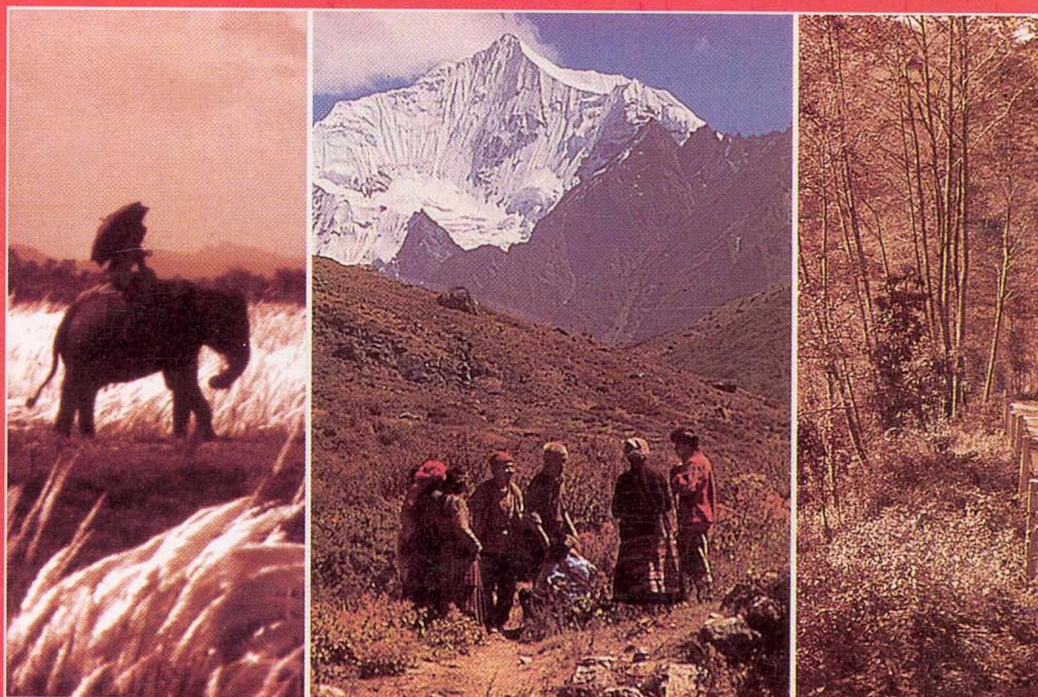
ROADSIDE Bio-engineering



REFERENCE MANUAL

Department of Roads
His Majesty's Government of Nepal

ROADSIDE Bio-engineering

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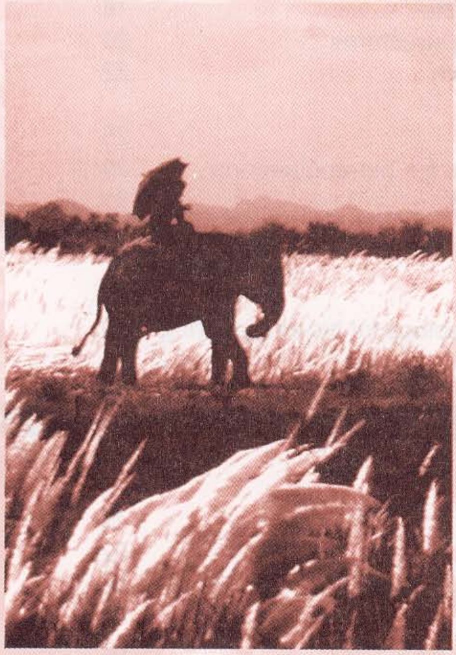

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This manual of Roadside Bio-engineering has been developed from an enormous amount of experience, gained throughout the road network of Nepal between 1984 and 1998. It is written for the exceptional conditions found in Nepal (characterised mainly by very active geomorphology, steep slopes, intense rainfall and a restricted economy) and the techniques have been tested under those conditions.

So many people have been involved that it is quite impossible to acknowledge them all. Nothing could have been achieved without the full support of the Department of Roads, the financial support of the Department for International Development of the United Kingdom and the administrative support of Roughton International. In writing this manual I have drawn on material and comments from a large number of people. In particular, parts of chapter 2 and Annex A were originally written by Cliff Lawrance of the Transport Research Laboratory and Samjwal Ratna Bajracharya of the Mountain Risk Engineering Unit, Tribhuvan University. Narendra Paudyal drew the botanical illustrations. Some other illustrations are based on the work of Jaquelien Chapman, formerly of FRR Limited, and also of Sue Wickison. The other main personal contributions and support are listed below.

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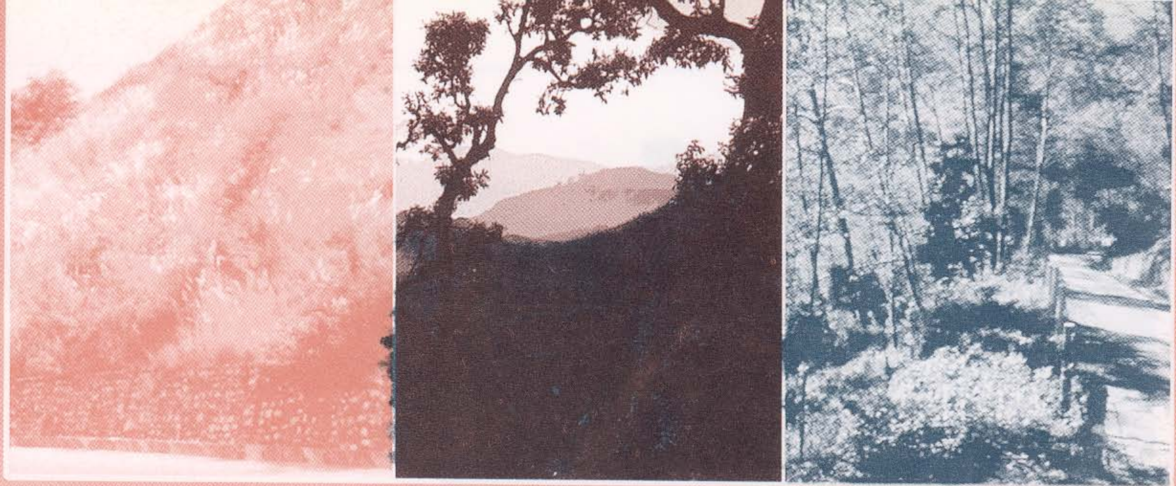
USING THE *REFERENCE MANUAL*

This provides a theoretical background for the use of vegetation in engineering. In addition to covering the principles underlying techniques of slope stabilisation, the manual outlines those aspects of the ecology, geology, geography and law of Nepal that would be of relevance to practising bio-engineers. The manual is intended for office use and provides standard specifications for bio-engineering works, profiles of the main bio-engineering species and rate analysis norms for bio-engineering approved by His Majesty's Government, Ministry of works and Transport.
(The companion *site handbook* provides the information needed to design, plan, implement and maintain roadside bio-engineering works and is intended for use on site.)



Vegetation in engineering

This chapter

- Defines bio-engineering and summarises its practical application,as given in the *Site Handbook* (1.1).
- Assesses the role of vegetation in engineering: the benefits and disadvantages (1.2).
- Describes the main bio-engineering systems and their effects (1.3).
- Discusses the integration of civil and bio-engineering (1.4).
- Describes the process for determining which species to use for each bio-engineering technique (1.5).
- Provides a brief introduction to general plant ecology in Nepal (1.6).
- Defines the site suitability of the main species used for bio-engineering (1.7).
- Discusses the importance of other aspects of plant ecology, including water and nutrient availability for plants (1.8), progression and regression (1,9), competition between plants (1.10) and common natural plant communities (1.11).
- summarises the implications of plant ecology for bio-engineering (1.12).

Downslope planting lines allow rapid surface drainage of this impermeable Siwalik mudstone, while still armouring the surface against erosion

1.1 INTRODUCTION TO BIO-ENGINEERING

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 bio-engineering techniques usually offers a more effective solution to the problem. The materials and skills are all available in rural areas, however remote.

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 slope failures.

Where the best quality engineering solution is being sought, designs that incorporate bio-engineering are usually the most effective and the most economic solutions for the shallow-seated problems listed above. Obviously the use of bio-engineering techniques costs more in the short term than the 'do nothing' approach. But in the long term, there should be additional benefits from reduced maintenance costs

How does bio-engineering work?

Bio-engineering systems work by fulfilling the engineering functions required for the protection and stabilisation of slopes. The difference between revegetation and bio-engineering is that plants must provide one or more of the roles of catching debris, armouring the surface, reinforcing the soil, anchoring the surface layer, supporting the slope or draining the material. This means serving an engineering function. This is examined in more detail in 1.2 below.

Potential uses of bio-engineering techniques

On small sites, where erosion or shallow planar failure are the only likely problems, bio-engineering techniques alone may be adequate. However, bio-engineering is more often closely integrated with civil engineering structures.

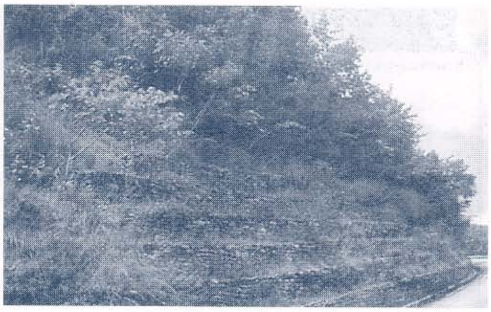
[1] Erosion is the gradual wearing away of soil (or other material) and its loss, particle by particle.

[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).

Large grasses planted at random provide complete surface armouring

Bamboos provide support to aid stability above this gabion retaining wall (right)



Examples are as follows:

- Prevention of scour around drain and culvert discharge points.
- Prevention of scour around civil engineering structures, particularly at the soil/structure interface.
- Protection against debris blocking side drains.
- Protection against debris coming on to the carriageway.
- Protection of uncompacted spoil.
- Protection of embankments and fill areas.
- Protection of bare cut slopes.
- Protection of bare surfaces on rehabilitated landslides.
- Protection of slope toes from erosion, where undercutting and over-steepening may arise.
- Stabilisation of gullies.
- Rehabilitation of quarries and borrow pits.
- Prevention of shallow planar failures (less than 0.5 m deep).
- Prevention of shallow slumps (less than 0.5 m deep).
- Reduction of minor rock falls in weak, shattered rock.
- Reduction of debris creep on steep, unconsolidated colluvial slopes.

Bio-engineering is mostly used for relatively small scale works, such as armouring bare cut and fill slopes against erosion, catching debris to reduce drain blockages and so on. In Nepal, bio-engineering is used more widely, on account of the extreme terrain conditions and the need for extensive low-cost techniques for protecting slopes and stabilising shallow-seated failures.

The many cuttings that make up these brush layers have dense, fibrous roots that reinforce the soil

Figure 1.1: Engineering functions of vegetation

ENGINEERING FUNCTION	REQUIREMENTS	EXAMPLES IN NEPAL	CIVIL ENGINEERING EQUIVALENT	COMBINATION OF BOTH
Catch eroding material moving down the slope, as a result of gravity alone or with the aid of water. The stems of the vegetation perform this function.	Strong, numerous and flexible stems. Ability to recover from damage.	Micro scale: clumping grasses in contour grass lines. Larger scales: shrubs with many stems; large bamboos.	Catch walls.	Catch wall with bamboos above.
Armour the slope against surface erosion from both runoff and rain splash. To be effective, this requires a continuous cover of low vegetation. Plants with high canopies alone do not armour the slope (the terminal velocity of a rain drop is reached after a fall of only 2 metres, and some canopies generate larger rain drops).	Dense surface cover of vegetation. Low canopy. Small leaves.	Grass lines or a complete grass carpet of clumping or spreading grasses.	Revetments.	Vegetated stone pitching.
Reinforce the soil by providing a network of roots that increases the soil's resistance to shear. The degree of effective reinforcement depends on the form of the roots and the nature of the soil.	Plants with extensive roots with many bifurcations. Many strong, fibrous roots.	Densely rooting clumping grasses planted in lines; some shrubs and trees.	Reinforced earth.	Jute netting with planted grass.
Anchor the surface material by extending roots through potential failure planes into firmer strata below. If the potential failure is deeper than about 0.5 metre, this is achieved only by large woody plants with big vertical roots (tap roots).	Plants with deep roots. Strong, long, vertically oriented roots.	Shrubs and trees which are deeply rooting.	Soil anchors.	Combination of anchors and trees.
Support the soil mass by buttressing and arching. Large heavy vegetation, such as trees, at the base of a slope can provide such support in the form of buttresses; or on a micro scale, clumps of grass can buttress small amounts of the soil above them. Across the slope, a lateral effect is created in the form of arching: this is where the soil between buttresses is supported from the sides by compression. The buttresses and arches of a building have the same engineering functions.	Extensive, deep and wide-spreading root systems. Many strong, fibrous roots.	Large clumping bamboos; most trees.	Retaining walls.	Retaining wall with bamboos above.
Drain excess water from the slope. The planting configuration of the vegetation can enhance drainage, avoiding saturation and slumping of material. Vegetation can also help to reduce pore-water pressure within the slope, by extracting water from the roots and transpiring it out through the leaves.	Plants small enough to be planted in closely-packed lines. Ability to resist scour. High leaf area to enhance transpiration.	Downslope and diagonal vegetation lines, particularly those using clumping grasses. Most shrubs and trees.	Surface or sub-surface drains.	French drains and angled grass lines.

After Clark and Hellin (1996).

Many plants provide root reinforcement without affecting the structure of a slope. These utis trees grow on a gabion without distorting it

Figure 1.2: Relative strengths of various plant categories in serving the main engineering functions (general case)

Engineering function	Woody: Trees	Woody: Shrubs	Woody: Bamboos	Non-woody: Clumping grasses	Non-woody: Matting grasses	Other herbs †
Catch	*	***	***	**	*	-
Armour	*	*	*	***	***	*
Reinforce	**	***	*	**	*	-
Anchor	***	**	-	-	-	-
Support	***	**	***	-	-	-
Drain	-	-	-	***	*	-

Certain functions require the plants to be in closely spaced lines. At the micro scale, small plants can provide functions of anchoring and supporting.

† Herbs are small plants without wood in the stems or roots.

Key:

***	Excellent
**	Good
*	Moderately useful
-	Not useful at all

1.2 ENGINEERING FUNCTIONS AND HYDROLOGICAL EFFECTS OF VEGETATION

Both bio-engineering and civil engineering systems perform engineering functions. Figure 1.1 shows the six main engineering functions of bioengineering systems; obviously plants cannot emulate all of the functions of civil engineering systems, particularly those having effects deeper than about 0.5 metre.

Plant types vary in their ability to serve the various engineering functions. Figure 1.2 compares the performance of the main categories of plants. Selecting the category best suited to fulfil the required engineering function is an important step in applying bio-engineering techniques.

Difference of rooting patterns

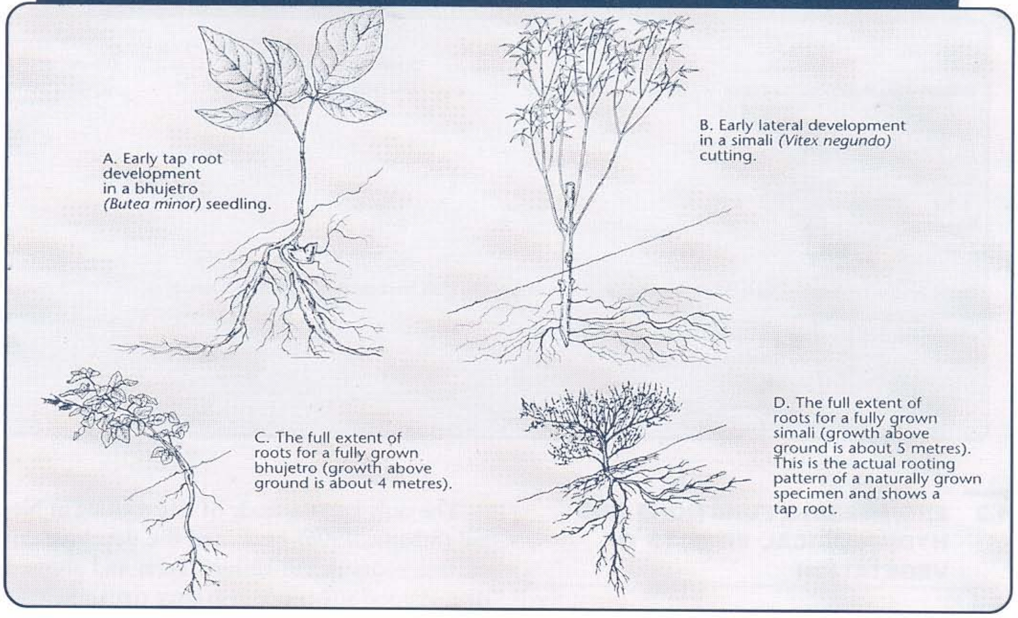
In assessing the engineering functions of plants, the pattern of plant rooting, and therefore the way in which they serve functions, is very important. The development of plant roots is highly variable and depends greatly on the characteristics of individual plants, on the conditions under which they are growing and often on the method of propagation. In woody plants (shrubs and trees) there are two main root types: tap roots, which grow predominantly downwards; and lateral roots, which grow predominantly sideways. The drawings in Figure 1.3 show the early development of these roots for two widely used bio-engineering species.

The only known study of tree rooting in Nepal (Sthapit, 1996) examined the development of tree roots in the eastern Terai and showed that, in good soil conditions large trees generally have a complex network of horizontal and vertical roots. These trees were mostly naturally sown *in situ*, and so the effects of planting technique were not apparent. Many trees developed 'sinker' roots, which branched vertically downwards from the laterals. It is not known whether the pruning of roots in polypot seedlings inhibits the later growth of tap roots or not. Cuttings tend to develop fibrous lateral roots and it is generally thought that plants propagated by this means rarely develop tap roots.

In practice, it appears that woody plants propagated from cuttings may well produce the best shallow rooting systems for reinforcement, whereas those grown from seed may produce the best roots for anchorage. Many bio-engineering techniques depend on a certain method of plant propagation: for example, brush layering, palisades and fascines are all constructed using hardwood cuttings. As a result, the propagation method can be an important consideration in the determination of the engineering effects of the different methods.

Grasses appear to be simpler in the development of their rooting patterns. Whether they are grown from seed or from slip or rhizome cuttings, they seem to develop a similar full root pattern which is determined by the species rather than by the method of propagation. This is shown in Figure 1.4. This demonstrates the significant dif-

Figure 1.3. Differences of root development in two shrubs used for bio-engineering



ferences between shallow-rooting grasses such as musekharuki, and the sizeable clump grasses like khar, which are favoured for bio-engineering: the roots of musekharuki penetrate to only about 50 mm, whereas the main root network of khar penetrates to at least 500 mm; and khar is one of the smaller clumping grasses.

The maximum effective depth of rooting of plants, and therefore the depth to which they can reinforce or anchor the soil, is also a subject for debate in the world-wide bio-engineering literature. In exceptional cases, it is clear that certain plants can have extremely long roots. Grass clumps can sometimes send roots to four or five metres below the surface, and trees can send roots even deeper. But on roadside slopes, where materials tend to be stony and rooting conditions are poor, far shallower rooting is normal. Figure 1.5 gives the maximum rooting depths for the classes of plants used for bio-engineering in Nepal: these can be used for design purposes and may be exceeded in many cases.

Other benefits from vegetation

Vegetation provides two further benefits that cannot be given by civil engineering. These are:

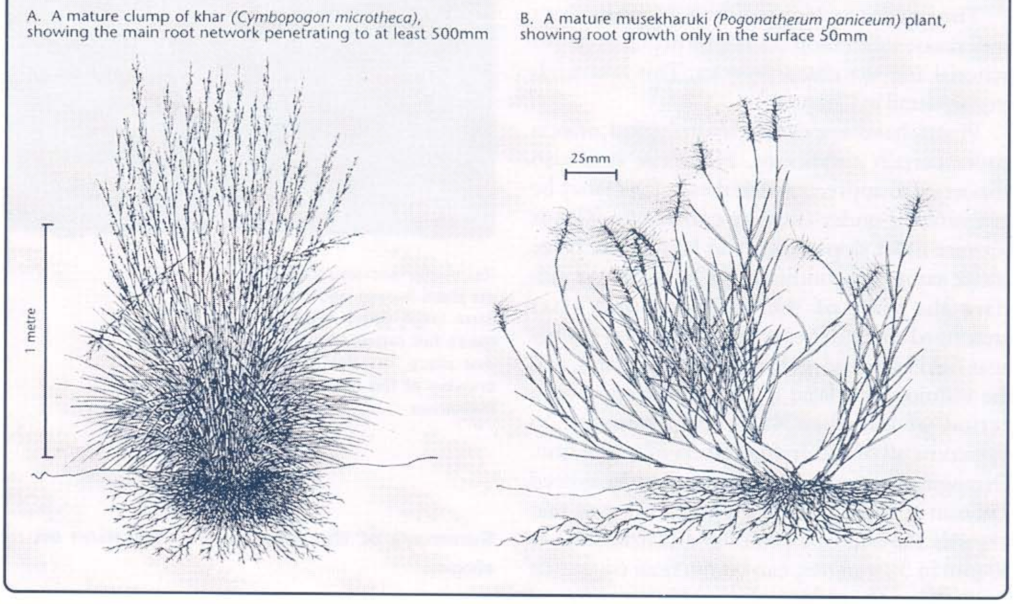
- environmental improvement: vegetation cover encourages other plants and animals to live on the slope, and gradually enables a better soil to form;
- limiting the lateral extent of instability: the rooting system of larger plants can interrupt a shear plane and stop it spreading further in the current phase of active instability.

Hydrological effects of vegetation

Plants affect the hydrological condition in and around a slope in a variety of ways:

- interception: rain strikes the leaves before striking the ground;
- evaporation: water may evaporate from the leaf surfaces;
- storage: leaves and stems hold water for some time before it eventually reaches the ground;
- leaf drip: accumulated water can drip off the leaves and fall to the ground;
- pool formation: stems may trap water running over the ground surface to form

Figure 1.4. Differences of rooting in two grass species. Note the significantly different scales



pools, preventing run-off;

- infiltration: stems and shoots roughen and loosen the ground, enabling water to infiltrate more easily;
- water uptake: plants take up water through their roots and return it to the atmosphere through transpiration, the release of water through the leaves. Plants that transpire relatively large volumes of water are sometimes referred to as phraetophytes.

Many of these effects serve to reduce the amount of moisture in the soil. During heavy rainfall, vegetation can significantly increase infiltration . All colluvial soils have very high infiltration rates; most *in situ* weathered soils are also very porous and so permit high rates of infiltration. Only the deeply weathered clay loams, usually known as rato mato, retain low infiltration

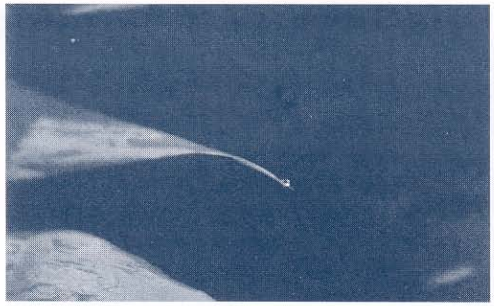
Figure 1.5. The main plant classes and their anticipated effective depths of rooting

PLANT TYPE	EXAMPLE		MAXIMUM EFFECTIVE ROOTING DEPTH
Small grass	Dubo Kikiyu	*Cynodon dactylon* *Pennisetum clandestinum*	100 mm
Large grass	Kans Amliso Khar	*Saccharum spontaneum* *Thysanolaena maxima* *Cymbopogon microtheca*	0.5 to 1 metre
Large bamboo	Mal bans	*Bambusa nutans*	1 metre
Shrubs	Dhanyero Bhujetro	*Woodfordia fruticosa* *Butea minor*	1.5 metres
Trees	Khayer Utis Bakaino	*Acacia catechu* *Alnus nepalensis* *Melia azedarach*	2 metres

rates even with dense vegetation cover and are therefore prone to high rates of runoff.

The extent to which it is desirable to increase or decrease infiltration on a slope depends on the material and site characteristics. This is considered in detail in Chapter 2.

Plants have important hydrological effects under certain conditions. However, it is also important to appreciate that these effects may be insignificant under extreme conditions. This is because most slope failures in Nepal take place under saturated conditions at least one month after the start of the monsoon and after prolonged spells of heavy rain. The soil is already near field capacity[1] before the storm starts, and the addition of at least 100 mm more rain over a period of less than 48 hours is enough to overcome all of the drying effects of vegetation. Damaging monsoon storms frequently exceed 250 mm in 24 hours, while a heavy burst of rain towards the end of a prolonged storm, such as 50 mm in 30 minutes, can be the final triggering factor. Thus the phraetophytic effect mentioned in text books, which may be significant in areas with lower rainfall intensities, may not be a relevant consideration under the monsoonal climate of Nepal.



Rainwater accumulates on plant leaves and can form large drips. When these fall repeatedly in one place, the risk of erosion at the micro level increases

Summary of the effects of vegetation on slopes

The beneficial and adverse effects of vegetation on slopes are summarised in Figure 1.6. Bio-engineering techniques must be selected so that the benefits outweigh potential disadvantages.

[1] Field capacity describes the degree of saturation that a soil has reached once water has been allowed to drain freely from soil pores and drainage ceases.

Figure 1.6: Summary of the beneficial and adverse effects of vegetation on slopes

	Mechanical mechanisms	Effect
1	Stems and trunks trap materials that are moving down the slope.	Good
2	Roots bind soil particles to the ground surface and reduce their susceptibility to erosion.	Good
3	Roots penetrating through the soil cause it to resist deformation.	Good
4	Woody roots bind fragmented rocks together.*	Good
5	Woody roots may open the rock joints due to thickening as they grow. *	Bad
6	The root cylinder of trees holds up the slope above through buttressing and arching.	Good
7	Tap roots or near vertical roots penetrate into the firmer stratum below and pin down the overlying materials.	Good
8	Vegetation exposed to wind transmits dynamic forces into the slope.	Bad

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

* The effects of root wedging vary from site to site. In many locations, roots help to bind fragmented rocks together while, in others, they tend to break them apart. It may be a function of the species more than of the rock condition: for example, utis (*Alnus nepalensis*) is usually observed as binding rocks together, whereas pipal (*Ficus religiosa*) is notorious for wedging masonry walls apart.

Figure 1.7. The main bio-engineering techniques used in the Nepal road sector, and their engineering functions

SYSTEM	DESIGN AND FUNCTION
Planted grass lines: contour/horizontal	Grass slips (rooted cuttings), rooted stem cuttings or clumps grown from seed are planted in lines across the slope. They provide a surface cover, which reduces the speed of runoff and catches debris, thereby armouring the slopes.
Planted grass lines: downslope/vertical	Grass slips (rooted cuttings), rooted stem cuttings or seedlings are planted in lines running down the slope. They armour the slope and help to drain surface water. They do not catch debris. Using this technique, a slope is allowed to develop a semi-natural drainage system, gullying in a controlled way.
Planted grass lines: diagonal	Grass slips (rooted cuttings), rooted stem cuttings or seedlings are planted in lines running diagonally across the slope. They armour the slope and have limited functions of catching debris and draining surface water. This technique offers the best compromise of the grass line planting systems in many situations.
Planted grasses: random planting	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.
Grass seeding	Grass is sown direct 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.
Turfing	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 function is armouring.
Shrub and tree planting	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.
Shrub and tree seeding	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: direct sowing and 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.
Large bamboo	Large bamboos can reduce movement of material and stabilise slopes. They are usually raised by the traditional method or by 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 serve an anchoring function; also, they can surcharge upper slope areas.
Brush layering	Woody (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 drainage.
Palisades	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 provide drainage.
Live check dams	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.
Fascines	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.
Vegetated stone pitching	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: reinforced toe walls; and 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.

Figure 1.7. The main bio-engineering techniques used in the Nepal road sector, and their engineering functions. *continued*

SYSTEM	DESIGN AND FUNCTION
Jute netting (standard mesh)*	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: (a) Protection of the surface, armouring against erosion and catching small debris; (b) Allowing seeds to hold and germinate; (c) Improvement of the microclimate on the slope surface by holding moisture and increasing infiltration; (d) As it decays, it acts as a mulch for the vegetation established.
Jute netting (wide mesh)*	A locally made geotextile of woven jute netting (mesh size about 150 × 450 mm) is placed on the slope. It is used to hold mulch on slopes that have been seeded and serves no engineering function itself.

* 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.

1.3 BIO-ENGINEERING SYSTEMS AND THEIR EFFECTS

Using vegetation for engineering purposes in practice differs somewhat from the theory. On gentle slopes (*i.e.* those < 30°), a simple planting pattern is often enough. On steep and often intrinsically unstable roadside slopes, however, experience has shown that only a relatively small number of robust techniques serve the range of engineering functions required.

The slopes addressed by the techniques in this manual are extreme in their length and steepness, the disturbance and weakness of the materials of which they are composed, and the intensity of periodic monsoon rainfall. All of these are considered in detail in Chapter 2. At this stage, it is necessary to consider only the engineering functions required to stabilise them.

So far in this Chapter, the principles of vegetation in engineering have been considered, and the contribution made by individual plants. Plants used in combination can provide much greater effects than can single plants. For example, a single grass plant can catch a small amount of debris and reinforce a small volume of soil with its roots. But grasses can be planted across a slope, to form a continuous line to catch debris, and so provide a line rather than a point of reinforcement. In the process of serving these functions, however, the contour line of grass will also increase the infiltration capacity of the soil. If this is likely to lead to a critical condition, then another function, that of drainage, will be required. This can be achieved using grass lines by angling the lines down rather than across the slope. The more the line is angled, the less it will catch debris and the more it will help to drain the slope. The approximate limits for the use of different techniques is given in practical detail in Section 1 of the *Site Handbook*.

The range of techniques adopted for use in the road sector of Nepal is described in Figure 1.7. This is based on experience gained over many years of trials and applications throughout Nepal. Each of these has identifiable engineering functions. Most techniques fulfil more than one function, and so can be used for more than one purpose.

Despite the versatility of the bio-engineering techniques, the complexity of most sites means that a range of techniques are usually required, just as civil engineering works usually require a range of different structures serving separate but complementary functions. It is not possible to tabulate this information, since the numerous factors contributing to slope instability (see Chapter 2) means that there is effectively infinite variability in site characteristics and require-

Shrubs planted above a toe wall catch loose debris moving down the slope

Figure 1.8. Techniques required to fulfil the engineering functions of slope stabilisation at different scales of seriousness

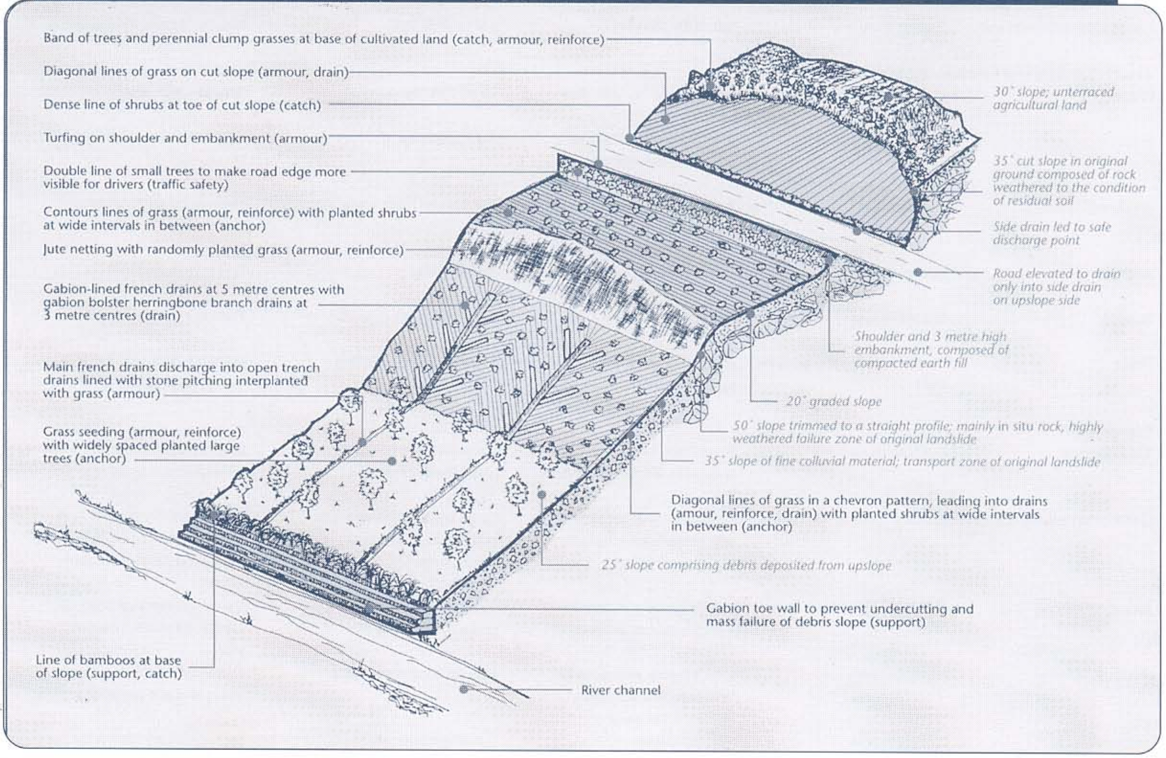
Engineering function	Small scale	Medium scale	Larger scale	Major scale
Simple (*i.e.* only one function required)				
Catch	Contour grass lines	Brush layers or palisades	Large bamboo clumps	Gabion catch wall
Armour	Grass lines	Standard jute netting and random grass planting	Not applicable	Vegetated stone pitching
Reinforce	Grass lines	Brush layers, palisades or fascines	Planted shrubs or trees	Reinforced earth or cement slurry
Anchor	Not applicable	Planted shrubs or trees	Planted trees	Soil or rock anchors
Support	Not applicable	Not applicable	Large bamboos or trees	Retaining wall
Drain	Diagonal or downslope grass lines	Angled brush layers, palisades or fascines	Vegetated stone pitching	Masonry or gabion drain
Composite *				
Catch/armour	Contour grass lines	Brush layers or palisades with grass lines in between	Large bamboo clumps with grass lines in between	Gabion catch wall with vegetated stone pitching
Catch/armour/reinforce	Contour grass lines	Brush layers or palisades with grass lines in between	Large bamboo clumps with grass lines and planted shrubs or trees in between	Gabion catch wall with vegetated stone pitching and reinforced earth or cement slurry
Armour/reinforce	Contour grass lines	Brush layers or palisades with grass lines in between	Planted shrubs or trees with grass lines in between	Vegetated stone pitching and reinforced earth or cement slurry
Reinforce/anchor	Not applicable	Brush layers, palisades or fascines with planted shrubs or trees in between	Planted shrubs and trees	Reinforced earth or cement slurry and soil or rock anchors
Anchor/support	Not applicable	Not applicable	Large bamboos and trees	Soil or rock anchors and retaining wall
Catch/armour/drain	Diagonal grass lines	Angled brush layers or palisades with grass lines in between	Large bamboo clumps with vegetated stone pitching	Gabion catch wall with vegetated stone pitching and possibly other masonry drains
Armour/reinforce/drain	Diagonal grass lines	Angled brush layers or palisades with grass lines in between	Planted shrubs or trees with vegetated stone pitching	Vegetated stone pitching and reinforced earth or cement slurry and masonry or gabion drains

* A few examples only are given: in theory 720 permutations are possible.

ments. This is why an engineer is required to assess every site individually to determine the optimum stabilisation procedure. Nevertheless, Figure 1.8 shows the techniques which can be used to fulfil the engineering functions in the simplest situations, as well as in some of the common combinations.

Figure 1.8 also demonstrates that, the larger the scale of problem, and the more functions that are required of the stabilisation measures, the more complex the solutions become. The smaller-scale problems can be resolved by straightforward and inexpensive measures; and it should be stressed that, even in the vast and dynamic terrain of the Himalayas, the majority of slope problems can be resolved using relatively small measures. The versatility of planted grass lines, and particularly of diagonal grass lines, has been shown on numerous sites where catching, armouring, reinforcing and draining, or some combination of these, are the main requirements to achieve stabilisation: these are the needs most commonly found.

Figure 1.9: A hypothetical scheme for stabilising a large slope, showing the ways in which civil and bio-engineering measures are commonly combined



1.4 INTEGRATION OF CIVIL AND BIO-ENGINEERING STRUCTURES

The engineer may choose to stabilise a slope by using

- civil engineering on its own;
- vegetative engineering alone;
- a combination of the two.

This manual is written with the underlying assumption that a combination of both normally offers the most complete solution to the variety of instability problems affecting a site. Road engineers need to understand the principles governing the relationship between vegetative engineering systems and civil engineering systems.

The previous sections have shown how slope stabilisation requires a number of engineering functions to be fulfilled. In most cases the complexities of the site mean that a range of different techniques, whether of civil or bio-engineering or both, are required to serve the purposes. Figure 1.9 shows how it is possible (and quite normal) to combine the range of measures to good effect.

Relative strength of structures over time

The strength of a structure at various stages of its life can be related to its maximum strength. Figure 1.10 shows how this is different for bio-engineering and civil engineering structures: vegetation takes a few years to reach maximum strength.

Figure 1.10: Life span of small civil engineering and vegetative structures (general case, assuming good maintenance)

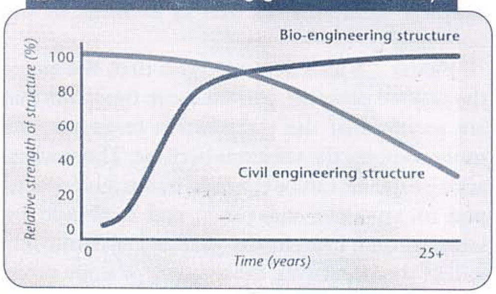


Figure 1.12: Hypothetical site requiring civil and bio-engineering works serving different functions

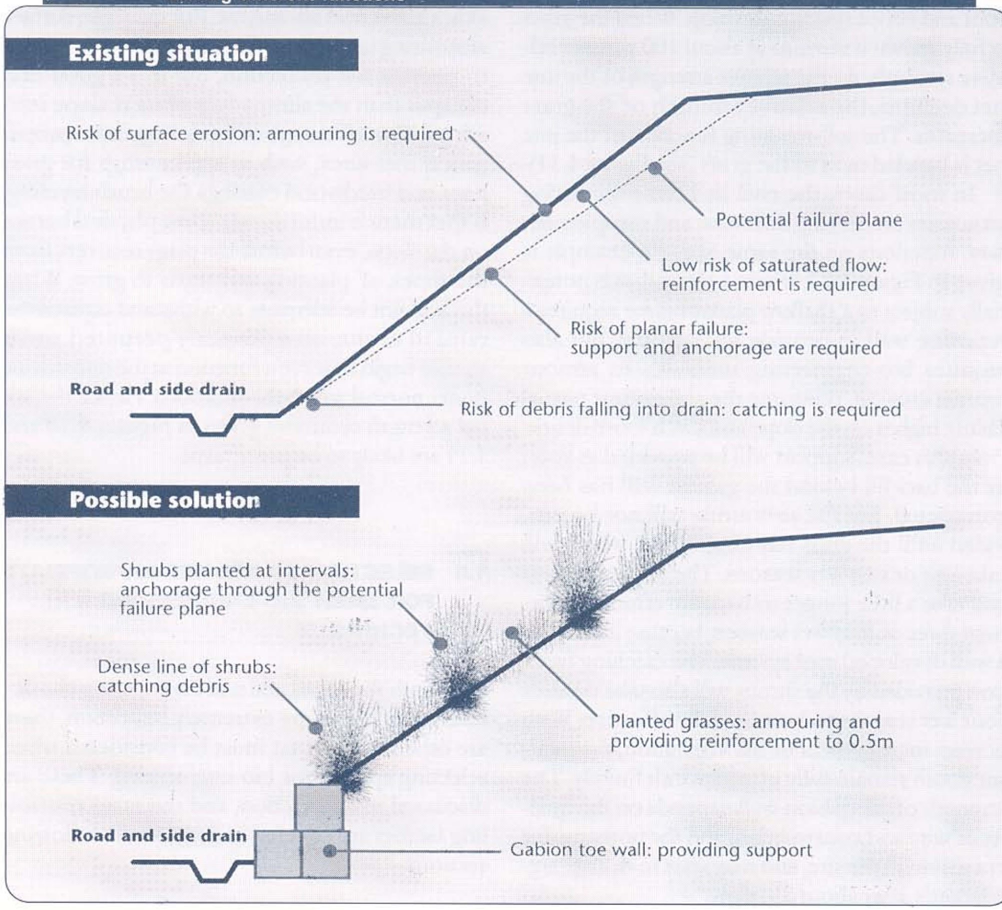
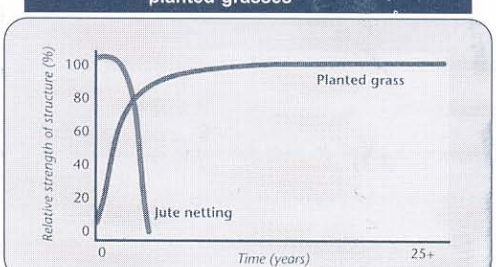


Figure 1.11: Life span of jute netting and planted grasses



Combined life spans: civil and bio-engineering structures serving the same function

As the relative strength of engineering structures decrease, the relative strength of plant structures increases. Note that these graphs compare the performance of each type of structure and not their actual strength.

An example on a micro scale is as follows. Jute net and grass can be used in combination to perform a catching function. The capacity of the jute net to retain soil is very high at first; each small square behaves as a mini check dam. With time the jute decays, which weakens the net and consequently its soil-retaining capacity decreases. Eventually the net will fail to carry out any retaining function at all. In contrast, grass slips are not immediately very effective, but their capacity to retain soil increases as the plants grow and their root and shoot systems develop. When the grass is fully grown it remains at about 100 percent relative strength. As the relative strength of the jute net declines, the relative strength of the grass increases. The soil-retaining function of the jute net is handed over to the grass (see Figure 1.11).

In most cases, the civil and bio-engineering structures are serving different, and complementary, functions on the same site. An example is given in Figure 1.12, where a slope that is potentially subject to a shallow planar failure requires a retaining wall to provide toe support, but also requires bio-engineering measures to armour against erosion, reinforce the soil against partial failure higher on the slope and catch loose debris.

In this case, support will be provided as soon as the backfill behind the gabion wall has been compacted, but the armouring will not be provided until the grass has established, which will take one or two wet seasons. The reinforcement will take a little longer to become effective, perhaps three or four wet seasons, because it relies on a well developed root system. The catching function provided by the shrubs will also take three or four wet seasons to become fully effective. With correct management of the vegetation, the treatment can remain fully effective indefinitely. The strength of the gabion wall depends on the quality of wire and construction, and the potential for corrosion in the site, and may start to decline significantly after about 25 years.

The bio-engineering techniques do not provide instantly strong solutions, but they do provide a lower cost alternative. For example, surface armouring using grass lines may take a few years to provide full protection, but it is a good deal cheaper than the alternatives of inert slope coverings. The advantage of using vegetative propagation measures, such as slip cuttings for grass lines and hardwood cuttings for brush layering, is that there is immediately some physical barrier on the slope, even before the plant recovers from the shock of planting and starts to grow. While this will not be adequate to withstand an extreme rainfall event, on a properly prepared site it should begin to serve a function at the micro scale under normal weather conditions. Hence the initial strength estimates given in Figures 1.10 and 1.11 are likely to be pessimistic.

1.5 SELECTION OF SPECIES APPROPRIATE FOR EACH BIO-ENGINEERING TECHNIQUE

Although the structural and engineering characteristics of plants are extremely important, there are other factors that must be considered when selecting species for bio-engineering. These are discussed in this section, and the main controlling factors are covered in detail in the following sections.

Figure 1.13. Methods of propagation for plants used in each bio-engineering technique

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

Method of propagation

Bio-engineering works require a large amount of planting material, especially grasses, as they are often planted densely over large areas. Plants that are propagated vegetatively (from cuttings) usually grow faster and larger than those they raised from seed. Planted lines of clumping grasses are often propagated from slips in order to provide a physical effect on the slope surface within a short period of time, and to develop rapidly into a strong plant (a slip is a piece separated from a clump of grass so that it has shoots with buds and as much root as possible). Therefore, if the bio-engineering technique to be used requires the use of grass slips, the species used must be easily propagated by this method. Figure 1.13 shows the relationship between bio-engineering techniques and methods of propagation.

Biological and social considerations

Once this point has been reached, it is clear as to what type of plant (*i.e.* grass, shrub, tree or bamboo) for each part of the bio-engineering measures; it is also known how the plants should be propagated (*i.e.* from seed directly, from slip or hardwood cuttings, from seed via polypots, or by some other method). The situation is summarised in Figure 1.13.

For each type of plant, there is a range of options which can be adopted as regards the actual species. But first it is necessary to satisfy four other criteria:

- what species will be robust enough to fulfil the bio-engineering function?
- what will grow on the site?
- are there possible species that can be put to additional uses by local farmers?
  and, if all those are satisfied,
- can it be made available in adequate quantities?

The paragraphs below address these issues briefly. As in the box on the right, these will lead to the final choice of species.

Establishment, vigour and persistence

In bio-engineering, plants should become well-established in the season of planting so that they are able to survive the dry months until the next monsoon. Many bio-engineering sites have extremely poor and stony soils, which drain rapidly. This makes good establishment very important.

Vigorous growth in a plant means that the plant establishes quickly and continues to grow well. Examples of plants which display vigorous growth and are commonly used for bio-engineering are: khar, saruwa, kans, amliso, simali, areri, assuro, sito.

Many plants are annuals. This means they complete their life cycle in less than a year and then die. If they were used for bio-engineering, they would have to be replaced every year and the root systems would never become strongly established. Bio-engineering requires perennial plants: those that grow and reproduce for many years.

The ability of a plant to live for many years and survive in harsh conditions is of fundamental importance in bio-engineering species. This is called persistence.

In exceptional conditions, annual grasses can be sown or planted to give surface protection through a single monsoon. This might be where major engineering works have had to be post-

Factors contributing to the final choice of species

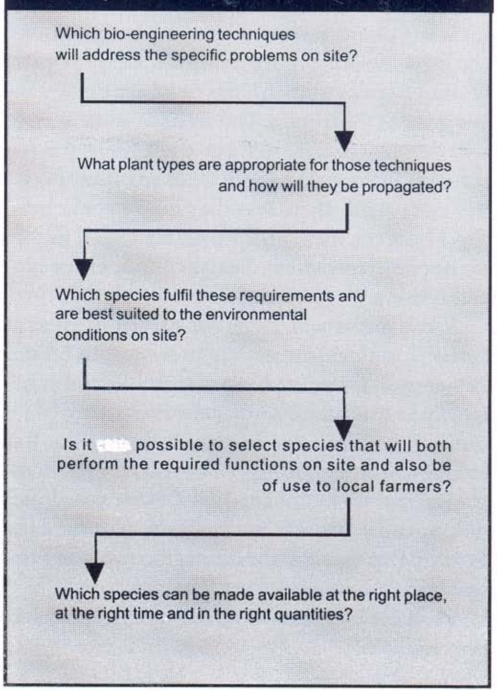


Figure 1.14: The main factors determining plant growth

Factor	Determined by
Temperature	Altitude mostly; to some extent also by aspect; there is also a variation of average temperatures from the east of Nepal to the west.
Moisture	The rainfall patterns on the site, which are in turn determined by the regional rainfall (more in the east than the west), the topography (uplift of rain-bearing winds is caused by large ridges), rain shadow effects (mostly in the lee of large ridges), aspect (northern aspects are shady and generally damper), altitude (there is less drying in cooler, higher locations) and soil characteristics (coarse textures hold less water).
Nutrients	The soil type (in general, fine textures and well developed topsoil or kalo mato hold more nutrients) and the local climate (generally, more nutrients become available to plants under warm, damp conditions).
Exposure to sunlight	Aspect; the presence of other large plants nearby.

poned due to budget constraints. An example might be where kodo (millet) is sown on a bare surface.

Site suitability

All plants are naturally adapted to grow under particular ecological conditions. The ability of a particular plant to grow in a certain site is determined by the suitability of the species to that site. The main factors determining growth are given in Figure 1.14.

Some plants require a long day length during the growing season: for example, many poplars (*Populus* species or varieties of lahare pipal) cannot grow in the tropics. The seeds of some species will not germinate unless they have passed through a very cold period; seeds of other species will not germinate unless they have experienced fire. However, these exceptional ecological factors do not normally affect the use of species for bio-engineering.

Some plants will thrive for part of the year in certain locations, only to die later on. Utis (*Alnus nepalensis*), for example, can be established at relatively low altitudes during the monsoon; but it can be killed by hot, dry winds during the following summer. Cuttings of bihaya (*Ipomoea fistulosa*) can be established on Churia cut slopes during the monsoon and will show good early growth. But they will die during the following dry season.

Plant ecology is covered in more detail in section 1.6 below.

Potential value to local farmers

Many roadside bio-engineering sites are in inhabited areas. In many cases, local farmers may be able to make use of the plants grown on the sites. The engineering functions must always be given priority and, on critical sites, utilisation may not be permissible. However, wherever possible, the choice of species should be made with the consideration that products are of potential use to local people. An example might be where babiyo (*Eulaliopsis binata*) is used instead of kans (*Saccharum spontaneum*), or amliso (*Thysanolaena maxima*) is used instead of sito (*Neyraudia arundinacea*). Wherever possible, it is best to discuss the choice with local people and make a tentative agreement on how they might use the products when the plants are big enough.

Availability

Availability means that the planting material must be obtainable at the right location, at an affordable price, at the right time and in the quantities needed.

Species that are local to the site are generally better suited to conditions there than species from another area. This means that the first choice should normally be a species found in the area where the bio-engineering is being implemented. Nurseries are established in order to provide the planting material that is required, at the right time and in the right place. If the availability requirement is to be met they must be well managed.

Plant species for bio-engineering

The species for bio-engineering are listed in Annex B of the *Site Handbook.* In addition, the main bio-engineering species are described in detail in Annex B of this *Reference Manual.* If the main species are used, they all have the correct attributes of establishment, vigour and persistence; between them they are suitable for practically any site beside a road in Nepal and can be propagated by the correct methods; and some of them are of value to farmers for a range of purposes.

The plants should be propagated in nurseries as described in Section 4 of the *Site Handbook.* Material for the species used as hardwood cuttings can usually be collected from forests and farms in local areas.

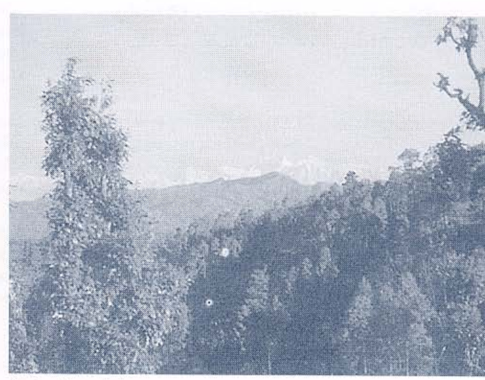
The rest of this chapter gives information on the ecology of plants in Nepal, why they grow where they do and in what combinations, and the ways in which this can be used to advantage in bio-engineering works.

Sal *(Shorea robusta)* in the western Terai

1.6 PLANT ECOLOGY OF NEPAL

Plant ecology is the study of plants in relation to the environment in which they grow. It was mentioned briefly in 1.5 in relation to the suitability of plants to grow in particular sites. This section examines in more detail the ways in which plants grow in different locations. It is a very complex subject about which much has been written; this section does not go into great detail. More thorough coverage is given in the books by the botanist Stainton (1972), the ecologist Dobremez (1976) and the forester Jackson (1994). However, there is still no complete and fully definitive account of the many rich vegetation communities found through the Nepal Himalayas.

A knowledge of plant ecology is necessary for understanding not only why particular plants grow in certain areas, but also how plants should be managed to obtain the maximum results for bio-engineering. In the *Site Handbook*, as in Annex B of this *Reference Manual*, recommended species are given for bio-engineering in Nepal. In drawing up these lists, consideration was given to the ecology of the plants. The main purpose behind this section, therefore, is to equip the reader with the knowledge required to add to those lists of potential bio-engineering species; this is often required when working in new or remote locations.



A dry forest type containing both oaks *(Quercus species)*, and pines *(Pinus species)*, in Far Western Nepal, (above)

Khote salla *(Pinus roxburghii)* forest on a south-facing slope at 1600 m, in central Nepal, (far left)

Chilaune-katus *(Schima-Castanopsis)* forest at 1800 m above the Kathmandu Valley. The area in the foreground has been cleared to allow the trees to coppice, (left)

Factors governing the distribution of vegetation in Nepal

The main factors that govern the distribution of vegetation are:

- the availability of moisture;
- temperature and the amount of sunlight; and
- the availability of nutrients.

These are in turn determined in Nepal by:

- altitude;
- aspect;
- other factors controlling the distribution of rainfall and site moisture;
- geology, geomorphology and soils.

Figure 1.6 (Page 28) gives more details.

In the mountains, altitude is the most important factor influencing the distribution of vegetation, with the effects of aspect on moisture and temperature being the next most dominant factor. The zonation of vegetation is therefore usually based on altitude, although it is stressed that this provides only an approximation and not a set of precise rules.

