental tree	Terai-1000 m	Varied and dry	Full light
Ipil ipil	इपिल इपिल	*Leucaena* species		Several species of small fodder trees	Terai-1500 m	Varied and dry	Full light
Jamun	जामुन	*Syzygium cumini*		Medium-sized evergreen tree	Terai-1600 m	Moist	Bears shade
Kadam	कदम	*Anthocephalus chinensis*		Large deciduous tree; horizontal branches	Terai-1000 m	Varied and moist	Bears shade

Local name	Coppicing	Best propagation	Seed collection time	Seeds/kg	Viability (months)	Comments
Acacia	Pollards well	Seeds/polypots	Mar-Apr	40,000	12	Best of all introduced acacias
Amp/aap	Can be lopped	Seeds/polypots	May-Jul	-	Sow immediately	
Ashare phul	?	Seeds/polypots	Jan-Feb	30,000	36	
Babul/kikar	Coppices poorly	Seeds/polypots	Dec-Feb (?)	9,000	12	Very successful in drier parts of India
Badahar	Can be lopped	Seeds/polypots	Jun-Jul	2,000	Sow immediately	Difficult to establish
Bakaino	**Coppices well**	**Seeds/polypots**	Nov-Mar	1,200	12	**Needs deep soil for really fast growth**
Bange kath	Pollards well	Hardwood cuttings	Use cuttings	-	-	Grows down to 1200 m in the Far West
Banghi	Coppices well	Seeds/polypots	Dec-Mar	100,000	15	
Birendra phul	Does not coppice	Seeds/polypots	Feb-Mar	50,000	24	
Champ	Coppices well	Seeds/polypots	Aug-Nov	14,000	1	
Chilaune	**Can be lopped**	**Seeds/polypots**	Jan-Apr	160,000	6	**Can colonise existing plantations**
Chiuri	Withstands lopping	Seeds/polypots	Jun-Aug	450	Sow immediately	Slow initial growth on poor, stony soils
Chuletro	Can be lopped	Seed/hardwood cuttings up to 2 m	May-Jun	25,000	Sow immediately	
Dabdabe	**Coppices well**	**Seed/hardwood cuttings up to 2m**	Jun-Sep	4,000	12	**Grows in most sites suitable for sal**
Dar/githi	Stands heavy lopping	Seeds/hardwood cuttings	Oct-Jan	2,000	3	Natural coloniser, often found with utis
Deshi katus	Coppices well	Seeds/polypots	Oct-Nov	250	Recalcitrant	
Dhale katus	Coppices	Seeds/polypots	Oct-Nov	1,300	Recalcitrant	Grows best in higher rainfall areas
Dhupi salla	?	Seeds/polypots	Oct-Nov	250,000	24	
Dudhilo	Can be lopped	Seeds/polypots	Jun-Aug	1,600,000	12	High grazing risk
Gobre salla	**Can be lopped**	**Seeds/polypots**	Oct-Nov	22,500	12	**Not moist sites; use exceptionally, with care (see Annex B5)**
Gliricidia	Coppices and pollards well	Seeds/hardwood cuttings up to 2 m	?	8,500	12	Has not performed well in Nepal so far
Gogan	Can be lopped	Seeds/polypots	Mar-Apr	4,000,000	12	
Golainchi/ goila	?	Seeds/polypots	?	-	-	
Gulmohar	Can be lopped	Seeds/polypots	Mar-May	-	-	
Ipil ipil	Coppices and pollards well	Seeds/polypots	Nov-Jan	20,000	> 60	pest problems (Use with care: see Annex B5)
Jamun	Coppices well	Seeds/polypots	Jun-Jul	1,000	2	
Kadam	Coppices well	Seeds/polypots	Oct-Jan	900,000	12	High grazing risk

LARGE TREES FOR BIO-ENGINEERING IN THE ROAD SECTOR (continued)

Local name	स्थानिय नाम	Botanical name	Rec	Character	Altitude	Sites	Light
Kagati	कागती	*Citrus aurantifolia*		Small fruit tree	500-1500 m	Varied	?
Kaju	काजु	*Anacardium occidentale*		Small nut tree	Terai-1600 m	Varied and poor	?
Kalki phul/ bottlebrush	कल्की फुल / बोटलब्रुश	*Callistemon citrinus*		Small ornamental tree (exotic)	Terai-1800 m	Varied; tolerates swampy sites	Full light
Kalo siris	कालो सिरिस	***Albizia lebbeck***	✓	**Medium-sized deciduous tree**	**Terai-1200m**	**Hot and dry; harsh**	**Full light**
Kangiyo	काँगियो	*Grevillea robusta*		Large exotic, straight-stemmed ornamental	Terai-1600 m	Varied; avoid windy sites	Full light
Kapur	कपूर	*Cinnamomum camphora*		Evergreen tree (exotic)	Terai-2000 m	Prefers moist sites	?
Kavro	काभ्रो	*Ficus lacor*		Small, nearly evergreen fodder tree	Terai-1600 m	Varied	Full light
Khanyu (khosro)	खन्यु / खोस्रो	***Ficus semicordata***	✓	**Small stature, heavy branching**	**Terai-2000m**	**Hot and dry; varied**	**Full light**
Khari	खरी	*Celtis australis*		Medium-sized deciduous tree	700-2400 m	Varied	Bears shade
Khasru	खसु	*Quercus semecarpifolia*		Large forest tree	1700-3800 m	Varied	Full light
Khayer	खयर	***Acacia catechu***	✓	**Large, thorny tree**	**Terai-1000m**	**Hot and dry; harsh**	**Full light**
Koiralo	कोइरालो	*Bauhinia variegata*		Medium-sized fodder tree	Terai-1900 m	Varied and dry	Full light
Kutmero	कुटमिरो	*Litsea monopetala*		Medium-sized evergreen fodder tree	Terai-1600 m	Varied to stony and dry	Light or shade
Lahare pipal	लहरे पिपल	*Populus x euramerica*		Large deciduous varieties (exotics)	Terai-1700 m	Moist	Full light
Lankuri	लाँकुरे	***Fraxinus floribunda***	✓	**Large deciduous tree**	**1200-2700 m**	**Varied; best in moist sites**	**Prefers light**
Lapsi	लप्सी	*Choerospondias axillaris*		Medium to large deciduous tree	950-1900 m	Varied and dry	Strong light
Makadamia	मकदमिया	*Macadamia tetraphylla*		Exotic nut tree	Terai-1600 m	Hot and dry; harsh	?
Mashala	मशला	*Eucalyptus camaldulensis*		Large tree with a thin crown	Terai-1800 m	Hot and dry; harsh	Full light
Mayal/mel	मयल / मेल	*Pyrus pashia*		Small tree, often spiny	1500-2500 m	Varied	?
Musure katus	मुसुरे कटुस	*Castanopsis tribuloides*		Large deciduous tree	500-2300 m	Varied and dry	Light or shade
Nebharo	नेभारो	*Ficus auriculata*		Medium-sized fodder tree	Terai-2000 m	Varied and dry	Full light
Neem	निम	*Azadirachta indica*		Large evergreen tree	Terai-900 m	Hot and dry	Full light
Okhar	ओखर	*Juglans regia*		Medium-sized nut tree	1200-2800 m	Varied and moist	Full light
Painyu	पैन्यु	***Prunus cerasoides***	✓	**Medium-sized flowering tree**	**500-2400 m**	**Varied and dry; stony**	**Bears shade**
Patle katus	पात्ले कटुस	*Castanopsis hystrix*		Large evergreen tree	1000-2500 m	Varied	Bears shade
Phalant	फलांट	*Quercus lamellosa*		Large forest tree	1600-2800 m	Moist sites preferred	Bears shade
Phaledo	फलेदो	***Erythrina* species**	✓	**Three fodder species**	**900-3000 m**	**Varied**	**Light**
Rajbriksha/ amaltas	राजवृक्ष / अमलटाश	*Cassia fistula*		Medium-sized ornamental tree	Terai-1400 m	Varied and dry	Light or shade
Rani (khote) salla	रानी(खोटे) सल्ला	***Pinus roxburghii***	✓	**Large coniferous tree**	**500-1950 m**	**Hot and dry; varied**	**Full light**
Rato siris	रातो सिरिस	***Albizia julibrissin***	✓	**Medium-sized deciduous tree**	**800-3000 m**	**Varied and moist**	**Light or shade**