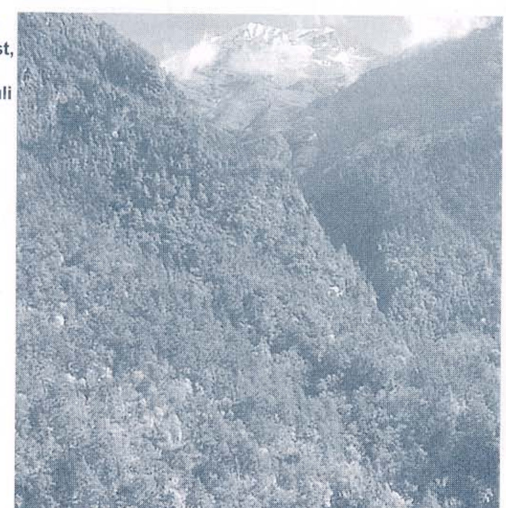
Figure 1.15: Eco-climatic zones, altitude and forest types

Zone	Altitudinal ranges	Main forest types (depending on site)
Alpine zone	Between the tree line and the line of perpetual snow.	Scrubby gurans species (*Rhododendron* species), armalito (seabuckthorn, *Hippophae rhamnoides*) etc.
Sub-alpine zone	3000 – 4500 m in the west 2800 – 4200 m in the east.	Talis patra (*Abies spectabilis*) forest; saur (*Betula utilis*) forest; high altitude gurans (*Rhododendron* species) forest; dhupi (*Juniperus indica*) steppe.
Upper temperate zone	2700 - 3100 m in the west; 2400 - 2800 m in the east.	Banjh (*Quercus semecarpifolia*) forest; upper temperate mixed broadleaved forest; lali gurans (*Rhododendron arboreum*) forest; upper gobre salla (*Pinus wallichiana*) forest.
Lower temperate zone	2000 - 2700 m in the west; 1700 - 2400 m in the east.	Banjh (oak) forest, three main types: *Quercus leucotrichophora/ Q. lanata*, *Q. floribunda* and *Q. lamellosa*, in differing sites; lower temperate mixed broadleaved forest; lower gobre salla (*Pinus wallichiana*) forest.
Sub-tropical zone	1200 - 2000 m in the west; 1000 - 1700 m in the east.	Khote salla (*Pinus roxburghii*) forest; chilaune-katus (*Schima-Castanopsis*) forest; utis (*Alnus nepalensis*) forest; riverain forest with tuni and siris (*Toona* and *Albizia* species).
Tropical zone	Upper boundary at about 1200 m in the west; 1000 m in the east.	Sal (*Shorea robusta*) forest with mixed tropical hardwoods; khayer-sisau (*Acacia catechu-Dalbergia sissoo*) forest; other riverain forest (mixed species); grassland of kans (*Saccharum spontaneum*), narkat (*Phragmites karka* and *Arundo clonax*) or babiyo (*Eulaliopsis binata*); saaj-banghi (*Terminalia-Anogeissus*) forest.

***Abies spectobilis* forest near the tree line at approximately 3500m, in Central Nepal**

The effects of altitude are well known and clearly visible throughout the country. Sal (*Shorea robusta*) forest is dominant in the Terai, Bhabar and lower valleys: this seems to be closely related to temperature. In central Nepal the hill sal forest disappears at almost exactly 1000 metres altitude. Lali gurans (*Rhododendron arboreum*) and banjh (*Quercus* species, or oaks) are other examples: they are common on ridges above 1500 metres, with variations depending on the actual species. For instance, khasru (*Quercus semecarpifolia*) grows from 1700 metres almost to the tree line at 3800 metres, mostly in western Nepal, whereas phalant (*Quercus lamellosa*) grows in central and eastern Nepal from 1600 to only 2800 metres altitude. Many middle mountain valley sides between 1000 and 1900 metres have khote salla (*Pinus roxburghii*) on the south-facing side and katus-chilaune (*Castanopsis-Schima*) forest on the north-facing side, demonstrating the effects of aspect. Khayer (*Acacia catechu*) forest grows below 1000 metres in many areas which are exceptionally dry, such as south-facing slopes in rain shadow areas. Utis (*Alnus nepalensis*) grows only in damp, shady areas or zones of higher rainfall, and is rarely found below 900 metres. Vegetation type can be an excellent initial indicator for the engineer, providing immediate information about the dryness of a site and the likelihood of water-related slope problems.

Mixed pine and hardwood forest, 2000-3000m, in the Upper Trisuli Valley, Central Nepal



From east to west in Nepal there is a general change in climate. The western part has warmer summers and colder winters, hence the higher summer temperature at Nepalgunj compared with Biratnagar. The lowest winter snowline is at about 2400 metres in the Mechi hills, 2200 metres on the ridges around Kathmandu and 1800 metres in the Far Western hills near the Mahakali valley. The effect is apparently due to distance from the maritime influence of the Bay of Bengal, and the increasingly continental climate towards the north-west. Although the change is gradual across the country, the line made by the Kali Gandaki and Tinau valleys, which cut across the geographical centre of Nepal (*i.e.* from Mustang to Bhairahawa) form the general line of change.

These broad variations in climate are reflected by differences in the forest types. West of the Kali

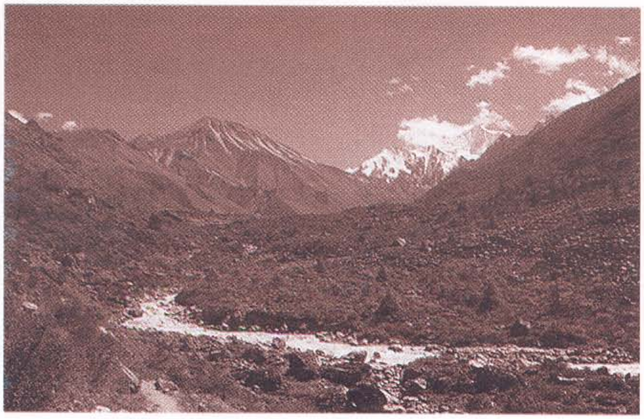
Gandaki-Tinau line, the lower forest in the Churia, inner Terai and valleys is drier and is commonly a sal-khote salla (*Shorea robusta-Pinus roxburghii*) mixture. Khote salla (*Pinus roxburghii*) and gobre salla (*Pinus wallichiana*) forests are much more common. The species of banjh (*Quercus* species, or oaks) are different, with a range more tolerant of dry sites; and chilaune-katus (*Schima-Castanopsis*) forest is not found.

Most roads in Nepal are between 80 and 2500 metres above sea level, and so fall only into the lower and warmer eco-climatic zones. The major exception to this is the Trisuli-Somdang road, which rises as high as 3650 metres at one point. That is the only area where the road network enters the high-altitude forest types dominated by talis patra (*Abies spectabilis*) and a mixture of yarla (*Acer* species) and seto gurans (white *Rhododendron* species).

Vegetation zones and forest types

In simplification, Nepal can be divided into five main landscape or physiographic zones, based on the geological origin. They are:

- Trans-Himalaya
- Higher Himalaya
- Lesser Himalaya (middle mountain)
  Midlands (middle hills)
  Mahabharat Range
- Sub-Himalaya (Siwaliks)
  Churia
  Inner Terai
- Terai and Bhabar



Low scrubby vegetation above the tree line, in the alpine zone of Cenral Nepal

However, there is no accurate relationship between these and the eco-climatic zones used to describe vegetation. The reason for this is that the mountain geological zones have extensive altitude

Figure 1.16: The relationship between altitude, longitude, and eco-climatic and geological zones

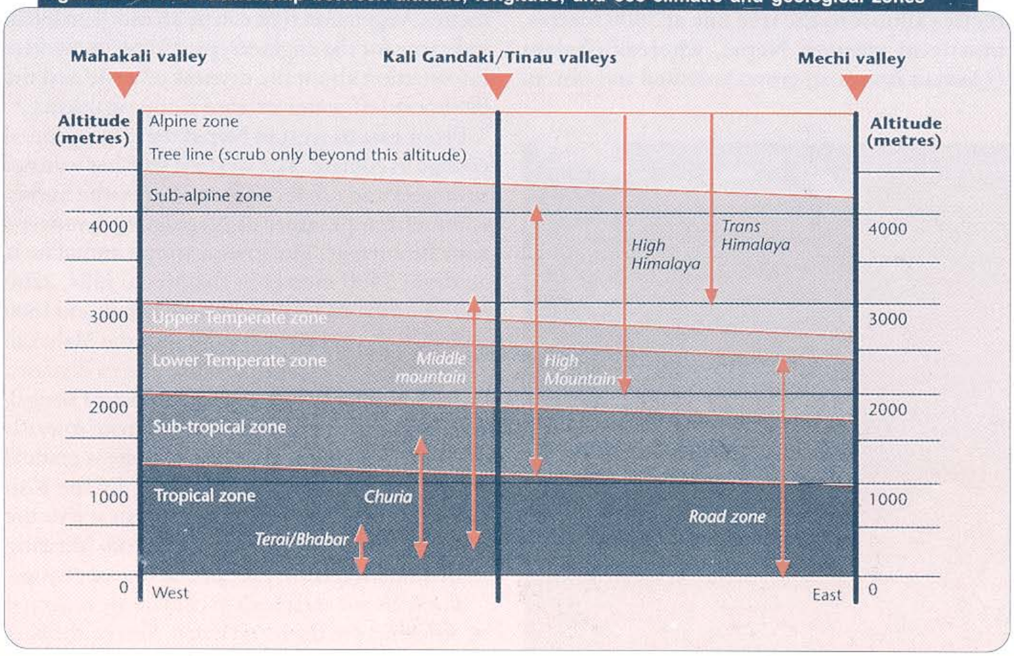
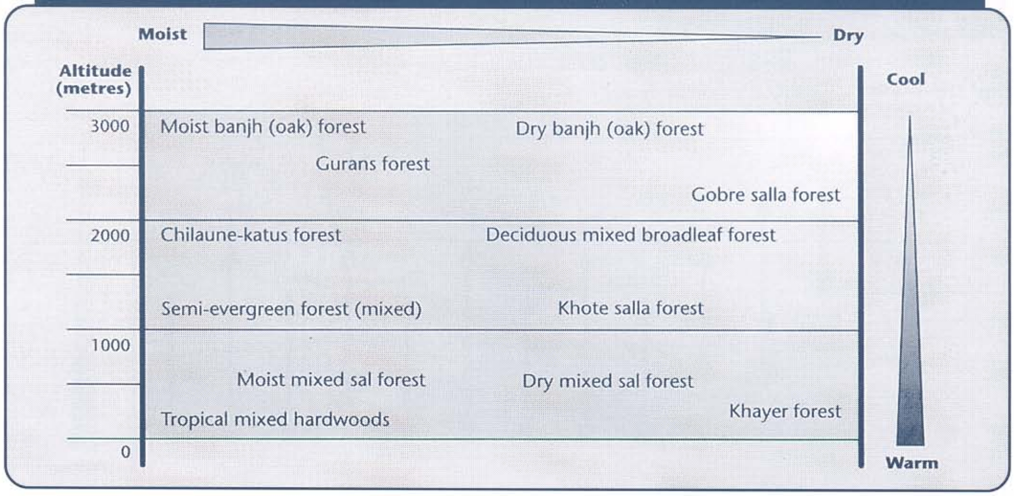


Figure 1.17: Major forest types expressed in relation to site moisture and temperature for central Nepal



ranges, from the bottom of the deep valleys (often less than 1000 metres above sea level and therefore sub-tropical) to the top of the high ridges (often 2500 metres high or more, making the climate cool temperate), and so cut across the climatic zones dominated by altitude-determined temperature patterns. The big valleys cutting right through the Himalayas, such as the Karnali, Kali Gandaki, Sun Koshi and Arun are the most spectacular examples. In places, valley side transects show a succession of different vegetation types and villages with different agricultural systems.

The simplified general zones used by both Dobremez and Jackson (modified slightly) and the main forest types which occur in them are shown in Figure 1.15, page 26. Note that the use of the term 'tropical' is based on the fact that the forest types extend south into the tropics although, technically, Nepal is in the sub-tropics.

Both the eco-climatic and geological zones are related to altitude and longitude (Figure 1.16). Within the broad eco-climatic zones of Nepal, there are various forest types, which have already been referred to. These occur in different areas depending on the temperature and moisture characteristics of each locality. Figure 1.17 shows how the main forest types are distributed in central Nepal.

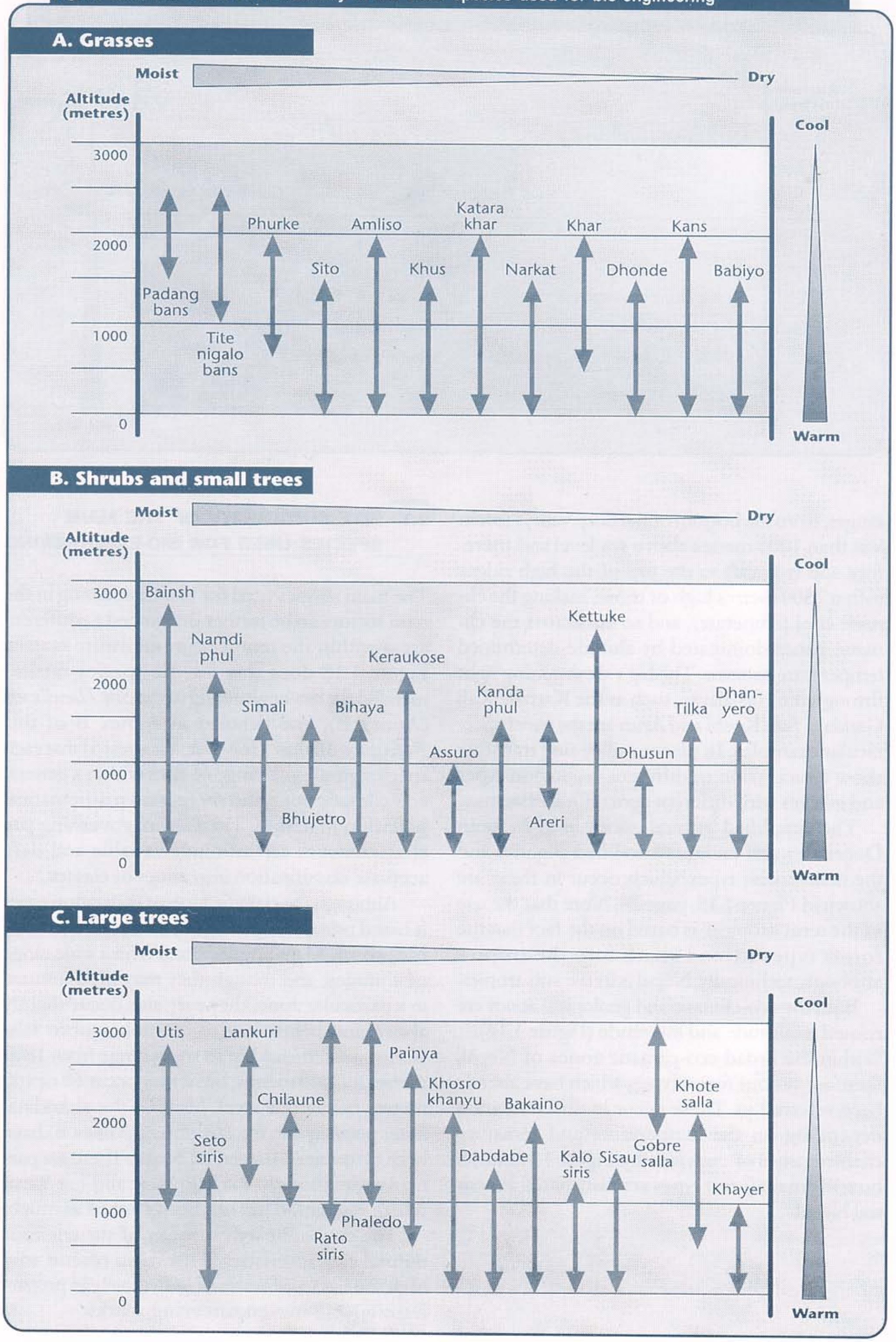
1.7 SITE SUITABILITY OF THE MAIN SPECIES USED FOR BIO-ENGINEERING

The main species used for bio-engineering in the road sector can be further designated to different areas within the temperature-moisture matrix. Figure 1.18 does this for the species recommended for bio-engineering in the *Site Handbook* (Annex B), and detailed in Annex B of this *Reference Manual*. However, it is stressed that each species grows in a range of sites within a general eco-climatic zone and there is no mathematical precision in nature. The factors governing site characteristics are infinitely variable and defy accurate classification into zones or classes.

Although the classification of vegetation types is based primarily on altitude, the stated limits are not precise. Many species occur over a wide range of altitudes, and though they may predominate in a particular zone, they may also occur slightly above and below it. For example, gobre salla (*Pinus wallichiana*) has its main range from 1800 metres to 3000 metres, but it may occur 80 or 100 metres below this level. Most of the altitudinal limits given in the *Site Handbook* (Annex B) have been determined for central Nepal. There are particular variations in the Mid West and Far West, where vegetation has not been studied as much.

The extraordinary variability of site environmental characteristics is the main reason why each site has to be assessed individually in preparing civil and bio-engineering works.

Figure 1.18: Indicative site suitability of the main species used for bio-engineering



This north facing slope in Eastern Nepal (right) is well shaded and therefore retains moisture, making it excellent for agriculture. In contrast, the south-facing slope across the valley (far right) is much drier and the land is consequently less productive

1.8 WATER AND NUTRIENT AVAILABILITY FOR PLANTS

Once a plant is environmentally adapted to a particular site, its growth depends on the availability of water and nutrients in the soil. An understanding of this topic helps the engineer to explain variations of plant growth between different sites.

Water in the soil

In the soil, either air or water occupies the spaces or voids between the soil particles. Unless the soil is fully saturated, water is held as a thin film on the soil particles; or if the particles are close enough, as bridges between the particles (see Figure 1.19).

There are three types of soil pore, described below.

- The largest pores are *macropores* and are >100 µm (> 0.1 mm). Water drains freely through a network of spaces and air is pulled in and roots proliferate. These are the main sites of air and roots.
- The *mesopores* are 30 - 100 µ m (0.03 - 0.01 mm). These larger pores are the right size for rapid capillary flow - the movement of water through the soil in any direction. This is the main source of water for plants.
- The *micropores* are <30 µ m (< 0.03 mm). They hold the water tightly, partly by chemical attraction. This means they retain the water and do not release it easily.

Water drains through clay soils at a fairly steady rate, but with sandy soils there is initially a rapid loss of water, and then the rate of drainage tails off. Most soils in Nepal, outside the lower Terai, have a relatively coarse texture and therefore drain quickly; the main exceptions are rato mato (red clay loam, semi-lateritic soils).

Saturated soils, such as khet (paddy) soils, give conditions which are suitable for particular plants like rice; but the majority of plants require oxygen in the rooting zone. As a result, plant growth is best when there is a good balance of the two: a moist, porous soil.

In the nursery, considerable efforts are made to ensure that these conditions are met. Loamy soil is brought in and is kept moist but not saturated. Bio-engineering site planting is carried out once the monsoon rains have broken, so that there is adequate moisture for the young plants. In some cases it is also necessary to add water by hand.

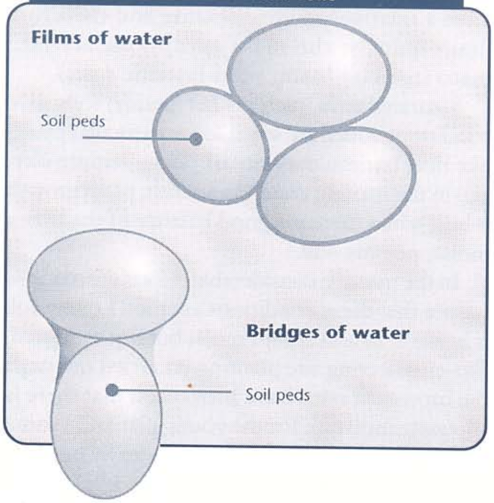
Availability of water to plants

Water drains freely from soil pores until it reaches a constant point called field capacity. Some water, however, remains in the soil as films or bridges that cling to the surfaces of soil particles (Figure 1.19). Field capacity, then, is a measurable limit that describes the amount of water that will be held in a freely drained soil.

Plants extract water most readily from the soil particle surfaces and larger voids. The main source of water for plants is the mesopores. As water is pulled out of the smaller voids it becomes progressively harder to extract. If the plant roots are not in the mesopores they obtain water by capillary attraction from the micropores, but this is much harder for the plants.

In practice, there is a moisture range within which soil must be kept. On site it is difficult to control, since it is determined by weather. Hot sun can dry the surface soil rapidly, and it is often not practical to add water. Heavy rain can saturate the soil, although it is usually only those with a high clay content, or with other impeded drainage, which remain waterlogged for more than a few hours. In the nursery, much depends on the naike's skill in keeping the soil in the beds within the critical limits. In planning nurseries, particularly in the Terai, drainage is an important consideration, to minimise the risks of the soil remaining saturated. Site implementation schedules must always be flexible to avoid planting works being done if the soil is too dry or too wet.

Figure 1.19: Films and bridges of water in unsaturated soils



Effect of stoniness in reducing available water in soil

Stoniness is the main factor affecting the amount of available water in the soil. As stoniness increases, the size of the pores also increases. This means that the water bridges form less easily and the water is held only in a thin film on the soil particles.

This effect is made worse in many Nepal hill slope soils because the colluvium is constantly moving down the steep slopes, and this keeps the soil very loose and open. The angular rock fragments result in larger voids with less contact between the particles to hold bridges of water. This seriously reduces the amount of available water in the soil.

Many materials found in Nepal have high proportions of stones. This is particularly the case with landslides in areas of harder rocks, such as the Mahabharat ranges, and certain river borne deposits and debris fans. Even in relatively moist sites, these materials can give rise to dry rooting conditions if rain is not regular. In stony sites, therefore, the choice of species for bio-engineering must take the greater risk of drought into consideration.

Plant nutrient requirements

The three main plant nutrients are:
- nitrate, which helps leaf growth and if available in adequate quantities results in generally increased growth;
- phosphate, which is important for root growth, helps plants to become established (and is particularly important for leguminous plants) and
- potassium, which is needed to keep plants healthy, is involved in the production and storage of sugar and starch, and helps drought resistance.

Plants need a balance of these nutrients and also require other nutrients in smaller quantities.

The low nutrient status of Nepalese soils

In general, most soils in Nepal are relatively low in nutrients. This is a natural occurrence in most cases and is mainly due to:
- hill slope soils containing many fragments of weathered rock, which has not been weathered adequately to release the nutrients;
- most hillslope and Bhabar soils being newly formed and highly dynamic, so there has not been long enough for nutrients to be released from rock material;
- high intensity monsoon rainfall leaching out a high proportion of the soluble nutrients;
- the high permeability of many soils allowing the maximum leaching effect;
- erosion, either now or at some stage in the past, removing topsoil, which contains organic matter and nutrients;
- high temperatures speeding up the breakdown of organic matter;
- on cultivated soils, heavy and repeated cropping with inadequate inputs of nutrients through compost or fertiliser;
- on forest soils, continuous removal of leaves and tree litter for fodder and compost;
- other human activities resulting in minimum vegetation cover.

Natural colonisation of utis *(Alnus nepalensis)* on bare landslide debris

The result is that even in forest and agricultural soils, the conditions for plant growth are far from ideal. Roadside slopes usually have skeletal soils and so are often extremely poor in nutrition.

Despite the inherent infertility of most soils, especially in the hills, the plants that have adapted to the Nepal Himalaya are capable of short bursts of rapid growth. During the dry season, a reasonable amount of nitrogen can be mineralised in the soil, so that as soon as the rains make the soil moist, it is mobilised and available to plants. The summer monsoon rains give rise to a warm, wet period, which is ideal for the weathering of rock and the release of nutrients. Plants are able to take up adequate nutrients in this period, despite the leaching of a large proportion of the most soluble elements. Nitrogen is particularly soluble and, if plants are not in the ground by early in the monsoon, they often suffer a deficiency of this major nutrient. Many plants improve noticeably in the early rains during the year after planting, when they benefit from the next season's flush of nitrogen.

Many of the recommended bio-engineering plants are pioneer species, which means that they are naturally adapted to grow and survive on poor sites with extremes of sunlight, heat, drought and low nutrition levels. This avoids the cost and difficulty of having to apply topsoil to steep and unstable slopes in order to allow plants to grow. The dynamic mountain geomorphology that has led to such poor soils and harsh sites, has also given rise to a range of plants well-adjusted for these conditions.

Use of leguminous plants to improve soil fertility

The legumes (Leguminosae) are a large family of plants whose seeds are formed in pods. They include a range of important crop plants (*e.g.* peas, beans, lentils) as well as a number of trees such as sisau (*Dalbergia sissoo*) and khayer (*Acacia catechu*). Most leguminous plants have special bacteria living in nodules on their roots called *Rhizobia.* These are able to take nitrogen from air in the soil and convert it to a form that is available to the plant. Because of this feature, legumes are often planted to enrich the soil. In general they do help to improve the soil because nitrogen is such an important nutrient, but it is still important to appreciate that heavy cropping of leguminous plants can deplete the soil of other vital nutrients.

1.9 PROGRESSION AND REGRESSION

Plants become established in any place that meets their basic requirements. In nature, there is a progressive development of vegetation on a fresh site. Some plants become established, then others come in and they interact with each other resulting in changes in the vegetation. Finally, stable vegetation becomes established. In Nepal, if it is left undisturbed, most bare ground will soon become covered with small plants and will gradually return to full forest cover. This can be seen with sand banks in river beds and landslides in many mountain areas.

A similar pattern of change and development is seen when bio-engineering plants are established on a site. In some cases, if the plants are left alone, an unsuitable balance of species may develop after a few years or the species planted may be killed off by weeds. By understanding the changes which occur in nature it is possible to plan the right balance of different species and manage maintenance so that a suitable balance is kept. The main rules governing this are as follows.

1. On a bare, inhospitable site, revegetation must start with pioneer species.
2. Once pioneer species have established, other plants will begin to colonise naturally. Many of these will not have the desired properties for bio-engineering and, if left undisturbed, they might kill the planted species.

3. Pioneer species cannot survive together in the long term (beyond about 10 years), because they compete with each other too much. They must give way to a community of climax species.
4. To establish a climax community, a different range of species must be planted to replace the first lot.
5. If the sequence is managed, it can be achieved much more quickly and effectively than if it is left to nature.

These are explained in more detail below.

Progression

This is the natural development of vegetation on a site over a period of time.

A fresh landslide will have a bare slope that consists of raw minerals, weathering products and fragments of rock. Within a couple of years it will probably be covered with vegetation such as tite pati (*Artemisia vulgaris*), kans (*Saccharum spontaneum*) and simali (*Vitex negundo*). These first plants on a bare site are called pioneers because they establish themselves easily in difficult conditions such as bare, infertile slopes. They grow from seeds, which may be blown, or be carried in by animals or birds.

Pioneer plants have special adaptations, which enable them to survive on harsh sites. These include:

- low nutrient requirement;
- drought resistance;
- ability to recover after disturbance caused by moving soil;
- produce large quantities of seeds to overcome poor germination conditions.

Their colonisation and development lead to better conditions, which other species then take advantage of. For example:

- vegetation cover increases the permeability of the soil, reducing soil capping and letting water in;
- leaves shade the surface so it is cooler and evaporation is reduced;
- leaves intercept rainfall, reducing raindrop impact and therefore lessening erosion;
- plants create a micro-environment below ground in which micro-organisms and small animals live and improve the quality of the soil;
- plants add humus to the soil, which helps to retain moisture.

The first plants to become established will be smaller grasses and herbs, but within two years large herbs will tend to dominate the site. Ban mara (*Eupatorium adenophorum*) is the most prevalent of these. This development continues and the grasses and herbs are gradually replaced by larger woody shrubs and trees. Examples of these plants are kunelo (*Trema orientalis*), utis (*Alnus nepalensis*) and bhujetro (*Butea minor*), and takal palm (*Phoenix humilis*) on the edge of forests. These species tend to be short-lived for woody plants, generally lasting only 10 to 15 years. As they develop, they tend to shade almost everything else out. Utis is a well-known example of this type of plant.

The following qualities make these plants successful:

- rapid growth: they may grow 1 metre in height and 20 mm in diameter each year, e.g. bakaino (*Melia azedarach*);
- efficient arrangement of leaves: they trap light well and the canopy closes quickly, shading out any competitors;
- produce many seeds which are efficiently dispersed, *e.g.* tilka (*Wendlandia puberula*);
- seed has long life and can lie dormant in the soil for many years until ideal germination conditions arise: this is seen when a tree falls, causing a gap in the canopy, and many seedlings suddenly develop in the light; the dormant seeds lying in the soil are called a 'seed bank'.

These short-lived trees are gradually replaced by trees that have a longer life-span. For example, painyu (*Prunus cerasoides*) and chilaune (*Schima wallichii*) often start to grow under utis (*Alnus nepalensis*) forest.

Development of organic top soil

At first the soil on a bare site is formed almost entirely from weathered rock. This bare soil can easily be eroded by rain water. When a vegetation cover has established, erosion is reduced and a better soil can develop.

The original mineral matter of the soil is supplemented by organic matter, which comes mainly from leaf litter. As well as providing organic matter, the leaf litter armours the surface,

Mixed hardwood forest on a south-facing slope at 1000 m in the Trisuli Valley. At this point, sal (Shorea robusta) is being replaced by a range of other species

further reducing erosion. As the process continues, a darker top soil develops. This has a greater content of organic matter and is more cohesive. It usually starts to have a higher proportion of sand, silt and clay, because the finer particles cease to be washed out. Its fertility increases. Below the soil surface an interdependent community of animals, micro-organisms and fungi becomes established. Decaying plant and animal remains are converted into nutrients that can be used by plants, and soil minerals are broken down to release the nutrients they contain.

Despite this process starting relatively rapidly, the formation of a good topsoil takes many decades to become significant. In the mountains of Nepal, even in good quality natural forest, the slopes are often too steep, and the geomorphological processes too dynamic for good topsoil ever to establish.

Establishment of stable vegetation

Established forests are seen in many areas. In some cases, such as sal (*Shorea robusta*) forest, there are tall trees with broad canopies. They reach an apparently stable mixture with a range of different species. They provide homes for larger animals such as monkeys, which in turn support the trees by contributing to seed dispersal. Dead trees become homes to insects and fungi, and as they gradually decay they return to the soil and feed other trees. The gap in the canopy produced by their death allows replacement trees of the same species to develop from the seed bank. If there is no major disturbance the forest may remain unchanged.

In the past this was described as climax forest. It was seen as the end product of progression. No further development was imagined and it was seen as the goal of environmental protection. Now we see this as a stage of stable development. The vegetation may stay in this state for a considerable time. But in its natural development gradual changes may occur which are acceptable.

Regression

Progression does not lead to a permanent state. However, changes may occur which disrupt the normal development towards stability. This is called regression.

Regression may be caused by several factors, including fire, grazing, cutting and landslides.

Fire can be very damaging, as it can destroy all seedlings and replacement growth. A less severe fire can still scorch and check the growth of larger trees and kill young trees.

Grazing by cows and goats destroys all the young, palatable growth within their reach. Goats also disturb the soil as they climb slopes and may lead to the reduction of vegetation cover and to small landslips.

Over-cutting by people may destroy mature trees and leave large openings in the canopy which allow other species to invade. Alternatively, cutting smaller trees for firewood may remove all the potential replacement trees.

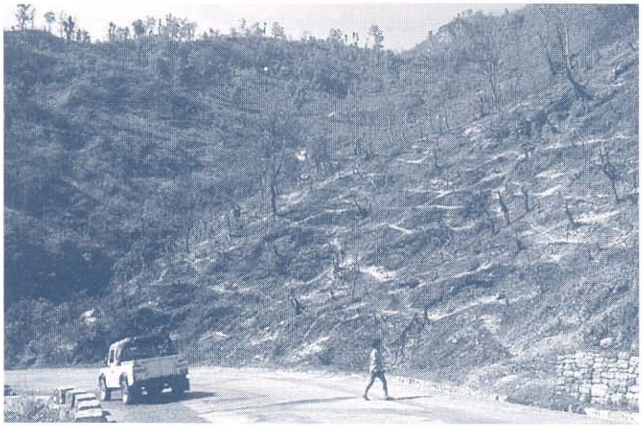
Landslides have a major, localised effect in destroying mature, stable vegetation.

In each case, one of the main effects is the destruction of young plants. This means that when the older plants reach maturity and die, they are not replaced.

Implications for bio-engineering

Pioneer plant species are important for bio-engineering because their adaptations are well-suited to the dry, infertile conditions characteristic of landslide sites, and bare cut slopes. In bio-engineering it is necessary to select species showing these characteristics.

The ability to cope with moving soil is less important because bio-engineering is only used for stabilising shallow failures up to about 500 mm. Deeper failures are managed by civil engineering structures, which should be constructed first. Nevertheless, bamboos are very sensitive to soil movement and should not be planted if there



Cutting and burning vegetation has reduced the stability of this slope and left it highly susceptible to erosion

is a risk of movement around their roots. The recommended bio-engineering grasses, shrubs and small trees are all tolerant of movement.

Large numbers of plants are required in bio-engineering. The ability to produce many seeds is not necessarily important because many species are propagated vegetatively. However, the ability to produce a large quantity of planting material, either by seed or from vegetative cuttings, is important.

In the absence of large quantities of natural leaf litter on bare sites, mulch can be used when establishing plants. Later the sites should develop their own leaf litter.

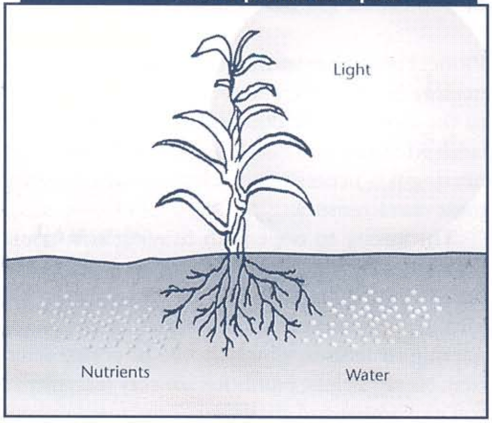
The main points related to the establishment of stable natural vegetation are:

- the use of fast-growing species for rapid establishment;
- the establishment of a stable, easily maintained plant community;
- the development of a vegetation cover that will reduce erosion;
- the development of a canopy, which shades the soil and improves rooting conditions.

Since it is usually necessary to establish a balanced plant community with a variety of plants carrying out different bio-engineering functions, one feature to avoid is an unbroken higher plant canopy, which shades out all shorter species such as grasses.

It is important to try to avoid all of the regression factors. Fire, grazing and cutting are tackled through protection of the site, and liaison with local people wherever possible. Landslide damage is avoided by careful stabilisation measures, using both civil and bio-engineering structures.

Figure 1.20: The main resources for which plants compete



Good management ensures that trees are well spaced and are lopped to keep them small, as in this roadside slope. Here, highly productive fodder grasses have been planted between the trees to provide complete surface cover

This plantation is well managed for soil conservation as it has been thinned to allow sufficient light to penetrate the canopy and for grasses to flourish. The result is a complete surface cover of grasses

1.10 COMPETITION BETWEEN PLANTS

Plants grow singly, in groups of the same species or with other species as a community. Each plant has a tendency to use as much of the available resources as possible. The resources for plants are water, nutrients and light, located both above and below ground (Figure 1.20). This usually leads to a problem between any plant and its neighbours. Obtaining any resource at the expense of another plant is termed competition. Competition takes place in two areas:

- above the ground, competition is mainly for light;
- below the ground, competition is mainly for nutrients and moisture (water). The manner in which root systems interact and compete is not completely understood.

Light

Plants will start to compete for light as soon as they form a continuous canopy. This starts when they are very small if the plants are growing close together. In trees the main problem is seen from four to five years onwards. If there is a higher canopy with an understorey below it, the shading of the understorey plants is a particular problem.

There are three main options for overcoming the problem:

- remove or space out the tall plants;
- reduce the volume of the canopy;
- introduce plants that are shade-tolerant into the understorey.

Since they have been put there to fulfil a bio-engineering function, it is not usually desirable to remove all the tall plants. However, once the vegetation has become established, it can be thinned to provide space for light to penetrate between the plants. This is generally necessary at intervals as tree plantations develop.

The volume of the canopy can be reduced in a number of ways. Pruning is the selective removal of branches. On most shrubs and trees it is safe to remove all the branches from the lower half or two thirds of the plant. This alone can improve light penetration when branching is heavy.

Complete thinning is the most common and effective way of increasing the light penetrating a closed canopy of larger plants. This is where a shrub or tree is cut off at the ground and not expected to re-grow from the stump. Where a complete canopy has formed, it is usually necessary to remove between half and two-thirds of the canopy. Full details of pruning and thinning are given in Section 5 of the *Site Handbook*, and are discussed comprehensively in Chapter 3 of this *Reference Manual*.

Some trees can also be pollarded or coppiced. In pollarding, the whole of the top of the tree is removed, typically at about 2 to 4 metres above the ground. After pollarding, new branches develop at the top of the trunk. Coppicing is a similar process, but the tree is cut off just above ground level. New branches then grow in the same way that they develop after pollarding. The advantage of these techniques is that a canopy can be completely thinned while still retaining the extensive network of roots from the larger plants. The lists of bio-engineering species in Annex B of the *Site Handbook* give details on the tolerance of different trees to coppicing and pollarding.

Shade-tolerant species can be used in the understorey, but there are not many species that provide the 100 percent ground cover that is required in bio-engineering. Almost all the grasses require full light in which to grow, and can tolerate only very limited amounts of shading. Therefore if a ground cover of grasses is required, the canopy must be kept very light.

Water

When there is not enough water to go round, plants compete for water and this can become a problem. Generally, this happens in Nepal from February to May. It varies from place to place and can be different from year to year. Some areas have extremely high rainfall but may still face problems for part of the year. (Lumle, with an average of over 5000 mm per year, suffers from a soil water shortage for nearly one month in May.)

Possible solutions involve providing more water, reducing the level of demand for water and using drought-resistant species.

It is possible to provide additional water in the nursery, and sometimes also on site when it is being planted. After that it is not a realistic solution. If conditions are dry, water may not be available within a reasonable distance. Even if it is available, watering is not a good solution. Plants that are regularly watered in dry seasons tend to develop shallower rooting systems and as a result they become more dependent on being watered and do not fulfil the engineering functions so well. Watering is also very labour demanding and labourers can be more usefully employed on other work.

Weeding can reduce the demand for water. This is important during establishment, so that the desirable species have the best opportunity for development. Pruning reduces water demand, and is often used on bamboos. Mulching can also reduce the loss of water from the soil. That involves placing a layer of cut vegetation on the surface of the soil. This should be close to the plant but not touching it. Mulching is described in Section 3.17 of the *Site Handbook*.

Finally, drought-resistant species can be selected. This is the best and most common approach in roadside bio-engineering. In an environmentally dry area, it is best to plan to use drought-resistant species from the beginning. Examples are all of those tolerant of dry sites in Figure 1.18 (see p30), such as khayer (*Acacia catechu*) and babiyo (*Eulaliopsis binata*).

Nutrients

The problem of competition for nutrients is similar to the problem of competition for water, except that it can occur during the warmer and damper part of the year since plants use nutrients whenever they are growing. If there are not enough nutrients in the soil, plants will compete for them. This can begin as soon as a seedling has put out roots and can no longer grow on its own food reserves.

Just as the problems of competition for water and nutrients are similar, the solutions are similar. More nutrients can be supplied through putting compost near the plant, or from the mulches that have been used to reduce water loss. Nitrates can be provided through using leguminous plants, which have bacteria on their roots that are able to use nitrogen from the air. These nitrates can then become available for other plants.

Experiments on roadside slopes have shown that adding chemical fertilisers does not give a response of improved growth in grasses. This means that either nutrition is not the factor limiting growth; or if it is, that it cannot be overcome using chemical fertilisers.

Weeding reduces the competition for nutrients on a site that is becoming established.

Plants that are able to tolerate low nutrient levels, such as kans (*Saccharum spontaneum*), can be used.

1.11 PLANT COMMUNITIES

A plant community is an established group of plants living more-or-less in balance with each other and their environment. The group can be natural or managed. The community is usually dominated by the main species of trees, but also contains lower plants, such as shrubs, grasses and herbs. Some trees tolerate large numbers of climbers and other parasitic plants, such as orchids. Figure 1.21 gives some examples of vegetation communities.

Most natural vegetation communities in Nepal are characterised by a large number of species. By comparison, planted communities have relatively few species. An ideal plant community for bio-engineering contains a carefully planned variety of different plants which together meet the

Figure 1.21: Examples of vegetation communities, based on forest types

Dominant species	Main associated species	Period of community survival	Comments
Banjh(*Quercus leucotrichophora* and *Q. lanata*)	Variable, depending on location; lali gurans (*Rhododendron arboreum*), angeri (*Lyonia ovalifolia*), bhalayo (*Rhus wallichii*), tite nigalo bans (*Drepanostachyum intermedium*) and lokta (*Daphne* species)are common in some areas;	Indefinitely	There are many types of banjh (oak) forest community across the length of Nepal. There are wet and dry types. *Quercus leucotrichophora* is more dominant in the west and *Q. lanata* more dominant in the east.
Utis (*Alnus nepalensis*)	Almost pure; some angeri (*Lyonia ovalifolia*) and often a dense understorey of ban mara (*Eupatorium adenophorum*)	Temporary: utis appears able to regenerate only on open ground; other species start to appear, such as chilaune (*Schima wallichii*) and katus (*Castanopsis* species)	
Chilaune-katus (*Schima wallichii*-*Castanopsis* species)	Variable, depending on location; often almost pure stands of these two species.	Indefinitely	A wide range of species is seen under chilaune forest, but in small quantities. Because this forest type occurs in the populated middle hills, it has often been seriously disturbed.
Khote salla (*Pinus roxburghii*)	Dhanyero (*Woodfordia fruticosa*), sal (*Shorea robusta*), chilaune (*Schima wallichii*), katus (*Castanopsis* species), khar (*Cymbopogon microtheca*) etc.	Salla acts as a pioneer species; after five to ten years, the associated species will start to establish and will last indefinitely	Salla can be planted as a pioneer species, as in Kavrepalanchok district, and gradually moved to a mixed forest as other species come in and are favoured in forest management operations.
Khayer (*Acacia catechu*)	Bel (*Aegle marmelos*), kadam (*Anthocephalus chinensis*), dhonde (*Neyraudia reynaudiana*) etc.	Indefinitely	In some cases the khayer becomes dominant, with a poor understorey which allows erosion to take place under the established forest.
Sal (*Shorea robusta*)	Saaj (*Terminalia* species); karma (*Adina cordifolia*); banjhi (*Anogeissus latifolia*); jamun (*Syzygium cumini*) etc.	Indefinitely	This community is found mostly in Terai sal forests; hill sal forests (on the lower slopes of deep valleys) are often almost pure sal.

engineering needs of the site. Examples of this might be:

- an open canopy of khayer (*Acacia catechu*) with a dense ground cover of babiyo (*Eulaliopsis binata*);
- an open canopy of mixed dhanyero (*Woodfordia fruticosa*) and areri (*Acacia pennata*), with a ground cover of kans (*Saccharum spontaneum*);
- an open canopy of mixed utis (*Alnus nepalensis*) and painyu (*Prunus cerasoides*), a middle storey of mixed bhujetro (*Butea minor*) and areri (*Acacia pennata*), and a ground cover of sito (*Neyraudia arundinacea*);

However, the exact community which is developed under bio-engineering depends on the engineering requirements of the site and the environmental conditions of the locality.

The general principles for managing plant communities in bio-engineering are as follows.

- Where possible, use a mixture of plants in the initial planting. If you rely on one species and this fails, there may be a complete loss of the planted material.
- Start with pioneer species. For example, with a damp and north facing slope you might introduce utis and some understorey grasses.
- Plan a balance of plant species in the community. Generally include grasses, shrubs and trees (but the exact balance is determined by the engineering requirements of the site).
- Remember that dominant plants such as utis must be replaced or thinned out within five to 10 years. Otherwise the understorey plants

will be overshadowed and eradicated completely, allowing erosion to start under the tree canopy.

- Thin the plants out properly to maintain a balance.
- Clear weeds to reduce competition.
- Re-plant gaps.

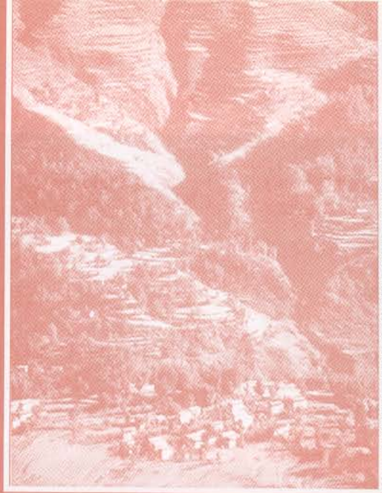
These are given in more detail in Section 5 of the *Site Handbook* and elaborated in Chapter 3 of this *Reference Manual*.

1.12 SUMMARY OF THE IMPLICATIONS OF PLANT ECOLOGY FOR BIO-ENGINEERING

- Vegetation in Nepal grows in zones determined mainly by the temperature and moisture conditions for which each species is adapted.
- The zones are recognisable and definable within certain limits. They do not coincide with the terrain zones.
- Each of the species used for bio-engineering has a tolerance for site conditions that is reasonably well defined. As a result, species can be found to grow on almost any site, depending on its characteristics.
- Water is the main factor limiting plant growth in the warmer months.
- Soil nutrition seems rarely to be a limiting factor; in any case, the species used for bio-engineering are tolerant of very low fertility.
- The use of pioneer species for bio-engineering on bare roadside slopes helps to allow a vegetation community to establish, through the development of shade and better soil.
- A number of factors can cause regression if the plants are not well protected.
- Plants compete with each other for resources.
- In bio-engineering, the competition for light is the most critical aspect. If not managed, the canopy of higher plants can shade out the ground cover.
- As a result, regular maintenance is required to ensure that bio-engineering systems develop as required.
- There is a range of natural plant communities. These do not hold all the engineering attributes required of bio-engineering vegetation systems. For this reason as well, regular maintenance of the vegetation is needed to ensure that the optimum mixture of plants is both attained and sustained.

The use of vegetation in engineering involves manipulating nature for specific purposes. It is not simply a matter of establishing a vegetation cover to become part of a long term natural plant community. Management of the plants to fulfil specific engineering functions can make vegetation play a much larger role in stabilising and protecting a slope than it would do otherwise.

Because of the harsh nature of bare landslide or other disturbed roadside slopes, it is rarely possible to establish the final plants straight away. Instead it is necessary to start with pioneers that are adapted to these conditions and then change the mixture of plants gradually to a community which is more-or-less stable. However, it is usually important to ensure that the slope is armoured against erosion. Grasses are by far the best plants to achieve this. But grasses mostly require full sunlight in which to grow; so to sustain a good cover of grasses it is necessary to keep the shrub or tree canopy as thin as possible. On the other hand, without the shrubs and trees, the deeper reinforcing and armouring functions required on many sites would not be provided.



Understanding the dynamic landscape

This chapter examines the factors affecting slopes and what makes them unstable. This starts with the underlying geological conditions and works through geomorphology, climate and materials to the implications of slope instability for road engineering. This chapter covers the following topics.

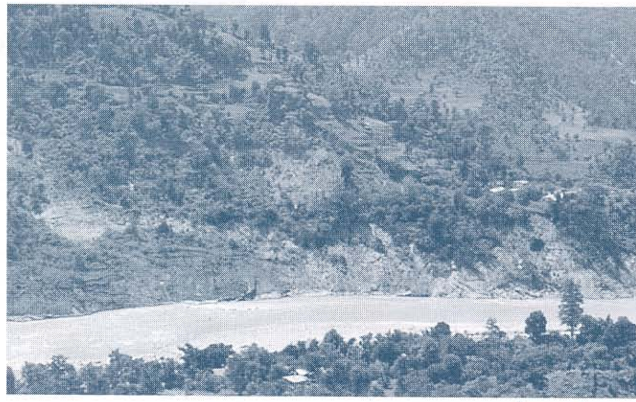
- The underlying geology of Nepal (2.1)
- The ways in which mountain slopes evolve (2.2)
- Engineering aspects of slopes and rocks (2.3 and 2.4)
- Soils and materials (2.5).
- The role of climate and water (2.6).
- Forms and mechanisms of instability (2.7).
- Practical aspects of site investigation (2.8).
- Site treatment (refer to the *Site Handbook*).

The mountain slopes of the Himalayas are large and complex. Their instability is well known, but the causes and mechanisms are often poorly understood. Sometimes it is not possible to do anything about them.

Figure 2.1 summarises the main factors affecting the slopes. These, in turn, may be influenced by many other factors, all of which produce certain effects on slopes: for example, the amount of rainfall in any particular location is determined by a wide range of site features to do with location and topography. The rest of this chapter addresses these in detail.

2.1 THE GEOLOGICAL FRAMEWORK OF NEPAL

The stability of Nepal's mountain slopes is determined largely by the geology that makes up their structure. In order to understand the principles of slope stabilisation, it is necessary to know how the slopes were formed, what they are composed of and how they are evolving. This section introduces these topics, and helps to provide a background to the site assessment procedures described in the *Site Handbook*.



Large deep-seated landslides can occur on a number of different planes, such as has happened in this example of a rotational faiture at Mulghat, Dhankuta District. A number of scars are visible to the left of the buildings

Geological synopsis

The physical environment of Nepal is dominated by a major mountain-building process caused by the collision of two continents.The meeting of two continental plates is not smooth, of course. The movement occurs in a series of jerks, or earthquakes. Great chunks of rocks have been pushed upwards, bending (folding) and breaking (faulting) in the process. As the mountains have arisen, so the forces of nature, particularly water and gravity, have started to cut them down again.

The two continental plates are still moving together, at the rate of a few centimetres per year, and so the mountains are still growing. There is a time lag between the growth and the wearing away of the mountains; hence nature has a substantial backlog of slopes to reduce.

It is on these slopes that Nepal is situated, and on which we are trying to build and maintain our roads. Nepal is situated in the central part of the Great Himalayan Arc, which extends for about 2,400 km from the Punjab Himalaya in the west to the North Eastern Frontier Area or Assam Himalaya in the east. The middle strip of 820 km constitutes Nepal.

The Earth's crust is composed of a layer of cool, brittle rocks, about 30 to 40 km thick where the main continents occur. These effectively float on the surface of the semi-molten rocks of the mantle below. Very slow, viscous flow in the mantle causes sections of the crust to move relative to each other over immensely long time periods. One large section (or 'continental plate'), known as the Indian Shield, has been moving towards and underneath another section, known as the Tibetan Plateau, for approximately the past 40 million years.

The continents meet through a series of thrust faults, where one rock type is pushed on top of another. It is assumed that the height of the Himalayas is attributed to a great thickness of crust rocks underneath them, since the northern part of the Indian Shield plate must now be underlying the southern part of the Tibetan Plateau plate. The principle of isostasy[1] means that the lighter but now thickened crust rocks, where are effectively floating on the viscous mantle below, rise higher than the surrounding areas of crust.

The southerly edge of the original Tibetan plate rocks can be seen as the Mahabharat range. The northern edge of the Indian Shield rocks are not visible, since they have been covered by huge volumes of sediments: these comprise the Churia, Bhabar and Terai, and lie on top of the older Indian rocks. The Churia have in turn been uplifted, distorted and eroded during the more recent part of the process.

The rate of geological evolution is not always constant. There appears to have been a very active tectonic regime from the late Tertiary to the present (*i.e.* from about 10 to 20 million years ago). This has given rise to the crushed, folded and fractured rocks, and at the same time has been combined with a period of relatively rapid sub-tropical weathering. Combined with the effects of monsoon storms on the near-surface hydro-geology, these factors explain why the mountains are so unstable today.

The physiographic north-south cross-section is similar throughout the Himalaya; therefore a simple geo-tectonic zonation, which is applicable to the whole orographic belt, is also valid for Nepal. These divisions are also well correlated with the zonal distribution of the geological formations and the structural arrangements along the Himalayan trend. The zonation is longitudi-

[1] Isostasy is the state of equilibrium, which 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.

Figure 2.1. Summary of the main factors affecting slope stability

← More stable	Less stable →	What can be done to resolve it
Slope		
Geology		
[Opposite does not occur]	Major disturbance (faulting, folding)	Nothing can be done
Older, more consolidated rocks	Younger, less consolidated rocks	Nothing can be done
Shorter slopes	Longer slopes	Slopes can sometimes be broken up by building large check dams or retaining walls.
Geomorphology		
Undisturbed ridges	Unstable valleys	Nothing can be done
[Opposite does not occur]	River cutting (down- and under-)	Large scale river training works are sometimes worthwhile
[Opposite does not occur]	Gravity and colluvium formation	Large retaining walls sometimes retard colluvial movements
Rocks		
Hard and cohesive rocks	Weak rocks	Nothing can be done under normal Nepalese conditions
Stable minerals (weather slowly)	Unstable, easily weathered minerals	Nothing can be done
Undisturbed rock masses	Fractures	Physical support can sometimes be provided
Hard, unweathered rocks	Weathering	Support, anchoring and reinforcement can sometimes be provided
Materials		
In *situ* and consolidated	Moved and unconsolidated	Materials can be anchored, supported and reinforced
Angular, inter-locking fragments	Rounded & poorly bound fragments	Materials can be anchored, supported and reinforced
Slow soil development	Fast soil development	The surface soil can be reinforced with plant roots
Low infiltration soil	High infiltration soil	Drainage can be improved to encourage runoff
High hydraulic conductivity	Low hydraulic conductivity	Drainage can be improved
Cohesive surface	Uncohesive surface layer	The surface layer can be armoured and reinforced with plant roots
Vegetated surface	Unprotected surface	All unprotected areas can be vegetated by bio-engineering
Water		
Low rainfall	High rainfall	More drainage can be given
Drier location	Damper location	Drainage can be improved
Low intensity rainfall	Intense rainfall	Preventative slope treatment can be increased

Combinations of these destabilising factors form the following main types of failures

Failure type	Main curative action required
Erosion	Surface armouring is required. Mainly done using bio-engineering, but check dams may also be needed.
Planar (translational) landslides	Support, anchoring and reinforcement are needed. Usually achieved by civil and bio-engineering works combined.
Shear (rotational failure)	Drainage, support, anchoring and reinforcement are needed. Usually achieved by civil and bio-engineering works combined, with the main support achieved by a heavy retaining wall.
Debris flow	Drainage and reinforcement are needed. Usually achieved by civil and bio-engineering works combined
Rock failures	Support is required. This can usually only be done using civil engineering techniques.

nally arranged from south to north as shown in Figures 2.2 and 2.3.