Local name	Coppicing	Best propagation	Seed collection time	Seeds/kg	Viability (months)	Comments
Kagati	?	Hardwood cuttings	Sep-Nov	-	-	
Kaju	?	Grows in steep, rocky sites	?	-	-	
Kalki phul/ bottlebrush	Can be lopped	Seeds/hardwood cuttings	Oct-Feb	850,000	-	Common ornamental
Kalo siris	**Coppices well**	**Seeds/polypots**	Nov-Jan	5,000	> 60	**High grazing risk**
Kangiyo	Can be pollarded	Seeds/polypots	Jun-Sep	100,000	12	
Kapur	Coppices well	Seeds/polypots	Sep-Nov	3,500	3	
Kavro	Can be lopped	Hardwood cuttings up to 2 m	Mar-May	-	-	High grazing risk
Khanyu (khosro)	**Coppices well**	**Seeds/polypots**	Jul-Oct	1,500,000	6	
Khari	Coppices and pollards well	Seeds/polypots	Oct-Dec	4,500	12	
Khasru	Coppices and pollards well	Seeds/polypots	Jun-Aug	150	Sow immediately	
Khayer	**Coppices well**	**Seeds/polypots**	Jan-Feb	30,000	24	
Koiralo	Coppices well	Seeds/polypots	Mar-May	2,500	12	
Kutmero	Can be lopped	Seeds/polypots	Jun-Aug	5,300	Sow immediately	
Lahare pipal	Coppices and pollards well	Hardwood cuttings	Use cuttings	-	-	
Lankuri	**Coppices well**	**Seeds/polypots**	Sep-Jan	60,000	Sow immediately	
Lapsi	Can be lopped	Seeds/polypots	Oct-Jan	300	12	
Makadamia	?	Seeds/polypots	?	-	-	
Mashala	Coppices well	Seeds/polypots	Jul-Sep	770,000	24	Stifles nearby plants. (Use with care :see Annex B5)
Mayal/mel	?	Seeds/hardwood cuttings	Nov-Jan	70,000	Sow immediately	Spreading superficial roots; root suckers
Musure katus	Coppices well	Seeds/polypots	Oct-Nov	400	Recalcitrant	Most widespread of all katus species
Nebharo	Coppices and pollards well	Seeds/hardwood cuttings	Mar-May	3,000,000	12	High grazing risk
Neem	Coppices well	Seeds/polypots	Jun-Jul	3,000	0.5	
Okhar	Coppices well	Seeds/grafting	Sep-Dec	35	Recalcitrant	
Painyu	**Coppices**	**Seeds/polypots**	Oct-Nov	2,500	9	
Patle katus	Coppices well	Seeds/polypots	Oct-Nov	600	Recalcitrant	
Phalant	Coppices well	Seeds/polypots	Oct-Dec	25	6	Best in areas of higher rainfall
Phaledo	**Can be lopped**	**Seeds/hardwood cuttings up to 2m**	Nov-Mar	2,000	60	**Long cuttings are very successful**
Rajbriksha/ amaltas	?	Seeds/polypots	?	6,300	> 60	Popular ornamental
Rani (khote) salla	**Can be lopped**	**Seeds/polypots**	Jan-Mar	8,000	12	**Not on moist sites; use exceptionally, with care (see Annex B5)**
Rato siris	**Coppices well**	**Seeds/polypots**	Sep-Feb	24,000	> 60	**Fast growing in damp sites**

LARGE TREES FOR BIO-ENGINEERING IN THE ROAD SECTOR (continued)

Local name	स्थानिय नाम	Botanical name	Rec	Character	Altitude	Sites	Light
Ritha	रिट्ठा	*Sapindus mukorossi*		Large tree	700-2000 m	Varied	?
Sahijan/ Shobhanjan	सहीजान / शोभान्जान	*Moringa oleifera*		Small ornamental tree	Terai-1000 m	Hot and dry; varied	Light or shade
Sal	साल	*Shorea robusta*		Large forest tree	Terai-1000 m	Varied; dry to moist	Light or shade
Saur	सौर	*Betula alnoides*		Small tree	1200-3000 m	Varied to moist	Full light
Seto siris	**सेतो सिरीस**	***Albizia procera***	✓	**Medium-sized deciduous tree**	**Terai-1350m**	**Moist**	**Full light**
Sisau	**सिसौ**	***Dalbergia sissoo***	✓	**Large broad-leaved tree**	**Terai-1400m**	**Varied**	**Full light**
Suntala	सुन्तला	*Citrus chyracarpa*		Small fruit tree	500-1500 m	Varied	Full light
Tanki	टांकी	*Bauhinia purpurea*		Medium-sized deciduous fodder tree	Terai-1600 m	Varied and dry	Needs light
Tendu	टेन्दु	*Diospyros malabarica*		Medium-sized evergreen tree	Tera-1500 m	Moist sites and good soils	Bears shade
Tooni	टूनी	*Toona ciliata*		Large deciduous tree	Terai-1700 m	Moist sites and good soils	Light or shade
Utis	**उतिस**	***Alnus nepalensis***	✓	**Large broad-leaved tree**	**900-2700 m**	**Varied and moist**	**Full light**

Rec: ✓ = particularly recommended for roadside areas.

Local name	**Coppicing**	**Best propagation**	**Seed collection time**	**Seeds/kg**	**Viability (months)**	**Comments**
Ritha	?	Seeds/polypots	Sep-Feb	600	12	
Sahijan/ Shobhanjan	Coppices and pollards well	Hardwood cuttings up to 2 m	Mar-Jun	3,000	1	
Sal	Coppices well	Seeds/polypots	Jun-Jul	450	Sow immediately	
Saur	?	Seeds/polypots	Oct-Feb	5,000,000	12	Natural coloniser
Seto siris	**Can be lopped**	**Seeds/polypots**	Dec-Jun	18,000	> 60	**Sensitive to grass competition**
Sisau	**Coppices and pollards well**	**Seeds/polypots / stump cuttings**	Feb-May	33,000	12	**Needs reasonable soil**
Suntala	?	Hardwood cuttings	Dec-Jan	-	-	
Tanki	Can be lopped	Seeds/polypots	Nov-Apr	4,000	12	High grazing risk
Tendu	Can be lopped	Seeds/polypots	Apr-Jun	800	2	High grazing risk
Tooni	?	Seeds/polypots	May-Jun	125,000	3	
Utis	**Probably does not coppice**	**Seeds/polypots**	Nov-Mar	500,000	18	***Alnus nitida* in the far west**

B5: PLANTS THAT ARE DIFFICULT OR POTENTIALLY DAMAGING

THESE PLANTS SHOULD NEVER BE USED FOR BIO-ENGINEERING

Local name	Botanical name	Reason for not using as a bio-engineering species
Ban mara	*Eupatorium adenophorum*	Very shallow rooting; stifles other plants; has become a damaging weed
Tite pate	*Artemisia vulgaris*	Very shallow rooting; stifles other plants; has become a damaging weed
Annual grasses	Various	Too short lived
Cassia (exotic)	*Cassia siamea*	Suffers from grass competition; creates heavy shade when canopy closes; competes heavily with other species
Patula salla	*Pinus patula*	Frequently suffers from either drought or nutritional problems in Nepal hill plantations
Sagawan (teak)	*Tectona grandis*	This tree tends to suppress all undergrowth and is known to give rise to conditions allowing extensive erosion below its canopy.

THESE PLANTS SHOULD BE USED WITH CARE

Local name	Botanical name	Reason for caution	Best way to use
Gobre salla	*Pinus wallichiana*	Tends to stifle nearby plants and, in particular, prevents the development	Plant as a 50% mix with other species. Once the trees are establish,
gradually			
		of a good ground cover. However, it is a good pioneer species and in a mixture can show excellent results.	eliminate the pines in subsequent thinning, leaving only other species
Ipil ipil	*Leucaena leucocephala*	Growth has been severely hampered by attacks of the insect psyllid throughout Nepal.	use Only if you can see ipil ipil growing well nearby. Plant in a mixture with other species, with never more than 50% of ipil ipil
Mashala	*Eucalyptus camaldulensis*	Tends to stifle nearby plants and in particular prevents the development	Plant as a 50% mix with other species. Once the trees are established,
gradually			
		of a good ground cover. However, it grows well on dry sites and in a mixture can show excellent results.	eliminate the eucalypts in subsequent thinning, leaving only other species
Rani (khote) salla	*Pinus roxburghii*	Tends to stifle nearby plants and in particular prevents the development	Plant as a 50% mix with other species. Once the trees are established,
gradually			
		of a good ground cover. However, it is a good pioneer species and in a mixture can show excellent results.	eliminate the pines in subsequent thinning, leaving only other species.

GRASS SLIP/HARDWOOD CUTTING REGISTER

Name of nursery: ____________________ **Division/Project:** ____________________

Species: ____________ **Identity no:** ____________ **Planting date:** ____________

Bed no: ______________________________ Number planted: ____________

Source of slips/cuttings: ______________________________________

Shoots starting Date started: ____________ Approx. percentage: ____________

Re-spacing (1) Date started: ____________ Approx. number: ____________

Bed nos.: ____________

Re-spacing (2) Date started: ____________ Approx. number: ____________

Bed nos.: ____________

Diseases/pests ______________________________________

Other notes ______________________________________

____

Distribution record

Date	Number	Location	Notes

SEEDLING REGISTER

Name of nursery: ____________________ **Division/Project:** ____________________

Species: ______________ **Identity no:** ______________ **Sowing date:** ______________

Bed no: ______________ Amount sown: ______________

Pre-treatment: ____

Germination Date started: ______________ Approx. number: ______________

Pricking out (transplanting) Date carried out: ______________ Number: ______________

Bed no: ______________

Root pruning Dates: ____

____

Spacing out Date: ____

Diseases/pests ____

Other notes ____

____

Distribution record

Date	Number	Location	Notes

SEED IDENTIFICATION REGISTER

Name of nursery: ______________________________ **Division/Project:** ____________________

Date supplied	Identity number	Species	Quantity (g or kg	Source: location and seedlot	Supplier	Date collected

SEED COLLECTION CALENDAR

Name of nursery: ______________________ **Division/Project:** ______________________

Month	**Seeds to collect**	**Locations**
Shrawan (July-August)		
Bhadra (August-September)		
Aswin (September-October)		
Kartik (October-November)		
Mangsir (November-December)		
Poush (December-January)		
Magh (January-February)		
Falgun (February-March)		
Chaitra (March-April)		
Baisakh (April-May)		
Jestha (May-June)		
Ashad (June-July)		