Trans-Himalaya or Tibetan Tethys Himalaya

The Tibetan Tethys Himalaya reaches to altitudes of about 5000 metres above sea level. In this zone, the Tethys sediments of the Palaeozoic to the early Cenozoic ages (*i.e.* from about 400 to only 50 million years old) are spread over an area underlain by granite bodies. The sedimentary rocks are highly fossiliferous. The Tibetan Tethys

Figure 2.2: The physiographic sub-divisions of the Himalayas

Zones		Faults	Rock Types
Trans-Himalaya			Tibetan Tethys (ancient marine) sediments: fossiliferous sandstones, claystones and others
Higher Himalaya			Gneisses, granitic rocks, schists and dolomites
		Main Central Thrust	
Lesser Himalaya: (middle mountain)	Midlands		Relatively soft rocks (gentler slopes, thicker soils): granitic gneisses, limestones and phyllites
	Mahabharat range		Relatively hard rocks (steeper slopes, thinner soils): quartzites, dolomites and schists
		Main Boundary Thrust	
Sub-Himalaya: (or Siwaliks)	Churia		Unconsolidated sandstones, shales, mudstones and **conglomerates**
	Inner Terai		Alluvial (boulder, gravel, sand, silt and clay)
		Main Frontal Thrust (or Himalayan Frontal Thrust)	
Terai:	Upper piedmont alluvial plain (Bhabar)		Alluvial (boulders, gravels and sands), gently sloping (5-8°)
	Lower piedmont alluvial plain (Terai)		Alluvial (silts and clays), very gently sloping (2-3°)

Note: 'piedmont' literally means 'foot of the mountain'. A piedmont alluvial plain is formed by the coalescence of numerous alluvial fans where rivers and streams discharge from mountains.

zone is bordered to the north by the Indus-Tsangpo Suture (a line of join or meeting), which stretches along the Indus and Tsangpo rivers. This fault zone signifies the collision trace of the Indian subcontinent with Eurasia. The width of the zone is approximately 40 km. The Thak khola area in Mustang is considered as the type example of this area in Nepal. So far it is the only geological division not touched by a part of the road network.

Trans-Himalayan terrain in the upper Kali Gandaki (Thak khola) Valley. Although this area is now at very high altitudes, these rocks were laid down under an ancient sea, and now comprise the main Tibetan plateau

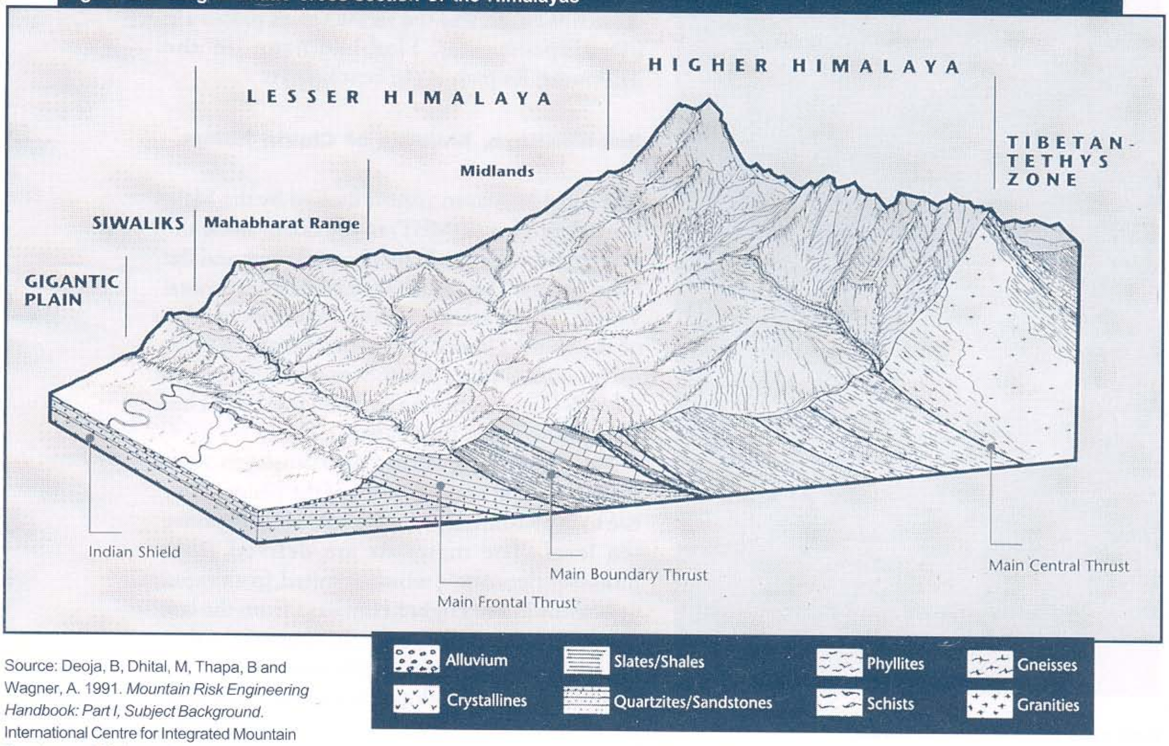
Higher Himalaya

The Higher Himalayan zone ranges from 2000 to more than 8000 metres. There are altogether 14 mountain peaks higher than 8,000 metres and, of these, the Nepal Himalaya contains eight (*i.e.* Mount Everest or Sagarmatha, Kanchenjunga, Lhotse, Makalu, Dhaulagiri, Manaslu, Cho-Oyu and Annapurna I). The upper parts of these mountains are formed by Tethys (ancient marine) sediments, which are underlain by the central crystalline rocks. The whole range consists mainly of high-grade metamorphic rocks, such as schist and gneiss. This zone is characterised by sharp peaks and deep gorges: the Kali Gandaki valley is the deepest gorge in the world.

Both the Higher Himalaya crystalline basement rocks and the Tibetan Tethys sediments thrust on the Lesser Himalayan rocks along the Main Central Thrust (MCT).

Few roads have been built in this zone. The most notable is the Arniko Highway, which uses the Bhote Koshi gorge to cut right through the Higher Himalaya at a relatively low altitude.

Figure 2.3: Diagrammatic cross-section of the Himalayas



Source: Deoja, B, Dhital, M, Thapa, B and Wagner, A. 1991. *Mountain Risk Engineering Handbook: Part I, Subject Background.* International Centre for Integrated Mountain Development, Kathmandu.

Lesser Himalaya or Middle Mountains

The Lesser Himalayan zone lies to the south of the Higher Himalayan zone. It is bordered by the Main Central Thrust (MCT) fault in the north, and the Main Boundary Thrust (MBT) fault in the south. This zone is characterised by medium- to low-grade metamorphic rocks, as well as some igneous and sedimentary rocks. Most of the Lesser Himalayan rocks are barren of fossils except for a few occurrences of stromatolites (fossilised coral), but the Gondwana[1] sediments of the Palaeozoic to the early Tertiary age (*i.e.* from about 400 to only 50 million years old) possess a large number of fossils.

It can be further subdivided physiographically into the Midland and the Mahabharat Range.

[1] Gondwanaland was the southerly of the two ancient continents, which once comprised the Earth's two big land masses (the other was Laurasia). The Indian Shield was once part of Gondwanaland.

Typical Midland terrain in the Lesser Himalayan (Middle Mountain) Zone. Relatively soft rocks give rise to gentler slopes suitable for cultivation

Midland zone

This lies immediately south of the Higher Himalayan zone. It consists of relatively low-lying hills, river valleys and tectonic basins. Its altitudes range between approximately 1000 and 3000 metres. The width is around 30 km. The Midland is represented by a rather dissected topography with predominantly dendritic, centripetal and sub-parallel drainage patterns. Residual soils are found on the ridges, while colluvial soils and talus deposits are present along the slopes. It consists mainly of metamorphic and igneous rocks. Due to the presence of soft rocks such as phyllite, the Midland is amenable to terrace cultivation; furthermore, it has a temperate climate. Since it is favourable for both cultivation and shelter, a dense population is concentrated within

Rato mato forms a distinct terrain type in many lower-altitude areas in the Lesser Himalaya

this zone and many major roads have been constructed to serve its numerous towns and villages.

Among the tectonic valleys, the most notable are Panchkhal, Banepa, Kathmandu, Pokhara and Mariphant.

Mahabharat range

This rises up to 3,000 metres above sea level and extends from the east to the west of Nepal with only minor breaks, in river valleys such as the Sapta Koshi, the Sapta Gandaki, the Karnali, and the Mahakali. It bears rocks from Pre-Cambrian to the early Palaeozoic age (*i.e.* from 2,000 or 3,000 to about 500 million years old) in different places, with Gondwana sediments as well. The rocks consist mainly of quartzite, granite, schist, marble and limestone. Most of the high peaks are found either on granite or limestone. The range is characterised by dendritic, radial and rectangular drainage patterns. These harder rocks give rise to steeper, more rugged slopes with thinner soils and less available water. This accounts for the relatively sparse population in the Mahabharat. Roads between the Midland and the Terai have to cross this range, and the ascents to its passes are often spectacular. Simbhanjhang on the Tribhuvan Rajpath is the best known.

Sub-Himalaya, Siwaliks or Churia Range

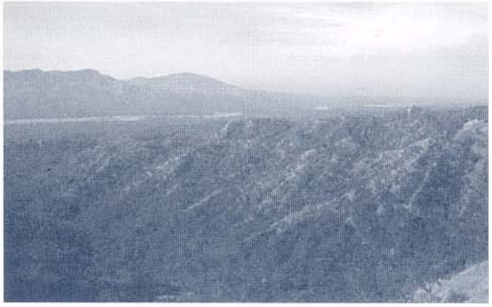
The sub-Himalayan zone is limited by the Main Boundary Thrust (MBT) to the north along the southern foot of the Mahabharat Range; and the Main Frontal Thrust (MFT) or Himalayan Frontal Thrust (HFT) to the south at the southern edge of the Siwalik Group. The Lesser Himalayan (middle mountain) rocks thrust over the sediments of the Sub-Himalayan zone (*i.e.* the Mahabharat has been pushed over the Churia).

The Churia hills of the Sub-Himalayan zone are the first hill range in front of the plains. They rise to approximately 1,000 to 1,200 metres above sea level. The materials are derived from molasses deposits[1], which resulted from rapid upheavals in the Higher Himalaya from the late Tertiary to the early Quaternary age (*i.e.* within the last 10 million years). Trellis, parallel, sub-parallel and rectangular drainage patterns, susceptible to flash floods, are characteristic features of this region. The topography is rugged, with numerous gullies and mounds of talus or scree. Streams are dry most of the time, but become hazardously active during the monsoon, leading to intense erosion, flash floods, debris flows and sedimentation.

The Churia hills make a continuous distinct range from east to west, except that in a few areas they merge with the Mahabharat Range. In some places they form Dun Valleys, which are intermontane basins.

With the exception of the Dun valleys, the Churia are generally too rugged, unstable and inhospitable to support much habitation. Roads

[1] Molasse is 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.



The unconsolidated rocks of the Sub-Himalaya of Churia Range give rise to inhospitable terrain, which remains largely forested

The Terai forms an extensive alluvial plain to the south of the Himalayas

passing through the Churia always have slope stability problems. All the south-north roads cross the Churia range at some point, and some road sections, such as between Chisopani and Surkhet, run through this terrain for very long distances.

The Siwalik Group has thrust over the Terai plain along the Main Frontal Thrust (MFT) fault. The MFT is not a continuous line, but rather it is in an echelon (stepwise) pattern. As with the Main Central and Main Boundary Thrusts, it is still active.

The Siwalik Group is divided into three major units: the Upper, Middle and Lower Siwaliks.

Lower Siwaliks

These consist of irregularly alternating beds of fine-grained, grey-coloured sandstones, variegated mudstones and pseudo-conglomerates. Sandstones are moderately hard, and cemented mostly by calcite. The upper part of this unit is composed of sandstones and variegated mudstones in roughly equal amounts. The thickness of individual beds of sandstones and mudstones varies from 1 to 10 metres, and 1 to 2 metres respectively.

Middle Siwaliks

This unit is further subdivided into two sub-units: the Lower Member and the Upper Member.

The Lower Member is represented by fine- to medium-grained, thick-bedded, compact, fairly hard, greenish grey to light brownish grey, micaceous sandstones, interbedded with greenish grey or brownish yellow to purplish grey mudstones and shales. In places, thin lenses of pseudo-conglomerates have been recorded, especially in the upper horizons. The size of the pebbles varies from 5 to 20 cm. Plant and animal fossils are preserved in both mudstones and sandstones.

The Upper Member is composed of medium- to coarse-grained pebbly sandstones with rare grey to dark grey mudstones, and occasionally silty sandstones and conglomerates. The thickness of the individual beds varies from 1 to 15 metres.

Upper Siwaliks

This zone is composed predominantly of gravel and conglomerate beds. Individual conglomerate beds of 2 to 8 metres thickness lie between the medium- to coarse-grained, brownish grey sandstones and occasionally siltstones. The size of the pebbles varies from several to 100 millimetres. The rock is loosely packed and consists of pebbles of quartzite, dolomite, marble, limestone, granite and Lower Siwalik sandstone and shale. The matrix is calcareous or clayey.

The Terai Plain

The Terai forms the main outwash plain below the Siwaliks and the middle mountains. It extends right across the south of the Himalayas, although in Nepal it is interrupted in places by outlying Siwalik ranges, which extend to the Indian border. To the south, it forms the great plain of the Ganges. It is an alluvial formation of sediments and composed mainly of gravels, sands and silts, of late Tertiary and Quaternary origin (*i.e.* within the last 10 million years). A striking feature is the abrupt shifting of river channels.

The Terai plain ranges in elevation from about 60 to 400 metres above sea level. The width varies between 10 to 50 km and forms a nearly continuous belt from east to west. It is divided into three parts: the Bhabar zone, middle Terai, and southern Terai.

Bhabar zone

This lies immediately south of the Churia range and is made up of alluvial fan deposits of boulders and pebbles sloping down towards the south. The southern margin of the Bhabar zone is marked by a spring line, which gives rise to many streams. The water table in the Bhabar zone lies at a considerable depth, and hence most stream courses are dry throughout the year except during the monsoon. The depth of the water table also explains why it is almost always unpopulated.

Middle Terai

The Middle Terai lies at the south of the Bhabar zone, immediately after the main alluvial fans. The area is composed of cobbles and sand on undulating terrain, with isolated pockets of waterlogged soils and marshes.

Southern Terai

This area lies further south and stretches along the Nepal - India border. It is the lowest terrain of Nepal and in some places, the altitude is less than 70 metres above sea level. It is composed of clays and silts with some sand layers. The water table is shallow and accessible using a hand pump throughout the year, making habitation possible.

In the Terai and Bhabar, bridging is the most problematic issue facing highway engineers. Slope stability problems related to roads are confined to embankment protection.

Regional geological structures

The main structures define the limits of the physiographic sub-divisions. There is often local instability on slopes where roads cross them, and so they are mentioned here as areas with potentially greater engineering problems.

Main Central Thrust (MCT)

The MCT is a conspicuous tectonic boundary throughout the Himalayas. The thrust dips gently northward along its east-west direction, and runs sub-parallel to the Himalayan zone. Augen gneisses (i.e. those with large minerals, usually feldspars, around which the foliation is wrapped) occur continuously throughout the MCT zone: these represent important geological and petrological evidence of tectonic development. The rocks of the Higher Himalayan zone have slipped and spread across the MCT towards the south, producing nappes[1] and klippens[2] on the Lesser Himalayan rocks in the Midland zone.

Main Boundary Thrust (MBT)

The MBT is a longitudinal structure that sharply separates the terrigenic sedimentary rocks of the Sub-Himalaya (Siwaliks) from the low-grade metasedimentary rocks of the Upper Nuwakot Group

The steeper,more rugged Mahabharat Range rises above the gentler slopes of the midlands

of the Lesser Himalaya (middle mountain). The MBT dips at 40-70° towards the north. It is conspicuously marked in aerial photographs and is well exposed in many places. In places it is cut by several NE-SW trending transverse faults.

Mahabharat Thrust (MT)

The MT nowhere appears as a clear-cut break like the MBT, but rather as a narrow transitional zone displaying reverse metamorphism. The underlying low-grade metamorphic rocks (quartzites and phyllites) of the Nuwakot Complex rapidly pass upwards into the overlying high-grade metamorphic rocks (garnetiferous schist) of the Kathmandu Complex[3]. The zone is characterised by coarse-grained garnetiferous schists that appear as cataclastic gneiss[4], due to the intense shearing and mylonitisation[5].

Main Frontal Thrust (MFT) or Himalayan Frontal Thrust (HFT)

The MFT dips north and brings the Siwaliks above the Terai plain. The Thrust plane can be traced out most easily in the Kailali and Koshi areas. This thrust is seismically very active.

Mahabharat Synclinorium

The Mahabharat synclinorium[6] consists of a huge, doubly-plunging syncline and numerous smaller anticlines[7] and synclines[8] trending WNW-ESE. Both the flanks are steep (dip >60°). Kathmandu valley forms the core of the synclinorium, which extends southwards as far as Hetauda. The northern flank (which extends to Trisuli) is generally steeper, in places almost vertical or even slightly overturned. The synclinal closure is perfectly developed in the western area (where it ends at Kuringhat), but in the east the

[1] Nappe is a French geological term that 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.

[2] A klippen is a series of nappes, and is also a term derived from Alpine geology.

[3] In general, low-grade metamorphic rocks were formed under conditions of low temperature and strong pressure, especially stress; high-grade metamorphic rocks were formed under conditions of high temperature and high pressures, especially hydrostatic.

[4] Cataclasis is a process of dislocation-metamorphism where bands are formed through the distortion of minerals within the rock.

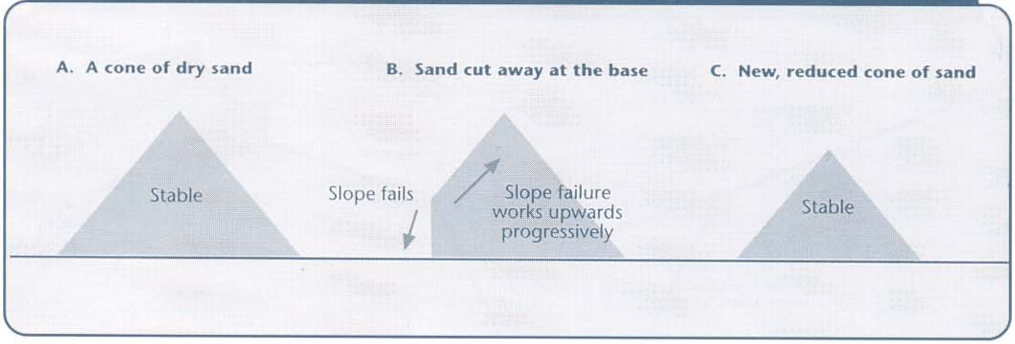
[5] Mylonite is a fine-grained rock formed through extensive cataclasis.

[6] A synclinorium is a huge trough, in form resembling a syncline, each limb of which consists of a number of small folds.

[7] The arch or crest of a fold in rock strata.

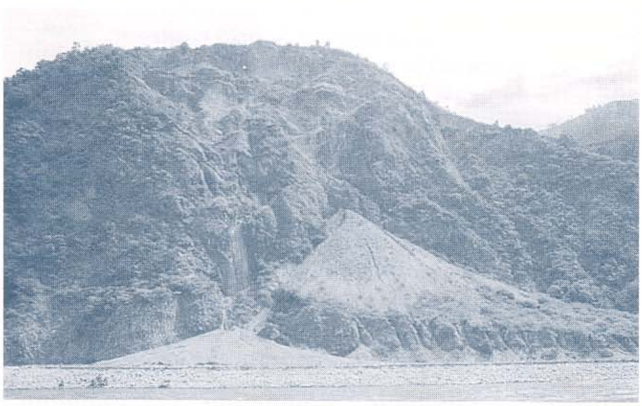
[8] A syncline is the trough or inverted arch of a fold in rock strata.

Figure 2.4: Slope evolution with the analogy of a pile of sand



synclinorium narrows down to the single long-stretched syncline of Sindhuli Garhi.

This assessment of the geological zones and structures shows how the mountains come to be there. The next section looks at the way that the rocks are being carved by water and gravity into the complex system of slopes, valleys and ridges which cut across these features.



Many landslides result from a complex mix of erosion and deposition processes. Successful treatment relies on a good understanding of the various processes at work on the site

2.2 THE EVOLUTION OF MOUNTAIN SLOPES

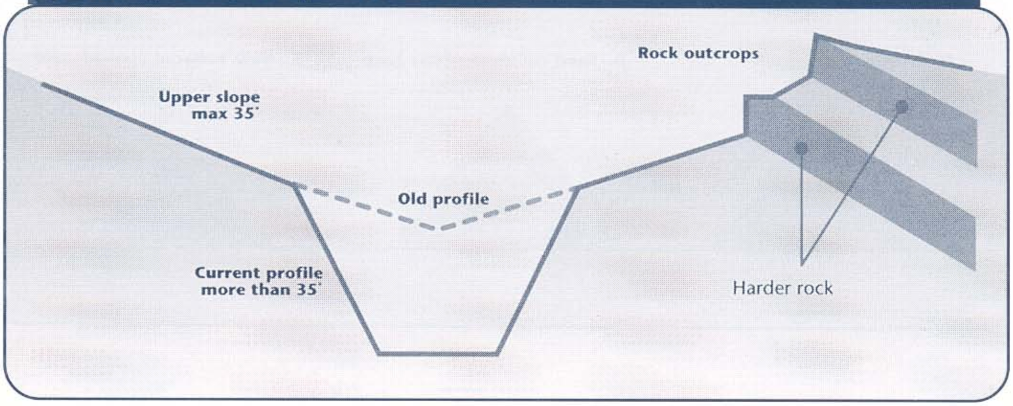
Few people appreciate the far-reaching effects that geomorphic (land-forming) processes have upon all aspects of land management in Nepal, especially highway engineering. This section describes briefly why the mountains are so unstable, and why roads can so easily trigger slope failures, with particular reference to the main middle mountains.

Within the major geological sub-divisions of the Himalayas, numerous geomorphological processes are at work. While movements of the continental plates are creating mountains, other forces of nature are wearing them down again. This is a constantly evolving pattern, and it is important to understand that any form of infrastructure built on mountain slopes will be subjected to damaging forces.

One of the major effects of the continental collision and the faulting and folding of great masses of rocks as a result, is that the rocks have been badly disturbed. They have been distorted, weakened and fragmented. Geological changes take place over a very long period, so that adjustment can take many thousands or even millions of years. When we look at a mountain, we see something which appears solid and permanent; but in geological time it is a temporary feature in the process of formation and removal.

The Middle Mountains consist of long slope components, separated by major breaks of slope. Ignoring irregularities produced by natural slope variation and rock outcrops, the slope components between the main breaks are almost straight. This fact is more obvious if the slope is viewed from a distance of a kilometre or more.

Figure 2.5: Typical major valley cross-section



The reason for this is that they are constantly and rapidly having to adjust to the effect of undercutting at the toe by streams.

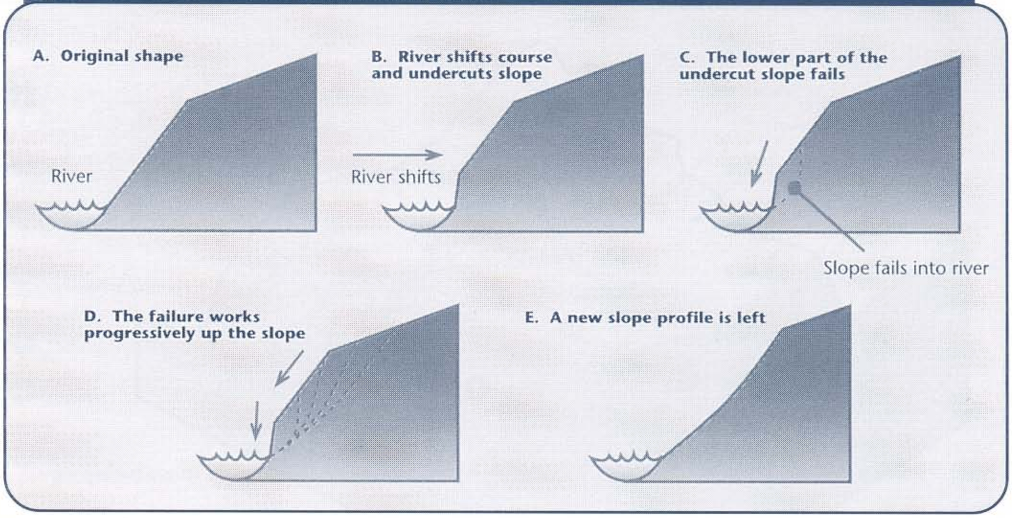
A simple analogy to explain this is a pile of dry sand. In its undisturbed state the sand forms a cone, but if the toe of the cone is scooped away, slope failure occurs and travels upwards from the base towards the apex (see Figure 2.4, page 49). The failure plane is a straight slope, parallel to the cone surface. If scoops are removed from the base of the cone regularly round the circumference, the cone will become covered with failures. Irregularities will develop on the side slopes depending upon whether the local slope is original surface, moved material, or headscar. But overall the straight-sided shape will persist. Eventually, if sufficient scoops are removed, the sand pile will become lower, though the angle of the cone will remain constant and the sides will remain straight.

The mountain slopes have developed in much the same way. The original straight-sided form was established long ago in the geological past by rivers as they cut down into the rising mountain chain. Uplift continues even today (through the mountain-building processes described in section 2.1), and downcutting in the valleys is still active (see Figure 2.5). The effect of river downcutting is to undercut the hillslope and leave the base unsupported, causing slope failure. The slope above the headscar now becomes unsupported, and in time this too will fail, and the landslide steadily elongates uphill.

The tension in the slope is indicated by cracks in the ground above the headscar. If the slope is near its critical angle of stability, a minor disturbance at the base can cause shallow slope failure to occur for many tens of metres above. Rock structure and the presence of springs create numerous points of local instability on the ridge flanks. Bedding planes and joint planes that are oriented roughly parallel to the hillside form inherent slide surfaces that readily shed their overburden of weathered material. Springs create very weak zones in the soil layer that slump out and leave the slope above unsupported. These local processes continue alongside the longer-term and more widespread process of slope reduction by landslides working uphill from the valley floors (Figure 2.6). The middle mountains region has evolved so rapidly that most slopes can be considered to be near their critical angle of stability. In this meta-stable state, only very minor disturbance may be required to destabilise them. Many Churia slopes are the same, but the less consolidated materials are even more fragile.

How is it that the mountains of the Himalayas, which are composed of rock, can be compared to a pile of sand? The answer lies in the weatherability of the rocks. The mountains consist for the most part of metamorphic and poorly consolidated sedimentary rocks. All are highly folded, which has produced numerous cracks (joints) throughout the rock mass. The monsoon rains, coming at the hottest time of the year, create a highly active chemical weathering environment, which vigorously attacks the rock fabric to a depth of several metres. Water penetrates all the joints and micro-fractures in the rock. The minerals, which in many cases have a

Figure 2.6: Evolution of a slope undercut by a river



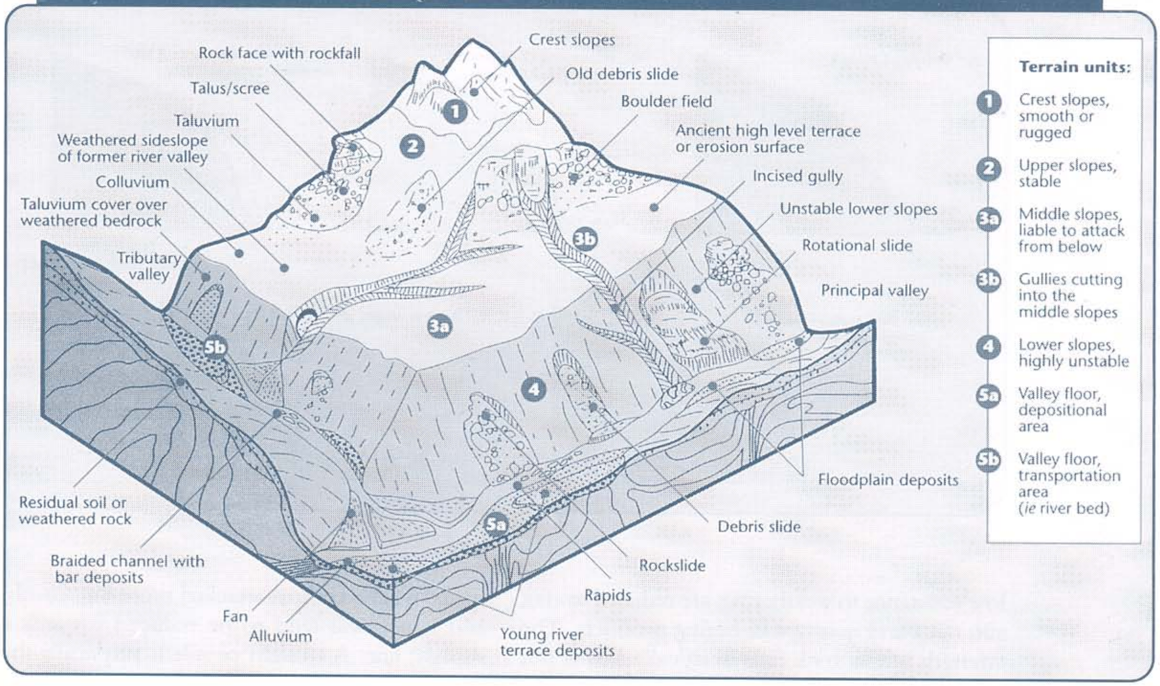
low resistance to weathering, are reduced to clay, silt, mica and quartz weathering products. The strength of the rock falls drastically and is not helped by the closely-spaced fracture planes. The weathered layer is not able to avoid shearing when part of the slope is over-steepened. Landslides on a hillslope tend to advance headwards until they run out at the top of the slope (Figure 2.6e).

Mountain slopes rarely achieve a truly straight profile because of variations in rock type, structure and weathering environment. But any 'high spots' will tend to be attacked more vigorously, and hence will tend to be reduced towards a straight line. A straight profile is physically the most stable configuration. Of course, there are many places where hard rocks resist the 'straightening' process and stand out as outcrops or major breaks in slope. The quartzites found in the Mahabharat Range are examples of a strong and chemically very stable rock that forms major ridges. But it is also highly fractured and brittle, which gives it poor resistance to earthquakes.

After a slide, the weathered layer quickly forms

Relatively gentle outwash fans remain stable long enough for elaborate agricultural terrace systems to be created

Figure 2.7: Schematic cross-section of a typical mountain-valley slope in the middle mountains



(After Fookes et al, 1985 and Transport Research Laboratory 1997).

again. The exposed head scar and slide plane commonly consist of partially weathered rock. These become subjected to weathering until a debris layer builds up, ready to fail when the slope is disturbed once more. The hillslopes gradually become covered in a mantle of soil and partially-weathered rock debris up to a few metres deep. Dormancy may last for a few years or a hundred years: some slides are continually active for many years and never seem to recover. Over thousands of years so many landslides occur that they begin to join up, to a point where almost no slope remains that has not slipped at some time in the past.

The final element in the evolution of mountain slopes is time. If river levels remain static for a long period (many thousands of years) the slope angles will be reduced to gentler grades and the whole landscape becomes more stable. The history of Himalayan geomorphology is one of a continuous succession of periods of rapid downcutting, alternating with static periods when a certain amount of adjustment towards a more stable state was achieved (*i.e.* slope angles had been reduced). In the present landscape of the Middle Mountains, five principal slope elements can be identified, from the ridge crests at about 2000 metres to the major river beds at about 500 metres (Figures 2.7 and 2.8). Recognising them in the field gives the observer an immediate impression of whether geotechnical problems are likely to be awesome or merely moderate.

2.3 SLOPES AND ROAD ENGINEERING

The role of vegetation and small-scale engineering works could be questioned in the face of the regional mass movements that are the essential feature of Himalayan geomorphology. It is true that for deep failures and major landslides, such methods are inadequate for slope control. But much of the instability is shallow-seated, and much begins in a small way and spreads only if unchecked. These sites can be stabilised with low-cost methods, and if a road is located on a fairly stable alignment it should be possible to maintain the stability with minimal investment.

The five terrain units in Figures 2.7 and 2.8 have very different stability limits, and each has its own range of typical failure mechanisms,

Figure 2.8: A generalised slope model for the middle mountains, with instability types

Terrain unit	Slope (approx.)	Type of mass-movement	Mechanisms and agencies controlling failure	Engineering features and low-cost remedial treatments
1 Ridge top (a) Hummocky crest	15°-45°	Erosion	Gully erosion in deep, cohesionless soils. Erosion on overgrazed slopes: piping.	Unstable ground usually easy to avoid. Arrest erosion in shallow gullies with small atchments with check dams or by backfilling with rubble. Stabilise eroding slopes with bio-engineering methods. Protect slopes below culvert outfalls.
(b) Rock ridge	45°-90°	Plane failure in rock	Gravitational displacement of steep rock with near-vertical or steeply inclined planes of discontinuity, weakened by weathering.	Avoid unnecessary disturbance by hand excavation. Blasting is not recommended, as it will cause rock joints to open further. Clear loose blocks from face.
2 Upper slope (not always present)	15°-25°	Gully erosion, rotational slips, piping	Stream erosion in deep, cohesionless soils, often deforested but grassy. Small rotational slips occur on the steep gully sides forming accumulations of debris that move downhill as earthflows in the gully bed. Piping occurs at the interface between granular soils and less-permeable lower layers.	Unstable ground usually easy to avoid. Arrest further erosion with horizontal vegetative methods. Provide culverts with energy dissipaters to protect outfalls. Rubble may be laid to load toes of *small* rotational slides on gully flanks. Larger slides may prove impossible to stabilise cheaply and should be avoided.
3 Mid slope (a) Slope	20°-30°	Gully erosion	Generally stable but uncontrolled irrigation waters can create problems. Large scale gully erosion, once started, is difficult to arrest with consequent loss of agricultural land.	Bare slopes can be stabilised with bio-engineering methods. Cross drainage should incorporate irrigation requirements for local farmers.
(b) Valley	20°-30°	Gully erosion advancing into large 'valley catchment' slips (with subordinate surface creep, rotational slips and earth flows)	Streams can set up gully erosion that advances headwards into slope. Stream banks are subject to rotational slips.	Cross at most stable situation, utilising solid rock outcrops to key foundations. Culverts need to be correctly designed, equipped with debris racks to avoid blockage, and energy dissipaters to protect culvert outfalls, carried a long way down slope.
4 Lower slope (a) Slopes on debris and completely weathered rock	30°-45°	Active debris slides and erosion (may advance uphill into mid-slope)	Oversteepening of slope caused by rapid dissection of river valleys in recent geological past. Combination of steep slopes, large water catchments and dormant landslips creates many unstable situations.	Avoid active and dormant landslides if possible. Seek stable slopes and excavate minimally, taking utmost precautions to dispose of spoil. Provide adequate cross drainage measures as above.
(b) Hard rock	45°-75°	Rock falls Rotational slips.	Gravitational displacement along steeply inclined rock planes. Weak metamorphic rocks can become saturated and fail rotationally.	Avoid overblasting of solid rocks. Avoid wet, weak metamorphic rocks.
5 River Valley (a) Terrace	Top 0°-15° Sides 25°-50°	Erosion and piping Rotational slips Collapse failure	Unconsolidated, layered terrace deposits of different ages are susceptible to erosion and river scour at base. Some piping occurs.	Avoid areas of sub-surface seepage and piping.
(b) Flood plain and river bed	0°-5°	Scour	Heavy stream flows in monsoon shifts gravel bars and wears away river banks.	Avoid except for bridge crossings.

although all mechanisms do occur on all units except 5(b).

- Unit 1, the ridge top, may have steep and unstable sides, and would normally be avoided altogether except when crossing over to the opposite hill flank.
- Unit 2, the upper slope, is the most stable as it consists of short, moderately-angled slopes. But it is not always present in the landscape, and if present, is vulnerable to encroachment from below by failures on Unit 3 or Unit 4 slopes.
- Unit 3 slopes are reasonably stable but are often wet and often affected by instability from cross-cutting valleys (3b) or from Unit 4 slopes below. Soils are usually several metres thick. Unit 3 slopes usually present large, more or less continuous areas for exploitation by road alignments to traverse or climb.
- Unit 4 slopes consist mostly of old landslide scars and are usually highly unstable. They are mantled in landslide debris and have many rock outcrops: they are not farmed but are covered in forest or degraded forest. Road alignments should be kept to a minimum on these slopes, although individual hill spurs have of necessity to be used for stacked loops to pass from Unit 3 to the valley floors. Good alignment of the road is of paramount importance, avoiding the worst areas at all costs. When the alignment is settled, design and construction of the cut section, drainage works and slope protection must be carried out with the utmost care.
- Unit 5 slopes, the terraces and valley floors, present few serious hazards to engineering apart from flooding and scour from the river. But terraces rarely afford exploitable routes because they are invariably discontinuous along the valley, cut off by the main stream as it swings across the valley from side to side.

The road at Anboo-Khaireni crosses the base of a semi-stable colluvial slope

2.4 ENGINEERING GEOLOGY

The next stage in understanding the characteristics of mountain slopes is to examine the rocks themselves. The strength and other characteristics of rocks also determine in part the nature of slope failures, and the ways in which we need to treat them.

The main types of rocks

Rocks are divided into three principal classes, as follows.

Igneous rocks
Rocks that have solidified from molten or partly molten material originating from a magma[1].

Sedimentary rocks
Rocks resulting from the consolidation of loose sediments, or from chemical precipitation from solution at or near the earth's surface.

Figure 2.9: The main rock types of the Lesser Himalaya (Middle Mountains).

IGNEOUS ROCK	SEDIMENTARY ROCKS	METAMORPHIC ROCKS
Granite	Mudstone	Slate
	Shale	Phyllite
	Siltstone	Schist
	Conglomerate	Gneiss
	Sandstone	Quartzite
	Limestone	Marble
	Dolomite	

[1] Magma is 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.

Figure 2.10: Diagnostic properties of the main rock types of the Lesser Himalaya (Middle Mountains)

ROCK TYPE	MAIN DIAGNOSTIC FEATURES
Igneous rock Granite	Hard, coarse, grainy texture, mixture of essential minerals of quartz, feldspar and mica (muscovite and biotite); no cementing material
Sedimentary rocks	
Mudstone	Clay minerals, massive (no lamination), smells like mud and is soft enough to be scratched by a fingernail
Shale	Like mudstone, but is formed from laminated layers
Siltstone	Silt size minerals, sharp edges, shining with mica flakes
Sandstone	Sand size grains held together by a cementing material, scratches a hammer or knife (*i.e.* it is harder than steel)
Conglomerate	Distinct rounded to subrounded fragments of grain to pebble size, held together by a cementing material
Limestone	Mostly grey, fine to crystalline variety, can be scratched by a hammer or (knife), effervesces strongly on the addition of dilute hydrochloric acid (HCl); used for road ballast and concrete; the raw material of cement
Dolomite	Similar to limestone, but the addition of dilute HCl gives effervescence only when it is in powder form (*i.e.* a feeble effervescence); used for road ballast and concrete
Metamorphic rocks	
Slate	Dark grey, thin foliation (splits easily); used for roofing and formerly for writing
Phyllite	Foliated (less perfectly cleaved than slate), light grey, clear joint set, small secondary quartz grains, dark minerals
Schist	Foliated, with an undulating or bulging surface (flow cleavage) due to mineralisation, coarser grain size than phyllite
Gneiss	Alternate bands of light (quartz, feldspar) and dark minerals of fairly coarse grain, highly foliated; used as the grinding stone in water mills
Quartzite	Banded, hard (scratches a hammer or knife; *i.e.* it is harder than steel), mostly consisting of mineral quartz, no cementing material; when struck by a hammer, it gives a metallic sound; used for slabs
Marble	Crystalline (sugary texture), effervesces highly on the addition of HCl; used as a facing stone

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.

Most of the mountain roads of Nepal pass through the rocks of the Sub-Himalaya (Siwalik or Churia) and Lesser Himalaya (Mahabharat Range and Midlands).

The main rocks of the Sub-Himalaya are all sedimentary, and consist of mudstones, sandstones and conglomerates.

The main rocks of the Lesser Himalaya can be sub-divided among the three classes, as shown in Figure 2.9. The diagnostic features of each are given in Figure 2.10.

Principal mineral groups in rocks and their weathering

Minerals are naturally occurring crystalline chemical compounds. Rocks are aggregations of minerals.

The mineral constituents of a rock may have very different chemical compositions and properties. For example, a fresh gneiss sample may contain the following mineral groups:

- dark minerals;
- light minerals (milky);
- dark mica;
- white or light mica (platy, translucent);
- quartz (sugary, translucent but can be milky).

Rocks are affected by weathering. Weathering is defined as *'the physical and chemical alteration of minerals into other minerals by the action of heat, water, and air'* and takes place constantly in nature. Higher temperatures and water contents increase the rate of weathering: when these occur at the same time, as they do during the summer monsoon rains, the rate of weathering can be relatively rapid.

A weathered rock sample will show some or all of the following features:

- softness (*i.e.* minerals can be rubbed off by hand);
- discoloration;
- loosening of grains;
- intact white mica;
- intact quartz.

The relative order of susceptibility to chemical weathering in the common mineral groups

Figure 2.11: Rock weathering grades

Weathering grade	Description
1a	Fresh rock. No visible sign of weathering. Rings when struck with a hammer.
1b	Faintly weathered. Discoloration on major joint surfaces. Rings when struck with a hammer.
2	Slightly weathered. Discoloration of all discontinuity surfaces or throughout rock. Rings when struck with a hammer.
3	Moderately weathered. Up to 50 percent of rock material decomposed and/or disintegrated to soil. Rock can be a continuous mass, or core stones. Rings when struck with a hammer.
4	Highly weathered. More than 50 percent of rock material decomposed or disintegrated to soil. Rock mass is discontinuous.
5	Completely weathered. All rock material decomposed and/or disintegrated to soil. Original mass structure still largely intact. Gives a dull thud when struck with a hammer.
6	Residual soil. All rock material converted to soil. Mass structure and material fabric destroyed.

Source: Geological Society Engineering Group Working Party, 1977. The description of rock masses for engineering geology. *Engineering Geology* 10 (4): 355-388.

is as follows:

- dark minerals — Least resistant to weathering (*i.e.* these weather the most)
- light minerals
- dark mica
- white mica
- quartz — Most resistant to weathering (*i.e.* these weather the least)

This means that a careful investigation of the minerals of a rock, and the degree of weathering to which they have been subjected, can reveal considerable information about the inherent strength of the rock. In a site investigation, this is valuable information in predicting possible slope instability. A hand lens is used to investigate the condition of the minerals.

In a soil, weathering has proceeded much further and the following features may be observed:

- particles are much smaller;
- clay minerals (fines) are present: these are new minerals derived from the weathering products of rock;
- quartz and white mica remain, as they are the most resistant to weathering.

The most intensively weathered soils are rato mato, the red clay loams found in many parts of the Middle Mountains, usually at lower altitudes. These are very old, probably greater than 100,000 years, and indicate a landform which is, or must have been, relatively stable if it has permitted such prolonged weathering.

The overall effect of weathering is to soften and weaken rocks. Many rocks have been weathered so much that in engineering terms they are described as 'residual soils'. The most common of these are the soft rocks (phyllites and gneisses), which are found throughout the middle hills. Since these characteristics are universal, a standard classification system for rock weathering can be used, as given in Figure 2.11. Because of the geological disturbances of Himalayan mountain building, it is relatively rare to find rocks of weathering grade 1 in Nepal.

The degree of weathering of the rock often controls the strength of the rock. A highly weathered rock may fail through the rock body rather than along the joints or fractures (see next section). However, rock strength is due to both:

- the degree of weathering of the body of the rock;
- the spacing and weakness of fractures.

Rock fractures

Fractures are an important feature of many rocks. Most fractures are approximately parallel to each other and constitute what is called a 'set'. They may be closely or widely spaced. Most rocks contain several fracture sets. The presence of fractures is the main cause of failure of rock slopes.

Note that rocks may split:

- along widely-spaced planes, following the grain of the rock;
- along many closely-spaced planes, following the grain of the rock;
- across the grain of the rock at a regular spacing and orientation: these fractures are called joints[1].

The grain of the rock is caused by layers of minerals, in different proportions or of different textures.

Friction along the interfaces between the blocks governs the shear strength of the rock. Shear strength is reduced when contact along the interfaces is lost.

Rock strength is related to the number and weakness of fractures. Open-jointed rocks are very weak because:

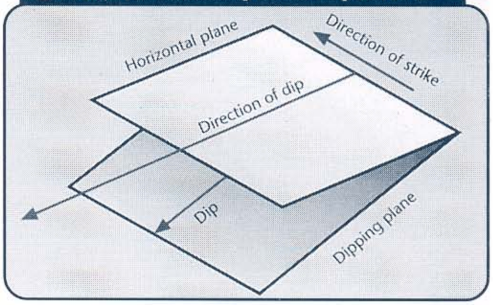
- water movement and weathering take place preferentially along the joint planes;
- there is a loss of frictional resistance along the interfaces.

Strong rocks have fewer fractures, or have closed and cemented fractures.

In sedimentary rocks, there is usually one set of joints parallel to the dip and another parallel to the strike. The dip is 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°. It is always written as a 3-figure number, *e.g.* 048, to distinguish it from the inclination, which cannot exceed 90°. A reading for the angle of dip which appears to be greater than 90° means that the slope is in fact dipping in the opposite direction. Conventionally the bearing of dip is written first, followed by the angle, *e.g.* 115/35.

[1] Joints are 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.

Figure 2.12. The relationship between dip and strike



The strike is the horizontal line contained in the plane of bedding, foliation, or jointing. It is perpendicular to the dip, just as a contour is to the maximum slope of the ground. The bearing of strike is measured with a compass. The figure is always given as a reading less than 180°. In practice strike is measured first because a horizontal line needs to be established in order to find the maximum inclination of the dipping plane. A dip of 115/35 would have a strike of 025°. This is shown diagrammatically in Figure 2.12.

Measurements of the dip and strike of rock joints and other fractures are a necessary part of detailed field site assessments in steeply sloping terrain. When combined with measurements of slope, they can provide useful information on the stability of the slope. Figure 2.13 shows examples of the relationship between the slope and discontinuities. Certain types of failure, such as translational landslides, are sometimes directly and clearly related to the slope and a major discontinuity such as a weak bedding plane being sub-parallel. Where there are several significant planes of discontinuity, such as two intersecting joint planes, wedge failures can occur; but

Disturbed rocks are very common and fractures are frequently visible, as on this gueiss in Eastern Nepal

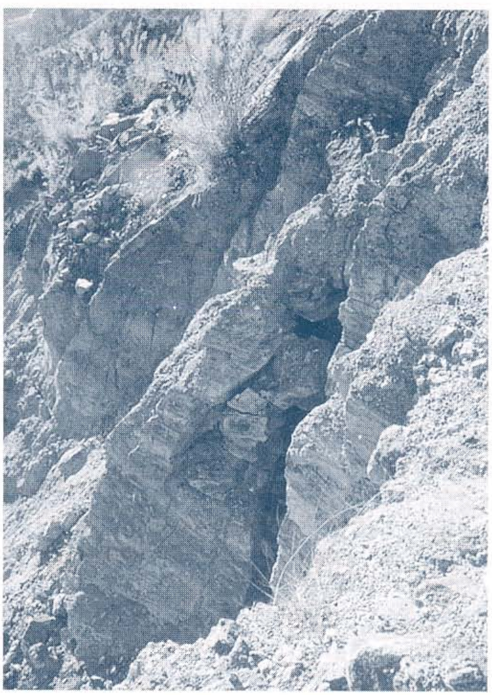
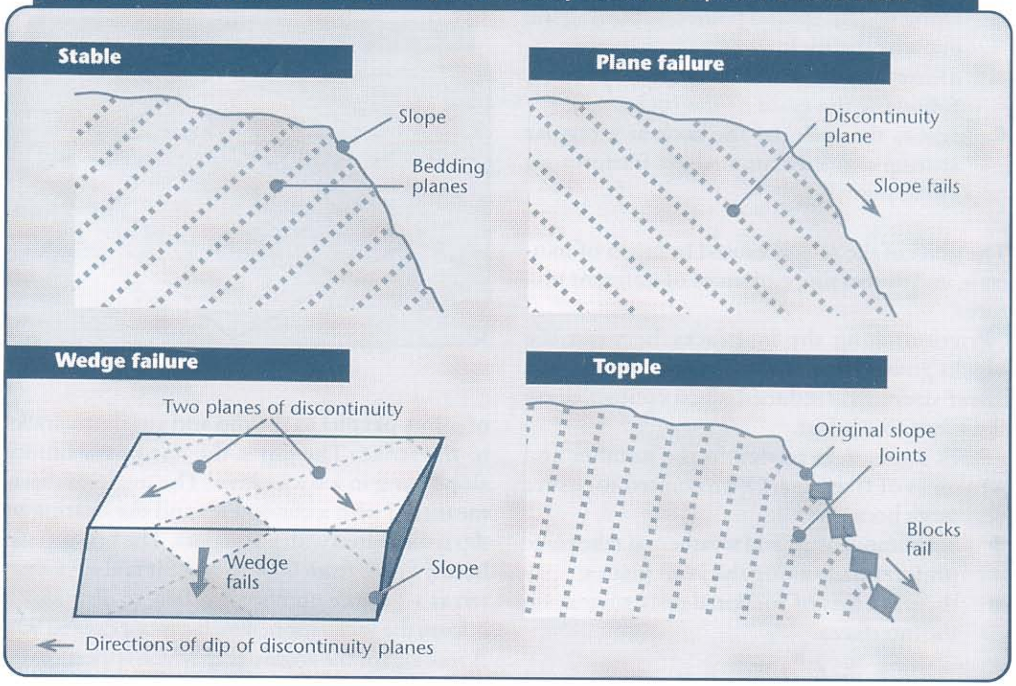


Figure 2.13: Examples of structural stability and instability related to slope and discontinuities



these are not so clearly visible in the field.

A useful way of plotting potential slope instabilities on the basis of field investigation is through the use of stereographic projection. This determines the angular relationship between planes in a slope, and clearly shows either why a slope has failed, or whether it is likely to fail in the future. This method is described in the ICIMOD *Mountain Risk Engineering Handbook*[1].

2.5 SOILS AND MATERIALS

In some locations, the rocks forming the original slope have been altered, disturbed and mixed so much that they have lost most of their original characteristics. The result is a material, which in engineering terms can cover anything not defined as a pure rock. Some materials have been altered sufficiently to be classed as a soil[2]. Whatever their state, all soils and altered materials have their own characteristics when subjected to geomorphological processes. For this reason, they must be examined separately in any consideration of slope stability.

Considering the topographic variations, there are relatively few distinct soil types in the Sub-Himalaya (Siwaliks) and Lesser Himalaya (Middle Mountain). This is because slope movement usually prevents the continuing development of soil profiles in any one place. Rocks break down under sub-tropical weathering into their constituent minerals and immediately begin to move downhill. The constant movement prevents a mature soil profile from developing: instead, the mineral particles become thoroughly mixed and produce a soil that typically consists of fragments

[1] Deoja, B, Dhital, M, Thapa, B and Wagner, A. 1991. *Mountain Risk Engineering Handbook: Part I, Subject Background*. International Centre for Integrated Mountain Development, Kathmandu

[2] Soil may be defined as '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'.

Figure 2.14: The main soil-forming factors

Soil-forming factor	Effects on soil development
Parent material	Parent material is the starting ingredient from which a soil develops. It is made up of minerals from degrading or deposited rock debris, and organic material derived mostly from plants. A study of the underlying strata does not always determine the main mineral composition of a soil, especially in the case of soils on active alluvial plains. Soil chemistry tends to be dominated by the mineralogy of the rocks forming the main part of the parent material. For this reason the plant-growing character of many soils is often governed by the original composition, especially the degree of acidity or alkalinity.
Climate	Climate governs the type and rate of soil formation, and the type of vegetation that can grow in the area. In general, warm and humid soils develop faster than dry or cold ones. This is seen in Nepal by the darker soils at higher altitudes, where cooler temperatures slow down the decomposition rate of organic matter and improve the soil in a number of ways. At the warmer, lower altitudes, the release of plant nutrients from both mineral and organic constituents can be very rapid during the monsoon. The climate also determines the micro-climate in the soil voids, greatly affecting the extent of microbiological activity. The result of these differences in Nepal is that at higher altitudes soils can be more fertile, better to work and more resistant to erosion. Despite this, the warmer climate at lower altitudes allows faster bio-chemical processes, so that plants still grow faster despite lower soil fertility.
Organisms	The organisms affecting soils can be classed as: higher plants; vertebrates, particularly mammals; micro-organisms (bacteria, fungi, algae, etc); mesofauna (worms, insects, etc.); and man. In general, the plants cycle matter from the soil and harness other matter from the atmosphere, while the animals alter it within the soil. This usually forms a very complex symbiotic relationship, whereby both plants and animals can live together in a mutually beneficial way. In newly developing soils, such as those common in Nepal, the system is very dynamic and has often not reached an equilibrium.
Topography	Topography is a significant determinant of geomorphology. This has been examined in considerable detail in relation to Nepal in the sections above. It includes important considerations such as the length of time in which soil development can take place in a given location; whether material is being removed or deposited; and so on.
Time	Soil formation is a slow process, especially in cooler locations. Some soils, such as **rato mato**, have taken many thousands of years to develop. Time also accounts for changes in the soil, which occur as a result of the interactions of the other factors.

of rock in a silty matrix of low plasticity. The resulting mixed soil without horizons (layers) is called colluvium. Plasticity is low because although weathering may have been rapid enough to break the rock down, it has not continued for long enough to reduce the weathering products to plastic clay minerals. Because the fragments are angular and the matrix lacks clay, colluvium is very permeable. This makes it very susceptible to infiltration and liquefaction during heavy rain, and therefore any attempt to stabilise a slope composed of this material must consider its likely behaviour carefully.