घांसको स्लीप र हार्डवुड कटीङ्गको रजिष्टर

नर्सरीको नाम: ________________ डिभिजन/योजना: ________________

प्रजाति: ____________ परिचय नं.: ____________ रोपेको मिति: ____________

ब्याड नं.: ________________________ रोपेको संख्या: ____________

स्लीप/ कटीङ्गको श्रोत ________________________________

टुसा पलाउन शुरु गरेको मिति: ________________ अन्दाजी प्रतिशत: ____________

दूरी बढाउने (१) दूरी वढाइएको मिति: ____________ अन्दाजी संख्या : ____________

ब्याड नं.: ________________

दूरी बढाउने (२) दूरी वढाइएको मिति: ____________ अन्दाजी संख्या : ____________

ब्याड नं.: ________________

रोग/किराहरु ________________________________

अन्य विवरण ________________________________

____

वितरण रेकर्ड

मिति	संख्या	स्थान	कैफियत

नर्सरी बिरुवाको रजिष्टर

नर्सरीको नाम: ______________________ डिभिजन/ योजना: ______________

प्रजाति: ____________ परिचय नं.: ______________ बिउ छरेको मिति: __________

ब्याड नं.: ________________________________ छरेको परिमाण: __________

पूर्व उपचार: ____

उम्रन शुरु गरेको मिति: __________________________ अन्दाजी संख्या: __________

सार्ने काम: __________ सारेको मिति: ____________________ संख्या : __________

ब्याड नं.: ____________________

जरा छाट्ने काम: छांटेको मिति: ______________________________

दूरी बढाइएको : मिति: ______________________________

रोग/किराहरु ____

अन्य विवरण ____

____

वितरण रेकर्ड

मिति	संख्या	स्थान	कैफियत

बिउको रजिष्टर

नर्सरीको नाम: ______________________ डिभिजन/योजना: ______________________

प्राप्त मिति	परिचय नं.	प्रजाति	परिमाण कि.ग्रा / ग्रा	बिउको लट नं. र श्रोत	सप्लायर	संकलन मिति

बिउ संकलन तालिका

नर्सरीको नाम: डिभिजन/योजना:

महिना	संकलन गर्नु पर्ने बिउ	स्थान
श्रावण		
भाद्र		
आश्विन		
कार्तिक		
मंसिर		
पौष		
माघ		
फागुण		
चैत्र		
वैशाख		
जेष्ठ		
आषाढ		

Alluvium Material, usually fine sand or silt with larger, rounded particles up to boulder size, deposited by a river, having been transpoted from elsewhere in suspension.
Annual Of plants that complete their life cycle from seed to reproduction, to death in one year.
Anticline The arch or crest of a fold in rock starata.

Bomboo A perennial grass with woody culms from rhizomes. The term is used loosely to cover anumber of genera other than just *Bambusa*
Bedding The layers of sedimentary rocks, as they were laid down. The layers are separated by 'bedding planes'.
Bio- engineering The use of living plants for engineering purposes.
Bolster A tube, usually of small- mesh gabion wire, containing stones. They are installed as scour checks or french drains, or both.
Botanical name The international system for the scientific naming of plants. These normally consists of two words: first the genus name and then the species name. For example, utis is the species *nepalensis* of the *Alnus* genus (which contains all alders): hence *Alnus nepalensis.*
Breast wall A wall provided to protect a soil slope without considereig retaining properties.
Broadcasting Where seed is thrown over the surface in as even a way as possible, but forming a totally random, loose cover.
Brush layering Live cuttings of plants laid into shallow trenches with the tops proturding. They are usually made to from a thick hedge and erasion barrier across the slope. This is different from a *layering* (see below)

Canopy The top layer of a forest, consisting of the crowns of trees.
Cataclasis A geological term to descrive a process of dislocation-metamorphism where bands are formed through the distortion of minerals within the rock.
Check dam A physical obstruction provided in water courses to control gully erosion.
Chevron A pattern like the stripes of an army sergeant:<<<<< Grasses are sometimes planted in this pattern to lead water into rills or drains. It is a form of localised diagonal grass planting.
Clay Mineral material < 2 µm. Also applied to a class of soil texture, and used to describe the silicate clay minereals.
Clinmax community A plant community that has reached stability under the prevailing climate.
Choche A temporary tunnel of clear polythene sheeting used in nurseries and horticulture farms during the winter. The tunnel produces a warm. sheltered micro-climate over young plants.
Colluvium Angular debris, usually loose and unconsolidated, found on slopes below rock outcrops. Other names are scree and talus, although these are normally of pure fragmented rock while colluvium can also contain fine meterial.
Colonise The establishment of the first plants on bare ground
Community development The involvement of people in development activities at the local level. Often this takes the from of awareness-rainsing and the formation of user groups to manage common resources.
Compost Decompost plant matter used as an organic fertiliser.
Continental drift The very slow, long term horizontal movement of sections (plates) of the Earth`s crust relative to each other and their position in relation to the poles.
Coppice A treatment in which the trunk of a tree is cut off about 30 cm above the ground to allow new shoots to come from the stump.
Cotyledon Part of the embryo of a seed palnt. The cotyledon often become the first photosynthetic (green, ligh-gathering) organ of the young seedling.
Crust The thin upper layer of the Earth, consisting of solid silicate rocks. the continental sections are between 20 and 40 km thick. Crust rocks have a lower density (about 2.8 or 2.9) than the molten mantle rocks below.
Clum The stem of a grass.
Cutting Any part of a plant (stem, rhizome or root) that is used for vegetable propagation. See also *Grass slip, Hardwood cutting and Slip cutting.*

Deciduous Of plants which shed their leaves at least once a year and remian leafless for weeks or months.
Dendritic A pattern like the branches and stem of a tree. It is often used to describe a drainage system where branch drains feed into a main drain.
Dentition The filling of cavities, usually on steep cut slopes.

Dip The line of maximum slope lying in a rock plane. The angle of dip is measured with a clinometer and the bearing of dip is measured with a compass. The bearing can be any figure from 000° to 360°, always expressed with three digits, e.g. 048, to distinguish it from the inclination, which cannot exceed 90°. Conventionally the bearing of dip is written frist, followed by the angle of dip, e.g. 115/35.

Direct seeding Where seeds are sown carefully by hand into specific locations in a slope, such as in gaps between fragmented rock.

Drill When grasses are propagated using vegetative parts, the planting drill consists of one or more grass slips or cuttings. See also *Planting drill.*

Erosion The gradual wearing away of soil (or other material) and its loss, particle by particle.

Evaporation The loss of water from the soil or another surface into the air in the form of water vapour.

Evapotranspiration The total loss of water from the soil in the form of water vapour, either by direct evaporation or from plants by transpiration.

Exotic Of a plant that has been introduced from another area.

Fallow Where land is cultivated but left unplanted to restore its fertility.

Fascine Bundles of branches laid along shallow trenches and buried completely. They send up shoots and can be used to form a thick hedge and erosion barrier across the slope, or a living subsoil drain.

Fault A fracture in the Earth`s crust along which movement has taken place, and where the rock strata on the two sides therefore do not match. The movement can be in any direction, but in the Himalaya the main faults are all thrust faults: this is where two rock masses have been pushed together and one has ridden over the other. In places this occurs when the rocks fracture as a result of extreme folding.

Field capacity The total amount of water remaining in a freely draining soil after the excess has flowed into the underlying unsaturated soil.

Fold A bend in rock strata caused by movements in the Earth`s crust. The strata are bent into a series of arches (anticlines) and troughs (synclines).

Frankia Actinomycetes (micro-organisms) that form a symbiotic relationship with the roots of certain species, and which fix nitrogen.

Friable A term applied to soils that when either wet or dry crumble easily between the fingers.

Gondwanaland The southerly of the two ancient continents which once comprised the Earth's two big land masses (the other was Laurasia). The continents broke apart and, through the process of continental drift, have re-formed into the land masses seen today. The Indian Shield continental plate was once part of Gondwanaland.

Grass A plant of the family Gramineae, characterised by long, then leaves and multiple tubular stems. It is a very large family and contains all the cultivated cereals (rice, wheat, etc.).

Grass slip This term is used loosely to describe any parts of grasses used for vegetative propagation, including fibrous roots, rhizomes, and stem or stolon cuttings. See also *Slip cutting.*

Hardwood cutting A woody stem from a shrub or tree, inserted in the ground for vegetative propagation.

Herb A small plant without wood in the stems or roots.

Herringbone A pattern like the bones of a fish, with a spine and ribs:>>>>> It is often used in slope drainage, where there is a main drain running straight down the slope, with feeder arms coming in at 45°.

Humus the more-or-less stable level of the fraction of soil organic matter remaining after the major portion of added plant and animal residues have decomposed.

Igneous rocks Rocks that have solidified from molten or partly molten material originating from magma

Isostasy The state of equilibrium that is thought to exist in the Earth's crust, where equal masses of matter underlie equal areas, whether of continental or oceanic crust rocks, to a level of hydrostatic compensation. An analogy is in wooden blocks floating in water: the bigger the block, the higher it rises above the surface and the deeper it goes below the surface: the thicker continental plates rise highter than the thinner oceanic plates.

Joints Cracks in rock masses, formed along a plane of weakness (the joint plane) and where there has been little or no movement, unlike a fault.

Klippen A series of nappes; a term derived from Alpine geology.

Lapse rate The cooling of air with altitude. The topographic environment lapse rate is the reduction of the temperature of static air with height. It is generally considered to be 6.5° C per 1000 metres of altitude. However, the exact rate is determined partly by atmospheric moisture, as well as by the movement of air. It also varies seasonally.

Laterite A reddish rock material produced by long-term, intensive weathering, usually in humid tropical conditions. It contains the hydrated oxides of iron and aluminium and sometimes has enough iron to be used as a source of the metal. It hardens on exposure to the atmosphere sufficiently to be used as a building material. The rato mato of Nepal are not fully developed laterites. True laterites are found, however, in some older landform areas of Karnataka and Andhra Pradesh.

Layering A plant that forms from the stem, stolon or rhizome of another plant. This can be used as a means of propagation. This is different from *brush layering* (see above).

Leaching The removal of soil materials and nutrients in solution or suspension.

Leat An irrigation channel (kulo in Nepali).