In the process of downhill movement, the fragments from the parent rocks also become mixed together. The fragments found in a soil thus may come from one parent rock, or from rocks of quite different type, depending on the outcrops on the slope above. Rocks rich in quartz tend to produce sandy soils. Metamorphosed sandstones produce a sandy, silty soil containing coarse, hard, irregular pieces of the original rock. Platy, splitting rocks such as phyllites weather to a finer material, but the derived soil usually also contains fragments down to a few millimetres in size of unweathered or partially weathered phyllite. Most rocks contain some light mica, which remains unweathered in the soil profile, though it breaks up into tiny particles.

The action of movement downhill causes stones to rub against each other, rounding off the corners, but the fragments in colluvium retain a noticeably angular shape. Debris flows (wet, flowing landslides) hasten the process of rounding and produce soil particles of wide size ranges, varying from boulders down to fines, all mixed together.

When colluvium reaches the valley bottom it is moved along by the river. The material becomes separated, the fines moving in suspension and the larger fragments rolling and bouncing along the river bed. If this material is deposited, it is called alluvium. The movement by water is much more dynamic than steady movement down hill, causing:

- separation of the particles according to size;
- breaking of the weaker rock fragments such as phyllite and highly weathered gneiss;
- rounding of the harder fragments (boulders, cobbles and gravels) to a spherical shape.

The most noticeable and easily recognisable characteristics of alluvium in mountain valleys are that:

- the fragments are clearly rounded, many almost spherical;
- it has a sandy texture and lacks fines;
- it usually shows signs of horizontal layering, due to steady deposition as the river flow rate declines after a surge.

Alluvium often contains fragments of weak rock and weathered rock. As mentioned above, these are quickly broken up during transport. Their presence in an alluvial deposit therefore indicates that the material has only recently been introduced into the river bed and has not travelled very far or been travelling for very long. Alluvium that is rich in such fragments cannot be used in engineering construction. When an alluvial deposit is selected as a source of material for crushing as aggregate, the hard cobbles often have to be picked by hand out of the river bed.

The rounded nature of the coarse fraction of river deposits generally makes them suitable for aggregate only after crushing, to increase their angularity and mechanical interlock. The presence of mica in the sand fraction can weaken concrete. Sand selected for high strength concrete, for example in bridge works, often needs to be washed to remove the mica.

Slopes cut through unconsolidated alluvial deposits can be highly unstable and very difficult to treat. This accounts for many intransigent stability problems in coarse Churia deposits.

Soil formation and soil types

An understanding of the development of soils is essential when examining the landscape and the kind of plants that will grow in it. Soil is the mixture of organic and mineral elements that forms at the surface of the Earth. It is essentially a living entity, since it contains many living organisms, especially microscopic ones, and it changes over time as a result of the influences working on it. One definition of soil is: '*soil is the space – time continuum forming the upper part of the Earth's crust*'. This apparent lack of specificity emphasises the fact that soil is infinitely variable and changeable. A more thorough definition is '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'.

Soils are formed from the interactions of five series of factors: parent material, climate, organisms, topography and time. These are explained further in Figure 2.14.

The soils of Nepal tend to be dominated by the effects of the extreme topography of the mountains, including their downstream effects on the piedmont alluvial plains. Some soils have been further developed by terracing, whether for dry farming (bari) or paddy farming (khet).

Mountain soils are affected most by the slope processes. On steeper slopes they are generally colluvial in origin, whereas on gentler slopes they may have developed from *in situ* materials. The five main types of hillslope soils are described briefly in Figure 2.15.These are only the main soil types, however. There are innumerable variations among these, particularly as a result of the variations of climate and their effects on the moisture of the soils and the weathering and decomposition rates.

In valley bottoms, as well as in the Bhabar zone and the Terai, the soils are dominated by active alluvial deposition. The frequency of deposition has often been so great that the soil is composed of distinct layers ranging from a few millimetres to perhaps 0.5 metre in thickness. These can have very different properties, depending on the source of the main parent materials. It is common to find layers of fine silt above or below horizons of coarse sands and, in the mountains, even of large cobbles. Buried surface horizons are also common. These are distinguishable by a darker colour and the presence of decaying fibrous roots. They result from the burying of a layer which formed the surface for long enough for plants to grow and improve the soil slightly.

Because of the numerous layers in alluvial soils, the hydrology can be very complex at the micro-level. In the Bhabar zone in particular, there can be such localised variation that soil pro-

Figure 2.15: The main mountain hillslope soils (Mahabharat and Middle Mountain)

Soil class	Description
Forest soils	
Colluvial soils	Highly active soils on steeper slopes. Formed from parent materials derived from higher up the slope. Characterised by mixed particles of angular shape, uncompacted and highly porous. Usually have a relatively high proportion of stones. There are two main phases. (a) Transportational. These are formed on steep side slopes. They are generally thin and the material is in the process of moving down the slope. Some are completely skeletal in nature, such as recent landslide debris. (b) Depositional. These are formed in cones at or near the base of steeper slopes. They are much deeper, often five metres or more, but are so stony that they are often extremely dry and infertile despite the location (which would normally be considered moist and fertile). The accumulation of debris is often too rapid for a well developed topsoil to form. The stone fragments forming the bulk of the soil tend to be hard if they have been transported this far, and therefore are relatively resistant to weathering.
Well-developed hill soils	Stable soils on gentler slopes. Mostly free of stones and providing good rooting conditions to plants. There are three main phases. (a) Deep soils derived from the weathering of softer rocks *in situ*. Frequent on weathered gneisses and other soft rocks. The soil merges gradually with the underlying strata. The relative hardnesses vary laterally as well as with depth, and it is often difficult to distinguish between soil and weathered parent material. Often highly erodible. Usually a low stone content. (b) Soils derived from the weathering of harder parent materials *in situ*. Common on ridge tops and gentle spurs on quartzites and other hard rock types. They are shallower (often less than a metre in depth) and have more stones in the profile. Between the stones, however, the soil has a finer texture and is much better developed than colluvial soils. The transition to rock is clearly defined. (c) Soils formed on ancient river terraces or old erosion levels. Deep and relatively well developed, but the main soil parent material has come from up valley or up slope. A low stone content unless they have developed on a deposit of stony alluvium, in which case they can contain a high proportion of rounded cobbles.
Rato mato (literally 'red soil')	A reddish clay loam soil often referred to as a laterite (but not displaying the features of a true laterite, which has much higher contents of iron or aluminium oxides). Usually deep and stone free. Heavy and difficult to cultivate. Highly erodible. Clay caps tend to form if the soils are exposed to the sun through the removal of vegetation. Occur at low altitudes. Poorly developed topsoils. Despite the rapid erosion now common on many rato mato, these soils have been subjected to prolonged weathering and demonstrate the presence of a stable landform.
Agricultural soils	
Bari terrace soils	Soils that are frequently cultivated and which have been terraced. As a result of the terracing, the rooting depth is extremely variable. The topsoil is ploughed at least once per year and so it is normally loose and friable. Well aerated. Usually a relatively low organic matter content, although compost and straw is present in some.
Khet (paddy) terrace soils	Soils that have been terraced and are cultivated for at least one crop of rice per year. The prolonged flood irrigation means that they are poorly aerated and show signs of iron reduction (pale grey mottling). Textures vary, usually according to the characteristics of the parent material (*i.e.* they tend not all to be fine-textured as in the Terai). Some are cultivated in the winter for a dryland crop, and these tend to be better aerated and friable for part of the year. Generally higher organic matter contents than bari soils, as a result of greater compost and mull applications.

files only 20 metres apart are completely different. Layers of fine silt and clay can reduce water percolation through the soil, resulting in a localised perched water table. This can have a drastic effect on sensitive plants, particularly trees: a plantation can appear patchy as a result of this localisation, with some plants suffering waterlogging only metres from others that are healthy or even suffering drought stress.

Alluvial soils tend to be more fertile than hill soils. There is also a variation here, often related to the textural class, with the coarser soils being noticeably less fertile.

2.6 CLIMATE AND MOISTURE

In assessing sites for bio-engineering, the effect of climate on plant growth is fundamental. It is also a very localised phenomenon. An appreciation of climate can, in addition, provide further understanding of the potential frequency of slope failures and major erosion events.

The monsoon climate

The climate of Nepal is tropical monsoonal, except for parts of the north of the country that are in the rain shadow of the Himalayas, which have a cold semi-desert climate and which are not discussed here.

However, the national climate is modified everywhere by high relief. The local climate experienced by each mountainside is governed by four factors:

1. monsoon rainfall;
2. seasonal variations of temperature;
3. temperature variations due to altitude; and
4. local topographic influences (slope and aspect), which affect both temperature and rainfall.

Rain can occur as a result of several causes. Convection rain is usually the result of intense heating of the land; in Nepal, this gives rise to most of the pre-monsoon thunderstorms. Orographic rain results from a humid air mass rising over a mountain range. Cyclonic rain occurs where warm air is caused to rise through the convergence of air masses in a low-pressure area: this can occur outside the monsoon when the relics of tropical cyclones penetrate from the Bay of Bengal. Variations in monsoonal rainfall are often related to cyclonic depressions within the monsoon air. Frontal rain is less common in Nepal, since it usually occurs where a front of warm, moist air rises over drier, colder air; most of the movements of air masses are seasonal in Nepal, unlike the situation in more dynamic climates.

The tropical monsoon[1] climate is dominated by the summer south-west monsoon rains, which affect the whole of South Asia. It seems to be controlled by a seasonal shift of the westerly jet stream in the upper atmosphere: this moves to the north of the Tibetan plateau, usually in late May, in response to the increased heating during the northern hemisphere summer. The equatorial low pressure trough moves northwards at the same time, increasing in intensity by thermally-induced low pressure, which results from the heating of the land surface. This gives rise to an area of low pressure over northern India and Nepal, and allows moist, low level air to move from the south-west, off the Indian Ocean, under higher level easterly winds.

By the time it reaches Nepal, the rain-bearing wind has been deflected so that it approaches from the south-east, blowing in from the Bay of Bengal. It brings abundant rain from June until September. The duration of the monsoon and amount of rain varies across Nepal, the western one-third of the country being drier than the east. Monsoonal depressions move from SE to NW, on average at the rate of two per month, bringing heavier bursts of rain. The monsoon is longest and wettest in the far east of the country.

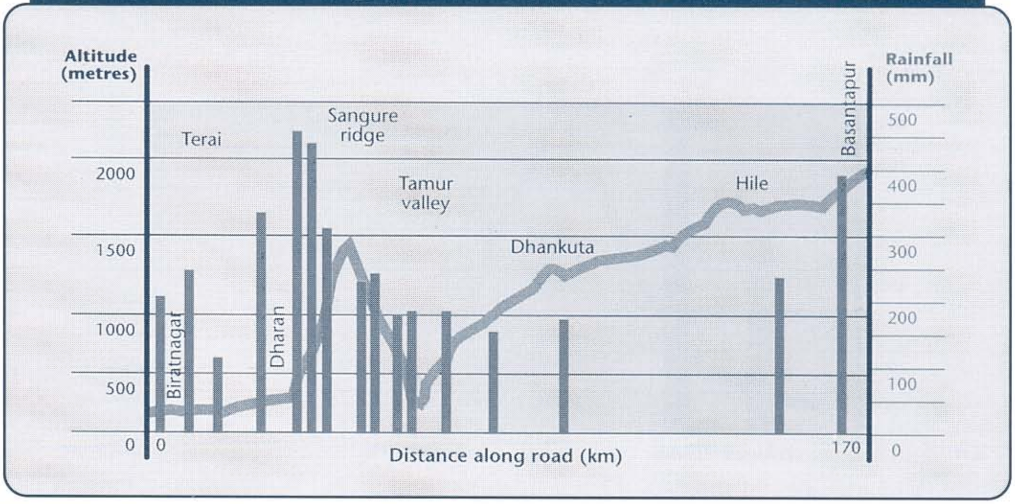
As the summer draws to a close and the area becomes cooler, the westerly jet stream re-establishes its southerly path, usually in October, restoring cooler conditions in the space of a few days. During the winter, the situation is dominated by high-level westerly winds. Air subsiding below these blows outwards from the continental interior of Asia. In Nepal, these appear as dry, cool, northerly winds, very light in the lee of the Himalayas. The dry months of the winter are often relieved in the west by showers that can provide up to one-fifth of the annual total: these originate in depressions from the west.

Rains outside the monsoon are much less likely to trigger slope instability, although there have been important exceptions to this rule, such as the disastrous debris flow at Bagarchhap in Manang District in November 1995. More important is the potential contribution of rainfall to plant growth. In cooler areas, there is sometimes enough winter rainfall to allow forestry planting during the dormant season, although this is rare on harsh bio-engineering sites. Pre-monsoon storms often allow established plants to start growing well before the monsoon sets in.

Heavy rainfall in November and December is rare. The monsoon itself is often preceded by thunderstorms during April and May which, although lasting for no more than a few hours, can be very heavy. The climate therefore shows a very marked dry season lasting from mid-October until May, during which plants in many locations experience severe drought. The total amount of rain, and the incidence of large thunderstorms, vary considerably from year to year.

[1] The name monsoon 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.

Figure 2.16: Comparison of terrain altitude and rainfall on the jogbani-Basantapur road



Although there are reasonably good rainfall records for Nepal, data for rainfall intensity are scarce.

Although it can rain continuously for days at a time, the monsoon is generally characterised by periods of rain lasting for a few hours, broken by dry spells of similar length. If the sky clears between showers, the heat of the sun can rapidly evaporate surface water. Half an hour of sunlight is often enough to dry a road surface and to bake a soft crust on exposed soil surfaces. Monsoon rain is often very intense.

The intensity of rainfall is very variable and poorly recorded. Short bursts of heavy rain appear to be common: rates of 100 mm/hr for five or 10 minutes seem to occur in many places each year. Longer bursts of heavy rain, such as 100 mm/hr for one hour are much less frequent. Rain of this intensity is very erosive, however, especially if the soil profile had already become well wetted. The burst of rainfall saturates the upper part of the soil profile, which liquefies and flows downhill in a destructive slurry.

Prolonged heavy rain storms, of the order of 200 to 300 mm/day for two days or more appear to occur almost every year somewhere in the southern Himalayas. It is these longer periods of rain that take the soil past saturation point and give rise to the biggest and most widespread slope stability problems. Guidelines for the estimation of these storms are available.[1]

On unprotected slopes, erosion can take place under almost any rain storm. The early rains are often the most damaging, however, especially when heavy storms occur early in the season, before plants have been able to establish. On freshly made slopes, poor compaction (usually due to a lack of water during construction) can give rise to loose, weak and highly erodible materials. This is why bio-engineering can play such an important part in protecting slopes.

Local effects on climate

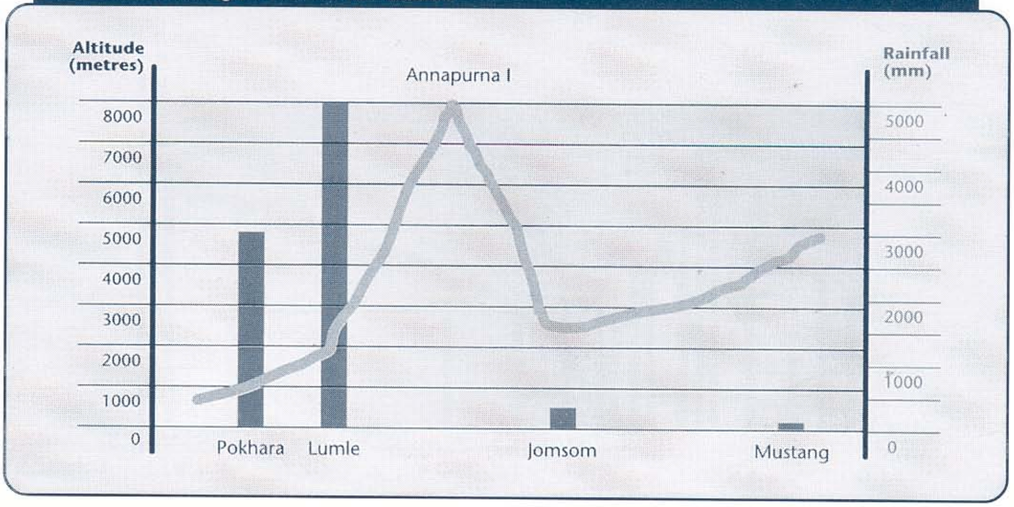
High relief and localised rainshadows greatly affect the distribution of rainfall, which varies considerably over short distances. An idea of the complexity is shown in Figure 2.16, which compares terrain altitude with monsoon (five-month) rainfall totals at 16 raingauge stations on the Jogbani-Basantapur road corridor in eastern Nepal.

Local climate is extremely difficult to predict because of the interaction of the dominating factors, and the extent to which their effects really are very localised indeed. The general pattern is that mountain ridges cause the rain bearing winds to rise and cool, allowing the moisture to condense and precipitate. Behind these ridges the air is more stable (until a higher ridge forces it to rise again): as a result, it rains less in these locations and forms a 'rainshadow'. At the same time, the steepness of the slopes means that sunlight is far more intense on some aspects than others.

The main factors determining site moisture and temperature are given in the paragraphs

[1] There is a chapter on this subject in TRL Overseas Road Note 16, *Principles of low cost road engineering in mountainous terrain* (chapter 8, *Hydrology and hydraulic design*, pages 82 to 96).

Figure 2.17: Schematic diagram showing the effects of the Annapurna Himal in Creating an extreme rain shadow



below, and summarised in Figure 1.16 (see p28).

Aspect. Aspect determines the amount of direct sunlight (insolation) that a site receives. There is a simplistic but frequently very clear distinction between south-facing (warm and dry) and north-facing (cool and damp) slopes. Slopes facing east and west are not quite so straightforward. In general, west-facing sites tend to be drier than east-facing sites. The reason for the main rule is that the air temperature is higher in the afternoon than the morning, and so there is more evaporation from slopes exposed to the sun at that time. Also, many areas have early morning mist, which reduces the effects of the sun. At low altitudes, however, east-facing slopes can be very dry. In areas of higher rainfall, the south-facing slopes tend to receive more rainfall during the monsoon, even if they dry out more during the dry season.

Altitude. Although the topographic environmental lapse rate[1] directly relates altitude to temperature, the relationship is complicated by air movements and ground warming. Even in the shade, southerly aspects can be warmer on sunny days than northerly aspects. The temperature affects the evaporation rate. Higher terrain is also susceptible to greater rainfall as a result of the orographic effects, and high ridges tend to be shrouded in clouds for lengthy periods. Hence ridges tend to have more moisture.

Topographical location. The location of any site on a major mountain slope has an effect on the accumulation and retention of moisture. Gullies and other areas where moisture tends to accumulate, and which are shaded for longer from the sun, tend to be damper than exposed spurs, ridges and steep side slopes.

Regional rain effects. In general, the east of Nepal is wetter than the west. This is apparently the case more in the hills than the Terai. The Terai weather stations show broadly similar rainfall levels across the country; the mean temperatures are also similar, but in the west the seasonal variation is greater, with hotter summers and cooler winters. This has the effect of causing greater drying during the later dry season. In the mountains the effects seem to be more pronounced, but this can only be inferred from the dominant vegetation types since the meteorological records are so localised. The Annapurna Himal, lying to the south of the main trend of the Himalayas, forms a major orographic barrier which causes greater rainfall in the area on its southern flanks.

Rain shadow effect. Rain shadow is the effect found behind major ridges. Moisture-laden air cools as it rises on the fronts of the ridges, so that the moisture condenses and precipitates out; behind the ridges, the air is stable and passes over with relatively little precipitation. This is very common throughout Nepal and can occur on a

[1] The topographic environmental lapse rate is the static reduction of temperature 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.

Figure 2.18: 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
Winds	Sites not exposed to winds	Large river valleys and the Terai
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
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, which produce a texture that is neither too gritty and loose nor too fine and clay, and is therefore conducive to plant growth.

range of scales. It can often be seen even on relatively small Churia ridges, but is much more apparent on the bigger lekhs of the Mahabharat and Middle Mountain formations. The extreme example is caused by the Annapurna Himal: Lumle, on the flank facing the rain bearing wind, receives an annual mean of 5,170 mm; Jomsom, about 70 km away in the lee of the massif, receives an average of only 250 mm per year. This is shown diagrammatically in Figure 2.17.

Winds. Winds are uncommon in the mountains except in the big river valleys. Here, during the afternoons, warm, dry winds tend to flow from the south, up the major river valleys. This is because the air warms in the sun but is laterally restricted by the valley sides; the result is a current generated which flows up the valley as an anabatic wind. In the Terai, warm, dry winds are common during the dry season, especially from the east. Both of these wind types can increase the evaporation significantly.

Stoniness and soil moisture holding capacity. The capacity to hold moisture is limited in many mountain soils by the high stone content. This reduces the pores in which moisture can be stored.

Dominant vegetation. This is a responsive, not determining factor. The main vegetation in an area is often a good indication of the site moisture characteristics (see Chapter 1, section 1.6).

It is important to note that the effects of total rainfall are completely different from those of intensity and duration. Low- rainfall sites can have a large proportion of their monthly rainfall in one prolonged storm, which can give rise to slope failures. Damaging high- intensity rainfall, as well as relatively prolonged storms, can occur anywhere, even in the driest rain-shadow areas. For this reason, total rainfall has a much clearer impact on vegetation cover than it does on slope stability.

Site moisture levels

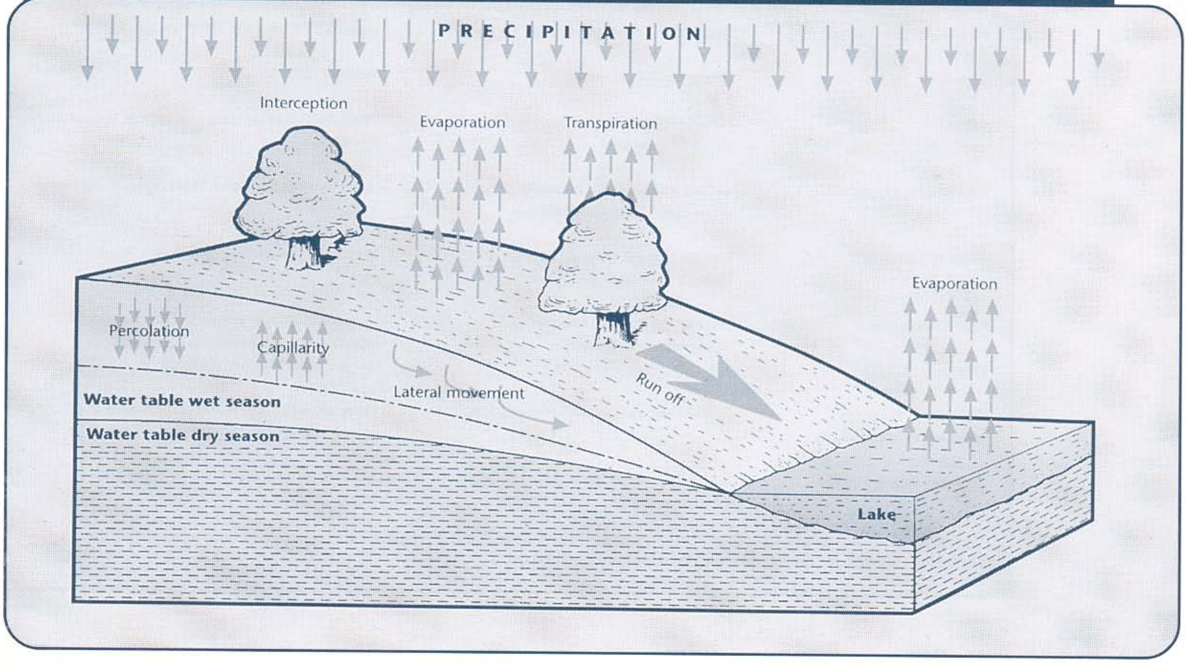
The main features of rainfall in Nepal are that:

- the summer monsoon rains bring 80 to 90 percent of the yearly rainfall; and
- the distribution of rainfall is severely affected by topographical and other factors.

As a result, the main factors making sites more moist are:

- exposure to rain-bearing winds;
- topography causing uplift of the wind; and
- shade from the sun (*e.g.* north-facing slopes);

Figure 2.19: Simpilified diagram of the moisture cycle under humid conditions



Source: Fitz patrick, E A. 1980. Soils: their Classification and Distribution Longman, London.

while those making sites drier are:

- rain shadow effect;
- exposure to the sun (*e.g.* south-facing slopes);
- higher site temperatures;
- soils with low infiltration rates; and
- dry winds in big river valleys.

Rainfall severely affects plants because water is essential for growth. The variations of rainfall, temperature and evapotranspiration can be measured. Their effects on soil water balances are shown in Figure 2.19. The interaction between them in Nepal is described in Figure 2.20.

Moisture and plants

The growth of plants in Nepal is controlled as much by the availability of water as by seasonal variations in temperature. The water balance tends to swing from a super-abundance of water in the monsoon to a severe deficit in the spring months. Much of the water precipitated during the monsoon runs off, evaporates or sinks deep into the ground beneath the rooting zone. The storage capacity of the best soils is estimated to be only about 150 mm in the top metre of soil where it is available to tree seedlings; in poor, stony soils it is much less.

When the monsoon arrives, the water quantity in the soil quickly rises to field capacity, well in excess of plant growth requirements. At this time transpiration is suppressed, despite temperatures greater than 20°C, because the relative humidity is very high (70 - 95 percent).

At the end of the monsoon, when the soil is fully charged with water, plants will grow freely until the forces of transpiration are resisted by soil suction. At this point the plants begin to experience water stress and continue to do so until the soil water is replenished by rain at the beginning of the next monsoon. During winter, when temperatures are lowest and days are shortest, water deficit is not a problem; but as temperatures rise during the spring, water stress for young plants can be acute. The greatest stress is experienced during March and April, but the level of stress is modified by the length and abundance of the rainy season. The wide range of temperatures and rainfall brought about by interactions between season, altitude and topography, means that the best guide to determining plant growth conditions at a site is to observe the state of the ground and to make use of plant types that grow in the vicinity.

Figure 2.20: Major factors affecting site moisture, where they are important and how to recognise them

Major factors affecting site moisture	Example where this is the most important factor	How this factor can be identified in the field
More moisture		
Exposure of the site to rain-bearing winds	On many higher ridges in the Mahabharat and middle mountain areas, *e.g.* along roads from Sindhuwa to Basantapur, Mude to Charikot and Sahajpur to Dadeldhura, and the Shivapuri Lekh above Kathmandu.	Higher ridge areas with good forest cover that excludes the drier tree types. Species such as chilaune, katus, banjh, gurans, utis and nigalo bans are found. If cultivated, there are often many fodder trees growing on the terrace risers and the land is relatively fertile.
Effect of topography in causing uplift of wind and condensation of moisture leading to rain	Southern side of the Mahabharat lekh, *e.g.* on the roads above Dharan, between Hetauda and Simbhanjyang, above Surkhet, and around Lumle on the Pokhara-Baglung road.	Major hill slopes (usually > 1000 metres) with no high topography to the south. Dense forest such as lampate, chilaune-katus and banjh-gurans.
Shade from the sun: north-facing slopes stay moister (also east-facing slopes to a lesser extent)	Most north- and east-facing slopes in the middle mountains, *e.g.* between Dhankuta and Hile, Balaju and Nagarjun, Kakani and Ranipauwa, and the eastern side of the Dauney Hills in Nawalparasi and many other north-facing Churia slopes.	Cool, damp slopes with a lot of shade, usually north-facing. Often growing utis trees. If cultivated, there are often many fodder trees growing on the terrace risers and the land is relatively fertile.
Less moisture		
Rain shadow effect: ridges shield the lower land behind them	Deep valleys in the lee of large ridges, *e.g.* the Tamur valley between Dharan and Dhankuta, the west Seti valley near Dipayal	Deep, sheltered valleys surrounded by high ridges. Hot, dry climate with species such as sugar cane, khayer, bel and khar.
Exposure to the sun: south-facing slopes become much drier (also west-facing slopes to a lesser extent)	Most south- and west-facing slopes in the middle mountains, *e.g.* around Dhading in the Trisuli valley. Most south-facing slopes on lower ridges, where topography is inadequate to cause significant uplift of the wind, *e.g.* western side of the Dauney Hills in Nawalparasi and many other south-facing Churia slopes.	Hot, dry slopes facing directly into the midday and afternoon sun. Dry forest types such as sal, salla, or shrubs such as dhanyero or tilka; poor bari land with maize or khar.
Higher site temperature	Lower altitude sites are generally warmer and drier than higher ones, *e.g.* although some parts of the Churia get more rain, evaporation in higher temperatures makes it drier than some higher ridges.	Vegetation and agricultural crop patterns vary significantly with temperature. Examples are numerous and well known throughout Nepal.
Soils with low rates of infiltration resulting in high runoff	Hill sal forest areas on rato mato, *e.g.* around Panchkhal on the Arniko Highway, and khayer forest on clay soils in the Bhabar zone near Kohalpur.	Clay soils with low infiltration rates, often with a problem of gullying. Often not cultivated and growing a poor forest cover of sal, khayer, salla.
Dry winds in big river valleys	The bottom few hundred metres of big river valleys, *e.g.* the Kali Gandaki near Baglung.	Dry sal or khayer forest types, cacti and xerophytes such as kettuke. If any cultivation, it is restricted to poor maize or khar bari.

Infiltration

Infiltration is the process whereby water enters the soil through the surface. It is influenced by the following factors.

- Intensity of rainfall: the faster that rain falls, the greater the chance that some will run off rather than infiltrate.
- Slope angle: the steeper the slope, the greater is the chance that water will run off.
- Soil texture: the finer the soil particles, the slower will be the penetration of water.
- Vegetation cover: vegetation helps to break up the soil and make it more porous, thus increasing infiltration; but it is necessary to look at the micro level: a short grass cover creates a very different effect from a few large trees with nothing in between.
- Surface openness or compaction: the less open or more compact the surface, the lower will be the infiltration; some soil surfaces are covered by caps of clay or algae.
- Stoniness of the material: the more stony, the less porous is the material and the more water will run off.
- Compaction of the material: the more

Figure 2.21: Aspects of water infitration into soils

(a) Average infiltration rates (IR) by soil texture

Soil texture (mm/hr)	Representative IR (mm/hr)	Normal range of IR
Clay	0.5	< 0.1 - 8
Silty clay	2	0.3 - 5
Clay loam	8	2 – 15
Loam	10	1 – 20
Sandy loam	20	10 - 80
Sand	50	20 – 250

(b) Indicative infiltration rates (IR) based on agricultural criteria.

Class	Infiltration category	IR (mm/hr)	Comments
1	Very slow	< 1	Suitable for rice
2	Slow	1-5	Marginally suitable for rice up to 3 mm/hr
3	Moderately slow	5-20	Unsuitable for rice
4	Moderate	20-60	
5	Moderately rapid	60-125	
6	Rapid	125-250	
7	Very rapid	>250	

(c) Average rainfall and infiltration measurements, Dharan-Dhankuta road

Site	Cover	Rainfall (mm/hr)	Infiltration (mm/hr)	Infiltration % of rainfall
DDR 3+800	Canopy (old debris)	106	74	70
DDR 7+300	Bare (fresh debris)	56	48	86
DDR 19+000	Canopy (old debris)	117	94	80
	Bare (old debris)	113	75	66
DDR 19+400	Canopy (old debris)	28	24	85
	Bare (old debris)	28	15	53

Sources: (a) and (b) Landon, J R. 1991. *Booker Tropical Soil Manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics*. Longman Scientific and Technical, Harlow.
(c) Clark, J. E. 1992. *Principles of Bio-engineering with Reference to East Nepal*. PhD Thesis, Cranfield University.

Note: The rice suitability qualifications in table (b) assume that options are available. On Nepalese hill slopes, the areas of land that can be irrigated and are climatically suitable for rice cultivation do not always coincide with soils displaying low infiltration rates. For this reason, some khet land has huge infiltration losses and can seriously change the ground-water hydrology for some distance down the slope. The figures given in table (c) are averages presented for comparative purposes only; there are considerable ranges hidden by these data. Canopies are mostly of grasses and other herbaceous vegetation. These measurements were made under simulated, not natural, rainfall.

Liquefied debris from a large landslide is deposited wherever the gradient allows. In this case, the natural deposition site was the point at which the road crossed the month of the valley

Figure 2.22. Approximate relationships between texture, structure and hydraulic conductivity

Texture	Structure	Indicative hydraulic conductivity (mm/hour)	(m/day)
Coarse sand, gravel	Single grain	> 500	> 12
Medium sand	Single grain	250 - 500	6 - 12
Loamy sand, fine sand	Medium crumb, single grain	120 - 250	3 - 6
Fine sandy loam, sandy loam	Coarse, sub-angular blocky and granular, fine crumb	60 - 120	1.5-3
Light clay loam, silt, silt loam, very fine sandy loam, loam	Medium prismatic and sub-angular blocky	20 - 60	0.5- 1.5
Clay, silty clay, sandy clay, silty clay loam, clay loam, silt loam, silt, sandy clay loam	Fine and medium prismatic, angular blocky, platy	5 - 20	0.1- 0.5
Clay, clay loam, silty clay, sandy clay loam	Very fine or fine prismatic, angular blocky, platy	2.5-5	0.05-0.1
Clay, heavy clay	Massive, very fine or fine columnar	<2.5	<0.05

Source: Landon, J R. 1991. *Booker Tropical Soil Manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics*. Longman Scientific and Technical, Harlow.

compact the material, the lower will be the infiltration rate; newly filled materials or recently cultivated bari can have very high infiltration rates.

The variability of infiltration in soils is demonstrated by the general data given in Figure 2.21(a) and (b). These can be compared with the actual measurements made by Clark (1992) on colluvial debris slopes in East Nepal given in Figure 2.21(c). These demonstrate that colluvial debris has moderate to high infiltration rates and that runoff will only occur under heavy rainfall.

Percolation and hydraulic conductivity

Percolation is the downward or lateral movement of water through soil. The rate of water percolation is measured as hydraulic conductivity.

The Law of Darcy (1856) is applied to soil to define its hydraulic conductivity. Saturated hydraulic conductivity is a constant (K) referring to the flow of a fluid through a saturated conducting medium. It is defined as follows:

$$q = K A \frac{h}{L}$$

Where: q = volume rate of flow across a plane normal to the direction of flow;

K = hydraulic conductivity, which is the volume rate of flow through a sample of unit cross-sectional area under the influence of a unit hydraulic potential or head gradient;

A = cross-sectional area through which flow takes place;

h = hydraulic head expended in moving water from one side of the sample to the other;

L = length of the sample in the direction of the flow.

No soil is sufficiently uniform that it could be measured perfectly by this means, however, and so only approximations can be made. In addition, observations are extremely difficult to make in the field. Figure 2.22 gives general approximate relationships between the texture and structure of soils, and their hydraulic conductivities. In the case of loose colluvial soils with large voids between the abundant stone fragments, percolation may be rather higher than is suggested here. Also, soil profiles do not necessarily have the same characteristics throughout their depths. This is particularly likely with alluvial soils, where a sandy surface horizon may be underlain by a fine-textured horizon with a much lower rate of hydraulic conductivity.

On hill slopes, failure may be induced through variability between the infiltration rate of the surface layer and the hydraulic conductivity of the underlying material. This might occur where recently deposited, porous material overlies more compacted 'original ground'; or where colluvial debris transported from above overlies a firmer material. In either case, the low internal drainage rate of the lower layer may allow the higher layer to reach saturation relatively quickly on account of its high infiltration rate. This can lead to a shallow debris flow. In treating such a slope, drainage would therefore be critical.

Other aspects of water movement

Water can move over the surface of the ground, into the surface to a depth of a few centimetres, further down into the soil profile, and deep into rocks. All these pathways can lead to instability in various forms.

Conditions that lead to overland flow are:

- when the soil has a capping (compacted surface): a soil cap will prevent infiltration even if the soil itself is highly permeable;
- when the rate of precipitation exceeds that of infiltration (when the soil is not saturated);
- when the soil is saturated;
- when impermeable rock or impermeable soil is at the surface;
- slope, to a limited extent, can determine whether or not overland flow takes place: if the slope is very steep, water will flow over it however permeable the surface is; however, for most practical situations slope does not *cause* overland flow, although it certainly influences the *rate* of overland flow.

The result of water flowing over the surface can be either flow without any damage to the surface if it is adequately protected; or erosion if it is not.

Nepalese soils and rocks are generally very permeable, containing voids and many fractures. These allow water in to various depths, all of which can cause instability of various kinds.

When water infiltrates into the soil, it enters the voids and starts to fill them up. As a result, pore water pressure starts to rise. Pore water pressure is the pressure acting on soil grains by water held in the pores. Pore water pressure can be positive or negative. It is negative when the voids are only partially filled with water (this state is also known as soil suction). Pore water pressure becomes neutral just before the point at which the voids become completely filled with water. Pore water pressure becomes positive at the point when all the air has been expelled from the voids and the water phase in the soil-water mix becomes continuous. At that point, the water phase effectively becomes a column and hydrostatic pressure, equivalent to the height of the column, is exerted within the pores. The pressure is transferred to the soil grains.

If the hydrostatic pressure is sufficiently high it will force the grains apart and the mixture will start to behave as a liquid. Hydrostatic pressure developed near the soil surface, as when the upper layer becomes saturated during heavy rain, causes the soil to flow.

When pore water pressure becomes positive along the walls of a fissure underground, a 'pipe' develops. A pipe is an enlarged fissure that forms underground in fine-grained, non-cohesive soil, especially silty or fine sandy soils. Enlargement of the fissure takes place when water, flowing along the fissure or into the fissure from the side walls, detaches particles of soil and carries them away in suspension. Pipes that have not broken through to the surface can still sometimes be detected by the presence of an elongated hollow of subsided ground pointing down the slope. The trench may be above the head of a gully and in the same alignment as the gully, indicating that water is moving into the gully head as ground water through a pipe.

If water travels downwards to the bottom of the soil profile it commonly becomes halted in its path by the impermeable surface of the rock beneath. It then migrates downhill along the interface until it emerges as a spring at a point where the soil becomes shallower or the rock outcrops at the surface.

Pore water pressure may become positive at the base of the soil profile, resulting in a deep translational landslide (the commonest deep type) or a circular failure.

If water goes deeper than the soil profile, it goes into the bedrock.

Water movement through rocks is controlled by:

- the permeability of the rock;
- the angle of bedding; and
- the number, orientation, openness and continuity of fractures.

Figure 2.23.Material types and likely failures

TYPE OF MATERIAL	UNDERLYING CAUSE OF FAILURE	LIKELY MECHANISM OF FAILURE
Debris	Surface water Ground water	Erosion or liquefaction Shear failure
Soft rock	Weathering	Plane or shear failure or disintegration
Hard rock	Weathering	Plane failure
Alternating hard and soft rock	Weathering	Differential weathering plus plane failure

In horizontal rocks it will move sideways, slowly, along the surface of an impermeable layer. In tilted beds it will move more rapidly down the slope. If the rock is fractured, the water will continue to go deeper. Hydrostatic pressure is exerted within the open joint systems of rocks in exactly the same way as in soils. If the water cannot escape as spring water, high pressure can develop and force the joints apart. This is the cause of many rock slides.

In practice, although rocks have been weakened physically by folding and faulting, and chemically by weathering, it is actually water that provides the mechanism of failure by exploiting those weaknesses.

Although this debris fan has been inhabited and cultivated for many years, it remains at serious risk of destruction from this tributary of the Tamur Kosi River

2.7 INSTABILITY

The combination of dynamic terrain, steep slopes, weak rocks and water is, inevitably, instability. This Section examines the actual mechanisms of instability and considers what can be done about them.

The stability of a slope is described in terms of the factor of safety. A factor of safety of 1 means that the slope is at the dividing line between being stable or unstable. If the factor of safety is more than 1, the slope is stable. If it falls below 1 it will be unstable.

Unstable slopes are always in a state of change, either towards a more stable or a less stable condition. Most failures are active for at least several years before they settle down. Only in a few cases will the life progression be known or be capable of being estimated.

Slope materials and components

The materials forming a slope can be categorised as:

- debris, which is not rock as such, since it also includes soil and other mixed materials;
- soft rock, which may be rock that is naturally soft *e.g.* mudstone, or hard rock that has become soft through weathering; and
- hard rock.

These are expanded in the paragraphs below.

Debris. Material deposited as a result of a slope movement. The group includes soil of any type, soil and rock fragments, and rock fragments wholly. The category 'debris' does not indicate a definition of particle size distribution or other physical characteristics. This is because the constituents of debris can range from boulders down

Figure 2.24. The four zones of a landslide

Landslide zone	Location and description
Zone of cracking	Above the slide and sometimes around its sides, visible as tension cracks and subsidence.
Zone of failure	The head scar (crown) and failure surface, which may occupy only a relatively small area at the top of the slide.
Zone of transport	A damaged slope, scarred by the passage of debris on its way downslope. This part of the slope may be stable, and may recover on its own.
Debris pile	The detached, mobile material, either on its way down or in a cone at the bottom.

to silt and clay, in any proportion, and these features would be separately noted in a soil classification carried out on the material.

Unconsolidated debris. Material deposited by a slope movement that has taken place within the last year. Debris which has been deposited recently has a low bulk density and consequently is susceptible to infiltration and failure by liquefaction. This form of failure has the potential to destroy any of the low cost systems designed to catch material moving down the slope, and to fill or over-flow even the biggest of structures.

Consolidated debris. Material deposited by a slope movement that took place more than one year ago. The term applies to old landslide debris and colluvium, which are much more resistant to erosion, liquefaction and internal shear than fresh debris.

Soft rock. Soft rock is *in situ* rock, usually of weathering grade 5, (*i.e.* it makes a dull thud when struck with a hammer). Failure occurs both along rock planes (plane failure) and through bodies of rock (shear failure). Disintegration failure may occur if rock is extremely permeable.

Hard rock. Hard rock is *in situ* rock of weathering grades 1 - 4, (*i.e.* the rock rings when struck with a hammer). Failure occurs only along pre-existing rock planes, by plane failure. Hard rocks have internal strengths much greater than the frictional strength along their fracture planes.

Alternating hard and soft rocks. Bedded rocks in alternating layers, whose susceptibility to weathering is contrasting. Alternating hard and soft rocks, although strictly falling within two rock groups, are included as a material type because the layers influence each other in a way that is different from each rock type alone. Failure is by differential weathering. These alternating bands are particularly common in the Churia ranges.

These material groups and the most likely underlying causes and mechanisms of failure are shown in Figure 2.23. Note that the underlying cause of failure is usually quite distinct from the triggering factor for slope movements. The triggering factor is usually water, but is occasionally an earthquake.

A landslide has distinct parts (see Figure 2.24). Recognising and assessing these individually helps the engineer to understand the character of the landslide and, in particular, its severity.

Types of instability

There are many types of erosion and instability found in Nepal. the most common ones are shown in Figure 2.25. They and others are described in more detail in the paragraphs below.

Erosion. Erosion is the removal of particles from the surface by flowing water. An arbitrary depth limit of 25 mm can be adopted for erosion: this depth refers only to the initial removal of particles and is used to distinguish erosion from mass movements; if particles are continually washd away, the surface will be progressively lowered, giving rise to the forms of erosion described below. For example, a gully 2 metres deep can be developed by the steady removal of particles from its base and sides to a depth of no more than 25 mm at a time.The process which causes this is still erosion.

There are numerous terms to describe erosion, and the most common ones are explained below. When it comes to the protection of critical roadside slopes, the distinctions are largely academic.

Figure 2.25. 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, but can be up to 3 metres or more (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.

Even the smallest gullies can damage roads

Natural or geological erosion: the wearing away of the Earth's surface by water, wind or ice under natural environmental conditions of climate and vegetation, undisturbed by man.

Normal erosion: the gradual erosion of land used by man which does not greatly exceed natural erosion.

Accelerated erosion: erosion which is much more rapid than normal, or natural or geological erosion, primarily as a result of the actions of man or animals.

Splash (or rainsplash) erosion: the spattering of small soil particles caused by the impact of rain drops on wet or weak soils; the loosened particles may or may not be subsequently removed by surface runoff.

Sheet erosion: the removal of a fairly uniform layer of soil from the land surface by runoff water (or overland flow).

Rill erosion: erosion whereby numerous small channels of the order of tens of millimetres in depth are formed.

Gully erosion: the process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area, often

Shallow planar failures on long steep slopes can give rise to large volumes of debris. Althought the debris in this example is about 5m deep, the depth of the failure itself is less than 1m

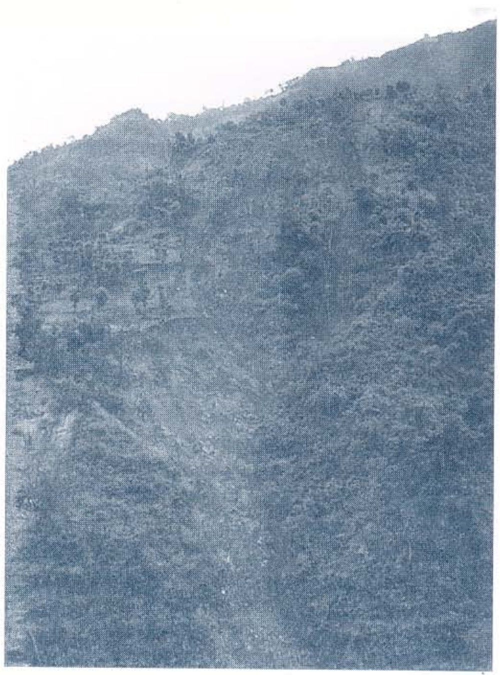
to considerable depths.
The exact conditions under which each of these occur varies greatly. Sheet erosion is uncommon on roadside slopes, but can be found on extensive bare soils with compacted surfaces. More common is the development of rill or gully erosion through the channelisation of surface runoff (when it occurs) at the micro level. Once drainage lines start to form rills on weak materials, they can enlarge rapidly into gullies.

Gullies. Gullies begin as very shallow, narrow incisions in the slope (rills). If a gully is deeper than 2 m, its sides fail in ways similar to a normal hill slope. Hill slope protection measures are then appropriate on the gully sides, as well as the gully floor requiring its own protection.

Erosion by piping. This is the removal of fines along an underground channel. Percolating ground water in permeable fine soils of low plasticity can remove fines along a fissure to a point where an underground stream is formed. The roof of this stream cavern can enlarge upwards towards the surface and eventually collapse to create an open, elongated chasm or pit.

Planar sliding or translational landslides. These are the most common form of slide in Nepal. In these a 'slab' of material of more or less uniform thickness slides off the surface. Translational slides are typically rectangular in plan, with a straight head scar and straight sides running parallel down the slope. They are frequently quite shallow (*i.e.* one metre deep or less). They can be caused by ground water pore pressure along a slide plane, or by weathering or undercutting of the slope. They can be shallow or deep, according to the structure of the superficial layers.

Shear failure or rotational landslide. Here, a rotational movement of material occurs, forming a spoon-shaped scar on the hillside which is roughly circular in plan. The debris forms a bulge near the toe. Slumps are commonly caused by high ground water pore pressures deep in the



Under very heavy rainfall, weak colluvial materials on steep slopes can reach a critical point of saturation. The material then liquefies and slides, giving rise to shallow failures

Extreme rainstorms can lead to alarming scales of debris flow. The average boulder size is about 2m diameter in this example from Palung, in 1993

hillside, and the slip circle usually goes several metres deep.

In practice in Nepal, deciding if there is a rotational or a translational mode of failure is usually extremely difficult. Many slides are a compound of the two types, in which a rotational component at the head degenerates into a translational component below. This is because coarse, non-plastic debris masses cannot sustain a circular slip plane except at the crown. Deciding which mode is dominant is useful because rotational failures indicate a deep failure plane and may therefore be more difficult to stabilise than a translational slide.

Debris flow. These are caused by the liquefaction of material, usually by the action of heavy rainfall upon a permeable soil surface. The soil literally flows down the slope. The failure plane is usually shallow, sometimes only a few centimetres deep. However, the fluid mass is very difficult to control or stop. Deep flows, which can travel a long way, are very destructive and potentially pose a high risk to life and property.

Plane failure in rock. Any mass movement whose failure plane or planes is controlled principally by fracture planes in rock, and whose debris consists chiefly of rock fragments. The weathering grade of the rock is 1 - 4 (the rock rings when struck with a hammer: see Figure 2.11, page 56). Failure types commonly include plane failure, wedge failure, and toppling (rockfall).

Disintegration. Tensile failure in very soft rock or consolidated soil. This is a special type of rock failure, found in massive or sparsely-jointed, permeable, weatherable rocks (e.g. porous sandstones) and in dense soils and unconsolidated materials that stand in a vertical or near-vertical face. Upon landing the material breaks up into a pile of loose debris, consisting mostly of loose rock mineral particles, such as sand containing a few boulders of weathering grade 4 or 5 (see Figure 2.11, page 56). All traces of rock structure or stratification are destroyed in the fall. For this reason the mechanism is distinguished from a fall of hard rock, which is considered a plane failure. The cause is weathering. Saturation and weathering cause the rock to fail by planar or arc-like shearing throughout the mass. Sometimes this is partially controlled by weakly-developed joint planes. Strictly, the mechanism is a 'fall', but the form of failure is distinctive. The mechanism is typical of thick beds of soft Siwalik sandstone and terrace deposits. It is very difficult to cure.

Differential weathering. Weathering of rock layers whose susceptibility to weathering is strongly contrasting. This failure occurs typically in alternating thin beds of hard and soft rock, such as sandstone and mudstone or siltstone. These formations are characteristic of the Middle Siwalik rocks of Nepal. The cause is a combination of weathering and erosion of the soft rock layers, and plane failure of the hard rock layers. The soft rocks erode back from the face to leave the hard rocks sticking out. Eventually the hard rocks overhang so far that they break off along vertical fractures. The process then starts again and the whole face retreats. This mechanism is very common in the Churia ranges.

Causes of failure

The causes of failure are numerous, but mainly come down to the action of water in some way.

Surface water. This gives rise to erosion, or soaking of the surface to cause shallow sliding. It results from water infiltrating from the surface. The failures caused are shallow, and there is usually clear evidence of the source or presence of water.

Ground water. Ground water causes increased pore water pressure at depth. This gives rise to a failure plane deeper than in surface water failures. In some geological conditions, a considerable amount of ground water can occur but is barely visible as a seasonal spring. Water percolating down through the ground from khet (paddy) terraces and leaking kulos (irrigation leats) can have a major effect a long way down the slope.

Weathering. Rock shear strength is reduced by weathering, as constituent minerals are broken down into weathering products and clay minerals. Physical bonds between rock constituents are weakened or broken. The rock can fail along weakened fracture planes or through its body. Weathering takes place over geological rather than human time, but the effects in weakening rocks can take many years to result in a failure.

Undercutting. A slope is undercut by a flowing stream or by the opening up of a road cutting. Incision (downcutting) or lateral scour by streams is a major cause of slope failure. The initial failure can work rapidly up slope.

Addition of weight. Weight is added usually in the form of landslide debris from a failure higher up the slope, or by the dumping of spoil.

2.8 SITE INVESTIGATION

A rapid procedure for site investigation is given in the *Site Handbook* companion to this volume (Section 1.2, page 15). It is recommended that it should normally be followed. A proforma and guidance notes are given in the *Site Handbook*, Annex A (page 126). In cases of more serious instability, however, a more thorough investigation may be required. That is described in this section, with the procedural guideline and check list required given in Annex A of this volume.

The various aspects of a site which should be investigated are considered in the paragraphs below, with explanations of the kind of problems that may occur.

Because of the range of failures that can occur, it is important to try to identify what is occurring in the ground. For example, as Figure 2.26 shows, cracking in the original hill slope above the road cut slope might be the result of one of three different possibilities, one of which is far more serious than the others.

Many of the investigation criteria involve relatively arbitrary quantifications (such as the length of slope affected by the failure). The reason for this is that these provide indications of the seriousness of the failures and are important in determining the priority and scale of rehabilitation work.

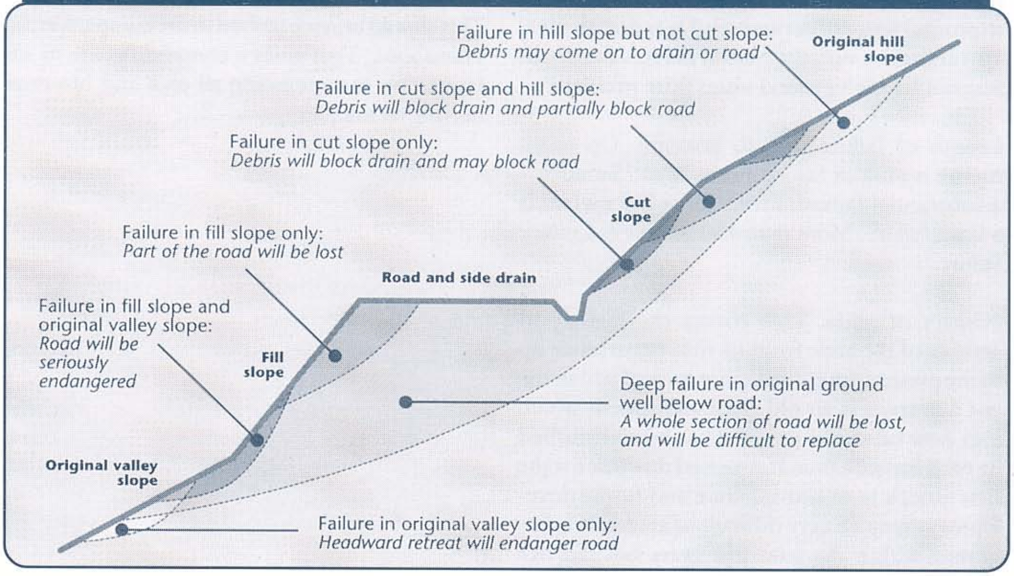
Location of slide. The initial criterion is to determine whether the failure is off the road alignment but within the Department's responsibility, above the road so that debris may come on to the road, below it so that it may be undermined, between road sections, or whether the slide failure plane passes beneath the road. The main options are given in Figure 2.26.

Type of slope affected. If the failure affects the road cutting but not the hill slope, then the slide has probably been caused by road construction; if it affects the hill slope but not the road cutting, then the slide has probably not been caused by road construction: it may be natural or induced by man, but there is a risk of enlargement up slope and deposition of debris on to the road and into the drainage system. If the slide affects the road cutting and the hill slope, it has probably been caused by road construction and is enlarging up the slope. If it is in the embankment, fill or spoil slope, then the slide has been caused by road construction and threatens the carriageway: there is a risk of erosion or liquefaction if the fill is uncompacted.