Loam A soil with moderate amounts of sand, silt and clay, and which is therefore intermediate in texture and best for plant growth.

Lop Where the branches of trees are cut to provide fodder or small firewood.

Magma The molten material that exists below the solid rock of the Earth's crust, and sometimes reveals itself on its emission from a volcano. It does not always reach the surface, however, and may cool and solidify underground, among older rocks.

Mantle The layer of viscous, molten rocks underlying the crust of the Earth, and extending to about 2,900 km below the surface. Mantle rocks have a higher density (about 3.3) then the solid crust rocks above.

Metamorphic rocks Any rocks derived from pre-existing rocks by mineralogical, chemical or structural change, especially in the solid state, in response to marked changes in temperature, pressure and the chemical environment at depth in the Earth's crust; that is, below the zone of weathering and cementation. Metamorphosis may be from contact (usually with a hot magma), where changes are usually at high temperature but low pressure; or dislocation, where changes occur under high pressure but low temperature. Changes due to both high temperature and high pressure are known as regional metamorphism. Most metamorphism in the Himalayas is dislocation metamorphism.

Minerals The naturally occurring crystalline chemical compounds found in rocks. Rocks are composed of aggregations of minerals.

Molasse A Swiss geological term to describe certain depositional materials found in fold mountain belts. Molasses are a continental (*i.e.* non-marine) deposit formed in marginal troughs and inter-montane basins during and after major tectonic movements. They are often cemented with calcareous and clay-rich materials. These materials are common in the Churia range.

Monsoon The name is derived from the Arabic word *mausim*, meaning season, which explains its application to a climate with large-scale seasonal reversals of the wind regime. In Nepal, 'monsoon' is usually used to describe the period of the south-west monsoon rains, which occur between June and September.

Mulch A layer of meaterial placed on the soil surface to conserve moisture.

Mycorrhizae A living arrangement produced between special fungi and the roots of a plant, which increase the growth of the plant considerably. This is a form of symbiosis, where two oraganisms live together for mutual benefit. Soils from pine forests contain the necessary fungi to bring this about.

Mylonite A fine-grained metamorphic rock formed through extensive cataclasis.

Naike (Nepali) A nursery foreman.

Nappe A french geological term which describes a sheet of rocks which has slid right over another series of rocks as a result of extreme folding due to a thrust fault.

Node The point on a stem from which a leaf or branch grows.

Nurse species A tough species planted initially on a site, to improve conditions for the desired final vegetation cover.
Orography Mountains, hills and ridges, or effects resulting from them. Orographic rain is caused by mountains in the path of moisture-laden air: the air is forced to rise, which cools it and causes the moisture to condense and precipitate.
Orthodox Seeds which need to be dried and kept dry during storage.

Palisade The placing of cuttings or seedlings across a slope to form a barrier against soil movement.
Perennial Of plants which grow and reproduce for many years.
Phraetophyte A plant with a high rate of water usage.
Physiography The study of the physical features of the earth, their causes and their relation to one another. Generally taken to be the same as geomorphology.
Piedmont Literally, 'the foot of the mountain'. Usually used to describe the piedmont alluvial plain(in Nepal the Bhabar and Terai).
Pioneer species The first plants to colonise bare ground.
Planar sliding A mass slope failure on a slip plane parallel to the surface (i.e. not rotational). It is the most common type of landslide and is usually relatively shallow)less than 1.5 metres deep). It is also called a debris slide or a translational landslide.
Planting drill When grasses are propagated using vegetative parts, the planting drill consists of one or more grass slips or cuttings. (see also ***drill***.)
Pollard A treatment in which the main trunk of a tree is cut off, usually two to three metres above the ground, to allow new, smaller, shoots to grow.
Precipitation In meteorology, the deposits of water, as rain, hail or snow, which reach the Earth from the atmosphere.
Prop wall A wall provided in a weaker portion of soil to give support to a stable portion above.
Prune To cut branches carefully in order to improve the shape of a plant or allow more light to penetrate.

Rato mato A red soil, normally of clay loam texture, formed from prolonged weathering (probably >100,000 years). It can be considered semi-lateritec, as it does not have all the characteristics of true tropical laterites. Because of the length it takes to form, the presence of rato mato indicates an old and stable landform.
Recalcitrant Seeds which must not be dried but have to be kept moist during storage.
Rhizobia The nitrogen-fixing bacteria that form nodules on the roots of many leguminous species.
Rhizome An underground stem that produces shoots and roots. Grasses naturally use rhizomes and stolons for vegetative propagation. Roots and shoots appear from the nodes on each and eventually they become individual palnts.
Rill A small gully, up to about one metre deep.
Road neighbours People living close to roads, in the corridor of land where different uses of the land affect or are affected by the road.
Root collar On a seedling, the line below which the roots emerge. It normally corresponds with the surface of the soil and often shows a change of colour or a slight swelling.
Rupture plane The plane of failure in any mass movement. Sometimes there is no distinct plane of sliding, but instead a zone of failure due to a weakness in the material.