Slope conditions above slide (or above road, if road is at top of slide). If it is at the crest of a ridge, or on a gentle slope (less than 35°), then the slide is unlikely to enlarge much up the slope. If it is a stable, undisturbed hill slope, the slide can be stabilised easily. On an unstable hill slope with cracked ground, another landslide or topography that collects water, more instability can be expected: there is a high risk to any stabilisation measures. If there is a cut-off drain or take-out drain, there is a high risk of leakage from a cracked drain. Where there is an irrigation channel (kulo), there is a very high risk of major erosion if the channel should leak or be damaged.

Slope conditions at base of slide or below slide (or below road if road is at base of slide). Where the road is intact, instability is from above only. The road may be buried but the road itself will not be disrupted by the slide plane. If the road is disturbed, then it is not at the base and so the slope condition at the base must come

Figure 2.26. Possible failure planes around a road on a hill slope



under one of the next three categories. If there is a stable, undisturbed hill slope, the slide can be stabilised easily. Where there is an unstable hill slope with cracked ground, a landslide or topography that collects water, there is a very high risk to the carriageway; remedial action is urgently required, still with a high risk of major damage. If there is a stream, there is a risk of scour and undercutting of the slope.

General type of failure. Erosion, rilling or gullying up to 2 metres deep caused by surface water is only a minor instability. Gullies more than 2 metres deep with a substantial watercourse have a probability of a significant amount of debris being brought down. Mass movements (slides, flows or falls) are deeper failures requiring more substantial works.

Material forming the original (failed) slope. Debris, which is material deposited as a result of a slope movement, may be unconsolidated or consolidated, depending on whether it is less than or more than a year old. Other possible materials are soft rock, hard rock and bands of alternating hard and soft rocks.

Failure mechanism. Erosion is the removal of particles from the surface by flowing water: this can be in the form of rills, gullies or pipes. Slides, within the soil or along the soil/rock interface, cover any mass movement of soil or debris down slope. Flows are caused by the liquefaction of material, usually by the action of heavy rainfall upon a permeable soil surface. Plane failures in rock are any mass movement controlled principally by fracture planes in rock, and whose debris consists chiefly of rock fragments. Disintegration is a tensile failure in very soft rock or consolidated soil. Differential weathering occurs in rock layers whose susceptibility to weathering is strongly contrasting.

Causes of failure. Surface water causes erosion, or soaking of the surface to cause shallow sliding. Ground water causes increased pore water pressure at depth, leading to failure planes deeper than in surface water failures. Rock shear strength can be reduced by weathering as constituent minerals are broken down. Slopes can be undercut by a flowing stream or by the opening up of a road cutting. Weight can be added usually by the dumping of spoil or by landslide debris.

Depth of failure. Up to 25 mm is a shallow surface failure caused by erosion. From 25 to 100 mm is a shallow mass failure, probably due to the liquefaction of surface layers. From 100 to 250 mm is a deeper mass failure that can involve water contributed both from infiltrating rain water and rising ground water. From 250 to 1000 mm is a deep mass failure probably due primarily to ground water pore pressure. Deeper than 1000 mm comprise very deep mass failures due to, or assisted by, high ground water pore pressure.

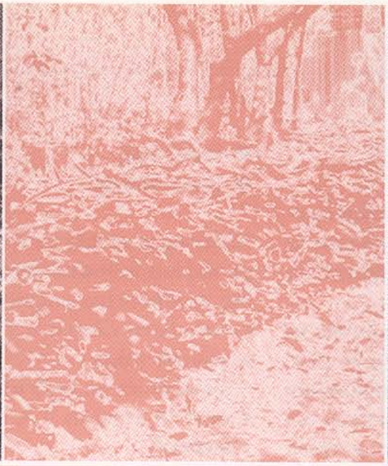
Length of failure (top to bottom). Up to 15 metres is a minor failure. From 15 to 75 metres is a substantial failure. From 75 to 150 metres is a large failure. More than 150 metres is a major failure.

History of slide. This covers the history of activity of the slide from its first occurrence up to the present time. if it has not moved within the last 5 years, it is an old slope movement which may now be stable, unless it has been disturbed by road construction. If it moved this year for the first time, it is an active failure and future development may be very difficult to assess. If it has moved within the past five years but did not move this year, it is a recent failure, but at present is inactive. If it moves every year at a diminishing rate by the initial mechanism, it is a continual failure, but holds distinct possibilities for improvement by remedial works. If it moves every year by the initial mechanism at a constant or worse rate, it is a continual failure which may be out of control and have little possibility for improvement.

Life progression of slide. The evolution of the slide from its current condition into the future. If a stable slope has formed, or will stabilise naturally, it may have been a single failure to a stable rock plane or stable slope configuration, which is a relatively rare situation. If further movement is expected by movement at a shallower depth than that of the original failure, then the instability is going through post-slide adjustment. If a repeated movement is expected, by the initial mechanism or another equally serious, full stability may not be achieved for some years.

2.9 SITE TREATMENT

This should be as described in the companion *Site Handbook*. That gives a complete guide to site treatment, incorporating all civil and bio-engineering techniques.


Maintenance of vegetation

This Section gives detail on certain aspects of roadside vegetation maintenance, and complements the practical guidelines given in Section 5 of the *Site Handbook*. This applies to all roadside vegetation, whether it originated from bio-engineering works or another plantation programme, or from a natural forest type.
Planning the maintenance of roadside vegetation is covered in detail in Section 5.2 of the *Site Handbook*.

3.1 INTRODUCTION

Vegetation on roadsides is a long-term management task. The 'maintenance' of vegetation in engineering is thought of as 'management' in forestry, horticulture and agriculture.

Vegetation must be maintained in order to maximise its engineering contribution, its productivity and its appearance. Most operations are similar to normal forestry practices, but there are some particular needs for bio-engineering which are specific to the road sector.

The management of vegetation is part of roadside support maintenance[1]. The two categories of maintenance are defined as follows.

- Routine maintenance is required continually on every road because of environmental degradation, whatever the road's engineering characteristics or traffic volume.
- Preventative maintenance is required to adapt the road to the changing nature of the slopes and streams (*i.e.* to the geophysical environment).

The maintenance tasks for vegetation can be listed according to the intervention frequency (as for on-road maintenance). In this manual, those tasks specifically related to vegetation are considered in detail; other aspects of maintenance in roadside areas are not covered (such as cleaning slope drains, checking structures, *etc.*). Nor is emergency maintenance covered.

To some extent all bio-engineering activities are covered by preventative roadside support maintenance. However, within this category some long-term maintenance requirements fall into routine operations because they are continuous or very regular, or require frequent checks.

In general, lengthmen can carry out *routine maintenance* activities and gangs should carry out *preventative maintenance*. However, the mode of operation depends on the scale of each site and should be kept flexible.

Routine maintenance

Routine maintenance involves simple protection and care of plants, such as weeding, mulching and grass cutting. The normal activities are:

- protection of planting sites from grazing, theft of firewood and timber, and fire;
- weeding;
- mulching;
- grass cutting.

Watering is usually carried out only if a long dry period has followed immediately after site planting, or where bio-engineering works have deliberately been carried out before the start of the monsoon rains.

Guidelines on each of the tasks above can be found in section 5.3, page 118, of the *Site Handbook*.

Preventative maintenance

Preventative maintenance is more complex than routine maintenance. Larger plants (shrubs and trees) require 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. The usual activities are:

- thinning of shrubs and trees;
- repair of vegetation structures: *e.g.* repairs to palisades, fascines, brush layering and turf;
- vegetation enrichment;
- removal of unwanted shrubs and trees.

Guidelines on each of the tasks above can be found in Section 5.4, page 121, of the *Site Handbook*.

3.2 STABLE VEGETATION COMMUNITIES

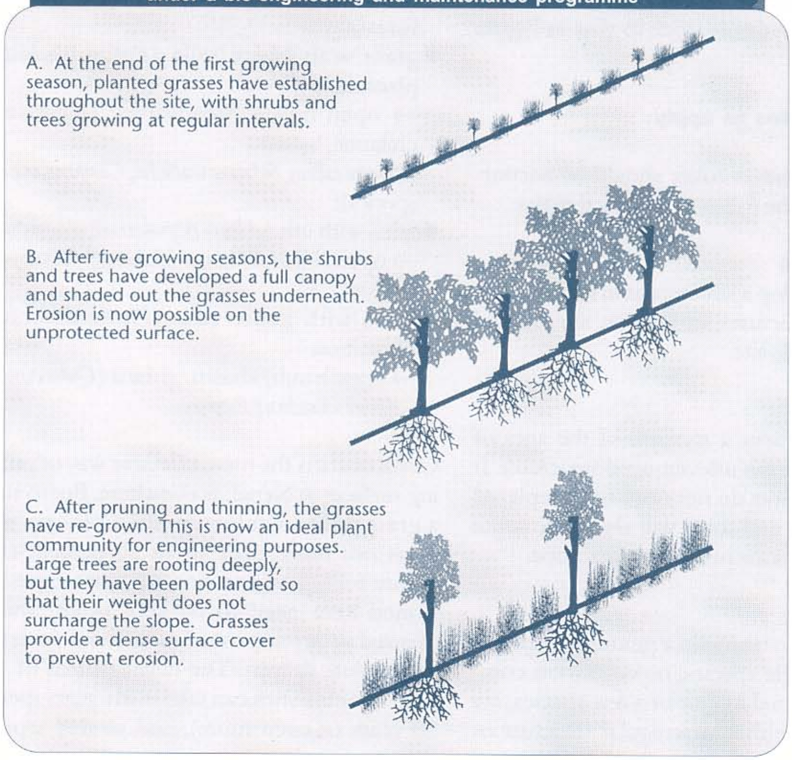
Vegetation development

Many natural vegetation communities[2] do not display the desired engineering properties for surface protection or slope stabilisation. This is because vegetation systems do not evolve specifically for these purposes. Indeed, some areas of apparently well-protected forest actually cover slopes with problems of erosion and shallow landsliding. Protecting vegetation alone does not solve many of the erosion problems that arise when a canopy develops but there is sparse ground cover. For this reason, some parts of the Nepal middle hills which are covered in heavily degraded forest and scrub actually have less ero-

[1] *Definition of Maintenance and Maintenance Activities*. Department of Roads, Marg 2051 (November 1994).

[2] 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'.

Figure 3.1: Typical development of plant communities under a bio-engineering and maintenance programme



sion than some areas with a dense, high forest canopy. Pine forest is notorious for providing the conditions where erosion can occur underneath large trees.

If the right balance of plants is to exist for engineering purposes, it must be designed and implemented specifically for each site, and then managed in such a way as to maintain the desired engineering functions. Left to their own devices, most bio-engineering sites would not immediately develop a stable arrangement of plants. Most of the species first populating a site are pioneer plants, which cannot survive in a community of other plants unless they are helped in some way, such as by reducing competition. In particular, grasses usually need a lot of sunlight to thrive: while this is available on newly planted sites, it diminishes as the canopy develops; however, grasses provide excellent surface protection and so are very important constituents of most bio-engineering sites. The theory of vegetation communities and competition is given in Chapter 1. Figure 3.1 shows the progression of plant development diagrammatically.

Keeping a vegetation community healthy requires careful maintenance. As the trees grow, their canopies spread and reduce the light reaching the ground. But most grasses (and many shrubs) require full sunlight to grow well, and die rapidly if they do not get it. This leads to a canopy of trees with a poor ground cover.

An ideal bio-engineering vegetation community is shown in Figure 3.1(c). It has the following features:

- Large trees that root deeply, giving maximum anchorage. In this example they have been pollarded[1] so that their weight does not surcharge the slope, but they could have been coppiced[2].
- Shrubs forming an intermediate (understorey) level, with strong, woody roots that are shallower than the tree roots.
- Large clumping grasses (like khar) to provide a thick surface cover to prevent erosion, with a dense network of fibrous roots close to the soil surface.

[1] Where the main trunk of a tree is cut off, usually two to three metres above the ground, to allow new, smaller, shoots to grow.

[2] where the trunk of a tree is cut off about 30 cm above the ground to allow new shoots to grow from the stump.

The central aim of vegetation maintenance is therefore to 'engineer' the plants so that they provide a community as close to that in Figure 3.1(c) as possible.

General principles to apply

Long-term vegetation cover should be encouraged to develop the following characteristics.

Mixed structure

This aims to develop a structure as in Figure 3.1(c) (an irregular structure) with trees, shrubs and grasses on a single site.

Mixed age

This aims to achieve a mixture of the ages of plants on one site (an uneven-aged structure). It 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.

Mixed species

The aim here is to maintain a mixture of species on one site. Single species, or vegetation communities dominated by one or a few species, are unlikely to have either an irregular structure or uneven ages.

Low maintenance

The aim is, as far as possible, to establish a vegetation community that does not need too much maintenance. This means moving towards long-term stability in terms of the vegetation community. For example, aim for: a mixture of species which can live together indefinitely; species that can regenerate naturally (without planting); species that do not grow too fast or too tall (less need for frequent cutting and removal); species that live longer, *etc.*

Natural progression

In bio-engineering it is often necessary to start with pioneer species and move towards a climax community (these terms are defined in the box overleaf). Examples of this include:

- grass with tilka/dhanyero (*Wendlandia puberula*/ *Woodfordia fruticosa*) scrubland
  →open mixed sal (*Shorea robusta*) forest
  (eventually → open mixed tropical hardwood forest);
- grass with khayer/sisau (*Acacia catechu*/*Dalbergia sissoo*) plantation
  → open mixed sal (*Shorea robusta*) forest
  (eventually → open mixed tropical hardwood forest);
- grass with khote salla (*Pinus roxburghii*) plantation
  → open mixed broadleaved forest (tooni, chilaune, katus)
  (*Toona ciliata*, *Schima wallichii*, *Castanopsis* species);
- grass with utis (*Alnus nepalensis*) plantation
  → open chilaune/katus (*Schima*/ *Castanopsis*) forest;
- grass with gobre salla (*Pinus wallichiana*) plantation
  → open banjh/khasru/gurans (*Quercus*/ *Rhododendron*) forest.

Grass cover is the most effective way of protecting surfaces in Nepal, as elsewhere. But to sustain a grass cover requires an open canopy, which gives not more than about 50 percent shade. Hence for bio-engineering, the forest types mentioned here need to be kept open, and not allowed to develop into dense climax forest with a complete canopy. The development of these final communities can take many years (perhaps 50 years or even more), and so this aspect of maintenance is truly long-term management.

In most vegetation types, an open canopy of forest with grasses in between is not a naturally occurring condition. There is usually a tendency for the trees to close canopy and shade the grasses out, in favour of other, more shade-tolerant understorey plants (but less effective than grasses for surface protection). As a result, regular maintenance of the site will be required to ensure that the balance of vegetation remains as desired.

3.3 MANAGEMENT OF GRASSES

Management of grasses is part of routine maintenance. It is a small-scale management operation that needs to be undertaken only once per year. In small areas, where extensive growth during the growing season impedes the vision of drivers and pedestrians, it should be undertaken monthly.

Grass management entails cutting the stems about 150 mm above the ground, using a karauti or hasiya (sickle). The material produced can then be used either to mulch the surface, or can be removed for mulching elsewhere, or taken for fodder, thatch, fibres or any other potential use. Stems should be cut only after the seeds have fallen: it should not be done before the beginning of Magh (mid January) but can be undertaken any time in Magh or Falgun (mid January to mid March). See Section 5.3, page 118, of the Site *H*andbook for details.

In most species, cutting encourages the grass plants to remain vigorous and to put up new shoots. Grasses grow from what are termed 'intercalary meristems'. This means that growth occurs through cell division at the bases of leaves and stems. This makes them fundamentally different from shrubs and trees, which grow from the tips of the branches or shoots (called 'apical meristems'). This is why it is possible to cut grass shoots without affecting the growing points; whereas with most woody plants, cutting the shoots can seriously affect the growth.

In many parts of the world, it is common to burn grassland in order to remove the old, coarse stems and leaves, and encourage a flush of new, tender shoots, which are more palatable and nutritious to foraging animals. In Nepal this is often done in the dry period at the end of the winter. While this is a valid operation on stable areas of extensive grassland, it should never be permitted in roadside areas. The main reason is that it kills larger plants, such as shrubs and trees. In recent years it has also been discouraged or banned in many countries because of the wider ecological damage caused, both by the fire killing insects and small animals, and destroying their habitats, and because of the perceived global problems of rapid carbon release.

In areas around side drains, grasses must always be cut, ideally using a karauti or hasiya (sickle), and must never be pulled out. Large grasses cannot be pulled out by hand in any case, but small plants can be. This can be very damaging to the toe of a cut slope.

PIONEER AND CLIMAX SPECIES

Pioneer or colonising species. These are the first plants to appear on bare ground and are naturally adapted to living on sites with harsh conditions.

Examples are:

- grasses: babiyo (*Eulaliopsis binata*), dhonde (*Neyraudia reynaudiana*), kans (*Saccharum spontaneum*), khar (*Cymbopogon microtheca*);
- shrubs: areri (*Acacia pennata*), bhujetro (*Butea minor*), keraukose (*Indigofera atroturpurea*), saruwa/bihaya (*Ipomoea fistulosa*);
- trees: bakaino (*Melia azedarach*), khayer (*Acacia catechu*), salla (both *Pinus roxburghii* and *P. wallichiana*), sisau (*Dalbergia sissoo*), utis (*Alnus nepalensis*).

Most of these species require full sunlight in which to grow, and they are relatively short lived. ***These plants are ideal for establishing on new sites.***

Climax community species. These are plants that can form apparently permanent natural forest or natural vegetation. They tend to require better sites to grow, and to grow more slowly. Within their ranges, they will grow in the same sites as the pioneers, but not until the pioneers have grown up and provided shade and other site improvements.

Examples are:

- grasses: amliso (*Thysanolaena maxima*), dangre khar (*Cymbopogon Pendulus*), padang bans (*Himalayacalamus hookerianus*);
- shrubs: bainsh (*Salix tetrasperma*), simali (*Vitex negundo*), sajiwan (*Jatropha curcas*);
- trees: chilaune (*Schima wallichii*), katus (*Castanopsis* species), lankuri (*Fraxinus floribunda*), sal (*Shorea robusta*).

These species are usually tolerant of some degree of shade, especially when young. They may also be long-lived. ***These plants should be encouraged when they start to appear on established sites, or they can be planted between existing plants.***

3.4 INTRODUCTION TO THE MANAGEMENT OF SHRUBS AND TREES

Under both routine and preventative roadside support maintenance, there is a variety of ways of managing shrubs and trees. Routine operations are required mostly in the first year or two after planting. Preventative maintenance operations are not required until about five years after planting. Section 5.4, page 121, in the Site *H*andbook 'Pruning and thinning of shrubs and trees', gives a simple practical guide. What follows explains in more detail the optimum management procedures for large and complex sites.

Early management

Early management (or maintenance) of shrubs and trees aims to establish the plants as quickly as possible. It is important that the plantation site is protected from grazing animals, people cutting fodder and firewood, and from fire. Small seedlings are particularly susceptible to damage.

There are basically two methods of protection. The easiest in the short term is to employ watchers to police the site throughout the day, to chase away unwelcome visitors. In many roadside areas this may be the only solution. Some road sections are subject to grazing from enormous numbers of animals. Often it is the physical damage from hooves, especially those of cattle, which do more damage than the actual grazing.

The harder, but in the longer term more rewarding, method of protection is to work with the road neighbours (local people) to gain their respect for the vegetation planted to protect slopes and their participation in its wise management. If there is a definite benefit for the people, then they will often respond favourably. Ways of doing this are given in detail in Chapter 5 of this volume. It has been achieved successfully in many parts of Nepal.

In areas where there are well defined community structures, liaison with the local people seems to have more success. Where many people have recently moved into an area from elsewhere, there is often not the societal cohesion necessary for the respectful management of resources, which are perceived to be common property. One result of the rapid expansion of Dhankuta town in the 1980s, for example, was unrestricted grazing, which damaged food crops as well as roadside bio-engineering works. Attempts to work with the graziers and firewood cutters of Barghat (Nawalparasi), also in the late 1980s, came to nothing. Site watchmen were deployed instead, and chased enormous numbers of animals away from the site. This increased from about 150 cows, 500 goats, 750 monkeys and 10 people per month during the dry season, to about 5,000 cows, 12,000 goats, 1,000 monkeys and 500 people per month during the monsoon (when all the cultivated land was growing rice)[1]. Despite these examples, there are many areas where liaison with local people has given rise to community groups and individual farmers making significant contributions to the quality of roadside vegetation. This is elaborated in Chapter 5.

Other early maintenance operations amount to weeding and mulching. Weeding is often needed in the first few years of growth to reduce the competition for the planted species, and to ensure that the site is not invaded by shallow-rooted annual species, which do not contribute the required engineering functions.

Mulching is usually done at the same time as weeding, and in fact the weeds can often be used as a mulch. Dead plants or compost are placed in a broad circle around each planted seedling. This helps to keep the rooting zone cool and moist, thereby improving the conditions for growth.

Watering is not a normal maintenance activity, but can be undertaken in exceptional circumstances to improve growth during dry periods. Difficult sites can be successfully planted before the start of the rains if the site can be watered regularly. Plants thrive in the combination of intense sunlight and adequate soil water; in addition, they make use of the annual nitrogen flush before the leaching caused by the first main rains.

Details of these maintenance operations are given in Section 5.3 of the Site *H*andbook (page 118).

Later management

After about five years, the management of shrubs and trees changes completely. Weeds are no longer a problem and protection is less critical. Grazing animals can no longer damage the plants, but in some locations heavy lopping for fodder or firewood can be damaging. Instead, the major maintenance consideration is to stop the canopy of larger plants becoming too thick and suppressing the lower plants (mainly grasses), which protect the surface.

The longer term management of shrubs and trees aims to:

- increase light penetration through the canopy to the ground so that plants (especially grasses) can grow better;
- keep a vigorous mixture of plants of various sizes and shapes;
- improve the mixture of ages and species in the plant community on the site;
- reduce the weight surcharge and wind resistance of large trees.

[1] *Banko Janakari*, 1992. 3 (3): 43-46.

Figure 3.2: Characteristics of vegetation canopies requiring thinning

Canopy characteristics	Method of assessment *
1. If the canopy cover (crown cover) is greater than 50 percent	Visual or spherical densiometer
2. If there is a tree canopy but no shrub layer or ground vegetation layer	Visual
3. If the tree canopy is mostly of a single species or more or less even-aged	Visual or measurement plots
4. If the tree canopy has dead or unhealthy trees in it, or if there are leaning trees	Visual
5. If the site is fully stocked or overstocked with trees	Measurement of basal area or stem counts in plots, or visual
6. If there are large heavy-crowned trees (especially on steep slopes)	Visual

* Descriptions of these methods are given in the box on page 86.

How to decide whether shrub and tree management is needed

If the site has one or more of the features described in Figure 3.2, then the trees and shrubs on the site will need management of some kind.

Measuring canopy cover and stocking

The percentage canopy cover is a good indicator of the amount of light reaching the ground. For bio-engineering purposes, the canopy cover need not be more than 50 percent. If it is greater than this, some canopy can be safely removed.

There are various ways to measure canopy cover.

Visually

Walk through the site and estimate at various points the percentage of the sky that is covered by tree canopy. Take the average from a number of points on the site. Note that this method can be quite inaccurate. The estimated percentage varies with the observer, according to weather conditions, season (some trees are deciduous), *etc.*

Spherical densiometer

This is a simple device which enables canopy cover percentage to be more accurately measured (see box on page 86). Note that several readings need to be taken, and the average of these used. Although more accurate than visual methods, this still suffers from seasonal changes. The Geo-Environmental Unit can supply the instrument required.

Another useful indicator of forest condition is a measurement of stocking. This can also be assessed visually, or by measurement (using a wedge prism or sample plots, see box on page 86). Stocking can be measured as stems per hectare or more usefully as basal area. Basal area is the amount of area actually covered by tree stems (as opposed to crowns) per hectare. It can be measured accurately, and is unaffected by seasons, weather, or observer bias. However, its measurement may take a little longer, and is more difficult to do on steep slopes. The Geo-Environmental Unit can supply the instrument required.

Basal areas range from zero to a maximum of about 45 sq. m/ha. Figures greater than 30 sq. m/ha are unlikely to be found. There is a weak relationship between canopy cover and basal area. Normally, anything with basal area > 25 sq. m/ha would have a canopy cover percentage > 80 percent. Sites with a basal area < 10 sq. m/ha would probably have an open canopy (< 50 percent).

3.5 CHOOSING THE APPROPRIATE THINNING OPTION FOR SHRUBS AND TREES

The results of visual assessment or measurement will enable you to answer the following questions (modified from Figure 3.2). If the answer to one or more of the questions is 'yes', then an appropriate management activity, or combination, will need to be selected.

- Is the canopy cover (crown cover) greater than 50 percent?
- Is there a tree canopy but no shrub layer or ground vegetation cover?

Figure 3.3: Determination of pruning and thinning

Assessment criterion	Action required
Does a study of the shrub and tree canopy show that there is not enough light penetrating to allow grass to grow underneath?	If 'yes', then prune fully and address the next question. If 'no', then re-assess the situation in one year.
Has the canopy been opened only by cutting off branches?	If 'yes', then only *pruning* was required. If 'no', then *thinning* is also required.
Can the trees withstand pollarding or coppicing (see boxes opposite)?	If 'yes', use *pollarding* where grazing is a problem, or *selection thinning*. If grazing can be controlled or is not a problem, then use *coppicing* or *selection thinning*. If 'no' then *selection thinning* is required (*i.e.* where shrubs or trees are cut off just above the ground and are not expected to re-grow).

- Is the tree canopy mostly of a single species or more or less even-aged?
- Does the tree canopy have dead or unhealthy trees in it, or are there leaning trees?
- Is the site fully stocked or overstocked with trees?
- Are there large heavy-crowned trees (especially on steep slopes)?

In every case, pruning should be carried out first of all. The bottom branches, up to half the total height of the shrub or tree, should be cut off. For large, mature trees only, branches can be removed up to two-thirds the total height of the tree.

Branches must be cut cleanly, using sharp tools. They are cut as close to the trunk as possi-ble without causing damage, starting with the branches nearest the ground and moving upwards. Where the branch is more than 50 mm in diameter, a small cut should be made under-neath the branch first, before removing it with a cut from above. The bark should never be torn: this can damage the plant badly.

Once pruning is complete, you will need to

METHODS OF ESTIMATING CANOPY COVER AND STOCKING

Visual skills

The best way to build your visual skills for assessing canopy percentage or stocking is to practice. Try going into different sites and assessing these indicators, first visually, and then by measurement. Remember to try this at different times of year. You should find that your estimates gradually increase in accuracy.

How to use a spherical densiometer *

- Hold the instrument level in front of the body and at elbow height with your head just outside the grid area.
- Assume 4 equi-spaced dots in each grid square. Count the number of dots in each quarter-square that lie in canopy openings.
- The total number of dots will give the percentage area not occupied by canopy. Subtract this from 100 to give the canopy percentage.
- Make four readings from each spot facing north, south, east and west, and take the average reading of these.

How to measure stocking using measuring plots

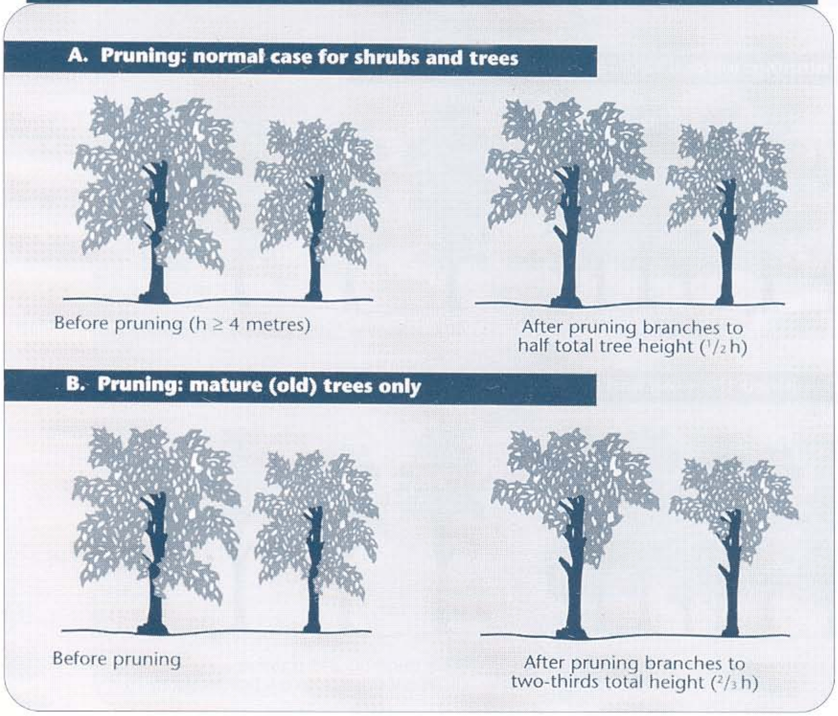
- Lay out a square or circular plot of known size and calculate the plot area (ha).
- Measure the diameter at breast height (1.2 m above ground level) of all trees in the plot.
- Calculate the basal area of each tree using the formula $A = \pi r^2$ where A is the area and r is the radius of the tree at breast height.
- Calculate the total basal area of all the trees in the plot (m^2).
- Calculate the basal area per hectare using the known plot size.
- Calculate the number of stems per hectare.

How to measure basal area using a wedge prism *

- Hold the wedge prism horizontally, at arm's length, with one of the flat sides held to the front.
- Look through the prism at the nearest tree. If the image of the tree as seen through the prism is displaced by more than the diameter of the tree, then do not count the tree. If the image is less than the tree diameter (i.e. there is overlap between the image as seen through the prism and the actual view of the stem) then count the tree as 'in'.
- View all trees in a circle from the measurement point counting those that are 'in'. After a full circle has been viewed, the basal area (m^2/ha) is calculated by the prism factor (written on the prism) multiplied by the number of trees counted.

* The Geo-Environmental Unit can supply the instrument required.

Figure 3.4: Diagrams showing the results of pruning



consider whether the site needs to be thinned, and if so, what sort of thinning. Decide this by asking the following question:

- Has pruning opened the canopy enough to allow sufficient light for grasses to grow under the trees?

If 'yes', then the operation is complete; if 'no', then thinning is needed.

When thinning, there are three options:

- pollarding: 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: this allows new shoots to grow out of the reach of grazing

SPECIES AMENABLE TO COPPICING AND POLLARDING

Species known to pollard

Shrubs/small trees
ambak, areri, armalito, assuro, bainsh, chiya, dhanyero, dhusun, ghurmiso, kimbu, kunyelo, namdi phul, nil kanda, rahar, sajiwan, simali, tilka

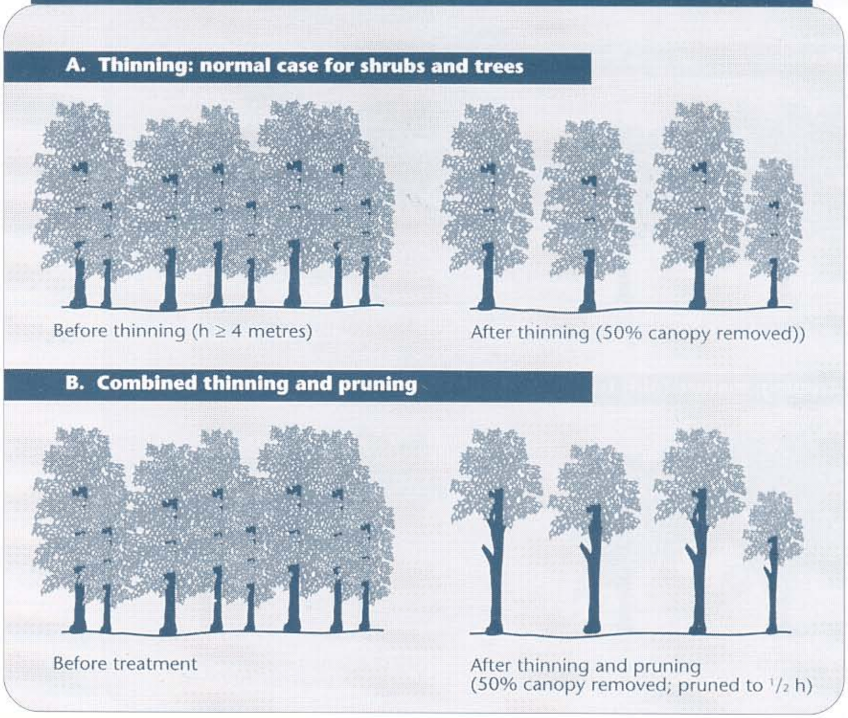
Large trees
acacia (*A. auriculiformis*), bakaino, bange kath, banjhi, champ, dabdabe, deshi katus, dhale katus, gliricidia, ipil ipil, jamun, kadam, kalo siris, kangiyo, kapur, khanyu, khari, khasru, khayer, koiralo, lahare pipal, lankuri, mashala, musure katus, nebharo, neem, okhar, painyu, patle katus, phalant, rato siris, sahijan, sal, sisau

Species known to coppice

Shrubs/small trees
areri, armalito, assuro, bainsh, dhanyero, dhusun, ghurmiso, kimbu, kunyelo, namdi phul, nil kanda, rahar, sajiwan, simali, tilka

Large trees
bakaino, banjhi, champ, dabdabe, deshi katus, dhale katus, gliricidia, ipil ipil, jamun, kadam, kalo siris, kapur, khanyu, khari, khasru, khayer, koiralo, lahare pipal, lankuri, mashala, musure katus, nebharo, neem, okhar, painyu, patle katus, phalant, rato siris, sahijan, sal, sisau

Figure 3.5: Diagrams showing the results of thinning



animals, but not all plants will tolerate this;
- coppicing: where the trunk of a tree is cut off about 300 mm above the ground to allow new shoots to grow from the stump, but not all plants will tolerate this; and
- selection felling: where the trunk of a tree is cut off about 150 mm above the ground, and it is not expected to shoot again.

The ability of a shrub or tree to coppice or pollard depends on the vigour and growth characteristics of the species. Plants commonly lopped for fodder will mostly tolerate it. All those grown from hardwood cuttings will certainly tolerate it. Some plants, such as utis (*Alnus nepalensis*) will coppice only under ideal growing conditions but otherwise will die; it is unlikely that conditions in roadside areas will be sufficiently good to allow this. With many species, large and older trees do not coppice as well as young trees. In these cases, selection thinning is a better option than relying on coppicing.

HOW TO MARK THINNINGS

Mark with paint the trees that should remain, and slash the bark of those which should be removed (once you are sure), according to the following criteria.

1. Remove all dead, dying, fallen, diseased or seriously damaged trees.
2. Next remove trees of unwanted species (note that a mixture of species should be retained if possible).
3. Next remove trees of bad shape (crooked, unevenly branched, *etc*). Note that straight stems are not necessarily required for bio-engineering purposes
4. Next remove trees that are spaced close to each other
5. Next remove trees with large crowns
6. Finally, select remaining trees to leave a variety of sizes and ages, forming only about 33 to 50 percent of the original canopy.

All ***unmarked*** trees can now be removed.

The box on page 87 lists the species known to coppice and pollard readily. In addition, the tables of species in Annex B of the *Site Handbook* page 130, give details on coppicing and pollarding potential, as far as they are recorded, for the bio-engineering trees.

The main advantage of coppicing and pollarding is that it creates a shrub or tree with an extensive rooting system but relatively little weight above ground. This means that the plant provides the optimum reinforcement, anchorage or support, without surcharging the slope. In certain cases, it is possible that the roots die back when the plant is cut above ground, but this is not well researched, certainly in Nepal. Pollarding also has the advantage of the new shoots emerging beyond grazing height.

If the species that require thinning will tolerate coppicing or pollarding, then the engineer has a choice of practice, and the choice can be left to the discretion of the individual. The simplest system, however, is to use selection thinning and remove enough plants to open the canopy.

The questions-and-answers in Figure 3.3 summarise the selection of management options to increase light penetration through the canopy by using pruning and thinning operations. For other purposes (*e.g.* removal of weight surcharge), then the most appropriate solution can be chosen according to the particular species and site.

Once the thinning option has been chosen, go through the site slowly and decide which trees must be cut (see box on page 88). The aim should be to remove 50 to 67 percent of the canopy. When marking the thinnings, also look at the ground vegetation. If there are younger trees and shrubs (regeneration), then it should be possible to remove trees from the main canopy to allow them to develop.

Every site must be assessed individually and it is not possible to make precise rules. Engineers and overseers will learn from experience what is the best range of options to use in each location.

The actual process of pruning and thinning is described in Section 5.4 of the *Site Handbook* (page 121). Figure 3.4 gives diagrams of forests before and after pruning, and Figure 3.5 before and after thinning.

3.6 FURTHER CONSIDERATIONS IN THINNING SHRUBS AND TREES

General

All pruning and thinning operations should be carried out between Poush and Falgun (mid December to mid March), when there is little or no growth.

Regular light pruning is better than infrequent heavy pruning.

Pollarding in the simple sense is uncommon in Nepal. More usual is a combination of pollarding and lopping where all branches are removed, leaving a single, more or less bare stem. This system is very similar to the fodder lopping carried out by farmers on their private trees. It is an acceptable alternative to pollarding.

It is better to coppice (and presumably also pollard) a group of trees together, rather than individual trees within a plantation or forest. If single trees are coppiced, the intensity of light on the cut stump is usually not great enough to encourage very vigorous regrowth. In these circumstances, the stump may die, or only put out weak shoots. If a larger gap is created (a 'coupe'), the increased light will give more vigorous regrowth.

Products

Firewood is the main product from pruning operations. But very little firewood 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*).

Much of the cut material will be suitable only for firewood if plants are not straight, or if they are an unsuitable species for timber.

Limitations of pollarding and coppicing

Pollarding and coppicing may be less successful on very dry sites. Also, large and old stems often coppice poorly.

If many shoots grow up from a pollarded stump, they may need to be removed after about five years. Otherwise, the canopy will become dense again, or the plant will again grow too large.

About five years after coppicing, a process of 'singling' may be required. This is where most of the coppiced shoots are removed from the stump, leaving only a single good stem. This can often be coppiced again in later years. More frequent coppicing will encourage a good root system and multiple smaller stems will create better ground cover. This means that tree species can be managed as large shrubs rather than tall trees.

Some species can only be pollarded or coppiced a few times before the plants lose their vigour.

Utis forest

Utis (*Alnus nepalensis*) is easy to establish and is a familiar tree on rehabilitated land between 1000 and 2500 metres. But varied plantations dominated by utis are difficult to sustain. This is because utis is essentially a coloniser, rather than a species that grows in a climax community (a permanent forest type). Also, it is often difficult to encourage a good understorey below utis. Therefore, in utis forest, thinning should always aim to remove utis and leave species such as chilaune (*Schima wallichii*), katus (*Castanopsis* species) and painyu (*Prunus cerasoides*). These species will often appear naturally among utis, but if they do not appear, it is worth planting them in gaps in the utis canopy. In Central and Western Nepal, thinning will eventually change the site from one of utis to a mixture based on chilaune-katus. If there is heavy ban mara (*Eupatorium adenophorum*) invasion, this may need to be cleared in patches to allow trees to regenerate or to be planted. Note that utis can coppice but only in the best sites and usually not very strongly.

Pine (salla) forest

There are two indigenous (local) pine species present in Nepal: khote or rani salla (*Pinus roxburghii*) below 1950 metres; and gobre salla (*Pinus wallichiana*) above 1800 metres. In some afforestation areas there are also introduced pine species, but these are more limited in range. Pines can be the best species to establish on many hot, dry sites, and in places also form impressive natural forest. Unfortunately, there is often very little vegetation underneath and so erosion can still take place in good pine forest. Therefore other species should be favoured. Pines should always be removed if there is a choice between them and another tree. If there is no choice, then other species can be planted. The aim should be for a pine plantation to be changed to one of mixed other species.

The creation of a less even-aged and mixed species forest from an originally pure pine forest is often possible by using natural regeneration. If the pine forest (or plantation) is not heavily grazed and is protected from fires, regeneration of pines and broadleaved species such as chilaune (*Schima wallichii*) or tooni (*Toona ciliata*) will normally occur.

Dry Churia scrub forest

This is dominated by tilka (*Wendlandia puberula*) and dhanyero (*Woodfordia fruticosa*). These are both pioneers but can also form a permanent forest type. However, other species should be favoured and tilka and dhanyero removed if there is another tree species present. Care often needs to be taken to encourage ground cover. In the driest areas, babiyo (*Eulaliopsis binata*) grass is the only robust surface cover that will survive.

In theory the climax vegetation community for these areas is sal (*Shorea robusta*) or mixed tropical hardwood forest. In practice, however, it may take so long to reach this in dry sites that management should aim to sustain a tilka-dhanyero scrub forest with a mixture of other species.

Sisau and khayer plantations

Both sisau (*Dalbergia sissoo*) and khayer (*Acacia catechu*) are easy to establish quickly, even on harsh, open sites. They are often used for bio-engineering at low altitudes. However, plantations of these species often have little ground cover. They should be managed so that other species are preferred. Eventually, sisau or khayer should form no more than 50 percent of the tree population.

Forests on *rato mato*

Red clay soils (commonly known as (*rato mato*), although there are local variants) often require special management. They provide poor rooting conditions for plants, as well as low fertility, and are highly erodible. They occur mostly at low altitudes and carry sal (*Shorea robusta*) forest, which is often degraded. Studies have shown that some shade from trees is important for maintaining a ground cover of vegetation, but that too much shade impedes the growth of grasses. It is therefore necessary to try to maintain a light or dappled shade. If possible, the surface should receive sunlight for between perhaps two and four hours of the day during the late spring and summer. Large gaps in the canopy must be avoided, and the canopy itself must be kept light. This is probably best achieved by the regular pruning of branches. Protection from uncontrolled grazing is also essential.

3.7 MANAGEMENT OF BAMBOOS

General

The establishment of bamboos often requires care, but after that their management is relatively straightforward.

Most bamboos require stable, moist conditions for early growth. This means that heavy mulching is an advantage for about the first three years. Some foresters advocate the use of a 'nurse crop' of trees, where bamboos are planted in the shade of existing trees, which are felled once the bamboo clumps have become established. In bio-engineering, however, it is more normal to plant the bamboos on bare sites and rely on a thick layer of mulch, which is renewed periodically, to keep the roots relatively cool and moist. If the rhizomes of older clumps have been exposed by erosion, they should be covered with mulch. See Section 5.3 of the *Site Handbook*, page 118 for details of mulching.

After about three years, large culm shoots start to appear from the rhizome. Once this happens, the plant can be considered to be successfully established. It is also resistant to grazing from this time onwards.

In later years, the large bamboos thrive best with very little shade from trees. However, the smaller bamboos, tite nigalo (*Drepanostachyum intermedium*) and padang bans (Himalayacalamus hookerianus) grow best under a light shade. For these species, therefore, it is best to try to keep a light canopy cover.

Thinning bamboo clumps

Large bamboo clumps start to become very dense after about 10 years. It is best to start harvesting well before this stage is reached, perhaps five years after planting. Culms should be removed annually, rather than taking many at one time. A clump is likely to be seriously damaged if all the culms are cut at once, and so this should not be done unless it is intended to kill the clump. Up to 25 percent of culms removed at one thinning, repeated every year, is a useful rule for sustained production; however, for bio-engineering purposes it may be preferable to remove a smaller proportion, so as not to over-stress the clump.

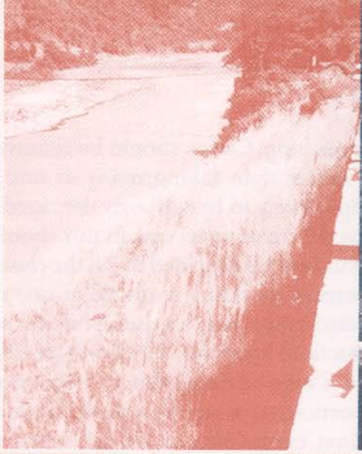
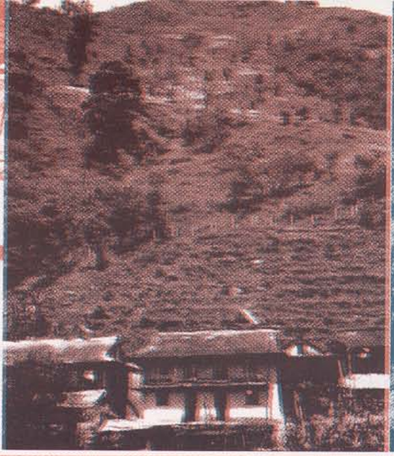
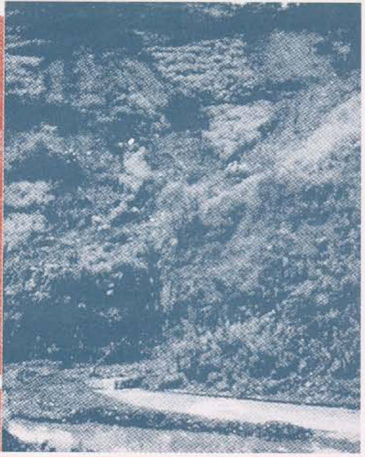
Most culms should be cut when they are mature, which means when they are at least four years old. If material is required for weaving, however, culms of only two years age can be harvested.

Culms must be cut just above a node and one or two full internodes above the ground. This allows the attached rhizome to shoot again before it dies. Farmers usually cut the culms close to the ground to maximise the length of culm, but this can cause more rapid death of the rhizome from which the culm is growing.

Thinning should be done in the dormant season, between Kartik and Falgun (mid October to mid March).

Culms must be cut from the inside of the clump, not just from around the edge. Harvesting from the middle of a dense clump is difficult, but is essential to keep the whole clump vigorous, and to encourage it to increase its size. One method is to cut lines through the clump to allow access to the middle culms.

If large clumps have been neglected, it is best only vigorous young ones. Grass, creepers and shrubs should also be removed if they are impeding growth.

The law and roadside vegetation

This Chapter outlines the law pertaining to the ownership and management of roadside vegetation at the time of publication of this manual. Interpretations are supported by accurate references to specific clauses in the relevant laws.

The following areas are covered:

- roads and their ownership (4.2);
- the ownership of trees in the road reserve (4.3);
- power delegation (4.4);
- disposal of forest products (4.5);
- removing trees on land adjoining the road reserve (4.6);
- disputes relating to trees (4.7);
- how to go about removing trees (4.8).

Note that some aspects are covered by implication rather than by specific mention in the law. Laws are constantly under review, and therefore the reader should check whether changes have been enacted since this manual was written.

4.1 INTRODUCTION

The Department of Roads is charged under the Public Road Act 2031 with the construction and maintenance of roads. It is therefore required to undertake this in any way that serves the public interest.

Four main documents cover the laws and regulations for the position of the Department of Roads regarding trees and other forest products. These are as follows:

- Constitution of the Kingdom of Nepal 2047;
- Land Acquisition Act 2034;
- Public Road Act 2031; and
- Arthik Prashasan Sambandi Niyamharu 2042 (incorporated into Arthik Ain Niyam Sangraha 2052).

This guide aims to provide a simple reference to those laws, as far as they cover the planting and removal of vegetation in roadside areas. This is not a legal document, and if the reader is in any doubt, he or she should seek further advice.

Vegetation in roadside areas must be managed as part of routine, recurrent and periodic maintenance operations. The main reasons for this are to maximise the bio-engineering potential of the vegetation, to ensure that trees do not become too big and destabilise the slopes on which they are growing, and to give useful products.

The removal of trees from road reserves is a good thing if it is for one of the reasons above and if it is done properly. Trees are normally managed for economic reasons and there is no point in planting them if they are not cut down and used later. However, if a tree is cut, it should normally be replaced by a number of new plants. It is essential that a good vegetation cover be maintained in the road reserve.

4.2 ROADS AND THEIR OWNERSHIP

The roads of the strategic network (*i.e.* Rajmargs or highways, and feeder roads) belong to His Majesty's Government of Nepal. The Department of Roads is responsible for all activities regarding the construction, maintenance and management of the roads, unless overridden by a higher authority (either the Cabinet or the Ministry of Works and Transport).

His Majesty's Government may acquire land for public property (*e.g.* roads) only if it is in the public interest.
Constitution of the Kingdom of Nepal 2047, Article 17(2)

Compensation must be paid on the acquisition by His Majesty's Government of any privately owned land.
Constitution of the Kingdom of Nepal 2047, Article 17(3)

The processes of acquisition and compensation are given in a special law.
Land Acquisition Act 2034

A 'public road' is any road that is not owned or used privately. The definition of a 'public road' includes everything associated with it, such as bridges, culverts, footpaths, *etc.*
Public Road Act 2031, Section 2(A)

The 'road boundary' is defined. It includes the road itself and the areas to right and left.
Public Road Act 2031, Section 2(B) Section 3

His Majesty's Government can classify any road as a Highway, Feeder Road, District Road or Urban Road. It may fix the boundary to a maximum of 31 metres on either side. It can also change these boundaries on account of topography or habitation.
Public Road Act 2031, Section 3

In practice, 'His Majesty's Government' means the Cabinet. Once the Cabinet has decided on a road and the width of the road boundary (or road reserve), this land becomes the responsibility of the Department of Roads. If the road crosses Government forest land, then this decision effectively means the land has been transferred from the Department of Forests to Department of Roads. From this point, Department of Roads has authority over everything within the boundaries of the road. This includes the use of trees and forest products on that land.

Where the ownership of roads is not registered with the Department of Roads, the Division Road Office should take all steps to get it registered. This will entail close collaboration with the local offices of the Department of Land Survey (Nappi Bibhag) and the Department of Land Revenue (Malpot Bibhag).

4.3 THE OWNERSHIP OF TREES IN THE ROAD RESERVE

Laws applying to trees generally cover all other 'forest products' as well, unless they are covered by another specific law. So under the same heading as 'trees' come grasses, shrubs, fruits, *etc.*, grown as a perennial (*i.e.* long term) crop rather than as an annual agricultural crop.

The Department of Roads may plant trees along the sides of the road, on land within the road reserve.
Public Road Act 2031, Section 16(1)

In areas around road boundaries (but not within the road reserve) the appropriate Village Development Committee or Municipality has the duty of protecting trees.
Public Road Act 2031, Section 16(2)

The Department of Roads is responsible for the thinning or removal of trees that create an obstacle to traffic.
Public Road Act 2031, Section 16(3)

The Department of Roads can delegate all powers to plant, protect and cut trees in the road reserve to any person or institution.
Public Road Act 2031, Section 16(4)

The Department of Roads can allow a Forest User Group to plant and manage trees on road reserve land. However, only the Department of Roads can use the products from that land. It cannot allow User Groups to use forest products (see under *Disposal of forest products*, Section 4.5).

The law governing forests states that other laws prevail over matters not otherwise mentioned in that Act. There is no mention of trees on road reserve land in the Forest Act. But there is in the Public Road Act.Therefore the Public Road Act applies to all matters relating to trees on road reserve land.
Forest Act 2049, Section 73
Public Road Act 2031, Section 16

All forest land other than that which is private, is owned by His Majesty's Government. However, once it is defined as part of a road, that land and everything on it is transferred and becomes the responsibility of the Department of Roads. All trees and forest products must be managed by the Department of Roads (unless it was stated at the time of transfer that they will be managed by the Department of Forests).
Forest Act 2049, Section 67
Public Road Act 2031, Sections 2 & 3

4.4 POWER DELEGATION

The delegation of power is essential to allow work to be undertaken by the Government. There is provision for any civil service officer to represent the Government in actions taken under the law.

His Majesty's Government may delegate any or all power of the Department of Roads to any authority. This authority can be a Division Chief or any individual officer.
Public Road Act 2031, Section 32

4.5 DISPOSAL OF FOREST PRODUCTS

Trees and their products within road boundaries belong to the Department of Roads. Being the owner of such forest products, the Department of Roads can either use them itself or sell them. There is no provision under the Public Road Act for the disposal of forest products. Therefore the normal procedures of His Majesty's Government apply.

As a branch of the Government, the Department of Roads must use the standard regulations and procedures for disposing of property. So it must complete the full process of Government tendering.
Arthik Ain Niyam Sangraha 2052

4.6 REMOVING TREES ON LAND ADJOINING THE ROAD RESERVE

If a person has left or thrown anything on a public road, the Department of Roads may issue an order in that person's name to remove that thing from the road. If the concerned person does not remove it, the Department of Roads may take that thing into its own possession and has the power to remove it from the road.

There is also provision for the Department of Roads to remove trees that obstruct traffic.

If any tree or its branches on land adjoining the road reserve disturbs traffic, the Department of Roads may issue an order for them to be removed within a reasonable time. If the order is ignored, then the Department of Roads may remove them.
Public Road Act 2031, Section 18

If any tree or its branches on Government forest land adjoining the road reserve disturbs traffic, the Department of Roads may write to the Department of Forests requesting them to be removed within a reasonable time. If the order is ignored, then the Department of Roads may remove them.
Public Road Act 2031, Section 18

4.7 DISPUTES RELATING TO TREES

The general rule is that the land owner has the full right to use his land as he wishes. This means that the Department of Roads has full authority over the planting and felling of trees on road reserve land. This cannot be interfered with by other bodies, even those empowered to acquire land in the public interest. Land acquired by the Government cannot be transferred to another purpose.

However, the Department of Roads should also respond in a reasonable way to requests from other branches of Government or national suppliers of services (*e.g.* the Nepal Electricity Authority) for permission to remove trees.

The law prohibits the construction of access roads from public roads, or digging to make drains or build houses or sheds, or do anything on the public road boundary without the permission of the Department of Roads. Action can be taken to stop these activities and remove anything constructed.
Public Road Act 2031, Section 19

There is provision of punishment by fine for the violation of Section 18 and for the cutting of trees planted under Section 16 (of the Public Road Act). The fine may be up to Rupees 2,000 for cutting trees.
Public Road Act 2031, Section 18

As a branch of His Majesty's Government, the Department of Forests has no right over the planting or felling of trees in the road reserve, without the permission of HMGN. This applies to all Government Departments as well as to individuals or national institutions, such as the Nepal Electricity Authority.

The Nepal Electricity Authority (NEA) is not a branch of the Government. As a Corporation, it has the status of a legal person. The Department of Roads can give the authority of planting or felling trees on road reserve land, with terms and conditions, to the NEA. But only the Department of Roads can sell the products.
Public Road Act 2031, Section 16(4)

In cases of timber theft from road reserve land, the Department of Roads should treat it as a criminal case and inform the police. There is no provision for this under the Public Road Act, and so the general laws are followed. The Department of Roads should issue a First Information Report to the police. This would include the nature and date of the crime, the amount of loss and, if possible, the name of the suspect and any other relevant information. It is then the duty of the police to investigate further.

4.8 THE PROCEDURE FOR REMOVING TREES

Trees and their products within road boundaries belong to the Department of Roads. Therefore the Department has absolute power over the use of all trees within legally defined road reserves.

The process of removing a tree is straightforward but each of the steps below should be followed carefully in order to avoid misunderstandings.

1 The tree(s) to be removed should be identified. There must be a valid reason for removal. Such reasons might be as follows.
- The tree is dead and may fall down.
- The tree is obstructing traffic or drivers'

sight lines.

- The tree is surcharging a steep slope.
- The tree is too big and unstable for the slope on which it is growing.
- The tree needs to be cut as part of a recurrent maintenance thinning programme. This will allow more light to penetrate and help the understorey grow.
- The tree needs to be cut so that coppice shoots will come from the stump.
- The tree needs to be cut to allow widening of the road.

2 A letter should be sent to the local District Forest Office. This will inform the DFO that Department of Roads is felling a tree or trees. It is not a legal requirement, but may help to avoid misunderstandings with the Department of Forests. An example of such a letter is given in the box opposite.

3 All necessary action should be taken to fell the tree. This will normally be done either by direct labour or by contract. In any case, normal HMGN procedures must be followed. The DFO can advise on this if necessary.

4 At the time of felling, ensure that all necessary safety requirements are in place. If in doubt, request the Traffic and Engineering Safety Unit for advice.

5 Have the tree felled and cut into sections. Store the products safely in the nearest Department of Roads camp.

6 Either use the products (*e.g.* as firewood for melting bitumen) or dispose of them according to normal HMGN procedures (Sections 39 to 41 of the Arthik Prashasan Sambandi Niyamharu 2042). This should be done within six months of felling. After this time, the products deteriorate and lose value.

Example of a letter to the Department of Forests informing the local District Forest Officer of the intention to fell a tree.

Felling of sal (*Shorea robusta*) tree by the Department of Roads.

There is a sal (*Shorea robusta*) tree situated on top of the road cut slope at km 72 (from Kohalpur) of the Ratna Rajmarg. The tree is dead and of no value as timber. It is giving rise to a weight surcharge to the slope in the vicinity of the southern anchorage point of the Bheri suspension bridge. There is a serious danger that the tree or part of it may fall into the road, and so it forms a hazard to road users. It is also contributing to slope instability. It lies within the legal right of way of the Ratna Rajmarg.

The Department of Roads, Mid Western Region Division Road Office Number 4 (Chhinchu) will remove the tree and dispose of it in accordance with the laws and regulations of His Majesty's Government of Nepal within the current Fiscal Year. In removing the tree, the Department of Roads is fulfilling its obligations under Sections 16(3) and 16(4) of the Public Road Act 2031, which is applicable in this case as stipulated in Section 73 of the Forest Act 2049. The wood from the tree will either be used by the Department of Roads for its own requirements or will be disposed of in accordance with Sections 39 to 41 of the Arthik Prashasan Sambandi Niyamharu 2042 (as incorporated in Arthik Ain Niyam Sangraha 2052).

The purpose of this letter is only to inform the Department of Forests of the intended action by the Department of Roads, to avoid any misunderstandings. Please also be informed that in this Fiscal Year, Chhinchu Division Road Office will be planting more than 100,000 grass plants and over 10,000 shrub and tree seedlings in the road reserves under its bio-engineering programme.

Road neighbours and roadside vegetation

Most roads in Nepal run through rural areas. These roads affect almost all of the land uses on the slopes they cross, and are in turn affected by them. They cannot be successfully maintained if they are treated as if isolated from other land uses.

This Chapter suggests ways in which the Department of Roads (and its associated consultants and contractors) can co-operate with rural road neighbours to mutual benefit. This is based on extensive research and trials on a number of roads.. Many of the principles also apply to work with bazaar and urban road neighbours.

This is beyond the normal scope of bio-engineering but is included in this manual because of the importance of improving roadside maintenance operations; and the indistinct boundaries between many bio-engineering sites and neighbouring farm and forest land. The inherent instability of many hill slopes in Nepal means that successful road construction and maintenance is not possible in isolation.

The following topics are covered in this Chapter.

- General background on community development (5.2);
- the reasons for working with rural road neighbours (5.3);
- community initiatives in the road sector (5.4);
- guidelines on how to collaborate with road neighbours (5.5).

A Code of Practice concerning Roads and Other Land Uses is given in the *Site Handbook* (page 125). This should be followed in all cases to ensure a high standard of professional conduct, whether there are plans for specific work with road neighbours or not.

5.1 INTRODUCTION

It is important that the roads of the strategic road network are managed in ways that promote development, both locally and nationally. It is the responsibility of the Department of Roads to ensure that its operations are not harmful to people or the environment.

Road neighbours is a term used to describe all people living near roads. As they are affected by roads, they are stakeholders[1] in the roads. They have an interest in how the roads are managed and maintained.

These guidelines deal only with road neighbours in rural areas, not in towns or commercial bazaars. Rural road neighbours are usually known as 'local people'; they are mainly farmers, living either in scattered farm houses or in villages with an agricultural economy.

The relationships between the Department of Roads and rural road neighbours are often strained by conflicts. This is usually because the Department has built a road through a rural area without paying enough attention to the people who live there and the way in which they use the land. Roads are a relatively new feature in the landscape and they do not always fit well. Few have been built with proper consideration for the local economy of the terrain which they cross.

Also, many rural communities are experiencing a good deal of change even without the coming of roads. Populations are rising fast in rural areas, and the fertility of the land is declining. This has led to over use and increased pressure on many agricultural areas .

Environmental degradation is therefore caused both by roads and by people living in rural areas. If this trend is to be halted, then the Department (as a body of central government) must take the initiative to halt it.

The strategic roads cannot be managed by rural road neighbours. The Department of Roads must manage them. However, there are often conflicts of interest on the slopes adjoining roads. This is where there is scope for joint work between the rural road neighbours and the Department. There follow some considerations to bear in mind when working with rural road neighbours and some practical guidelines on how staff of the Department of Roads might move forward.

At this stage, the involvement of rural road neighbours in the management of roadside land is not a policy issue. These guidelines are designed only to help staff in specific situations where this option would be advantageous to the Department.

5.2 GENERAL BACKGROUND ON COMMUNITY DEVELOPMENT

What is 'community development'?

Community development is the involvement of people in development activities at the local level. It is a general term covering many procedures. People may be involved in organised groups or as individuals. This section looks only at the use of rural resources by communities.

The use of community approaches in development has been very successful in many cases. It works by raising awareness among people of what development initiatives can offer, and by giving people responsibility for improving their own living conditions. These are often the trig-gers required to enable people to work positively for change.

Background

Over the past 20 years or so, community approaches have contributed to many successes in rural development . Mostly, these have built on traditional community structures for the management of local resources. Often they have been more successful than the original management systems because they have involved a wider range of people than were traditionally involved in management (such as low-caste groups). They have reversed a number of failed attempts at management by central government.

The main areas where these community initiatives have been successful are in forestry, agriculture, irrigation and, to some extent, local roads. All of these are involved in resource man-agement at the village level; normally on a ward level, rather than a VDC level.

A number of major requirements appear to be needed for a successful community management initiative. These are as follows:

- A vested interest for the community in managing the resources;
- Resources of a scale and type that can be managed at the village level;
- Appropriate legislation and government support at all levels;

[1] A *stakeholder* is any person, group or institution that has an interest in the activity in question. It includes both beneficiaries and those who lose out, as well as those involved in or excluded from decision-making processes.

Road neighbours can benefit from community management of roadside plantations. Members of this forest user group share the firewood from a roadside plantation

- An agency supporting and enabling the communities in their work;
- Stability of the system to allow long term vision and investment by the community.

Example of community forestry

The forest sector is often considered to be one of the most successful in this area. In order for community forestry to be undertaken on a broad scale, a completely new Forest Act was required; the Department of Forests had to re-train a large number of staff and completely revise its working practices; as a result, communities with the right scale of forests nearby have been able to manage their own resources.

Community forestry aims to meet the basic needs of all rural people for forest products. Forests that are mismanaged become degraded: these are a familiar sight in Nepal. They are usually 'controlled' by certain local people (the more powerful individuals in the area). These people do not have the capacity to manage the forest properly. If a rapid attempt is made to set up a Forest User Group, only these 'controllers' are represented. The unrepresented people will continue causing the mismanagement, which led to degradation in the first place.

Therefore, it is necessary to identify all actual and potential users, who must then be brought together into the Forest User Group. This entails consulting every household in the area. It is often necessary to bring people together in the Forest User Group who have never co-operated before. Successful Forest User Groups are frequently entirely new to the area in terms of their composition of people. They are all the people interested in the forest, irrespective of caste, wealth or status. In many cases, the establishment of a Forest User Group represents a big assault on existing local power relationships.

Under the Department of Forests, the process of extension depends entirely on the Forest Rangers. These staff had to be re-trained and re-oriented into their new jobs. In many areas, the success of community forestry relies heavily on the skill and interest of these people.

General principles of working with communities

There is no prescription for working with communities, but some facts are now well established.

- A positive, sympathetic approach yields better results than one based on conflict and negativity.
- A government authority must be beyond reproach if it is to convince the public to be positive towards it. This means that it must fulfil its legal obligations and should be reasonably transparent in its operations.
- Public-funded bodies should be humble (*e.g.* 'we are here to serve you') while still retaining authority to manage public works in the national interest.
- The more communication there is between stakeholders, the better is the relationship. Communication should not just be started when there is a problem.

Limitations

Not all resources can be managed by rural communities. There are many forest areas, which cannot be, for example. There are few examples of successfully established community roads; and for those which exist, doubt remains over their long term sustainability.

All community development initiatives require large inputs by specialised staff. Without an understanding of the process, or time to build up the relationships that are required, or continuity of involvement, efforts in this direction may be wasted.

For the Department of Roads, the provision and maintenance of the strategic roads will always be a function of central government. But rural road neighbours can be involved in managing the fringe areas, such as the vegetation on slopes close to roads.

5.3 WHY WORK WITH RURAL ROAD NEIGHBOURS?

Roads and their neighbours do not always exist in harmony. Often the activities of one affect the other.

Problems caused by roads to rural road neighbours

The construction and subsequent operation of roads through rural areas in steep terrain have considerable effect on the people living beside them. These include the following:

- loss of land (sometimes with no compensation paid);
- damage to agricultural and forest land by construction;
- debris falling on to agricultural land, sometimes covering it completely;
- interruption of irrigation systems;
- re-activation of gullies and landslides by alterations to slope stability and drainage;
- interference to drinking water supply systems;
- noise, dust and social pressures.

Problems caused by rural road neighbours to roads

Particular problems identified on mountain roads are:

- extensive over-grazing of roadside slopes resulting in removal of vegetation and physical damage to the slope surface;
- cultivation, without terracing, on steeply sloping terrain (up to 40° slopes);
- cultivation to the very edge of terraces and cut slopes;
- uncontrolled quarrying of stone from road cut slopes;
- construction of houses on unstable land immediately above the road;
- poor construction and maintenance of leats (irrigation channels), allowing large amounts of water to seep into slopes adjacent to road cut slopes.

All of these practices can damage the road under certain conditions. At the least, they add to the burden of road maintenance. They are caused by one or more of the following:

- lack of interest in the maintenance of public property;

Heavy grazing seriously inhibits vegetation re-colonising bare surfaces

- absence of choice to use better practices in marginal situations;
- ignorance of the risks of careless practices to the environment;
- deliberate neglect of public property in the pursuit of short term gain.

This scenario is not in anyone's interest. Things can be improved if there is better understanding between each interest group (*i.e.* between the staff of the Department of Roads and the rural road neighbours). This requires communication on the basis of mutual benefit. It can lead to a sharing of responsibility for the problem, rather than a continuation of blaming each other.

The stability of roadside slopes will only be improved when the Department of Roads works with local people towards better land management.

5.4 COMMUNITY INITIATIVES IN THE ROAD SECTOR

Experience from the Koshi Rajmarg

A series of projects has maintained the Dharan-Dhankuta-Hile-Basantapur roads from 1984 until 1996 and 1997. Among the innovative approaches tested to find the best ways of improving slope stability and slope protection, was an 'extension programme'[1].

The project extension effort consisted of a small programme run over a number of years. Only two to four staff were employed. Their job was to raise awareness among the rural road

[1] An *extension programme* is a planned process of raising awareness of a certain topic over a wide area. In rural development, this approach is often used to extend understanding of particular subjects or opportunities.

neighbours of the issues concerning the Department of Roads. They encouraged the farmers to manage their land in ways that reduce erosion and shallow landsliding. They distributed grass slips and tree seedlings from the bio-engineering nurseries for planting on land that can be improved. They assisted the people to tap the development resources available to them, for example through the Departments of Forestry and Agriculture.

A study of this work in 1996[1] showed that the programme had been successful in many ways. For example:

- The road, drains and slopes above and below the roads were found to be well maintained throughout the section.
- A large number of trees and grasses were seen planted in both the road reserve and the road corridor (the wider area affected by the road).
- Many local people appreciated the project's efforts for roadside slope protection with the collaboration of road neighbours.
- The extension programme seemed to be successful in making the road neighbours aware of the mutual advantages of roadside slope protection by planting vegetation in the road reserve and road corridor.

The programme operated on the Koshi Rajmarg seemed to have been successful in helping to meet the project's objectives. It enhanced the condition of the slopes significantly. This reduced the costs of road maintenance while assisting the farmers.

5.5 HOW TO COLLABORATE WITH ROAD NEIGHBOURS

What areas of land?

Any areas of marginal (*i.e.* uncultivated) land in, or close to, the road reserve.

Any land that needs improved vegetation cover for better erosion protection and stability.

Very steep and unstable areas should be maintained only by the Department of Roads using standard procedures.

What might be achieved?

Working with road neighbours could eventually lead to:

- respect for public property and therefore and end to damage caused through thoughtlessness or contempt for the 'establishment'.
- exclusion of grazing animals from steep roadside slopes.
- careful community management of vegetation in the road reserve.

Ideally, people should manage their own land carefully where it adjoins the road reserve. This means, for example, very careful management of leats (kulos) and irrigation water; no cultivation on steep slopes, but only on well maintained terraces; large grasses (*e.g.* amliso, khar and babiyo), small trees and other perennial crops used wherever possible, especially on terrace edges and risers; no throwing of debris down slopes on to roads; no excavations just below roads.

Farmers should ideally benefit from their proximity to the road. They should gain from developmental inputs and their ease of reaching markets. If they can be helped to manage their land better, it would almost certainly help the Department of Roads as well. In general, long-term profitable forestry and agriculture benefit everyone. This is because they use careful and sustainable methods of cultivation.

Who should take the initiative?

The Department of Roads must take the initiative in establishing a working relationship with rural road neighbours.

To do this means committing a considerable input of staff time and energy.

What criteria must be met?

If the Department is to work with road neighbours, then all of these criteria must be met.

- The area of land must be clearly defined and agreed.
- Full agreement on the management of vegetation must be made, in a way that is acceptable to all parties to the agreement.
- All users of the area must be represented. Influential people may resist the involvement of disadvantaged groups. However, success will not be achieved unless everyone using the area is involved. The interests of the poorest section of the community must be

[1] *Road Neighbours Case Study* (1996) commissioned by the Bio-engineering Component of the Road Maintenance Project, Department of Roads.

Informal discussions with road neighbours are essential in building good relationships (left)

Amliso grass *(Thysanolaera maxima)* planted extensively as a cash crop close to a road (right)

especially safeguarded.

- The Department of Roads' interest in the area must be clearly stated. Once agreed, the course of action must be followed according to plan. Clear rules for compensation must be agreed, in case the Department of Roads has to cancel the agreement: for example in the case of road widening requiring the re-cutting of slopes.
- There must be clearly defined reasons for the rural road neighbours to be involved in any joint work.
- There must be clear benefits for all of the parties involved.

How to approach local people

Use a friendly approach. Be humble, not authoritative.

Involve everyone. Do not take the word of local leaders that all people are involved without double checking.

Follow the *Code of Practice Concerning Roads and Other Land Uses* (given in the *Site Handbook*, page 125): behave well and consistently.

Utilising the Department of Roads' resources

Distribute plants from Department of Roads bio-engineering nurseries.

If they can be justified for maintenance reasons, carry out civil works to assist the needs of the road neighbours.

Utilising the resources of other agencies

Encourage the rural road neighbours to find out what is available for them from agencies such as:

Department of Forests;
Department of Soil Conservation;
Department of Agriculture;
Department of Horticulture;
Agricultural Inputs Corporation;
research centres;
projects and NGOs.

Check these agencies yourself to see what they offer. Discuss their policies of working close to roads as opposed to remote areas. Ask them to support your plans if this is appropriate.

Examples of good collaborative work with rural road neighbours

In this section are given some examples of good work by rural road neighbours in support of slope protection and stability. In many cases they were assisted by a road project, but in some cases the initiative was entirely by the road neighbours themselves.

- Planting of large clump grasses on road cut slopes to provide useful products. Common examples are amliso, khar, babiyo and napier (respectively: *Thysanolaena maxima*, for brooms; *Cymbopogon microtheca*, for thatch; *Eulaliopsis binata*, for fibres; and *Pennisetum purpureum*, for fodder).
- Planting of fodder trees seedlings on terrace edges above the road. Fodder trees are lopped

regularly and so do not surcharge the slope.

- Planting of a mixture of trees and grasses along road cut and fill slopes, and on terrace edges above the road. Examples are: utis and napier (*Alnus nepalensis* and *Pennisetum purpureum*); rai khanyu and kikiyu (*Ficus semicordata* and *Pennisetum clandestinum*); khayer and babiyo (*Acacia catechu* and *Eulaliopsis binata*); nebharo and amliso (*Ficus auriculata* and *Thysanolaena maxima*); and many more combinations are possible.
- Farmers protect roadside vegetation in exchange for using the grass and fodder (ghans and dale ghans).
- Cultivation of utis and alainchi (*Alnus nepalensis* and cardamom) on steep slopes adjoining roads.
- Establishing plantations of sisau on embankments and other roadside areas.
- Seeding of khar on former gravel quarries to establish khar baris.
- Planting large bans clumps along kulos (irrigation leats).
- Planting napier (*Pennisetum purpureum*, a fodder grass) on old tip sites to provide 'banks' of fodder grass.
- Planting banana trees on gentle cut slopes.
- Establishment of Forest User Groups to manage forest areas adjoining the road reserve as community forests. This is usually done in conjunction with the Department of Forests or through the Department of Soil Conservation.
- Establishment of other User Groups to promote different aspects of development (*e.g.* rabbit farming) in roadside areas, with one stated aim being the improvement of agricultural land use. This is usually done in conjunction with other line agencies.
- Planting kimbu (mulberry, *Morus alba*) trees on roadside slopes to provide foliage for sericulture.

These are only some of the examples known from the road sector. Other sectors of development have numerous good examples of different activities, which help to strengthen and protect steep slopes.

Khar (Cymbopogon microtheca) sown as part of a programme to rehabilitate a gravel quarry

Standard specifications for bio-engineering works

The standard specifications for bio-engineering works given in this chapter cover all of the techniques described in the *Site Handbook*. They are based on field experience and have been devised on the basis of standard contracting procedures for works. They follow the sequential numbers given in the Department of Roads' standard specifications (the sequence 2800 being assigned to bio-engineering). They are approved for use by the Department of Roads.

6.1 INTRODUCTION

The list below shows the full range of specifications given in the Department of Roads Standard Specifications and are approved for use by the Department of Roads.

2800 PROVISION OF SEED
- 2801 Grass seed collection
- 2802 Tree and shrub seed collection

2810 PROVISION OF PLANT CUTTINGS
- 2811 Provision of grass cuttings
- 2812 Provision of hardwood cuttings

2820 NURSERY CONSTRUCTION
- 2821 Nursery establishment
- 2822 Construction of nursery beds

2830 NURSERY OPERATION AND MANAGEMENT
- 2831 Nursery production of grass
- 2832 Nursery production of trees and shrubs in polypots
- 2833 Nursery production of hardwood plants by vegetative methods
- 2834 Extraction of plants from the nursery
- 2835 Compost and mulch production

2840 SLOPE PREPARATION FOR BIO-ENGINEERING
- 2841 Slope trimming
- 2842 Disposal of spoil
- 2843 Final cut slope preparation for grass planting and seeding
- 2844 Final preparation of fill and debris slopes for bio-engineering

2850 SITE PLANTING AND SOWING
- 2851 Sowing of grasses on site
- 2852 Direct seed sowing of shrubs and trees on site
- 2853 Site planting of grass slips and cuttings
- 2854 Site planting of shrubs and trees raised in polythene pots
- 2855 Site planting of hardwood cuttings
- 2856 Brush layering, palisades and fascines
- 2857 Use of fertiliser

2860 JUTE NETTING WORKS
- 2861 Supply of jute netting
- 2862 Placement of netting

2870 WIRE BOLSTER CYLINDERS
- 2871 Fabrication of bolster panels
- 2872 Placement of contour bolsters
- 2873 Placement of herringbone bolsters

2880 SITE PROTECTION
- 2881 Provision and role of site watchmen
- 2882 Fabrication of bamboo tree guards
- 2883 Placement of bamboo tree guards

2890 SITE AFTERCARE AND MAINTENANCE

These specifications can simply be copied directly from this book for use in contracts. They provide for changes to be specified 'by the Engineer' so that particular sites can be treated on an individual basis.

2800 PROVISION OF SEED

1. The Contractor shall provide or collect seeds of the required species in accordance with the requirements described hereafter, of the species and quantities required, as and when required. He shall supply all necessary expertise, resources and facilities to ensure that these requirements are met in full. It is essential that the seed is of a high quality as it forms the basis to the success of any bio-engineering programme.

2. The Engineer will give indications as to the expected amounts of seeds required and the time of availability. But it is the Contractor's responsibility to ensure that adequate quantities of seeds are obtained in a timely fashion.

3. The weights to be specified are for sun-dried seeds separated completely from fruiting bodies and other unwanted parts, and ready for storage and subsequent sowing. There is usually a large discrepancy between this weight and that of the freshly collected, untreated fruits.

4. Should the Contractor be unable to supply the specified seeds, the advice of the Engineer should be sought. It may be possible to substitute other species. Some commercial seed sources in Nepal and India are known to supply old or badly treated seeds. For this reason, seed should not be obtained commercially without the Engineer's written authority.

2801 GRASS SEED COLLECTION

1. The species of grass seeds to be collected will be determined by the Engineer. The

Contractor will be responsible for determining seed sources, though these may be specified by the Engineer's instructions. Seeds should normally be collected in or very close to Division of use or the project area.

2. If the Engineer does not specify the species, then the current approved list of bio-engineering plants, as determined by the Geo-Environment Unit of the Department of Roads should be referred to.

3. Seeds must be collected from as many individual plants as possible. With grasses, it is difficult to determine the best genetic material from the appearance of form; but it is generally sound practice to select from the largest and most vigorous plants.

4. The Contractor may under no circumstances damage or remove the roots of grass plants while collecting seed. The Contractor is responsible for safety measures and for making all necessary arrangements with landowners, farmers and the local District Forest Office, as applicable, before the collection of seeds.

5. Seeds may only be collected when fully ripe. Seeds collected early are not viable when planted and will cause a failure of the planting programme. The Contractor will be held liable if the germination rate of seeds is seriously lower than the normally expected percentage (as defined in publications issued by the Geo-Environmental Unit).

6. Immediately after collection, seeds must be separated from flower heads by the method normally used by farmers for other grasses. Once separated, the seeds must be sun-dried before storage.

7. Seeds must be stored in a cool, dry, ventilated building with adequate precautions taken against pests. Containers should be raised above the floor. They should not be kept in the same building as cement, or any chemicals, fuels or lubricants. Grass is best stored in bags made of hessian (jute) sheet. Seeds should be carefully inspected on a weekly basis to ensure that there is no deterioration or mould formation, or pest attack. Seeds can only be stored successfully if they have been properly dried in the sun beforehand.

2802 TREE AND SHRUB SEED COLLECTION

1. The species of tree and shrub seeds to be collected will be determined by the Engineer. The Contractor will be responsible for determining seed sources, though these may be specified by the Engineer's instructions. Seeds should normally be collected in or very close to the working area.

2. If the Engineer does not specify the species, then the current approved list of bio-engineering plants, as determined by the Geo-Environmental Unit of the Department of Roads should be referred to.

3. Seeds must be collected from as many healthy individual plants as possible. In any event, they must be collected from at least ten individual plants. The plants from which the seeds are collected must show vigorous growth and good form. Mis-shapen and stunted plants should not be considered.

4. The Contractor must under no circumstances damage plants while collecting seed. The Contractor is responsible for making all necessary arrangements with landowners, farmers and the local District Forest Office, as applicable, before the collection of seeds.

5. The collection of seeds from trees can be a dangerous business, placing the collectors at considerable personal risk. Specialist equipment and training is available in Nepal for this purpose. It is the Contractor's responsibility to ensure safe working conditions for his employees or subcontractors.

6. Seeds may only be collected when fully ripe. Seeds collected early are not viable when planted and will cause a failure of the planting programme. The Contractor will be held liable if the germination rate of seeds is seriously lower than the normally expected percentage.

7. Immediately after collection, seeds must be separated from fruit by the method normally used by farmers and foresters for this purpose; this depends on the individual species but may

be a time-consuming process for certain fruits. Once separated, the seeds must be sun-dried before storage.

8. Seeds must be stored in a cool, dry, ventilated building with adequate precautions taken against pests. Containers should be raised above the floor. They should not be kept in the same building as cement, or any chemicals, fuels or lubricants. If kept in sealed containers, the seeds should be carefully inspected on a weekly basis to ensure that there is no deterioration or mould formation. Seeds can only be stored successfully if they have been properly dried in the sun beforehand.

2810 PROVISION OF PLANT CUTTINGS

1. The species of plants to be collected for vegetative propagation will be determined by the Engineer. The Contractor will be responsible for determining plant material sources, though these may be specified by the Engineer's instructions. Plants should normally be collected in or very close to the working area.

2. If the Engineer does not specify the species, then the current approved list of bio-engineering plants, as determined by the Geo-Environmental Unit of the Department of Roads should be referred to.

2811 PROVISION OF GRASS CUTTINGS

1. Cuttings of various types must be taken from grass species which are known to propagate easily by vegetative means.

2. Cuttings must be made from as many healthy individual plants as possible. The plants from

Local name	Botanical name	Best propagation	Details
Amliso	*Thysanolaena maxima*	Rhizome cuttings	Stem: 100 - 150 mm; rhizome: 50 - 80 mm
Babiyo	*Eulaliopsis binata*	Slip cuttings	Stem: 100 - 150 mm; root: 30 - 60 mm
Dhonde	*Neyraudia reynaudiana*	Stem/slip cuttings	Stem cuttings: 2 nodes plus 50 mm each side Slips: stem: 100 - 150 mm; root: 30 - 60 mm
Kans	*Saccharum spontaneum*	Slip cuttings	Stem: 100 - 150 mm; root: 30 - 60 mm
Katara khar	*Themeda* species	Slip cuttings	Stem: 100 - 150 mm; root: 30 - 60 mm
Khar	*Cymbopogon microtheca*	Slip cuttings	Stem: 100 - 150 mm; root: 30 - 60 mm
Khus	*Vetiveria lawsoni*	Slip cuttings	Stem: 100 - 150 mm; root: 30 - 60 mm
Napier	*Pennisetum purpureum*	Stem cuttings	Two nodes plus 50 mm each side
Narkat	*Arundo clonax*	Stem/slip cuttings	Stem cuttings: 2 nodes plus 50 mm each side Slips: stem: 100 - 150 mm; root: 30 - 60 mm
Padang bans	*Himalayacalamus hookerianus*	Large slip cuttings	Stem: 750 - 1200 mm; root: 100 - 200 mm
Phurke	*Arunduella nepalensis*	Slip cuttings	Stem: 100 - 150 mm; root: 30 - 60 mm
Sito	*Neyraudia arundinacea*	Slip cuttings	Stem: 100 - 150 mm; root: 30 - 60 mm
Tite nigalo	*Drepanostachyum intermedium*	Large slip cuttings	Stem: 750 - 1200 mm; root: 100 - 200 mm

which the cuttings are taken must show vigorous growth and good form. Grass clumps showing stunted growth should not be considered as sources.

3. Apart from the clumps which are dug up to make cuttings, the Contractor must under no circumstances damage other plants. The Contractor is responsible for making all necessary arrangements with landowners, farmers and the local District Forest Office, as applicable, before the excavation of plants to make cuttings.

4. The type of cuttings to be made depends on the species and should be as shown in the table below. If the species used is not listed here, then the latest technical information provided by the Geo-Environmental Unit should be consulted. If the species is still not covered, then stem and root slip cuttings should be used.

5. Where roots are required for the cuttings, grass clumps should carefully dug up. They must not be pulled hard, as this can damage the material. They must be separated carefully by hand, using a sharp khukuri or razor blade when necessary. There must be no tearing of the plant fabric.

6. Stem cuttings must be made using sharp secateurs. The top cut should be made at right-angles to the stem and the bottom cut should be made at 45° to the stem: this is to show the orientation of planting.

7. Once cuttings have been made, they must be wrapped in wet hessian jute immediately. At all times, cuttings are to be kept moist and as cool as possible, and should be wrapped in wet hessian between all operations such as digging out of the ground, splitting out, trimming and planting. Under any circumstances, all cuttings must be planted the same day that they are made.

2812 PROVISION OF HARDWOOD CUTTINGS

1. Hardwood cuttings must be taken from shrubs and trees of species which are known to propagate easily by vegetative means.

2. Cuttings must be made from as many healthy individual plants as possible. The plants from which the cuttings are taken must show vigorous growth and good form. Mis-shapen and stunted plants should not be considered as sources.

3. The species from which hardwood cuttings are to be made for bio-engineering works normally includes assuro (*Adhatoda vasica*), bainsh (*Salix tetrasperma*), kanda phul (*Lantana camara*), namdi phul (*Colquhounia coccinea*), saruwa or bihaya (*Ipomoea fistulosa*) and simali (*Vitex negundo*)

4. Apart from the branches from which cuttings are taken, the Contractor must under no circumstances damage plants while taking cuttings. The Contractor is responsible for taking safety precautions and for making all necessary arrangements with landowners, farmers and the local District Forest Office, as applicable, before the making of hardwood cuttings. In no event is more than 60 percent of the aerial parts of a single plant to be removed in the making of cuttings.

5. Hardwood cuttings must be made from stems which are between 6 and 18 months old. Materials outside this range are not normally vigorous or strong enough to survive as cuttings. The Contractor may be held liable if the success rate of cuttings is seriously lower than the normally expected percentage.

6. Hardwood cuttings must be made using sharp secateurs or a sharp saw. The top cut should be made at right-angles to the stem and the bottom cut should be made at 45° to the stem: this is to show the orientation of planting. Under no circumstances must there be any damage to the bark of the cutting.

7. Hardwood cuttings are normally 20 to 40 mm in diameter and of the following lengths: 300 to 500 mm for palisades, vegetated stone-pitched walls and for pegging jute netting; 450 to 600 mm for brush layers; and a minimum of 1000 mm for fascines. For live check dams, all cuttings are to be 2000 mm in length; the cuttings for cross pieces should be 20 to 50 mm in diameter and the truncheon cuttings for the vertical elements should be

30 to 80 mm in diameter: truncheon cuttings are made from the species listed in paragraph 8 below. This size should not be exceeded for the majority of species unless specified by the Engineer.

8. A number of species can be propagated using large truncheon cuttings. In this category fall chuletro (*Brassaiopsis hainla*), dabdabe (*Garuga pinnata*), kavro (*Ficus lacor*), phaledo (*Erythrina* species) and *Gliricidia sepium*. Hardwood cuttings for these species should be in the range of 1500 to 2500 mm in length and 30 to 80 mm in diameter unless otherwise specified.

9. Once cuttings have been made, they must be wrapped in wet hessian jute immediately. At all times, cuttings are to be kept moist and as cool as possible, and should be wrapped in wet hessian between all operations such as taking from the parent plant, trimming and planting. Under any circumstances, all cuttings must be planted the same day that they are made.

2820 NURSERY CONSTRUCTION

1. The Contractor shall provide nurseries to contribute stocks of grasses, shrubs and trees for planting operations as required by the Engineer. This shall be done according to the specifications described hereunder, as and when required by the Engineer. The Contractor shall supply all necessary expertise, resources and facilities to ensure that these requirements are met.

2. The establishment and effective operation of plant nurseries is a skilled business requiring experienced and trained staff. These specifications alone do not provide all the information needed to set up and run nurseries. The Contractor should seek the advice of specialist agencies and should refer to the large number of reference books available on the subject..

3. The purpose of a nursery is to supply good quality, healthy plants of the correct type and species, at the precise time they are required, and at a reasonable cost.

2821 NURSERY ESTABLISHMENT

1. The Contractor shall provide nursery facilities adequate to supply all of the stock required for planting operations. Alternatively, he may procure planting stock from elsewhere at the time of site planting, providing it is of a standard acceptable to the Engineer and as described hereunder.

2. In selecting a site for a nursery, the Contractor must fulfil the following requirements.

   (i) Nurseries must be as close as possible to all sites to be planted. They must be at the same altitude as, and in an identical climatic area to, the sites to be planted.

   (ii) Wherever possible, nurseries must be established on land owned by the Department of Roads if it is available and biophysically suitable. If it is not, other land of His Majesty's Government should be used if it is available.

   (iii) Nurseries should have a reliable and adequate supply of water which remains constant throughout the later part of the dry season.

   (iv) Nurseries should have all weather vehicular access.

   (v) Nurseries should have a perimeter of stock proof fencing, effective against all domestic animals.

   (vi) Nurseries should have a weather- and pest-proof office cum seed store and proper storage facilities for seed. Seed must be kept cool, dry and in sealed containers, as specified in clauses 2801 an 2802.

   (vii) All nurseries should be provided with at least two above-ground compost bays, built of stone, brick or timber. These will be used on an alternate basis to ensure a continual supply of compost.

   (viii) Where a nursery is established on a slope exceeding 2°, the ground must be levelled by terracing before beds are constructed.

(ix) A constant staff of qualified and experienced people must be provided.

(x) There must be adequate space in each nursery location for all operations to be performed in the cycle of work. In particular, all plants need to be spaced out periodically as they grow and there must be adequate bed area to accommodate them.

2822 CONSTRUCTION OF NURSERY BEDS

1. Nursery beds must be made in a different way according to their purpose. The Contractor must ensure that there are adequate beds available for all the operations to be undertaken in the nursery.

2. There must be paths around all beds to ensure the best possible access for operations such as weeding and watering.

3. The table below summarises the construction details of the four main bed types, which are described in full in paragraphs 4 to 7.

4. Soil beds should be constructed to hold grass seeds, grasses being propagated by vegetative means and tree stool cuttings. These can be of any practical length but must be flat and of one metre in width. They should rise to a height of 250 mm above the surrounding ground. They are made up as follows: 50 mm of washed gravel is placed above the ground; then 50 mm of 1:1 mix of sieved soil and compost; and the bed is topped with 150 mm of 3:1 mix of sieved fertile, loamy forest topsoil and washed sand. All sieving should be done with a mesh size of 2 mm or smaller. One square metre of such a bed will contain 100 grass slips spaced at 100 mm centres within rows at 100 mm centres and will produce at least 300 slips for planting out, depending on the particular species, and the soil and climate of the nursery.

5. Seed beds must be made very carefully for germinating small seeds of shrubs and trees. These can be of any practical length but must be flat and of one metre in width. They should rise to a height of 170 mm above the surrounding ground. They are made up as follows: 50 mm of washed gravel is 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 the bed is topped with 20 mm of washed, sieved and sterilised sand. All sieving should be done with a mesh size of 1 mm or smaller.

6. Standout beds should be constructed to hold seedlings in polythene pots. These can be of any practical length but must be flat and of one metre width. Bed floors should be above surrounding ground level and they should have a 50 mm layer of gravel placed above compacted ground. They should have a surround, preferably made from flat stones or bricks. One square metre of standout bed will contain an average of 115 filled pots of the size specified (100 × 180 mm) when spaced out.

7. Beds for the propagation of bamboo culm cuttings should be made specially. These can be

Bed type	Beds for grass seeds, grass slips and tree stool cuttings	Seed beds for tree seedlings	Stand out beds for polypots seedling	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 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.

of any practical length but must be flat and of one metre width. They should rise to a height of 300 mm above the surrounding ground. They are made up as follows: the ground below the bed is dug to a depth of 300 mm; the bed itself is then made with 100 mm of unsieved soil on the original surface, and 200 mm of sieved soil above this. All soil sieving should be done with a mesh size of 2 mm or smaller. Finally, a bund 100 mm high is formed around the edge.

8. Shades must be constructed over the beds and kept in position over delicate seedlings during hours of intense sunlight, according to need. Shades should be 750 to 1000 mm above the soil or the top of filled pots, and angled so as to be effective for as much of the day as possible (*i.e.* with the lower side to the south). Bamboo strips laced together with coir (coconut fibre) string are particularly suitable in most cases; but over tree and shrub seed beds, thatched shades with a polythene lining must be used.

2830 NURSERY OPERATION AND MANAGEMENT

1. The contractor must operate the nursery according to a high standard. The nursery is to be staffed well tended at all times. It must be maintained in a clean, tidy and efficient manner at all times. Plants must always be healthy and vigorous.

2. Due to the nature of bio-engineering works, nurseries will normally be operated and managed by small local contractors with a range of agricultural skills. Nurseries may also be operated and managed by direct employees of the Division Road Office.

3. Plants must be kept properly weeded at all times.

4. Watering, as required for good plant growth, must be carried out regularly in the cool of the evening between sunset and dusk. The Contractor must ensure that the soil in all beds is kept moist but not saturated at all times. Beds must be kept moist even when empty, so that the soil is kept in good condition.

5. The timing of many nursery operations is of the utmost importance. Activities such as seed sowing and the taking of cuttings must be carried out within the critical few weeks when they will yield the desired results. Most other operations, such as spacing out, root pruning and watering, must also be carried out in a timely manner. The contractor is responsible to keep works to the strict schedule required and under no circumstances to permit delays.

2831 NURSERY PRODUCTION OF GRASS

1. Grass will be propagated in nurseries either by seeding in carefully prepared beds or by vegetative propagation.

2. Where grass seeding is required in the nursery, finely sieved fertile soil mixed with clean sand to a texture of sandy loam must be placed in beds before the seeds are sown. Seeds will be covered with a sheet of hessian jute until they have germinated, when it will be carefully removed. Watering of fresh seedlings will be by a fine spray and *not* by the rose of a watering can.

3. Grasses to be propagated by vegetative methods will be of the species instructed. The Contractor should obtain adequate quantities of the plant material required, but under no circumstances is he to cause serious depletion of grass stocks in any steep or erosion-prone area.

4. Vegetative propagation will normally be by rhizome cuttings. With this method, the grass is treated in exactly the same way as a bamboo being propagated by the traditional Nepalese farmer's technique. A clump is carefully dug up and brought to the nursery, being kept cool and damp at all times. Stems are cut above the first or second node above the ground: this usually gives a length of 100 to 200 mm. The clump is separated carefully, with the minimum of damage to the rhizomes and fine roots. Slips should be separated out which keep a length of stem and about 50 mm of the rhizome. Each slip should have some buds on the rhizome, but in some grasses these can be difficult to see.

The slips should be planted with the soil surface at the same level as it was originally, in rows at 200 mm centres; slips should be at 200 mm centres within the rows. A sheet of hessian jute should be placed over the tops of the cuttings. When the new shoots are about 50 mm long, it can be removed.

5. Every two to three months, all grasses should be lifted from the beds, split carefully and replanted. It is normal that, once split out, three times the previous bed area is required. This is a standard practice to bulk up the supply of planting stock without having to degrade the natural vegetation cover in the region of the nursery.

2832 NURSERY PRODUCTION OF TREES AND SHRUBS IN POLYPOTS

1. Trees and shrubs will be seeded either in seed beds or directly in polythene pots ('polypots'). Finely sieved fertile soil mixed with clean sand to a texture of sandy loam must be placed in well shaded beds for seeding. Watering of fresh seedlings will be by a fine spray, and *not* by the rose of a watering can.

2. All plants must be grown on in pots of dimensions 100 × 180 mm (4 × 7 inches) or greater when laid flat. The pots should be of black, 200 gauge polythene. They must have adequate drainage holes at the bottom and be filled with fertile forest topsoil mixed with clean sand to a texture of sandy loam.

3. Roots protruding from the bottom of pots must be pruned with a razor blade on a regular basis which will not exceed weekly and may need to be more frequent. Protruding roots should never be allowed to become more than 25 mm in length.

4. When polypot seedlings begin to compete with each other for light, they should be re-spaced as required. This would typically mean doubling the bed space occupied by the plants.

5. To be acceptable for planting on site, trees and shrubs must be healthy, vigorous and showing no signs of damage, wilt, irregular growth, fungal or pest attack, or nutrient disorders. They must be at least 300 mm in height above soil surface level and of good form. The roots must be in good condition and there should be no signs of disturbance to the soil in the polythene pot, even after transport to site.

2833 NURSERY PRODUCTION OF HARDWOOD PLANTS BY VEGETATIVE METHODS

1. Trees and shrubs which can be propagated by vegetative methods may be specified by the Engineer. The Contractor should produce these by the appropriate method, as required.

2. All cuttings and stools must be made as specified in clause 2812 and planted in fertile soil beds of the type specified in clause 2822.

3. Cuttings must be planted 300 mm apart in holes slightly larger than their diameter. They must be placed at such a depth that only one bud remains above the soil surface (*i.e.* about 30 mm of the cutting).

4. When plants compete with each other for light, they should be cut back as necessary.

5. To be acceptable for planting on site, trees and shrubs produced in this way must be healthy, vigorous and showing no signs of damage, wilt, irregular growth, fungal or pest attack, or nutrient disorders. They must be at least 500 mm in height above soil surface level and of good form.

2834 EXTRACTION OF PLANTS FROM THE NURSERY

1. The Contractor is responsible for extracting plants from nursery beds and preparing them ready for transport. They should be extracted from the beds only on the morning that they are required for planting on site.

2. Plants must be hardened off, starting at least two weeks before they are to be taken out of the nursery. This process requires a gradual reduction in the amount of watering and shading. The aim is to prepare them for transfer to a much more hostile location.

3. The night before the plants are to be lifted, they should be thoroughly watered. This is to make the soil softer and ease the business of extracting the roots.

4. Plants growing in soil beds should be carefully lifted from the soil. There must be no pulling of stems or roots, but they must be dug out and extracted with no strain on any part of the plant.

5. Plants from soil beds must be wrapped in wet hessian jute. Hardwood plants should have a ball of soil around the roots. Grass clumps can have most of the soil shaken or washed off.

6. Polypot seedlings should be lifted and stacked neatly in metal or wooden trays. They must always be lifted by the pot and *never* by the stem or leaves.

7. All plants are to be kept moist, in a cool, shady place, until they are loaded for transport to site. In the vehicle, they must not be stacked high. For transport on rough roads, they must be packed in carefully so that they do not fall over or roll around. The vehicle must be shaded.

2835 COMPOST AND MULCH PRODUCTION

1. The Contractor is to produce compost and mulch for nursery or site operations. It is to be produced in a timely manner, in the quantities required. Compost is normally required to sustain the long term fertility of nursery beds. Mulch may also be used in the nursery, but is normally produced to enhance site planting works, particularly the direct seeding of grass.

2. Compost and mulch should be made from annual and perennial weeds of poor rooting characteristics, such as ban mara (*Eupatorium adenophorum*) and tite pate (*Artemisia vulgans*). The greenery should be collected when there is most material available but before it forms seeds. This is most often in Shrawan and Bhadra.

3. Collected material should be chopped finely and stored in a mound, compost bay or pit. The maximum size for chopped compost is 50 mm; the maximum size for chopped mulch is 150 mm.

4. Both compost and mulch should be kept moist but not waterlogged and in an aerated condition. They should be completely turned once a month on a regular schedule. Compost can have cow manure mixed in to assist the process of decomposition.

5. Neither compost nor mulch should be applied until they are fully rotted. By this time they should be black and the parts of individual plants should be indistinguishable. Early application can lead to a nutrient loss in the soil if microbes extract nitrogen to decompose the added organic material.

2840 SLOPE PREPARATION FOR BIO-ENGINEERING

1. The Contractor shall prepare slopes for planting operations as required by the Engineer. This shall be done according to the specifications described hereunder, as and when required. The Contractor shall supply all necessary expertise, resources and facilities to ensure that these requirements are met.

2. In the course of all slope preparation works, it is essential that no damage is done to existing vegetation unless the Engineer's instruction specifically requires certain plants to be removed.

3. The timing of many bio-engineering operations is of the utmost importance. Activities such as planting and seed sowing must be carried out within the critical few weeks when they will yield the desired results. All other operations must be carried out in a timely manner to permit this to happen. The contractor is responsible to keep works to the strict schedule required and under no circumstances to permit delays.

2841 SLOPE TRIMMING

1. Slope trimming is the main activity where debris masses and inherently unstable slope sections are removed, and the slope made sufficiently sound for civil and bio-engineering

works. The Contractor must first check that all prior construction work has been completed and that the site is clear of equipment. It is the Contractor's responsibility to ensure that there is safe access to the site. On very steep slopes, new paths must be made, and ropes or ladders provided as necessary. All site staff and labourers must be issued with safety helmets and protective footwear.

2. The Engineer will issue an instruction for the details of trimming required on each site. If this has not already been issued it is the Contractor's responsibility to request it from the Engineer and agree the details before work is commenced. Possibilities for slope trimming 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; others, as determined by the individual site.

3. A trimming survey must first be carried out. Pegs and lines must be placed as necessary to show the workers how much material to trim. Notches must be cut through the mass to be trimmed to give the final cut lines.

4. When trimming a site, work must be started from the top of the slope segment. The slope is trimmed in steps from the top, using the steps as ledges for the workers to stand on during trimming.

5. If backfilling is required behind a retaining structure below, the trimmed material must be compacted at intervals as the operation proceeds. This will require halting the trimming, redistributing and compacting the debris as backfill. Compaction is carried out in level layers approximately 100 – 150 mm thick, laid back into the slope at about 5°. If possible, water should be added while compacting the material.

6. When the main trim has been completed, the workers should return 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.

7. The final trim line should then be checked to ensure that it is straight and accurate throughout the site. If protrusions or indentations remain, they must be removed or filled with compacted material. Once the profile has been satisfactorily obtained, all debris must be removed from the site to an approved tipping area and the site left in a tidy condition.

2842 DISPOSAL OF SPOIL

1. In mountainous areas, the disposal of spoil can lead to many problems of erosion and slope instability. The Contractor must follow the Engineer's instructions in disposing of surplus spoil in approved locations.

2. Where a landfill site is created, maximum use must be made of terraces, level ground and spurs. If spoil tipping has to be done on steep slopes, it is essential to 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.

3. During tipping, the Contractor must build many small spoil benches, rather than a few large ones, to avoid slope overloading. A drainage blanket must be installed beneath a spoil bench where there is any indication of a spring seepage at or near the spoil site. Spoil benches must be compacted during tipping. While benches cannot be compacted in the formal sense, they can be constructed 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.

4. Where spoil benches are constructed on agricultural land, the Contractor must 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.

5. Where the top surface of the bench is large, runoff must be reduced 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.

6. On completion, the Contractor is to leave spoil benches in their required shape and plant them with grasses, shrubs and trees to encourage maximum stability and resistance to erosion.

7. Where the tipping of spoil has been permitted on steep slopes above major rivers, the spoil should be completely removed from the slope and thrown into the river. The original ground should be restored with a full cover of vegetation.

8. Under no circumstances are the following permitted: 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.

2843 FINAL CUT SLOPE PREPARATION FOR GRASS PLANTING AND SEEDING

1. The objective of final cut slope preparation is to produce a surface adequately prepared for grass planting or grass seeding. Grass lines are used to provide a strong surface cover but need a well prepared surface in which to be planted; if grass is to be an effective form of slope protection, it must be allowed to establish properly on a slope which does not subject it to undue stress from erosion and mass movement in its initial stages.

2. The Contractor must ensure that the slope under instruction is trimmed to a straight angle, according to the Engineer's specification. Cut slopes to be planted with grass will normally be instructed as 3 vertical:2 horizontal, but this may be varied at the Engineer's discretion. In any event, a straight profile must be obtained. Concavities must be filled with well compacted material or, in some cases, with dry stone dentition. Convexities must be removed and it is essential that the general profile does not have a shape giving over-steep segments.

3. All loose material must be removed from the slope and tipped elsewhere in an approved location, as per the requirements of standard specification 2842.

2844 FINAL PREPARATION OF FILL AND DEBRIS SLOPES FOR BIO-ENGINEERING

1. The objective of the final preparation of fill slopes and slopes comprising unconsolidated landslide debris is to produce a surface adequately prepared for shrub or tree planting or grass sowing, or a combination of these. Vegetation is used to provide a strong surface cover but needs a well prepared surface in which to be planted: if it is to be an effective form of slope protection, it must be allowed to establish properly on a slope which does not subject it to undue stress in its initial stages.

2. The Contractor must ensure that the slope under instruction is trimmed to a straight angle, according to standard specification 2841. In any event, a straight profile must be obtained. All masses of loose debris, especially where it has previously been tipped at the head of the slope, must be removed. Concavities must be filled with well compacted material or, in some cases, with dry stone dentition. Convexities must also be removed and it is essential that the general profile does not have a shape giving over-steep segments.

2850 SITE PLANTING AND SOWING

1. The Contractor shall plant or sow grasses, shrubs and trees as required by the Engineer. This shall be done according to the specifications described hereunder, as and when

required. The Contractor shall supply all necessary expertise, resources and facilities to ensure that these requirements are met.

2. Due to the nature of bio-engineering works, they will normally be undertaken by small local contractors with a range of agricultural skills. Any bio-engineering site activity may also be managed by direct employees of the Division Road Office.

3. It is the Contractor's responsibility to ensure that all planting stock, whether provided from a nursery under a separate contract or through a separate instruction, is of high quality and is vigorous enough to grow on the site to be planted.

4. All seeds and other planting stock must be of species indigenous to Nepal unless otherwise specified. All species must be covered in the current approved lists of species produced from time to time by the Geo-Environmental Unit of the Department of Roads. They must be appropriate for the precise site conditions in which they are to be planted and the Contractor must ensure that they apply to the specific altitude and other environmental characteristics of the site in question.

5. The timing of many bio-engineering operations is of the utmost importance. Activities such as planting and seed sowing must be carried out within the critical few weeks when they will yield the desired results. All other operations must be carried out in a timely manner to permit this to happen. The contractor is responsible to keep works to the strict schedule required and under no circumstances to permit delays.

2851 SOWING OF GRASSES ON SITE

1. The sowing of grasses is intended to create a strengthened slope surface which is resistant to erosion. The Contractor is required to carry out the sowing of grass seeds according to the Engineer's specific instructions.

2. It is assumed that the site will already have been prepared for seed sowing, under a separate instruction; but it is nevertheless the responsibility of the Contractor to ensure that the condition of the site is good enough for the successful establishment of grasses.

3. The Contractor is required to supervise all field operations very closely. The sowing of grass seeds is a delicate business and should be approached in the same way as for agricultural crops. The Contractor should employ experienced agricultural labourers for this work.

4. Seed will have been collected and stored under a separate instruction well before the time of sowing. However, it is the Contractor's responsibility to check that it has been carefully stored and remains fully viable.

5. Immediately before sowing, the ground surface should be lightly scarified to ease early root penetration. Seeds should then be laid thinly over the surface. Under no circumstances should they be broadcast, because the lightness of perennial grass seeds and the steepness of the slopes to be treated give a poor cover using such a technique. The Contractor is responsible for ensuring that the correct quantities of seeds are used, while giving a good, even cover.

6. A cover of 25 grammes of grass seed per square metre of surface should be achieved unless otherwise specified.

7. After sowing, a mulch of prepared and dried cut herbs should be laid over the whole seeded area in a thin layer. If the mulch is too thick it will prevent light from getting to the seed and will inhibit germination. Herbs suitable for this and locally available in large quantities are:
   tite pate (*Artemisia vulgaris*);
   tapre (*Cassia* species);
   ban mara (*Eupatorium adenophorum*).
   However, freshly cut herbs should not be used because of the danger of resprouting and weeding.

8. If specified, the mulch should be secured with jute netting of mesh size 300 × 500 mm and the netting fixed in place using suitable live pegs or hardwood cuttings (*e.g.* simali, *Vitex negundo*) at one metre centres.

2852 DIRECT SEED SOWING OF SHRUBS AND TREES ON SITE

1. The direct sowing of shrubs and trees is intended to create a strengthened slope surface which is resistant to erosion, and anchorage of unstable surface layers. The technique is particularly effective where very stony materials preclude the use of other planting techniques or where the site will be badly affected by disturbance during the planting of polypot seedlings, or where the site is still unstable and does not warrant the costs involved in planting but would benefit from relatively cheap seeding. The Contractor is required to carry out the sowing of shrub and tree seeds according to the Engineer's specific instructions.

2. It is assumed that the site will already have been prepared for seed sowing, under a separate instruction; but it is nevertheless the responsibility of the Contractor to ensure that the condition of the site is good enough for the successful establishment of shrubs and trees.