Sand Mineral or rock fragments in the diameter range of 2 to 0.02 mm. Also applied to a class of soil texture.
Scour The physical removal of soil from the surface by erosion. In some text books it is used to describe erosion in broad, shallow rills which can coalesce to give sheet erosion.
Sedimentary rocks Rocks resulting from the consolidation of loose sediments, or from chemical precipitation from solution at or near the Earth's surface.
Seedling Any plant raised from seed.
Shoot The general name for any stem above the ground.
Shrub A small woody perennial plant with branches from ground level upwards.
Silt Mineral particles in the diameter range of 0.02 to 0.002 mm (20 to 2 μm). Also used loosely to describe any accumulation of fine material, and applied to a class of soil texture
Slip cutting A cutting made from a grass that has fibrous roots but no rhizome system. See

also *Grass slip*.

Slumping A form of saturated flow of soil or debris. It occurs mostly in weak, poorly drained materials, when a point of liquefaction is reached following heavy rain. In effect, the addition of water to the material causes a reduction in cohesion to a point of limited friction. It is usually shollow (less than 500 mm deep).

Soil The collection of natural materials occupying parts of the Earth's surface that may support plant growth, and which reflect pedogenetic processes acting over time under the associated influences of climate, relief, living organisms, parent material and the action of man.

Soil capping The formation on the surface of a thin layer that is harder or less permeable than the soil below. In many bare soils in Nepal, cappings can be formed of clay through the effects of rain drops on surface unprotected by vegetation.

Stakeholder Any person, group or institution that has an interest in the activity in question. It applies to both beneficiaries and those who lose out, as well as those involved in or excluded from decision-making processes.

Stem The part of a plant with nodes, buds, and leaves; usually above ground, but some (such as rhizomes) are underground.

Stolon A stem that grows along the ground, producing at its nodes new plants with roots and upright stems

Stratum (*pl.* strata) A layer of rock, distinct from its neighbours, occurring as part of a series in rocks. It is usually applied only to sedimentary rocks, but some metamorphic rocks also have visible strata.

Strike The horizontal line contained in the plane of bedding, foliation, or jointing of rock. It is perpendicular to the dip, just as a contour is to the maximum slope of the ground. It is always expressed as a reading less than 180°.

Subsoil In a moderately or well developed soil, the layer(s) or horizon(s) below the topsoil. It is usually made up almost entirely of mineral constituents, and is less fertile than the topsoil. It is distinguished from weathered parent material by the absence of any structural characteristics of the parent material.

Sward An area of vegetation consisting mainly of grasses; a low, dense mass of ground-covering vegetation.

Syncline The trough or inverted arch of a fold in rock strata.

Synclinorium A huge trough, in form resembling a syncline, each limb of which consists of a number of small folds.

Tethys The ancient sea which separated two ancient continents. Marine deposits laid down in the Tethys Sea now form part of the Tibetan Plateau.

Texture In soils, the 'feel' of moist soil resulting from the mixture of different particle sizes and organic matter. Texture is classified into groups of soils with similar properties on the basis of the mineral component. For example, clay loam contains 27 to 40 percent clay, 15 to 55 percent silt and 20 to 45 percent sand.

Thin The removal of a proportion of the plants in a given area, to allow the others to grow bigger. This is a standard nursery and forestry procedure.

Thrust or thrust fault See under fault.

Toe wall A wall of low height provided to protect the toe of a soil mass.

Topography A detailed description or representation of the features, both natural and artificial, of an area, often with special reference to the relief (differences of altitude).

Topsoil In a moderately or well developed soil, the darker, more fertile and organically rich upper layer or horizon of soil. In a cultivated soil, it is often the plough layer.

Transpiration The process by which palnts, having taken in moisture through their roots, return it to the atmosphere through the pores in their leaves in the form of water vapour. This can cause a major loss of soil moisture.

Tree A woody perennial plant that usually grows with only one or two stems rising from the ground, and branches out higher up.

Turf The surface layer of soil, usually the top 100mm, matted with the roots of grasses.

understorey The part of a forest underneath the canopy, consisting of shrubs, saplings and herbs.

Viability The length of time that the majority of seeds remain able to germinate. After a certain period of storage, seeds will not germinate once sown. This varies for each species.

Warp In weaving, the length-ways threads first placed on the loom.
Weathering The physical and chemical alteration of minerals into other minerals by the action of heat, water and air.
Weft In weaving, the cross threads woven into the warp by passing the shuttle across the loom.

Xerophyte A plant that lives in a desert or other dry habitat.

INDEX OF BOXES

ROADSIDE Bio-engineering

Site Handbook

This handbook provides the information needed to design, plan, implement and maintain bio-engineering works on steep slopes, with specific reference to roadside areas. It also covers the establishment and operation of bio-engineering nurseries.

It is intended that the handbook cover all subjects that an engineer would need on site. The companion Reference Manual provides background and supporting information and is intended for office use.