3. The Contractor is required to supervise all field operations very closely. The sowing of any seeds is a delicate business and should be approached in the same way as for agricultural crops. The Contractor should employ experienced agricultural labourers for this work.

4. Seed will have been collected and stored under a separate instruction well before the time of sowing. However, it is the Contractor's responsibility to check that it has been carefully stored and remains fully viable.

5. Sowing should start at the top of the slope and the labourers should work downwards. Care must be taken not to disturb areas already seeded.

6. To sow the seeds, a small hole should be made in the slope. The tool used to do this depends on the size of the seed. For some seeds, a piece of gabion wire is adequate; for others, a piece of mild steel with a flattened end is required. The hole should be in the best soil available but if there is little real soil, then a crevice between two stones is acceptable. Two seeds should be placed in each hole and a covering of soil or whatever fines are available should be placed over them. This covering should never exceed 10 mm and should preferably be about 5 mm; it should never be less than this. Seeds should be placed at 50 to 100 mm centres, as ground conditions dictate.

7. In some cases the seed can be broadcast starting at the top of the site and working down slope as evenly as possible so that the whole site is lightly covered. This is used where the site is still active and only warrants minimum expenditure, or where the site is naturally rough, providing plenty of niches in which the seed can catch. Quantities of seed depend on the type of seed involved but are generally half that of the quantities used in the nursery. With utis (*Alnus nepalensis*) seed it should be at a rate of 1 gramme of seed per square metre.

2853 SITE PLANTING OF GRASS SLIPS AND CUTTINGS

1. The planting of grass slips and cuttings is intended to create a strengthened slope surface which is resistant to erosion. The Contractor is required to carry out the planting of grass seedlings or rooted cuttings, according to the Engineer's specific instructions. The configuration of planting will be determined according to individual site conditions. It will be either random, contoured or downslope.

2. It is assumed that the site will already have been prepared for planting, under a separate instruction; but it is nevertheless the responsibility of the Contractor to ensure that the condition of the site is good enough for the successful establishment of grasses, and accords with the specifications given in clauses 2840, and 2841 or 2842.

3. Using appropriate tools (such as tape measures and spirit levels), planting lines must be marked out with string as required. Unless specified differently by the Engineer, the row spacing to be marked out is as shown in the table below.

4. The Contractor is required to supervise all field operations very closely. The planting of grass slips is a delicate business and should be approached in the same way as the transplanting of millet seedlings. The Contractor should employ experienced agricultural labourers for this work.

5. The plants supplied to the Contractor should be prepared for planting by the Contractor as given below. The Contractor is to transport them from the nursery wrapped in hessian jute. At all times, plants are to be kept moist and as cool as possible, and should be wrapped in wet hessian between all operations such as extraction from the bed, pruning and planting. Under any circumstances, all plants supplied must be planted the same day that they are lifted from the nursery.

6. Grass slips or cuttings should be carefully separated from the clumps to give the maximum viable planting material. Any roots in excess of 25 mm should be cut off using a sharp khukuri or razor blade. Shoots and stems should be lopped off 100 mm above ground level.

7. Planting should be started at the top of the slope and under no circumstances should new plants be walked on or otherwise disturbed. Using a small bar (usually made of mild steel and with a flattened end), a hole should be made that is just big enough for the roots. The slip or cutting is inserted; care must be taken that the roots are not tangled or bent back to the surface. Soil is then replaced around the roots and firmed with the fingers. The spacing of plants within rows should be 100 mm unless otherwise specified.

8. If the soil is dry and there is no rain within 16 to 24 hours of planting, the site should be watered carefully with a fine spray. The Contractor will be required to water for the first two weeks after planting in the event of inadequate rainfall.

9. In certain circumstances it may not be possible to provide grass plants from a nursery. In this case the Engineer will specify the species and expected source of grass plants. It is important to minimise disruption to neighbouring land, in the event that species are collected from areas surrounding the road. It is the Contractor's responsibility to collect the stock required from a wide area and not to give rise to any soil erosion through the excessive removal of plants in one locality.

2854 SITE PLANTING OF SHRUBS AND TREES RAISED IN POLYTHENE POTS

1. The planting of trees and shrubs is intended to replace or restore something of the natural vegetation on the slope to be treated. The Contractor is required to carry out the planting of seedlings to the Engineer's specific instructions.

2. It is assumed that the site will already have been prepared for planting, under a separate instruction; but it is nevertheless the responsibility of the Contractor to ensure that the condition of the site is good enough for the successful establishment of delicate young plants.

Planting configuration	Slope angle	Row spacing
Random lines	Slope less than 30 degrees	1000 mm centres
	Slope 30 to 45 degrees	500 mm centres
	Slope more than 45 degrees	250 mm centres
Contour lines	Slope less than 30 degrees	1000 mm centres
	Slope 30 to 45 degrees	500 mm centres
	Slope more than 45 degrees	250 mm centres
Diagonal lines	All slopes	500 mm centres
Downslope lines	All slopes	500 mm centres

3. The spacing of plants will be determined according to individual site conditions. However, it will normally be at one metre centres unless otherwise specified.

4. The Contractor is required to supervise all field operations very closely. The planting of trees and shrubs is a delicate business and should be approached in the same way as the planting of horticultural seedlings. The Contractor should employ experienced agricultural or forestry labourers for this work.

5. The plants supplied to the Contractor will normally be from a nursery as arranged by separate instructions, and will be ready for planting. They should be at least 300 mm in height above the soil surface and hardened off in the normal way. The Contractor is to collect the plants from the nursery and transport them to site with all due care. The plants will normally be supplied in polythene pots, which should not be removed until the moment of planting. Plants are to be lifted by the pots, *never* by the stem or leaves. At all times they are to be kept as cool as possible. The Contractor is responsible for ensuring that the soil around the roots does not dry out. Under any circumstances, all plants supplied must be planted within three days of removal from the nursery.

6. Planting should be started at the top of the slope and under no circumstances should new plants be walked on or otherwise disturbed.

7. A planting pit wide and deep enough for the main root to be buried in without bending it and wide enough for all the roots and surrounding soil ball should be made at the time of planting. Some compost if available should be mixed with the soil from the slit prior to backfilling around the roots. The polythene pot must be removed from the seedling by cutting it away with a razor blade. The plant should then be carefully placed into the hole, the compost and soil packed in, and all surrounding soil firmed up, taking care not to cause any damage to the plant or its roots. The surface over and around the pit should then be mulched using any appropriate, locally available material, such as manure, compost, dead leaves or cut herbage. The use of freshly cut ban mara (*Eupatorium adenophorum*) and tite pate (*Artemisia vulgans*) should be avoided, since it can resprout from the buds after being cut.

8. The Engineer may specify bigger seedlings for specific areas, such as those to be used intensively for amenity purposes. These will normally have been growing in a nursery for at least a year and should have well developed roots as well as aerial parts. They will be provided either as bare root stock with a substantial root ball, or in pots of a minimum of 100 × 180 mm laid flat dimensions. When these larger seedlings are planted, the pits will be of 300 mm diameter and 300 mm depth. In addition, well-rotted compost will be mixed with the soil backfill in a ratio of at least one part compost to ten parts soil.

2855 SITE PLANTING OF HARDWOOD CUTTINGS

1. Certain trees and shrubs can be planted on site by means of hardwood cuttings. Where these are specified, the Contractor is required to carry out the planting of cuttings as required in the Engineer's instructions.

2. It is assumed that the site will already have been prepared for planting, under a separate instruction; but it is nevertheless the responsibility of the Contractor to ensure that the condition of the site is good enough for the successful establishment of delicate young plants.

3. The spacing of hardwood cuttings will be determined according to individual site conditions. However, it will normally be at 500 mm centres unless otherwise specified.

4. The Contractor is required to supervise all field operations very closely. The planting of tree and shrub cuttings is a delicate business and should be approached in the same way as the planting of horticultural cuttings (*e.g.* those of tea). The Contractor should employ experienced agricultural or forestry labourers for this work.

5. The cuttings are normally to be made as per

standard specification 2812 or will be supplied to the Contractor by separate instructions, and will be ready for planting. The Contractor is to collect the cuttings from the nursery and transport them from the nursery wrapped in hessian jute. At all times, cuttings are to be kept moist and as cool as possible, and should be wrapped in wet hessian between all operations such as cutting from the parent plant, trimming and planting. Under any circumstances, all plants supplied must be planted the same day that they are lifted from the nursery.

6. Planting should be started at the top of the slope and under no circumstances should new plants be walked on or otherwise disturbed. Using a small bar (usually made of mild steel and with a flattened end), a hole should be made that is just big enough for the cutting. The cutting is inserted and the soil is replaced around it and firmed with the fingers. The cutting should be inserted to a depth such that two-thirds to three-quarters of it is buried.

7. If the soil is dry and there is no rain within 16 to 24 hours of planting, the site should be watered carefully with a fine spray. The Contractor will be required to water for the first two weeks after planting in the event of inadequate rainfall.

8. Where rooted cuttings have been supplied from a nursery, they must be planted in such a way that the roots are not damaged or badly bunched in the planting hole; the hole must be big enough to take the roots so that they are properly spaced out all around the plant.

9. The Engineer may specify bigger cuttings for specific areas, using large truncheon cuttings. In this category fall chuletro (*Brassaiopsis hainla*), dabdabe (*Garuga pinnata*), kavro (*Ficus lacor*), phaledo (*Erythrina* species) and *Gliricidia sepium*. Cuttings of these species should planted at 1000 mm centres. A large crowbar should be used to make the planting hole, but otherwise the technique is as described above for smaller cuttings. Under no circumstances should these cuttings be hammered into the ground.

2856 BRUSH LAYERING, PALISADES AND FASCINES

1. Under certain conditions, the Contractor will be required to construct vegetation structures using hardwood cuttings. Where these are specified, the Contractor is required to carry out the necessary preparation and planting works as required in the Engineer's instructions.

2. It is assumed that the site will already have been prepared for planting, under a separate instruction; but it is nevertheless the responsibility of the Contractor to ensure that the condition of the site is good enough for the successful establishment of delicate young plants.

3. The cuttings supplied to the Contractor may be from a nursery as arranged by separate instructions, and will be ready for planting. They should be at least 400 mm long for brush layering, 600 mm long for palisades and 1000 mm in length for fascines. The Contractor is to collect the cuttings from the nursery and transport them from the nursery wrapped in hessian jute. At all times, cuttings are to be kept moist and as cool as possible, and should be wrapped in wet hessian between all operations such as cutting from the parent plant, trimming and planting. Under any circumstances, all plants supplied must be planted the same day that they are lifted from the nursery.

4. If the instruction to the Contractor includes the provision of cuttings, then the Engineer will specify the species and expected sources, and the Contractor must then obtain the cuttings required. This will be done in the manner described in clause 2812 except that the size of cuttings will be of a minimum length of 600 mm for brush layering on landslide debris, 450 mm for brush layering on road embankments, 600 mm for palisades and 1000 mm for fascines, and minimum diameters of 30 mm for brush layering, 40 mm for palisades and 50 mm for fascines.

5. Cuttings of the following species, if specified, should be a minimum of 2000 mm in length: chuletro (*Brassaiopsis hainla*), dabdabe

(*Garuga pinnata*), kavro (*Ficus lacor*), phaledo (*Erythrina* species) and *Gliricidia sepium*.

6. The Contractor is required to supervise all field operations very closely. The planting of tree and shrub cuttings is a delicate business and should be approached in the same way as the planting of horticultural cuttings (*e.g.* those of tea). The Contractor should employ experienced agricultural or forestry labourers for this work.

7. Planting should always be started at the top of the slope and under no circumstances should new plants be walked on or otherwise disturbed.

8. Brush layering should be constructed as given below, unless specified differently.

   (i) Starting at the bottom of the area to be treated, and using appropriate measuring equipment, exact lines should be marked out. From 1 metre above the bottom of the slope, a precise contour line should be marked out every 1 metre up the slope.

   (ii) Starting at the bottom, terraces approximately 450 mm wide on landslide debris or 350 mm on road embankments should be excavated along the lines.

   (iii) Cuttings should then be placed into each trench at 50 mm centres, the correct way up and angled so that they are at right-angles to the maximum slope angle. All cuttings should be inserted to a depth such that two-thirds to three-quarters of their length is buried.

   (iv) The trench should then be partially backfilled and another line of cuttings placed along the trench at 50 mm centres and 100 mm behind the first line, and with the individual cuttings offset to coincide with the gaps between the cuttings in the first line. This results in cuttings at 25 mm centres in each brush layer (*i.e.* 40 cuttings per running metre). The trench is then completely backfilled and gently compacted. Any loose or excess material is cleared down the slope before the next line is planted.

   (v) In some cases it will be specified that cuttings should be placed in a criss-cross fashion. Where this is to be done, one layer of cuttings is laid in the trench at 30° to one side of the line of maximum fall of slope. A second layer of cuttings is laid on top of this, at 30° to the other side of the line of maximum fall of slope. Backfilling and compaction are then completed.

9. Palisades should be constructed as given below, unless specified differently.

   (i) Starting at the top of the area to be treated, and using appropriate measuring equipment, exact lines should be marked out. From 1 metre below the top of the slope, a precise contour line should be marked out every 1 metre down the slope.

   (ii) Starting at one end and using a small bar (usually made of mild steel and with a flattened end), a hole should be made that is just big enough for the first cutting. The cutting is inserted and the soil is replaced around it and firmed with the fingers. The cutting must be the correct way up and angled so that it is vertical. The cutting should be inserted to a depth such that two-thirds to three-quarters of it is buried.

   (iii) This process should be repeated along the entire line, with a series of cuttings placed at 50 mm centres.

   (iv) If a double line is specified, then a second line of cuttings must be placed in the same way, 100 mm behind the first and with the individual cuttings offset to coincide with the gaps between the cuttings in the first line.

   (v) The soil around the single or double line is then completely backfilled into any remaining gaps and gently compacted. Any loose or excess material is cleared down the slope before the next line is planted.

10.Fascines are bundles of hardwood cuttings laid horizontally in trenches, and parallel to the line of the trench. The bundles are thereby completely buried. Fascines should be constructed as given below, unless specified differently.

(i) Starting at the bottom of the area to be treated, and using appropriate measuring equipment, exact lines should be marked out. From 1 metre above the bottom of the slope, a precise contour line should be marked out every 1 metre up the slope.

(ii) Starting at the bottom, trenches approximately 200 mm in depth should be excavated along the lines.

(iii) Cuttings should then be laid along each trench, so that they lie horizontally along the trench. There should normally be eight cuttings together, although where material is short a minimum of four cuttings is permissible. They must be overlapped so that no two ends coincide. The cuttings must then be tied using jute or coir (coconut fibre) string at 500 mm intervals to form a bundle. As the fascine is created, it thereby forms a continuous bundle right across the slope.

(iv) The trench should then be backfilled and gently compacted. The top of the fascine should be 50 to 100 mm below the surface. Any loose or excess material is cleared down the slope before the next line is planted.

Commercial name	Chemical formula	Percentage N P K
Sulphate of ammonia	$(NH_4)_2SO_4$	21 0 0
Urea	$CO(NH_4)_2$	46 0 0
Triple superphosphate	$CaH(PO_4)$	0 21 0
Muriate of potash	KCl	0 0 49
Complexol	Unknown	20 9 0
Diammonium phosphate	$(NH_4)_2HPO_4$	18 20 0

11. The Engineer may specify that orientations other than along the contour of the slope are used. In this event, the Contractor must alter the laying out of lines accordingly and meet the precise angle required.

12. If the soil is dry and there is no rain within 16 to 24 hours of planting, the site should be watered carefully with a fine spray. The Contractor will be required to water for the first two weeks after planting in the event of inadequate rainfall.

2857 USE OF FERTILISER

1. Under certain circumstances, the use of chemical fertilisers may be specified in place of farmyard manure or mulching. Unless otherwise specified, the rates given below should be used.

2. Levels of fertiliser application vary according to soil type and nutritional content. However, if nutritional data are not available, the following figures can be used as a rough guide:
Nitrogen: 10 g/m^2;
Phosphorus: 5 g/m^2;
Potassium: 4 g/m^2.
The table below lists the chemical composition and percentage of the major plant nutrient elements in the chemical fertilisers commonly available in Nepal.

2860 JUTE NETTING WORKS

1. The Contractor shall provide and install jute netting as required by the Engineer. This shall be done according to the specifications described hereunder, as and when required. The Contractor shall supply all necessary expertise, resources and facilities to ensure that these requirements are met.

2. The Engineer may instruct that jute netting applications be used in conjunction with other techniques, particularly the sowing or planting of grasses. In this event, the netting should be applied before the plants are introduced. When planting, the labourers must take care only to hold or stand on the pegs and not to disturb the netting except when carefully placing grass seed underneath on the soil surface.

2861 SUPPLY OF JUTE NETTING

1. The Contractor will manufacture or obtain a supply of jute netting to the Engineer's specification.

2. The detailed specifications for *standard* jute netting are as follows. 'Standard' jute netting is used for placing on bare slopes and is normally planted with grasses. [Note: warp ends are the length-ways threads and weft strands are the cross-ways threads]

(i)	Material:	High quality tosa (special grained), 100% natural jute fibre from the latest harvest, properly treated and dried.
(ii)	Yarn:	Handspun 5 to 8 mm.
(iii)	Strip size:	minimum 1.0 × 10.0 metres; maximum 1.5 × 11.5 metres.
(iv)	Warp ends:	27 ends per 1000 mm.
(v)	Weft strands:	20 to 24 strands per 1000 mm.
(vi)	Mesh size:	40 mm square mesh holes.
(vii)	Weight:	0.8 to 1.2 kg per square metre.

3. The detailed specifications for *wide mesh* jute netting are as follows. 'Wide mesh' jute netting is used for holding mulch on to slopes which have been sown with grass seed. [Note: warp ends are the length-ways threads and weft strands are the cross-ways threads]

(i)	Material:	High quality tosa (special grained), 100% natural jute fibre from the latest harvest, properly treated and dried.
(ii)	Yarn:	Handspun 3 to 5 mm.
(iii)	Strip size:	minimum 1.0 × 10.0 metres; maximum 1.5 × 11.5 metres.
(iv)	Warp ends:	7 ends per 1000 mm.
(v)	Weft strands:	3 strands per 1000 mm.
(vi)	Mesh size:	150 × 500 mm rectangular mesh.
(vii)	Weight:	0.2 kg per square metre.

2862 PLACEMENT OF NETTING

1. The Engineer will normally instruct the placement of standard jute netting on slopes in excess of 40°. It is therefore a difficult task to place the netting in an effective manner which fulfils the Engineer's purpose. Carelessly placed netting is often useless and can actually be detrimental to the slope surface.

2. It is assumed that the site will already have been prepared for the application of jute netting, under a separate instruction; but it is nevertheless the responsibility of the Contractor to ensure that the condition of the site is good enough for the optimum effect to be attained. In any event, a smooth profile must be obtained. All loose debris must be removed. Concavities must be filled with well compacted material or, in some cases, with dry stone dentition. Convexities must also be removed and it is essential that the general profile does not have a shape giving over-steep segments.

3. Starting at one end of the site to be treated, a roll of netting should be pegged 300 mm above the slope to be covered.

4. The netting should be rolled slowly down the slope. Hardwood cuttings, ideally of simali (*Vitex negundo*) or pegs (usually made from split bamboo culms) should be hammered through the netting at centres of 500 to 1000 mm; they should protrude about 80 mm. Labourers must stand on these cuttings or pegs and not hang on to the netting.

5. This process should be repeated until the entire slope surface is covered. The strips are then laced together with lengths of the same jute yarn, to form a continuous net. The lacing must form joins every 250 mm or less.

6. The tension of the netting must now be reduced so that it hugs the slope surface precisely. This is done by pulling up about 200 mm at the bottom of the netting and hooking it on to the pegs a little higher up. This process is repeated up and across the slope until the netting rests snugly against the surface and is nowhere tight or pulled away from the surface in minor concavities.

7. The netting should then be pegged at 1000 mm centres with staples of 10 mm reinforcing bar at least 100 mm wide and 300 mm long, firmly hammered into the slope face. Additional staples should be used to hold netting closely against the face of concave slope segments.

8. Finally, the bottom of the netting is trimmed to give a tidy finish.

9. In the case of wide mesh jute netting, it will only be specified for use on slopes which have already been treated with grass seed and mulch. These will usually be less than 45° and are therefore easier to work on. However, the process of placing the netting is similar to that for standard netting.

10. Wide mesh netting should be pegged securely at the top and rolled slowly down the slope. Hardwood cuttings, ideally of simali (*Vitex negundo*) or pegs (usually made from split bamboo culms) should be hammered through the netting at centres of 1000 mm; they should protrude about 80 mm. Labourers must stand on these cuttings or pegs and not hang on to the netting. This process should be repeated until the entire slope surface is covered. The strips are then laced together with lengths of the same jute yarn, to form a continuous net. The lacing must form joins every 500 mm or less.

11. The tension of the netting must now be reduced so that it hugs the slope surface precisely and holds the mulch firmly against the surface throughout the area covered. The netting should then be pegged at 1000 mm centres with staples of 10 mm reinforcing bar at least 100 mm wide and 300 mm long, firmly hammered into the slope face. Additional staples should be used to hold netting closely against the face of concave slope segments. Finally, the bottom of the netting is trimmed to give a tidy finish.

2870 WIRE BOLSTER CYLINDERS

1. The Contractor shall provide and install wire bolster cylinders as required by the Engineer. This shall be done according to the specifications described hereunder, as and when required. The Contractor shall supply all necessary expertise, resources and facilities to ensure that these requirements are met.

2871 FABRICATION OF BOLSTER PANELS

1. Bolster panels will be either 5 × 1 metres or 5 × 2 metres in size, according to the type of bolster to be used. They will be woven with an hexagonal mesh in the same way as normal gabion panels. For the panel frame, 10 swg galvanised wire should be used; for the mesh, 12 swg is adequate. Wire should preferably have a high grade zinc coating. Failing this, a medium grade zinc coating is acceptable.

2. Weaving should start from one of the long sides. A total of 83 coils of wire should be spaced evenly along the 5 metre length. This gives a mesh width of about 60 mm. Each weave should have three twists, as for normal hexagonal mesh. If done reasonably tightly, this gives a length of about 80 mm to each mesh link. In any event, the mesh length should not exceed 90 mm. The mesh should be turned on to the larger frame wire at least one and a half turns and made fully secure.

2872 PLACEMENT OF CONTOUR BOLSTERS

1. A contour bolster treatment gives a series of stone-filled wire tubes of 300 mm diameter, laid in trenches cut across the slope. The tops of all the tubes should be flush with the surface of the slope in which they are placed. The purpose is to check scour of the slope surface

by preventing the development of rills and gullies.

2. The site to be treated should be given final preparation immediately before bolster installation. All small protrusions and depressions must be obliterated by cutting, or by infilling and compaction.

3. Starting at the base of the area to be treated, and using appropriate measuring equipment, exact lines should be marked out. From 2 metres above the base of the slope, a precise contour line should be marked out every 2 metres up the slope.

4. Starting at the bottom, trenches with circular base should be dug along the lines, adequate to take the final 300 mm diameter tubes.

5. Bolster panels should then be laid along the trenches and shaped to fit neatly into the base of the trenches, as well as into any curves formed as a result of the slope contours; each panel should be securely joined to the next panel, to form a continuous bolster tube.

6. The panels should be packed with stones, closed over and the edges wired together. All stones must be bigger than the mesh size. The same care should be taken as when filling a conventional gabion basket, and stones must be carefully placed to give good structural integrity.

7. The ends of the bolsters should be closed over and wired together. The trenches around all the bolsters should then be filled and compacted with material left from the excavations.

8. Once all of the lines are in place, all surplus debris should be cleaned off the slope. Mild steel bars of at least 10 mm diameter should then be driven into the slope through the lower sides of the contour bolsters. These should be at least every 2 metres along the lines. Bars should be 2 metres in length on slopes composed of soft materials, but at the Engineer's discretion, on slopes comprising hard rocky materials, bars of 1 metre length will be adequate. All bars must be driven home until the tops protrude no more than 25 mm above the slope surface.

2873 PLACEMENT OF HERRINGBONE BOLSTERS

1. A herringbone bolster network is in essence a system of wire tubes of between 300 mm to 1200 mm in diameter depending on the amount of water flowing through the site, laid in trenches cut into the slope. A main bolster runs straight down the slope (the spine) with others running into it at an angle of 30 to 50 degrees to the fall of the slope (the herringbones or branches) depending on slope angle and terrain morphology. The tops of all the tubes should be flush with the surface of the slope in which they are placed or inlaid to allow boulder pitching to be laid over the top. The purpose is both to check scour of the slope surface by preventing the development of rills and gullies, and to drain the surface material in a similar way to a french drain. The diagonal components should be at 2 to 5 metre centres if measured straight down the slope.

2. The site to be treated should be given final preparation immediately before bolster installation. All small protrusions and depressions must be obliterated by cutting, or by infilling and compaction.

3. Starting at the base of the area to be treated, and using appropriate measuring equipment, exact lines should be marked out: every 7.1 metres across the slope, a line should run straight up to the top of the slope (these form the main bolster spines). From the base of the line, and every 3 metres above this, other lines of 5 metres length should be marked at 45 degrees to the main line (these will form the herringbones).

4. Starting at the bottom, trenches with circular base should be dug along the lines, adequate to take the final 300 mm diameter tubes, or 600 mm diameter tubes if larger (5 × 2 metre) panels are specified.

5. If it is specified that an impermeable lining should be used, then 20 gauge black polythene sheeting must be laid along the bot-

toms of the trenches and the bolsters constructed on top of this.

6. Bolster panels should then be laid along the trenches and shaped to fit neatly into the base of the trenches, as well as into any curves formed as a result of the slope contours; the panels of the herringbones should be securely joined to the panels of the main bolster.

7. The panels should be gradually closed together and secured, working up from the bottom of the slope, while stones are passed in from above to fill them. The stones should be randomly packed so as to allow free drainage, and all stones must be bigger than the mesh size. The same care should be taken as when filling a conventional gabion basket, and stones must be carefully placed to give good structural integrity.

8. The upper ends of the herringbones should be closed over and wired together; they should touch the ends of the next herringbones but should not be secured to each other. The trenches around all the bolsters should then be filled and compacted with material left from the excavations.

9. Once all of the lines are in place, all surplus debris should be cleaned off the slope. Mild steel bars of at least 10 mm diameter should then be driven into the slope through the sides of the main spine bolsters and the lower sides of the herringbone bolsters. These should be at least every 2 metres along the lines. Bars should be 2 metres in length on slopes composed of soft materials, but at the Engineer's discretion, on slopes comprising hard rocky materials, bars of 1 metre length will be adequate. All bars must be driven home until the tops protrude no more than 25 mm above the slope surface.

2880 SITE PROTECTION

1. The Contractor is to protect a planted site for the period specified. Protection is to include the prevention of damage to all manner of site works and plants by local people and domestic or wild animals. It also includes an active role in tending the plants and improving their growth, as specified below.

2. Because of the long time required for plants to become robust, the period of maintenance by the contractor will normally be for twelve months. However, in the case of small contracts, a period of only six months may be specified.

2881 PROVISION AND ROLE OF SITE WARDENS

1. The Contractor is required to provide an adequate number of site wardens to fulfil the specified requirements. The function of a warden is broader than that of a watchman, chowkidar or heralu. It involves a number of routine maintenance operations.

2. Wardens must be mature and reliable characters who need little supervision for the adequate fulfilment of their duties. They must be active and physically fit. Old people who are losing their strength should not normally be employed. They must be experienced agricultural workers familiar with caring for plants. They must be prepared to remain on site through all hours of daylight and through all adverse weather conditions. They must eat their meals on site and at no time leave the site untended for any reason whatsoever.

3. The role of the warden is primarily to tend the plants. He or she must take the initiative in weeding, mulching, replanting failed plants, pruning and protecting plants against all pests. This is an active role requiring individuals with considerable energy and initiative. The warden must work constantly to maintain and improve the site and its bio-engineering plants.

4. The warden is also required to protect plants on the site from damage by local people, domestic and wild animals. In doing this he or she should use a friendly approach to the people as far as possible. The Contractor must educate the warden fully in the reasons for the job, so that he or she can explain to others the importance of safeguarding plants on the site. Wardens should be effective communicators with others since they also fulfil an inevitable function as the ambassador between the Department of Roads and local road neighbours.

2882 FABRICATION OF BAMBOO TREE GUARDS

1. The Contractor shall provide bamboo tree guards as required by the Engineer. This shall be done according to the specifications described hereunder, as and when required. The Contractor shall supply all necessary supervision, resources and facilities to ensure that these requirements are met.

2. The bamboo strips used to make bamboo tree guards are to be made from mal bans (*Bambusa nutans* subsp *cupulata*) whilst the uprights are to be made from tharu or dhanu bans (*Bambusa nutans* subsp *nutans* or *Bambusa balcooa*). Bamboo tree guards shall be a minimum of 450 mm in diameter by 1300 mm in height so that they are able to provide sufficient protection from grazing and from the elements for the first 18 months after planting the seedling.

3. The guard is made by cutting five bamboo posts which are a minimum of 50 mm wide by 10 mm thick and at least 1600 mm long. The posts should be cut so that they have a strong spear-like point at the bottom that can be driven into the ground when placing out on site. The bamboo poles used to make the uprights should be a minimum of 3 years old.

4. Bamboo strips, a minimum of 5 mm thick and 50 mm wide are cut from poles that are at least 2 years old. The bamboo used must be split so that the outer wall remains intact. Only lengths with the outer wall intact are to be used. The split bamboo should be the length of the whole bamboo pole that it is cut from, or as long as possible. The split bamboo must be woven in and out of the bamboo uprights and pulled tight, so that it is firm and strong. The end of each of the strips must be woven back into the basket and tied with binding wire to keep it in place. End pieces must not be left sticking out and unbound, because they quickly get broken and the basket starts to unravel from this point. The split bamboo should be woven round the poles so that when they are tightly pressed down there are no gaps in the guard.

2883 PLACEMENT OF BAMBOO TREE GUARDS

1. Tree guards are to be installed on site at the time of planting, no later than the second week of July, and must be placed carefully around the planted seedlings.

2. The tree guards should be placed over the seedling immediately after planting. The upright posts must be firmly driven at least 200 mm into the ground so that the guard is able to resist bashing and rubbing from cows, buffalo, goats and people. The woven slats should be pushed down firmly from the bottom upwards so that they touch one another and are free from large gaps.

3. Tree guards alone are not adequate protection for small plants. The Contractor must provide a site watchman in addition, for the time specified, to maintain the tree guards and ensure that local people respect them, and generally fulfil all the requirements of clause 2881.

2890 SITE AFTERCARE AND MAINTENANCE

1. The Contractor shall maintain planted bio-engineering sites as required by the Engineer. This shall be done according to the specifications described hereunder, as and when required. The Contractor shall supply all necessary expertise and resources to ensure that these requirements are met.

2. The Contractor shall carry out weeding as required throughout the site. All annual weeds and other unwanted plants shall be cut just above the ground and the aerial parts will be used to make compost or mulch. Weeds must not be pulled out by the roots since this disturbs the ground surface.

3. Weeding should be carried out throughout the growing season. It must be undertaken with particular diligence at the end of the monsoon, so that there is the minimum amount of competition during the subsequent dry season.

4. The Contractor shall carry out mulching as required throughout the site. All plants required under the bio-engineering specifications will be mulched using material prepared as specified in clause 2835, or the aerial parts of weeds cut on the site or brought from elsewhere for the purpose. The desired plants should be kept mulched at all times but especial care must be taken in the spring, when the soil moisture deficit is at its greatest.

5. The Contractor shall replace failed, damaged, diseased and very weak plants, using fresh, healthy plants of the same species, at the correct time of year for planting. This replanting operation will normally be carried out during the monsoon in the year following the first planting works. Vegetation structures will be enriched by the planting of additional cuttings or seedlings, as instructed by the Engineer. Failed seeding areas will be reseeded at the appropriate time of year.

6. In replanting and enrichment works, the Engineer may specify the use of different species. This will be done where failures or poor performance of plants may be attributed to poor stock or an incorrect initial choice of species.

7. All bio-engineering sites must be maintained so that there are at least the following two storeys of vegetation. In certain locations, however, there may be a number of additional vegetation storeys.

   (i) A dense ground cover of healthy grass plants, in the configuration specified at the time of planting.

   (ii) An open canopy of shrubs or trees with a deeper rooting network.

8. In general it is necessary to keep the upper canopy thinned in order to maintain the lower ground cover. Most grasses require high light intensities and become degraded if subjected to excessive shade from the overstorey. It is therefore the Contractor's responsibility to thin the canopy as necessary to permit adequate levels of light to penetrate for the optimum growth of the grass understorey.

9. All thinning and pruning operations are to be undertaken in accordance with the guidelines issued by the Geo-Environmental Unit. Since these are skilled silvicultural operations, the Contractor must take appropriate professional advice and employ suitably skilled personnel.

10. All products from thinning and pruning operations are to be disposed of in accordance with the regulations of His Majesty's Government. The Contractor should follow the instructions of the Engineer in this regard.

11. Other maintenance operations are to be undertaken by the Contractor according to the instructions of the Engineer.

Bio-engineering case studies

JOGBANI-DHARAN ROAD, km 33+840

Brief site history

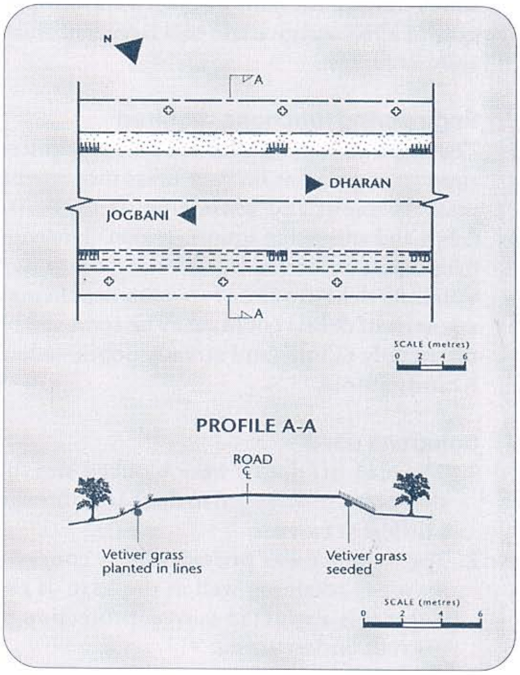
This section of road was rehabilitated in 1991/92. At the same time, the embankment was raised slightly and the road pavement widened to occupy the entire top of the embankment.

Engineering functions required

The shoulders of the embankment were unconsolidated and needed armouring. Considerable amounts of water runs off the pavement in heavy rain.

Solutions used

1. Grasses were used to armour the shoulders. They were planted on one side and seeded on the other, mainly for comparison. The lines planted on the eastern side grew faster, but adequate armouring was provided by both methods. The species used was khus (*Vetiveria lawsoni*).
2. Ornamental shade trees were planted at intervals on the ground between the embankment and the original borrow pits.



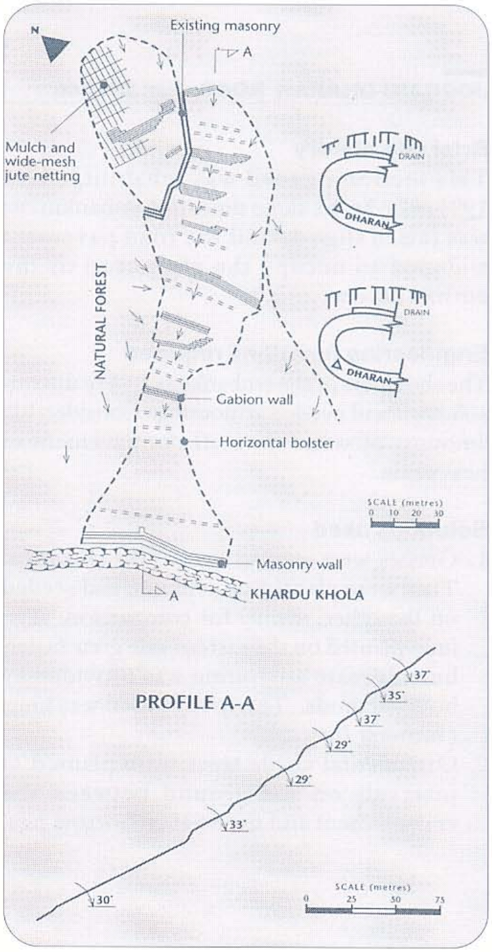
DHARAN-DHANKUTA ROAD, km 5+700

Brief site history

A complicated failure occurred in a gully to the west of a hairpin stack on the steep Mahabharat ascent above Dharan. A long masonry cascade, which drained the hairpins, failed catastrophically in 1988 and give rise to a large landslide-gully complex.

Engineering functions required

The slope remaining after the failure required support to prevent further mass movement, reinforcement and anchoring of the loose debris,and armouring against erosion. Drainage needs were removed by diverting the water. Catching debris was not important, as small amounts of debris could easily be removed by the steeply falling (and already debris-laden) Khardu khola.



Solutions used

1. The lead-off drains were blocked and the side drains re-arranged to discharge through a different cascade.
2. Toe support was provided by a concrete masonry retaining wall at the base of the slope; this also acted as river protection to prevent undercutting.
3. The slope was broken into smaller segments through the construction of seven major gabion check dams: each of these also served a support function, since they were designed as retaining walls for the slope segments above.
4. All walls were backfilled with compacted spoil. Excess spoil was removed to a safe tipping area.
5. Armouring and shallow reinforcement were provided by gabion wire bolsters, which were installed at 2-metre centres on all fill and loose debris areas.
6. Additional support was provided by planting bamboos above the toe wall. The species used was tharu bans (*Bambusa nutans*).
7. Tree seedlings were planted at 1 metre centres between the gabion wire bolsters on all fill and loose debris areas. The species used were khanyu (*Ficus semicordata*), various siris species (*Albizia* species) and tanki (*Bauhinia purpurea*). These were to provide reinforcement and anchoring.
8. Slips of the grass sito (*Neyraudia arundinacea*) were planted on particularly critical sections of the middle slope, to provide more armouring and reinforcement.
9. The upper section, which consisted of the failure head scar, was seeded with the grasses phurke (*Arunduella nepalensis*) and sito (*Neyraudia arundinacea*); the seeds were covered in mulch, which was in turn held in place with wide mesh jute netting. This provided complete armouring (and later, reinforcement as well).
10. The upper section was also seeded with bhujetro (*Butea minor*) to provide anchoring of the remaining loose debris.

The masonry cascade that drained this hairpin failed catastrophically in 1988 and produced a large landslide cum gully complex (left). A series of gabion check dams, which also had a retaining function, were constructed to break the site into smaller segments. The bio-engineering package included bamboos planted above the toe wall to increase support. Planted seedlings of khanyu, tanki and siris grew to reinforce and anchor fill and loose debris areas. Sito slips armoured and reinforced the most critical areas. The head scar was seeded with phurke and sito, mulched and held in place by jute netting. This provided complete armouring. Bhujetro anchored remaining loose debris. The slope is now well protected by a combination of civil and bio-engineering works(right)

DHANKUTA-HILE ROAD, km 4+700

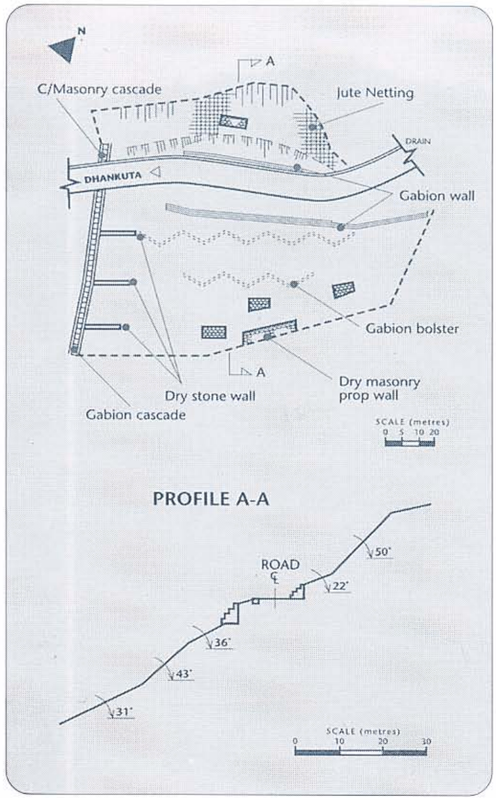
Brief site history

An inherently unstable slope in weak, deeply weathered gneiss was disturbed by road construction. Gradual subsidence was noticed following construction. During upgrading in 1990, the worsening mountain-side failure required complete rehabilitation. At the same time, it was decided to attempt stabilisation of the steep valley side slope to reduce distortion of the new metalled road surface and prevent a possible catastrophic failure.

Engineering functions required

Valley side. Ideally, major toe support was required, but foundations were poor and the estimated cost was prohibited. Support to the road itself was therefore planned, with extensive drainage, reinforcement and anchorage of the slope. Armouring of the weak, erodible, gneiss-derived soil was also essential.

Mountain side. Toe support was required to support the remaining debris mass. Otherwise mainly armouring was required, with some reinforcement of the debris above the support wall.



Solutions used

Valley side

1. The road itself was supported by a gabion retaining wall at the top of the valley side slope. The other measures were therefore critical in stabilising a slope which was already subsiding and now additionally surcharged.
2. The slope was re-graded following the construction of the gabion wall, and concavities were filled with dry masonry to provide local support. On the steeper southern flank, the slope was broken into shorter segments using 3-metre high dry masonry support walls.
3. Drainage was provided through a range of measures. Herringbone gabion wore bolsters were installed. The existing cascade was improved. Fascines of simali (*Vitex negundo*) were laid in subsoil drains.
4. Armouring and shallow reinforcement were achieved by sowing phurke (*Arunduella nepalensis*) throughout the slope.
5. Deeper reinforcement and anchorage were provided by planting seedlings of utis (*Alnus nepalensis*), nebharo (*Ficus auriculata*) and other trees.

Mountain side

1. Toe support was provided by a gabion breast wall. A concavity in the head slope was filled with dry masonry to provide local support. Additional support was provided by planting large bamboos (bans or *Bambusa* species) to the south of the breast wall.
2. The head slope was trimmed and armoured with standard jute netting and slips of kans (*Saccharum spontaneum*).
3. The shrubs areri (*Acacia pennata*) and keraukose (*Indigofera atroturpurea*) were planted to reinforce the debris above the gabion wall.
4. Trees were planted around the head of the scar to provide products for local farmers.

This section of the Dhankuta-Hile road failed some years after construction (top, left). The likelihood of poor foundations ruled out the provision of major toe support, which could otherwise have been provided. Phurke was sown to armour the slope and provide some reinforcement. Seedlings of utis and nebharo were planted to offer deeper reinforcement and anchorage (top, right). Toe support was provided by a gabion breast wall and, later, supplemented by a plantation of large bamboos (above).

Baglung loop, December 1994

Monsoon rains badly damaged the Pokhara-Baglung road shortly after construction in 1993. Material from road cuttings had not been tied to slopes, leading to massive scales of erosion and gullying. Loose soil and debris dislodged by heavy rain blocked the road and drains and damaged the road surface, hindering traffic. Material cascaded down the steep slopes to smother cultivated farmland below.

Baglung loop, September 1997

Rahabilitation called for the construction of toe walls to support actively unstable sections of the slope, and the rebuilding of drains. Bio-engineering measures included checking further erosion by planting dense line of grass and seeding the largest areas of coarse debris with grasses, shrubs and trees. Babiyo, a clump grass that prefers harsh, dry sites, was planted to bind the finer soil between rock fragments.

MAPPING OF LARGE AND COMPLEX LANDSLIDES

The *Roadside Bio-engineering, Site Handbook* gives a simple procedure and proforma for site assessment, as a guide to assessing the treatment needs of bare and unstable slopes. That is adequate for the majority of cases. However, in the case of large and complex landslides, a more detailed procedure for site assessment is required. This is necessary to ensure that all aspects of the failure are addressed. It can then be used either as a basis for determining the remedial treatment or in discussing the need for a full investigation by specialists. However, an experienced and conscientious professional will be able to assess almost every aspect of a landslide from the procedure described here.

This procedure will help you to map an unstable site and observe all its significant features. The procedure is given in logical order but you do not have to follow this order in every case. An advantage of observing the site in a methodical way is that there will be less risk of missing an important feature. The column on the right suggests the action you should take.

The basis of the site record is a drawing of the site. A simple sketch will do. It does not have to be to scale. Its purpose is to help you to understand the geometric relationships between features of the landslide. It also enables you to record concisely your measurements and where you took them from. Any notes you make can also go on the drawing, but if they are lengthy, or if you wish to describe some detail of the slide by additional drawings and notes, these are best recorded separately in your notebook. It is good practice to make all your drawings and notes in one notebook. In this way pages do not get lost and records are kept in sequence.

The equipment you will need is as follows:

- clipboard, pen and paper;
- a copy of Annex A of the *Roadside Bio-engineering, Reference Manual*; optionally, you can take the whole *Reference Manual* to refer to on site;
- a copy of the *Roadside Bio-engineering, Site Handbook*;
- a hammer;
- a compass-clinometer (available from the Geo-Environmental Unit of the Department of Roads); alternatively, a simple compass and an Abney level;
- (optionally) 30-metre and 3-metre tape measures;
- (optionally) a geological hand lens for close inspection of rock conditions (available from the Geo-Environmental Unit of the Department of Roads).

Procedure for the mapping of large and complex landslides

Procedural steps			Action
Stage 1		**Initial observations of the geomorphology.** Look at the general locality and situation of the site: • make a note of the exact location so that you can direct others to the site if necessary; • see if it is in a part of the landscape where instability would be expected (refer to Figures 2.6 and 2.7 in the *Reference Manual* pages 51,52); • see if the orientation of the rocks, outcropping on the hillside around the site, indicate that the cause of the failure may be due to rock structure, either as planes of weakness or movement of water along fractures; • look at other sites in the area: they may have a similar geomorphic situation and a similar life progression.	**Observe**
Stage 2	(a)	**Sketch the site from the road or other good observation point** Draw the main features: • concentrate on getting the general proportions correct; • estimate the length from top to bottom: record this on the drawing; • estimate the width across the base: record this; • sometimes the landslide may be very complex, and some additional sub-drawings may help.	**Draw**
	(b)	Look for the landslide zones: • scar; • transport; • debris. Note that you cannot yet see whether there is a zone of cracking above the scar. You do not have to record these zones on the drawing, but the completed drawing should be sufficiently well illustrated and labelled to let another person recognise which zones are present and where they are.	**Draw**
	(c)	Examine the material forming the original hill slope: • debris; • soft rock; • hard rock; • alternating hard and soft rocks. All of these could be present on one landslide. The drawing should show where they are. You will have to check your classes during the site walkover (Stage 3b).	**Describe and draw**
	(d)	Sketch a slope profile of the site from top to bottom. Angles do not have to be precise, but should indicate relative steepness. It can be augmented with more detail (*e.g.* with slope measurements) as you walk up the slide. Note that slopes >35° tend to be unstable unless composed of solid rock.	**Draw**
	(e)	Sketch the surface water drainage: • streams; • any springs that may be visible from where you are standing.	**Draw**
	(f)	Sketch areas of rock outcrop.	**Draw**
	(g)	Landmarks: note any obvious landmarks on the site, such as prominent trees. This will help you to keep your bearings as you walk over and around the site.	**Draw**

Procedure for the mapping of large and complex landslides *continued*

Procedural steps		Action
Stage 3	**Walkover survey**	
(a)	Walk up the centre of the slide to the crown (head of scar). Measure the angles of major slope units. If the slope is too steep or dangerous, walk around the edge, looking into the scar.	**Measure**
(b)	Rock: visit each rock outcrop. Measure any relevant rock planes (see Chapter 2.4c of the *Reference Manual*, page 54, or observe how the planes relate to the slope and failure planes. Make sure that the rocks observed are true outcrops (attached to solid rock beneath) and not simply large boulders partly buried on the slope. Check the weathering grade: hard rock is from weathering grades 1 to 4 and rings when struck with a hammer); soft rock is in weathering grade 5 or softer, and gives a dull thud when struck with a hammer). Note the: • uniformity or layering (bedding) of the rock units; • degree of weathering (hardness and discoloration of minerals) of the rocks; • degree of fracturing, especially any open fractures; • signs of water movement along fractures.	**and describe**
(c)	Debris and slope: indicate the area of the slide that is occupied by debris: • location and extent of landslide debris; • composition of debris; • wetness of debris; • depth of debris / depth of failure plane; • location, orientation and size of any cracks in the debris or on the slope; • any back-tilted slope, where water may collect (if this is present, it indicates a deep-seated circular failure – a shear failure); • tilted trees: these can indicate subsiding ground; • disrupted engineering structures, *e.g.* masonry surface drains; • points of ground water seepage.	**Describe and draw**
(d)	Margins and top. Look for the following. • Cracks in the ground: cracks are most frequent above the head of a slide, but they often occur also around the sides. The presence of cracks shows that the ground is under tension and that it will probably fail, and soon. Note the location, dimensions and orientation of the cracks. This information tells you where, and in which direction, the ground is under tension. The area of cracking tells you the area over which failure is about to take place; • Streams, springs, irrigation channels or drainage structures, especially masonry drainage ditches. These features may be sending water into the slide. They may either have caused it in the first place, or they may be contributing to further failure. Irrigation channels and masonry drainage ditches should be inspected closely for any signs of cracking and leakage; • Irregular topography, not due to rock outcrops. This may indicate the presence of an old landslide, in which case you will have to survey the whole of this, too. Continue walking up the slope above the landslide until there is no further evidence of instability. This may mean walking at least 50 metres higher than the landslide scar, and much further if necessary.	**Draw**
(e)	Base of the slide: describe the features and ground conditions at the base. Possibilities are as follows. • Intact road. Instability is from above only. The road may be buried but the road itself is not disrupted by the slide plane. Note: if the road is disturbed, the road cannot be at the base and the slope condition at the base must come under one of the three categories below. • Stable, undisturbed hill slope. • Unstable hill slope. Cracked ground, landslide or topography that collects water. • Stream, with a possible risk of scour and undercutting of slope.	**Describe**

Procedure for the mapping of large and complex landslides *continued*

Procedural steps			Action
Stage 4		**General assessment**	**Describe**
	(a)	Causes and mechanisms of instability. Based on your observations, assess whether any part of the failure is due to the following causes. Mark them on your plan of the site. Surface water • Erosion, or soaking of surface to cause shallow sliding. • Effects of water infiltrating from surface. Causes shallow failures. Ground water • Ground water causes increased pore water pressure at depth. • Failure plane is deeper than in surface water failure. Weathering • Rock shear strength is reduced by weathering. Rock strength is reduced as constituent minerals are broken down into weathering products and clay minerals. Physical bonds between rock constituents are weakened or broken. The rock can fail along weakened fracture planes or through its body. Undercutting • Slope is undercut by a flowing stream or by the opening up of a road cutting. • Incision (downcutting) or lateral scour by streams is a major cause of slope failure. The initial failure can work rapidly up slope. Addition of weight • Weight added usually by landslide debris from above or by the dumping of spoil.	
	(b)	History and life progression of slide. Assess the likely evolution of the slide from its current condition into the future. Possibilities are as follows. • Stable slope formed, or will stabilise naturally • Single failure to stable rock plane or stable slope configuration. This is a relatively rare situation. • Further movement is expected, by a less serious mechanism. 'Less serious mechanism' means a movement at a depth shallower than that of the original failure. This means that the instability is going through post-slide adjustment. • Repeated movement expected, by the initial mechanism or another equally serious. • Further movement is expected, by a more serious mechanism. 'More serious mechanism' means a movement at a greater depth than that involved in the original failure, or a mass movement involving a different cause or mechanism.	**Describe**
	(c)	Severity of instability Fill in the *Check List for Assessing Severity of Slope Instability*. (*Reference Manual*, Annex A). This does not quantify the severity (it is still impossible to do so in a way which permits meaningful comparisons) but allows you to assess the severity rapidly. On the check list, the criteria in each category get progressively larger, more difficult and harder to rectify. Therefore in assessing severity, you should look at how far down each list you have ticked each of the twelve categories.	**Check list**
Stage 5		**Determination of site treatment** You should now have as much information as you are able to obtain from a straightforward site investigation without specialist advice and equipment. Refer to the companion volume, *Site Handbook* of *Roadside Bio-engineering*, Section 1, for instructions on how to determine the site treatment. If the site is large and your investigation shows that the instability is the result of a deep-seated failure, you should contact the Geo-Environmental Unit of the Department of Roads, and discuss the need for a special site investigation.	**Refer to Site Handbook**

CHECK LIST FOR ASSESSING SEVERITY OF SLOPE INSTABILITY

Within each section of the Check List, the conditions are described in order of increasing severity. A site that can be described by the first category in each section is relatively mild and straightforward to stabilise. A site that is described by the last category in each section is a severe problem, often requiring large scale civil engineering works to repair.

Road: ____________ **Chainage:** ____________ **Observer:** ________ **Date:**

1 LOCATION OF SLIDE
- ☐ Off road alignment but within DOR responsibility
- ☐ Above road - any distance
- ☐ Below road - any distance
- ☐ Between roads, *i.e.* above one road and below another
- ☐ Through road (slide is above and below road)

2 TYPE OF SLOPE AFFECTED
- ☐ Road cutting but not hill slope
- ☐ Hill slope but not road cutting
- ☐ Road cutting plus hill slope
- ☐ Embankment, fill or spoil slope

3 SLOPE CONDITIONS ABOVE SLIDE (above road, if road is at top of slide)
- ☐ Crest of ridge, or gentle slope (less than 35°)
- ☐ Stable, undisturbed hill slope
- ☐ Unstable hill slope. Cracked ground, another landslide or topography that collects water
- ☐ Cut-off drain or take-out drain
- ☐ Irrigation channel (kulo)

4 SLOPE CONDITIONS BELOW SLIDE (or below road, if road is at base)
- ☐ Stable, undisturbed hill slope
- ☐ Intact road at base of slide (road may be buried, but if it is disturbed, road is not at base)
- ☐ Unstable hill slope. Cracks, landslide or topography collecting water
- ☐ Stream

5 GENERAL TYPE OF FAILURE
- ☐ Erosion, rilling or gullying up to 2 m deep
- ☐ Gully more than 2 m deep
- ☐ Mass movement (slide, flow or fall)

6 MATERIAL FORMING ORIGINAL (FAILED) SLOPE
- ☐ Debris, colluvium or alluvium
- ☐ Soft rock (weathering grade 5 or equivalent)
- ☐ Hard rock (weathering grades 1 - 4)
- ☐ Alternating hard and soft rocks

7 FAILURE MECHANISM
- ☐ Erosion (rill, gully or pipe)
- ☐ Plane failure in rock (slide, fall)
- ☐ Collapse (fall with disintegration)
- ☐ Flow or shear failure (slump or slide)
- ☐ Undermining

8 CAUSE OF FAILURE
- ☐ Surface water. Erosion, or soaking of surface: shallow slide/flow
- ☐ Ground water, causing increased pore water pressure at depth
- ☐ Addition of spoil or landslide debris
- ☐ Weathering
- ☐ Undercutting of slope by stream or road cutting

9 DEPTH OF FAILURE

☐	Less than		25 mm	Erosion
☐		25 -	100 mm	}
☐		100 -	250 mm	} Slide, slump,
☐		250 -	1000 mm	} flow or fall
☐	More than		1000 mm	}

10 LENGTH OF FAILURE (top to bottom)

☐	Up to	15	m
☐		15 - 75	m
☐		75 - 150	m
☐	More than	150	m

11 HISTORY OF SLIDE
- ☐ Not moved within the last 5 years
- ☐ Moved within the last 5 years but not this year
- ☐ Moved this year for the first time
- ☐ Moves every year by initial mechanism - diminishing
- ☐ Moves every year by initial mechanism - constant or getting worse

12 LIFE PROGRESSION OF SLIDE
- ☐ Stable slope formed, or will stabilise naturally
- ☐ Further movement expected, by less serious mechanism (post-slide adjustment)
- ☐ Repeated movement expected, by initial mechanism or another equally serious

DETAILS OF THE MAIN BIO-ENGINEERING SPECIES

GRASSES

AMLISO

Thysanolaena maxima

Character

Large clumping grass.

Role in bio-engineering

Used in all configurations of planted grass lines.

Description

The grass is used to make kuchos. It is a large-leafed grass closely resembling a bamboo. It has broad culms, perhaps 10 mm in diameter, and leaves about 80 mm wide at their broadest, tapering to a point and about 500 mm long. The leaves are dark green and have a distinctive pattern of indentations running across them about two-thirds of the way up. There are no branches from the stem and the culm is not hollow. The clumps can be a metre or more in diameter. The culms and flower heads are up to 2 metres in height. It has a massive rooting system similar to a small bamboo.

Sites

Terai – 2000 m

Common in the damper areas of forests throughout much of Nepal. Despite its apparent preference for cool, damp areas, it grows well when planted on reasonably dry, stony sites, and in some hot but relatively humid areas. However, it is not as tough as many other grasses.

Propagation

It is easy to propagate from rhizome cuttings, though success is much greater in hot locations. There is also evidence that single-node culm cuttings can be successful if carried out with care. Seeds are very small and seem to be difficult to germinate in nurseries. Seeds are collected between Falgun and Baisakh (March to April).

Cultivation and maintenance

Depending on the site, amliso may require the following:

- weeding;
- protection from grazing.

It should normally be cut in Magh or Falgun.

Uses (other than bio-engineering)

Brooms, fodder.

BABIYO

Eulaliopsis binata
Also called sabai grass.

Character
Medium-sized clumping grass.

Role in bio-engineering
Used in all configurations of planted grass lines. Also used for direct seeding.

Description
The grass has very strong fibres and is normally used to make dori. It is a clumping grass with very thin leaves and a coarse feel. It is of medium stature, growing to a height of about 750mm. Babiyo has a characteristic droop, hanging down steep slopes as if laid on purpose as a kind of thatch. Flowers are white.

Sites
Terai – 1500 m
Occurs in the Terai, Churia and lower river valleys throughout Nepal. It grows well on very harsh, hot, dry sites and on steep slopes, even on very stony sites.

Propagation
The most common method of propagation is by splitting out clumps to makes slip cutting. It can also be propagated from seeds. Seeds are collected between Poush and Falgun (January to February).

Cultivation and maintenance
Depending on the site, babiyo may require the following:
- weeding;
- protection from grazing.

It should normally be cut in Magh or Falgun.

Uses (other than bio-engineering)
Ropes, paper, fodder.

DHONDE

Neyraudia reynaudiana

Character
Large clumping grass.

Role in bio-engineering
Used in all configurations of planted grass lines. Also used for direct seeding.

Description
A large-stature forest grass. The leaves are thin but grow to about 400 mm in length. The stem is hollow like a bamboo and it has a single small branch from every node. It forms thick clumps of at least 750 mm in diameter and puts up rhizomatous shoots similar to those of bamboos. The seed head is large and bunched but lighter than that of sito.

Sites
Terai – 1500 m
Common in many dry forest types, particularly in eastern Nepal. It grows in the dry, south-facing rain shadow areas where its natural sites are very harsh. Dhonde tolerates the very driest of sites; equivalent to sito in its range.

Propagation
It is easy to propagate from slip cuttings or from seeds. It can also be propagated from culm cuttings. Seeds are collected between Mangsir and Magh (December to January). There are approximately 15,520,000 seeds per kilogramme.

Cultivation and maintenance
Depending on the site, dhonde may require the following:

- weeding;
- protection from grazing.

It should normally be cut in Magh or Falgun.

Uses (other than bio-engineering)
Fodder, poor thatch.

DUBO
Cynodon dactylon

Character
A low, short grass which forms a continuous cover rather than producing clumps.

Role in bio-engineering
Used only for turfing.

Description
A common, invasive creeping grass which forms a tough sward in many bare areas. It has leaves of about 50 to 75 mm in length and is green with a slightly blue hue. It rarely stands more than 100 mm in height, or 50 mm if grazed.

Sites
Terai - 1800 m
Known to produce good growth on fertile sites but is less productive where the site is poorer. It is a secondary coloniser and appears in most areas that are regularly grazed. It is stoloniferous, so spreads well and is invasive in many areas. Dubo tolerates fairly intense grazing.

Propagation
This is most easily done by either root or stolon node cuttings. It grows vigorously from both. Seeds are very difficult to collect.

Cultivation and maintenance
Dubo requires little attention once it is established, although it may require weeding in the first growing season. It does not need to be cut. Protection from grazing is not required, and in fact this may lead to it being overwhelmed by other, larger species.

Uses (other than bio-engineering)
Fodder.

KANS

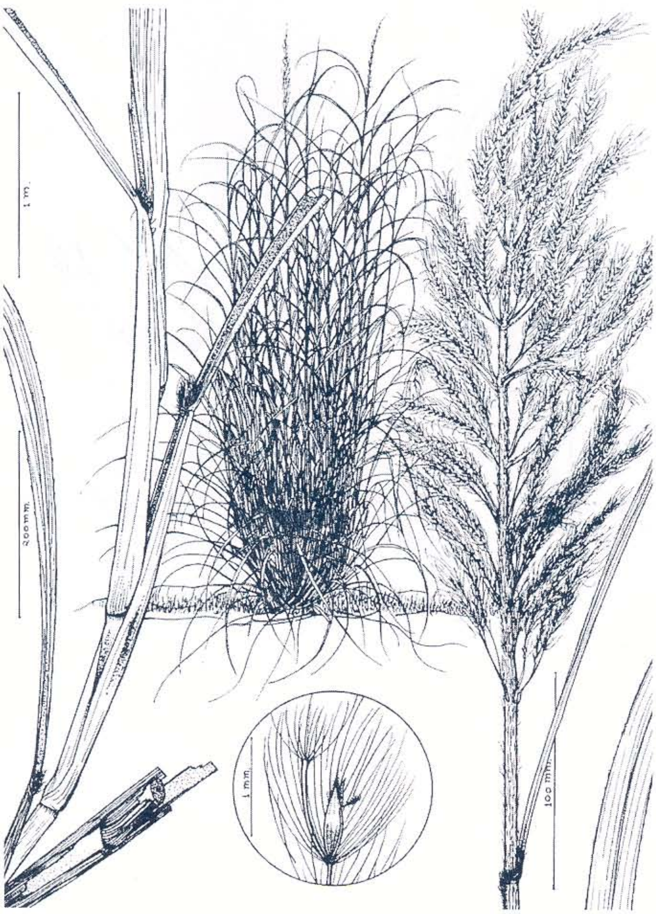
Saccharum spontaneum

Character

Large clumping and spreading grass.

Role in bio-engineering

Used in all configurations of planted grass lines. Also used for direct seeding.



Description

There are two varieties of kans, which have slight differences. One type is a root developer and sends shoots from every node of the roots, but it does not have a proper rhizome. It forms dense clumps, up to about 750 mm in diameter. The other type has a semi-rhizomatous root system but develops mainly by stolons. These can spread rapidly and put roots down from the nodes, although moisture is needed for kans to do this vigorously. The appearance is similar to an enormous spider crawling across the ground. Both types have similar leaves although the stems and leaves are slightly softer in the case of the stoloniferous variety. The leaves are slightly blue in colour, long, very thin and coarse, with a channel running up the middle. The flower heads can be 2 to 3 metres in height and are a brilliant white, making this grass highly distinctive in the autumn.

Sites

Terai - 2000m

The most widespread large indigenous grass in the Terai and lower mountains throughout most of Nepal. It occurs naturally on coarse alluvial soils, including very gravelly and stony areas beside rivers. Kans withstands waterlogging, inundation and severe drought. It also withstands grazing, but will not thrive if the shoots are eaten repeatedly. When planted, it survives well on very hot, dry and harsh sites. It is probably the toughest of the low-altitude grasses, with a deep rooting system and widely spreading stolons.

Propagation

It can be propagated most easily from slip cuttings, and in fact is the easiest of the grasses to grow by this means. It can be grown from stolons if they are available. It grows from seed but not so well. Seeds are collected between Kartik and Poush (November to December).

Cultivation and maintenance

Depending on the site, kans may require the following:

- weeding;
- protection from grazing.

It should normally be cut in Magh or Falgun.

Uses (other than bio-engineering)

Poor fodder, poor thatch.

KATARA KHAR
Themeda species

Character
Large clumping grass.

Role in bio-engineering
Used in all configurations of planted grass lines. Also used for direct seeding.

Description
A large-stature forest grass. The stem is thick, usually up to 10 mm in diameter. The colour makes it distinct from the smaller khar: it has grey colouration where as khar is brownish red when it ripens. The seed head is long (approximately 500 mm) and spiky in appearance; it also curves downwards like dhan (rice).

Sites
Terai - 2000m
It is a widely occurring species and grows in many forest types in its range. However, although katara khar does grow on dry, south-facing slopes in wetter areas, khar is tolerant of much drier sites.

Propagation
It can be propagated from slip cuttings. It also grows from seed. Seeds are collected between Aswin and Mangsir (October to November).

Cultivation and maintenance
Depending on the site, katara khar may require the following:
- weeding;
- protection from grazing.

It should normally be cut in Magh or Falgun.

Uses (other than bio-engineering)
Fodder, thatch.

KHAR

Cymbopogon microtheca

Character

Medium large clumping grass.

Role in bio-engineering

Used in all configurations of planted grass lines. Also used for direct seeding.

Description

The grass most commonly used for thatch. It is a medium-stature grass, of a similar size to phurke but not as large as sito or dhonde. Clumps are perhaps 500 mm in diameter and the flower heads are up to 2 metres high. Leaves are similar to those of kans, but are greener (rather than with a blue hue), shorter and curve downwards. But they are thin (less than 5 mm), pointed, have a channel running along them, and are rough to the touch. The flower/seed head has a characteristic multi-spiked appearance. The plant turns a brownish red as the seeds ripen.

Sites

Terai - 2000m

A tough forest grass common throughout the lower Middle Mountains and parts of the Churia range, where it is much used for thatching. It is often cultivated on marginal land by farmers. It grows well on many hot, dry, south-facing slopes. Although not really indigenous to the very driest sites, it grows well on many harsh, dry sites.

Propagation

It can be propagated from slip cuttings. It also grows very easily from seed. Seeds are collected between Mangsir and Magh (December to January). There are approximately 1,681,000 seeds per kilogramme.

Cultivation and maintenance

Depending on the site, khar may require the following:

- weeding;
- protection from grazing.

It should normally be cut in Magh or Falgun.

Uses (other than bio-engineering)

Thatch, fodder (when shoots are young).

KHUS

Vetiveria lawsoni

Also called sinki. This is the north Indian form of *Vetiveria zizanioides*, but is more fertile (*i.e.* produces more viable seeds) and has a different rooting pattern.

Character
Medium-large clumping grass.

Role in bio-engineering
Used in all configurations of planted grass lines.

Description
A medium-stature grass with culms 0.5 to 1.5 metres long and forming dense clumps up to a maximum of 0.5 metres in diameter. There are no rhizomes or stolons. Leaf blades are glossy and a vibrant yellowish green and can easily be split down one side to reveal a white pith; they are up to 750 mm long and 8 mm or less in width; the edges feel rough if stroked downwards. A very thin, darker green line runs up the centre of the leaf, and is a useful distinguishing feature. The roots are many and spongy in mass, with a dominant downward direction.

Sites
Terai - 1500m
Grows naturally along rivers throughout the Nepal Terai and among other grasses in areas prone to seasonal waterlogging. It grows well in dry sites on fill materials but does not grow so well on hard cut slopes. Experience in the Nepal road sector has demonstrated that this species is not as tough and versatile as the widespread literature devoted to vetiver suggests.

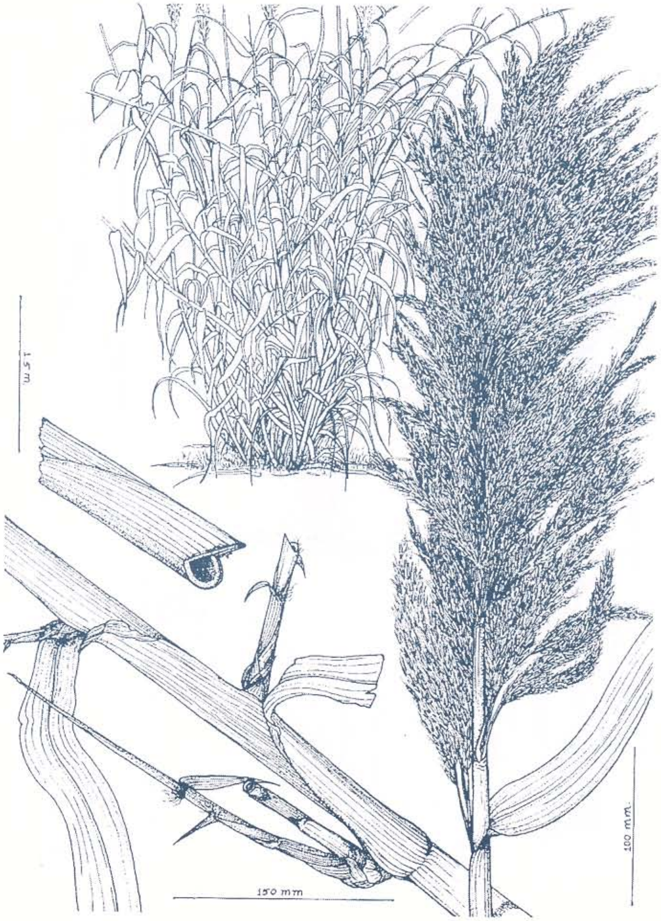
Propagation
It is easy to propagate by root splitting. It seeds, but not prolifically, and can also be grown from them. Seeds are collected between Aswin and Mangsir (September to November). There are approximately 1,712,000 seeds per kilogramme.

Cultivation and maintenance
Depending on the site, khus may require the following:

- weeding;
- protection from grazing.

It should normally be cut in Magh or Falgun.

Uses (other than bio-engineering)
Fodder, poor thatch.



NARKAT

Arundo clonax

Character

Large clumping and spreading grass.

Role in bio-engineering

Used in all configurations of planted grass lines.

Description

A large-stature forest grass. The stem is hollow and similar in appearance to bamboo but less woody. The leaves are a pea green colour, thick, pointed and about 15 mm wide. They grow opposite each other in a regular and distinct pattern, with the ends bending downwards in a semicircular arc.

Sites

Terai - 1500m

It grows on hot, south and south-west facing slopes. In the Terai, it grows in sal (*Shorea robusta*) forest. It thrives most vigorously in wet and waterlogged sites.

Propagation

It can be propagated easily from seed, slip and stem cuttings. For stem cuttings, material more than two years old with heavy branches should be used. Seeds are collected between Mangsir and Magh (November to January).

Cultivation and maintenance

Depending on the site, narkat may require the following:

- weeding;
- protection from grazing.

It should normally be cut in Magh or Falgun.

Uses (other than bio-engineering)

Poor fodder.

PADANG BANS

Himalayacalamus hookerianus

Character

Large clumping grass. A small stature bamboo.

Role in bio-engineering

Used in all configurations of planted grass lines.

Description

A small stature bamboo with blue culms and distinctive culm sheaths which narrow from the base upwards. It tends to form clumps rather than spreading like the other small bamboos.

Sites

1500 - 2500 m

Prefers cool, damp sites with some shade and moisture. It is not as drought resistant as the large bamboos.

Propagation

It is easily propagated by the traditional bamboo planting method. Seeding is very rare.

Cultivation and maintenance

Depending on the site, padang bans may require the following:

- weeding;
- protection from grazing.

Bamboos should not be cut completely like other grasses, but partial cutting can be done in Magh or Falgun.

Uses (other than bio-engineering)

Weaving.

PHURKE

Arunduella nepalensis

Character

Medium sized clumping grass.

Role in bio-engineering

Used in all configurations of planted grass lines. Also used for direct seeding.

Description

Smaller in stature than many of the other forest grasses, this grows to a height of only about 1.5 m. The leaves are similar to dhonde but with a rough edge; they are pointed and there is an angle of about 35 degrees between the stem and the leaves. The culm is hollow and only has branches from the nodes on material of two or more years in age. Also, the seed head is finer than that of sito or dhonde, and the seed husks are rougher. Clumps do not exceed 0.5 metres in diameter.

Sites

700 - 2000 m

Grows naturally on relatively damp south-west to north facing slopes. It is tough and colonises landslides, therefore growing in harsh, stony sites. It probably does not do well on hot sites in the full sun.

Propagation

This is easily done either by splitting clumps into slip cuttings, or by seed. Seeds are collected between Mangsir and Magh (December to January). There are approximately 1,809,000 seeds per kilogramme.

Cultivation and maintenance

Depending on the site, phurke may require the following:

- weeding;
- protection from grazing.

It should normally be cut in Magh or Falgun.

Uses (other than bio-engineering)

Thatch, fodder.

SITO

Neyraudia arundinacea

Character

Large clumping grass.

Role in bio-engineering

Used in all configurations of planted grass lines. Also used for direct seeding.

Description

A large-stature grass very similar in overall appearance to dhonde but which occurs under wetter climatic conditions. The stem is not hollow, but is thicker than dhonde (up to about 20 mm), and the leaves are wider and longer. When the stem nodes are more than two years old, roots and branches can begin to emerge from them. It reaches a height of about 2.5 metres; clumps grow to be about 0.75 metres in diameter. Young shoots are poisonous to animals, but are grazed when there is no other grass.

Sites

Terai - 1500m

Common in many forest types in the damper parts of Nepal. Sito grows in harsh sites, including south-facing slopes, but in areas of higher rainfall. It grows in dry sites if planted, and is the equivalent to dhonde in its range, occurring in similar sites but in areas of higher rainfall.

Propagation

It propagates readily from slip cuttings, culm cuttings or seed. Seeds are collected between Mangsir and Magh (December to January). There are approximately 16,390,000 seeds per kilogramme.

Cultivation and maintenance

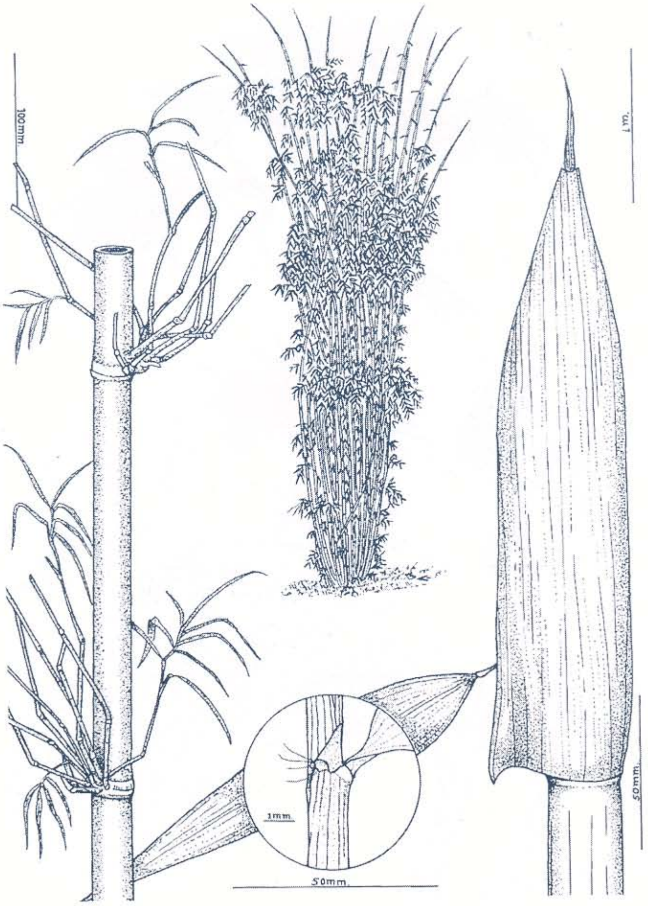
Depending on the site, sito may require the following:

- weeding;
- protection from grazing.

It should normally be cut in Magh or Falgun.

Uses (other than bio-engineering)

Poor thatch, poor fodder.



TITE NIGALO BANS

Drepanostachyum intermedium

Character

Large spreading grass. A small stature bamboo.

Role in bio-engineering

Used in all configurations of planted grass lines.

Description

A small stature bamboo. Leaf sheaths are hairy and culm sheaths narrow from about half way up. A spreading, rather than clumping bamboo.

Sites

1000 - 2500 m

Common throughout the middle mountains. This is the most resilient small-stature bamboo. It is found on relatively hot, dry and exposed banks, and in rocky sites in its range. But it is not as resistant to drought as the larger bamboos and grows best in damp, shady sites.

Propagation

It is easily propagated by the traditional bamboo planting method. Seeding is very rare.

Cultivation and maintenance

Depending on the site, tite nigalo bans may require the following:

- weeding;
- protection from grazing.

Bamboos should not be cut completely like other grasses, but partial cutting can be done in Magh or Falgun.

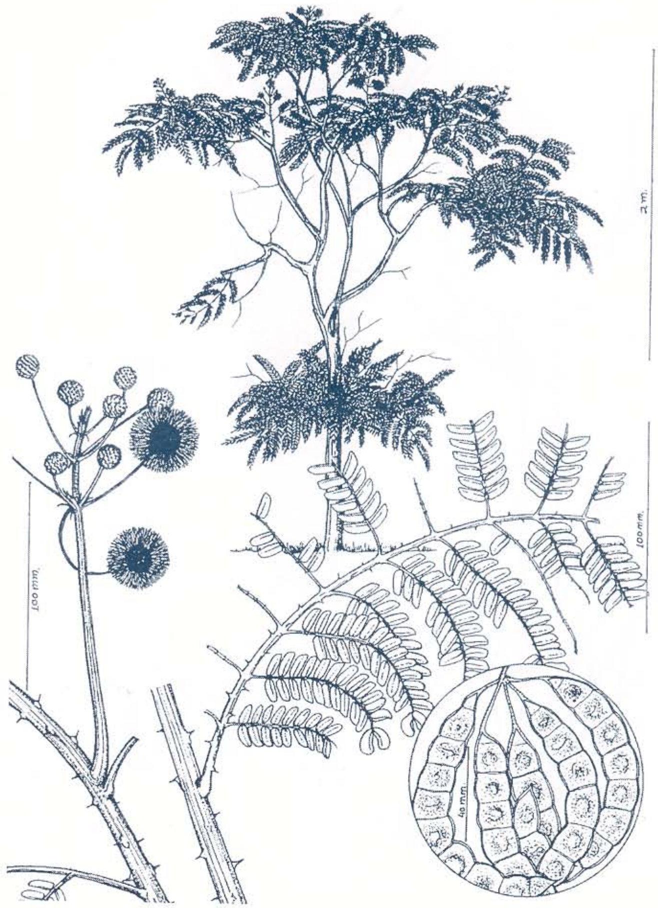
Uses (other than bio-engineering)

Weaving, fodder.

SHRUBS AND SMALL TREES

ARERI

Acacia pennata



Character

Small thorny tree, up to 5 m.

Role in bio-engineering

Used for shrub and tree planting or shrub and tree direct seeding.

Description

A small tree or large shrub, with either a single trunk or branches rising from ground level. Rarely greater than 5 metres in stature. It is extremely thorny and the branches snap very easily.

Sites

500 - 1500 m

Occurs throughout Nepal on disturbed land in the Churia and lower mountains. It colonises landslides naturally, but tends to be found more in damp sites or areas of higher rainfall. It is very resilient and grows on harsh sites and in very stony places, although it will not thrive on the very driest sites where khayer (*Acacia catechu*) will grow..

Propagation

It seeds abundantly and is easy to propagate by this method. Direct sowing on site is usually successful. Seeds are collected between Kartik and Poush (November to December). There are approximately 36,000 seeds per kilogramme; they remain viable for about 12 months.

Cultivation and maintenance

Depending on the site, areri may require the following:

- weeding;
- protection from grazing in the first year; after this it is not damaged by grazing.

Thinning should be carried out when the plantation gets too dense. Areri can be lopped heavily but full coppicing or pollarding tends to kill it.

Uses (other than bio-engineering)

Normally none, although it can be used for hedging.

ASSURO

Adhatoda vasica

Character

Shrub up to 3 m high.

Role in bio-engineering

Used for brush layering, palisades, live check dams and fascines.

Description

A shrub which forms a dense bush up to 3 metres high. The leaves are a brilliant green, showing up distinctly during the late dry season. It has stems, which are shiny, and green when young but change to be white when they mature.

Sites

Terai - 1000m

It occurs in the Bhabar sal forest and the Churia. It appears to be an understorey plant and is certainly tolerant of shade. But although it grows best in damp, shady sites, it will also survive in dry, stony areas.

Propagation

Hardwood stem cuttings can be taken and have a high success rate. They can be planted in a nursery or directly on site. Cuttings can be planted at any angle, but upside down is not recommended.

Cultivation and maintenance

Depending on the site, assuro may require the following:

- weeding;
- protection from grazing.

Thinning should be carried out when the plantation gets too dense. Assuro can be lopped heavily, and thinning can be achieved by full coppicing or pollarding.

Uses (other than bio-engineering)

Compost, medicines, hedging.

BAINSH

Salix tetrasperma

Character

Tree up to 15 m high.

Role in bio-engineering

Used for brush layering, palisades, live check dams and fascines.

Description

A fodder tree grown mostly at higher altitudes. Leaves are feathery , both in shape and the way they hang and flutter in a breeze; the undersides of leaves are white. They grow in a regular pattern along the branches. Branches are long and thin, and hang down like hair.

Sites

Terai - 2700m

Bainsh grows naturally along stream channels and it is in this situation where it can mostly be found. It grows in drier locations when planted but only thrives in damp and north-facing sites. It should not be used in dry sites below 2000 metres.

Propagation

Hardwood stem cuttings can be taken and have a high success rate in damp sites. They can be planted in a nursery or directly on site.

Cultivation and maintenance

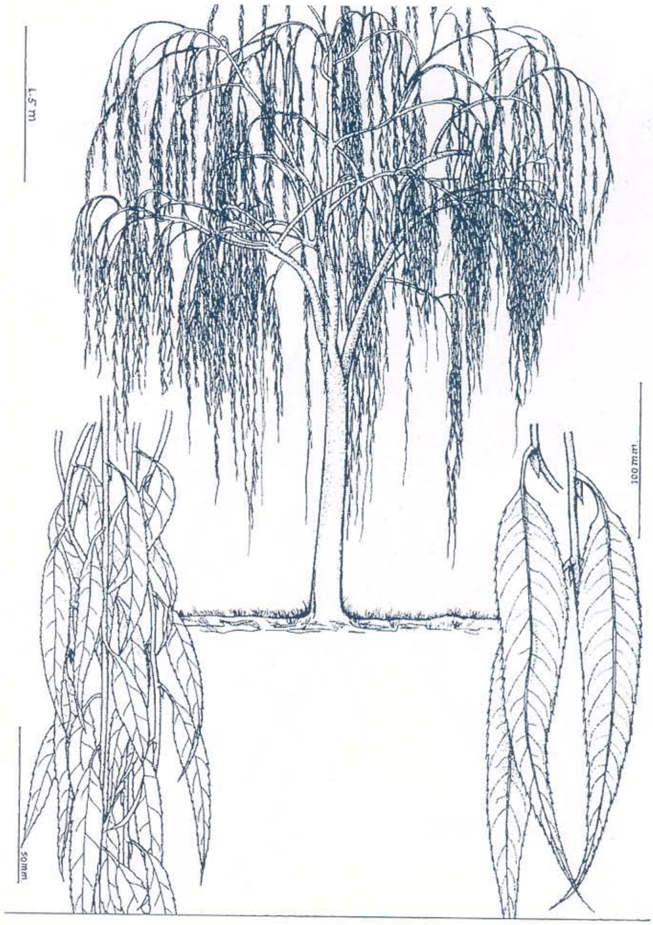
Depending on the site, bainsh may require the following:

- weeding;
- protection from grazing.

Thinning should be carried out when the plantation gets too dense. Bainsh can be lopped heavily, and thinning can be achieved by full coppicing or pollarding.

Uses (other than bio-engineering)

Weaving, fodder, small timber.



BHUJETRO

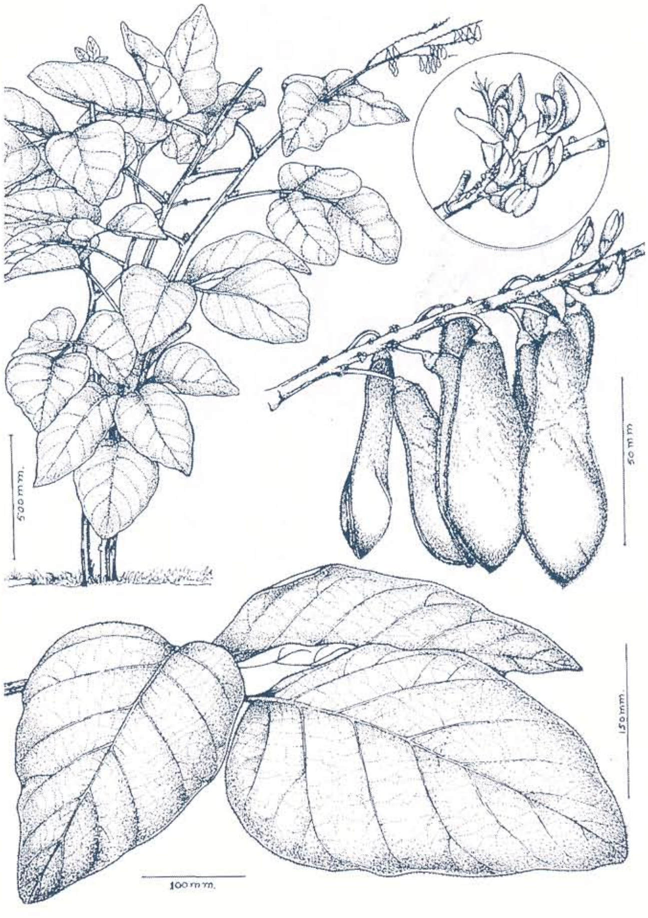
Butea minor

Character

Shrub up to 4 m high.

Role in bio-engineering

Used only for shrub and tree direct seeding.



Description

A straggly plant with furry, brown stems and large, fleshy triple leaves at the end of each. Flowers during the early monsoon rains are a brilliant red. Plants have between one and six stems, but are never more than 4 metres high. The roots mostly grow downwards, with a dominant tap root, and they are exceptionally large and strong for the size of the plant. The stem dies back in the winter and the plant sends out complete new shoots very early in the monsoon.

Sites

500 - 1500 m

Occurs naturally in areas of higher rainfall in the Churia range and lower mountains of eastern Nepal. It grows well when planted in dry, south-facing sites and in dry, stony ground. It also grows well in rocky crevices in its climatic zone. But it does not perform well in the very driest places and hardest materials. It has been planted up to 2000 metres in warm sites in the upper Trisuli valley.

Propagation

It seeds in large numbers, with one large seed in each pot. Germination of six-month old seed is nearly 100 per cent and, because of the large tap root, it is best not transplanted. Direct sowing on site, with the seed still in its pod, gives excellent results. Seeds are collected between Kartik and Poush (November to January). There are approximately 450 seeds per kilogramme; they remain viable for about 18 months.

Cultivation and maintenance

Once the seed has been sown, the only maintenance required is protection from grazing while the shoots are young. The stem dies back in the winter and the plant sends out complete new shoots very early in the monsoon, so thinning is not required.

Uses (other than bio-engineering)

Animal bedding, umbrellas, meat packing.

DHANYERO

Woodfordia fruticosa

Character

Shrub up to 3 m high.

Role in bio-engineering

Used only for shrub and tree planting.

Description

A rather untidy, straggling shrub which reaches a maximum height of about 3 metres. Leaves are smooth and pointed, and grow opposite each other in a regular pattern. The flowers grow from nodes on the stem and are a brilliant red.

Sites

Terai - 1500m

It occurs mostly on the drier Churia slopes and on dry sites in the lower middle mountain valleys, and is very common throughout Nepal. On some south-facing slopes it forms almost pure stands. Dhanyero grows in the very harshest of hot, dry and very steep sites, including rocky slopes.

Propagation

Seeds are very small but germinate easily in a carefully prepared nursery seed bed. It cannot be grown from hardwood cuttings. Seeds are collected between Falgun and Baisakh (March to April). There are approximately 1,000,000 seeds per kilogramme; they remain viable for about 12 months.

Cultivation and maintenance

Depending on the site, dhanyero may require the following:

- weeding;
- protection from grazing.

Thinning should be carried out when the plantation gets too dense. Dhanyero can be lopped heavily, and once the plant is established, thinning can be achieved by full coppicing or pollarding.

Uses (other than bio-engineering)

Bedding, firewood, wine (from flowers).

DHUSUN

Colebrookea oppositifolia

Character

Shrub up to 2 m high.

Role in bio-engineering

Used mainly for shrub and tree planting.

Description

A small shrub growing to a height of about three metres. It has pointed leaves about 100 mm long, with serrated edges and a spongy feel. The flowers are white, and are also spongy.

Sites

Terai - 1000m

A constituent of the drier forest types of the Bhabar and Siwalik zones. It also grows on hot, dry slopes where there is little else, and is probably a coloniser of such sites. Dhusun grows reasonably well when planted in the hottest places in the Churia range.

Propagation

The seeds are very small but can be germinated readily in a carefully prepared seed bed. Seeds are collected between Falgun and Chaitra (March). There are approximately 1,000,000 seeds per kilogramme; they remain viable for about 12 months.

Cultivation and maintenance

Depending on the site, dhusun may require the following:

- weeding;
- protection from grazing.

Thinning should be carried out when the plantation gets too dense.

Uses (other than bio-engineering)

Medicine.

KANDA PHUL

Lantana camara

Also called sutkeri phul.

Character

Shrub up to 2 m high.

Role in bio-engineering

Used mainly for brush layering, palisades, live check dams and fascines.

Description

A bushy shrub which forms dense thickets. Its maximum height is about 2 metres. Leaves are coarse and the stems thorny. Flowers vary, individual plants having either yellow, white, pink or mauve flowers.

Sites

Terai - 1750m

An invasive weed on many dry slopes throughout the lower mountains; common around towns and in other areas disturbed by man; it grows when planted on many dry, stony and degraded sites.

Propagation

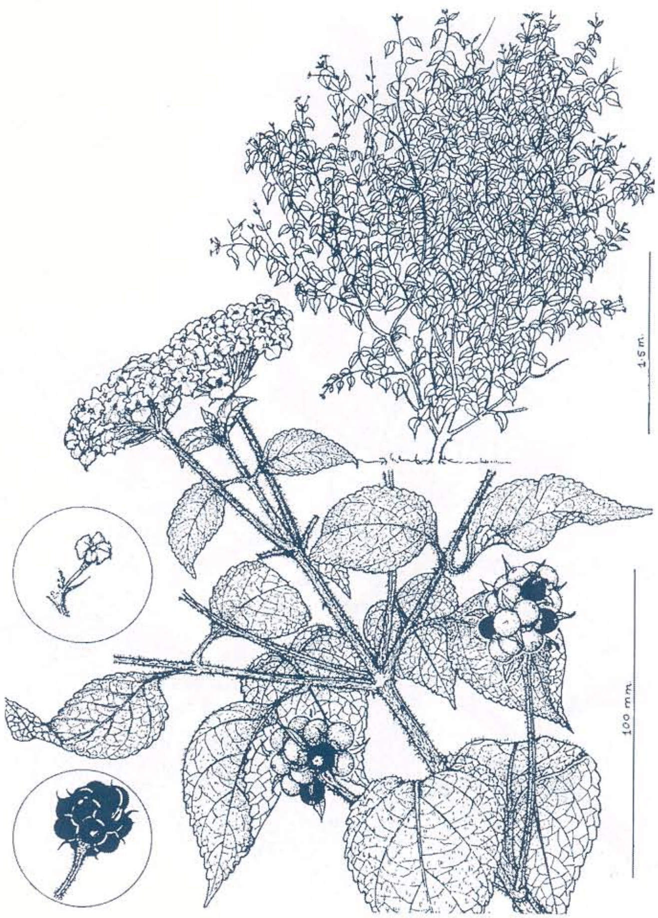
Although it seeds prolifically, the seeds are difficult to germinate under nursery conditions. Stem cuttings, however, are usually successful. They should ideally be between 10 and 30 mm in diameter and at least 300 mm long. Cuttings buried in trenches (as fascines) are usually more successful than normal cuttings.

Cultivation and maintenance

Kanda phul is slow to establish. Weeding may be required. The shrub is resistant to grazing and if used properly can make a good but thick hedge. It has no understorey and gullying can start underneath even dense stands of bushes. However, careful thinning and coppicing reduces erosion to some extent.

Uses (other than bio-engineering)

Poor ornamental, hedging.



KERAUKOSE

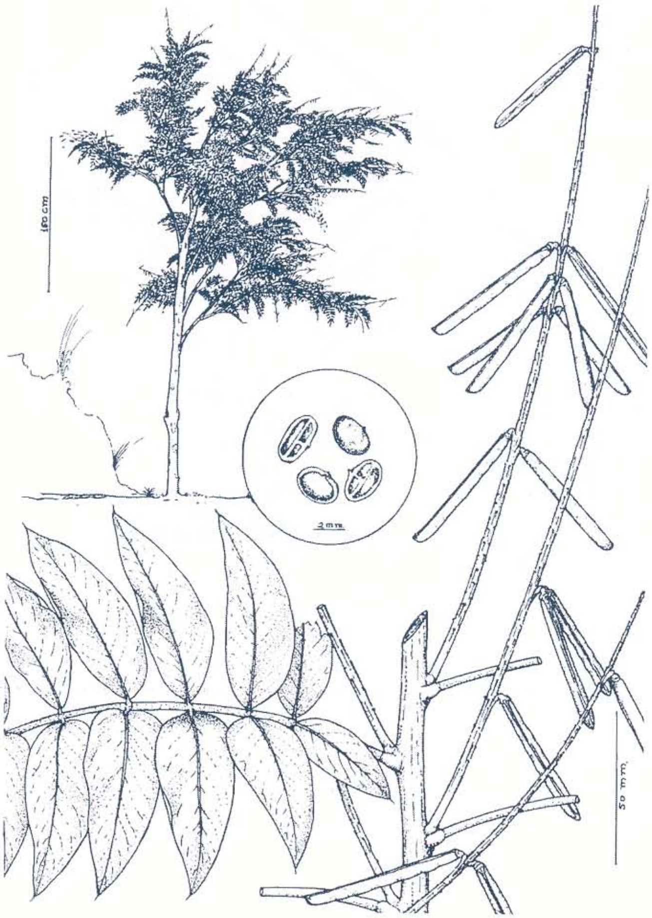
Indigofera atroturpurea

Character

Tree up to 8 m high.

Role in bio-engineering

Used for shrub and tree planting or shrub and tree direct seeding.



Description

A small stature tree with irregular branching and rising to a maximum height of about 8 metres. The bole and branches are slender. Leaves are smooth, spear-shaped (lanceolate) and about 60 mm long by 15 mm wide. The leaf tips are sometimes round rather than pointed. Flowers are generally white or purple and occur around and near the ends of the stems. The fruit hangs in pods about 50 mm long, like dal, with 10 to 25 seeds per pod.

Sites

Terai - 2000m

It colonises landslides and other disturbed land in the wetter areas of the Siwaliks and southern Mahabharat. It seems to grow well in almost every site in which it is planted, within its altitudinal range. It does well on very dry and hot south-facing Churia slopes, and on dry, stony fill material.

Propagation

The seeds can be germinated easily in the nursery, or sown direct to site. Although early growth can be slow in the nursery, it speeds up once the seedling has reached a height of about 400 mm. It cannot be propagated from hardwood cuttings. Seeds are collected between Kartik and Poush (November to January). There are approximately 94,000 seeds per kilogramme; they remain viable for about 12 months.

Cultivation and maintenance

Depending on the site, keraukose may require the following:

- weeding;
- protection from grazing in the first few years: after this, keraukose is resistant to grazing even though it is leguminous.

Thinning should be carried out when the plantation gets too dense. It can be lopped heavily and pollarded (except on very dry sites, but full coppicing tends to kill it).

Uses (other than bio-engineering)

Firewood, shade tree (particularly in tea gardens in the Terai of West Bengal).

KETTUKE

Agave americana

Character

Large cactus; sub-species with and without thorns.

Role in bio-engineering

Used mainly for shrub and tree planting.

Description

A cactus growing so that almost the entire visible plant comprises only leaves. A mass of fibrous, succulent leaves grow upwards to a maximum height of about 1.5 metres. They usually have a bluish colour. Leaves are up to 100 mm wide and 20 mm thick. In thorny varieties, the leaf edges and tips are fringed with upwards-pointing thorns.

Sites

Terai - 2000m

Kettuke grows on hot, dry, south-facing slopes. It is not found in damp or shady sites, and seems to require full sunlight to thrive. Throughout its range, it grows in the driest sites available.

Propagation

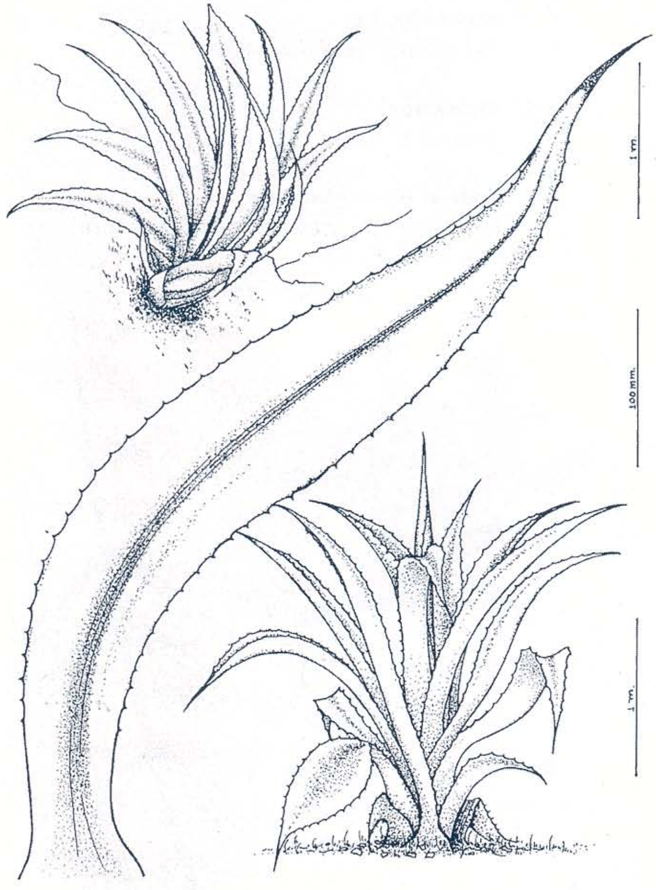
Seeds are rare. It is grown by separating a section of rootstock or a sucker (a small shoot coming up from the roots of a bigger plant). There is no need of growing these on in a nursery unless large, strong plants are needed.

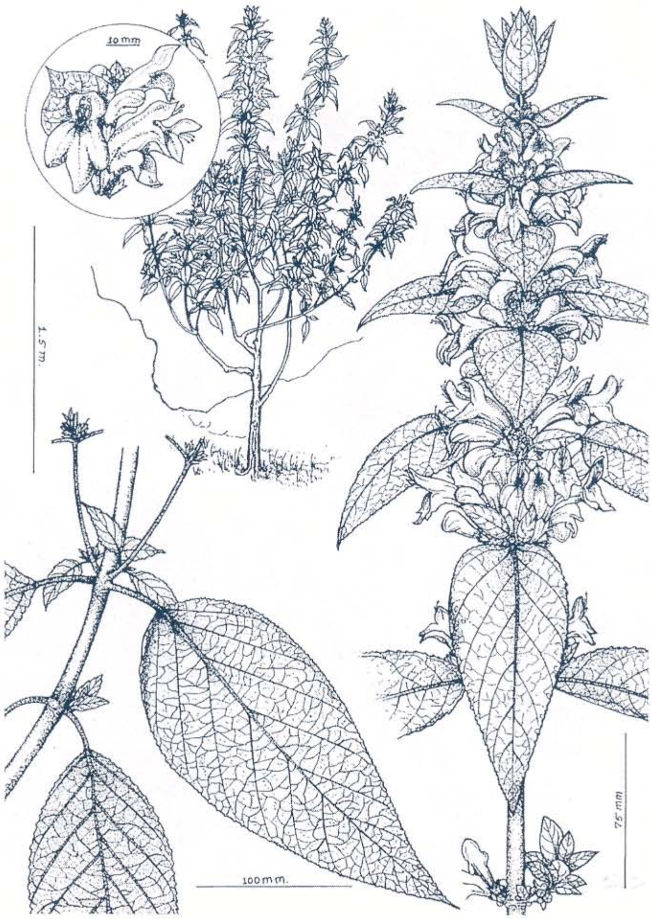
Cultivation and maintenance

Once established, kettuke needs no maintenance. It is resistant to grazing.

Uses (other than bio-engineering)

Hedging.





NAMDI PHUL
Colquhounia coccinea

Character
Shrub up to 3 m high.

Role in bio-engineering
Used for brush layering, palisades, live check dams and fascines.

Description
A small shrub with medium-sized, pointed leaves and striking red flowers in Mangsir and Poush. The leaves are spongy and grey on the underside.

Sites
1000 - 2000 m
Namdi phul occurs in damper sites in its range. It grows best on north-facing sites. It tends to grow extremely well on colluvium and debris slopes.

Propagation
It can be propagated very easily from hardwood stem cuttings.

Cultivation and maintenance
Depending on the site, namdi phul may require the following:

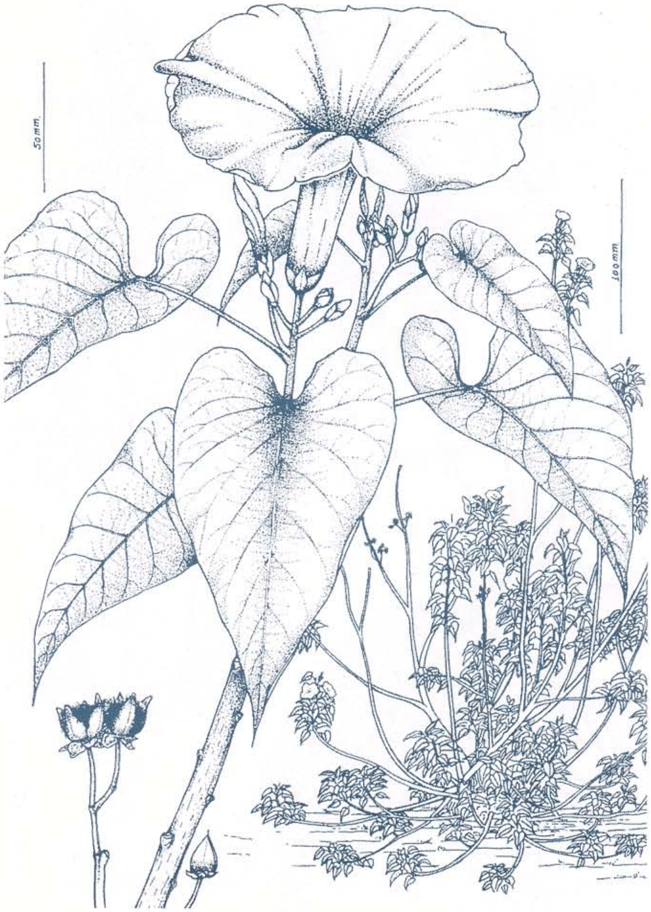
- weeding;
- protection from grazing.

Thinning should be carried out when the plantation gets too dense. Namdi phul can be lopped heavily, and thinning can be achieved by full coppicing or pollarding.

Uses (other than bio-engineering)
None known.

SARUWA/BIHAYA

Ipomoea fistulosa



Character

Recumbent shrub.

Role in bio-engineering

Used for brush layering, palisades, live check dams and fascines.

Description

A low-lying shrub with straggling stems up to 3 metres long. The stems have few branches and clumps of leaves at the ends. Leaves are shaped like a heart with an extended point. The flower is from pale pink to purple in colour and shaped like a trumpet. Mature clumps of this weed are extremely dense and impenetrable to animals.

Sites

Terai - 1500m

An invasive weed growing abundantly in wet, marshy depressions in the Terai and lower hill valleys; frequently found in the old borrow pits beside road embankments. It grows well when planted on hot, dry sites, but only if the soil is loose: therefore it can be highly successful on fill material but may fail completely after a promising first season on cut slopes. It needs full sunlight to grow and cannot tolerate shading.

Propagation

It takes very easily and rapidly from stem cuttings. Since there is such a ready supply of material in the Terai, there is little point in collecting seed.

Cultivation and maintenance

Depending on the site, saruwa needs little maintenance. It grows vigorously and so does not require weeding. Protection from grazing may be required when young; after the first growing season it is resistant to grazing. Thinning should be carried out when the plantation gets too dense. Saruwa can be lopped heavily, and thinning can be achieved by full coppicing. It will die out completely if it is shaded.

Uses (other than bio-engineering)

Poor firewood when there are no alternatives.

SIMALI
Vitex negundo

Character
Small tree, up to 6 m high.

Road in bio-engineering
Used for brush layering, palisades, live check dams and fascines.

Description
A small, vigorous tree growing to a maximum height of about six metres. Branches tend to be heavy, giving the plant an irregular form. Leaves are smooth and pointed and, characteristically, in groups of three or five. Flowers are white, later becoming pink, growing upright at the ends of the stems.

Sites
Terai - 1750m

A common small tree throughout the lower mountains. It occurs naturally along rivers and in gullies where it grows on very stony ground. Despite this obvious preference for moist, shady places, it grows when planted on dry, stony sites and on hot, dry road cuts.

Propagation
Seeds are very small and difficult to germinate under nursery conditions. Hardwood stem cuttings give excellent results, however. Material should ideally be between 10 and 30 mm in diameter, but cuttings up to 50 mm are also successful. They should be at least 300 mm long, although cuttings of up to 1.2 metres have been successful. They can be planted direct on site any way up, but upside down is not recommended.

Cultivation and maintenance
Depending on the site, simali may require the following:

- weeding;
- protection from grazing.

Thinning should be carried out when the plantation gets too dense. Simali can be lopped heavily, and thinning can be achieved by full coppicing or pollarding.

Uses (other than bio-engineering)
Hedges, firewood.

TILKA

Wendlandia puberula

Character

Tree up to 10 m high.

Role in bio-engineering

Used for shrub and tree planting.

Description

A medium sized tree growing to about 10 metres in height. Leaves are fairly large and fleshy. The flower is white.

Sites

Terai - 1500m

It occurs mostly on the drier Siwalik slopes and on dry sites in the lower mountain valleys. On some south-facing slopes it forms almost pure stands. It will grow moderately well on the harshest of hot and dry sites and on hard clay soils.

Propagation

Seeds are small but germinate easily in a carefully prepared nursery seedbed. Tilka cannot be raised from hardwood cuttings. Seeds are collected between Magh and Chaitra (February to March). There are approximately 1,000,000 seeds per kilogramme; they remain viable for about 12 months.

Cultivation and maintenance

Depending on the site, tilka may require the following:

- weeding;
- protection from grazing.

Thinning should be carried out when the plantation gets too dense. Tilka can be lopped heavily, and once the plant is established, thinning can be achieved by full coppicing or pollarding.

Uses (other than bio-engineering)

Firewood.

LARGE TREES

BAKAINO

Melia azedarach
Persian lilac

Character
Medium to large deciduous tree.

Role in bio-engineering
Large tree planting. Can also be sown directly on site (direct seeding or broadcasting).

Description
The trunk and branches of this tree are very smooth. They have a bluish hue when young, turning to brown as they mature. The trunk is usually quite straight. Branches are relatively few and are thin, straight and brittle. The leaves are similar to neem (pointed with serrated edges) and come in composite groups. The fruit hangs in clusters, with one seed per fruit.

Sites
Terai – 1800 m
A fast-growing tree which thrives in many warm sites. Although a good soil is required for best growth, it survives well on shallow, stony, infertile and very dry soils. It does much better on fill materials rather than on cut slopes.

Propagation
Propagation is by polypot seedlings raised from seed in a nursery. There are 1,200 seeds per kg, collected between Mangsir and Falgun (November to March). They remain viable for about 12 months.

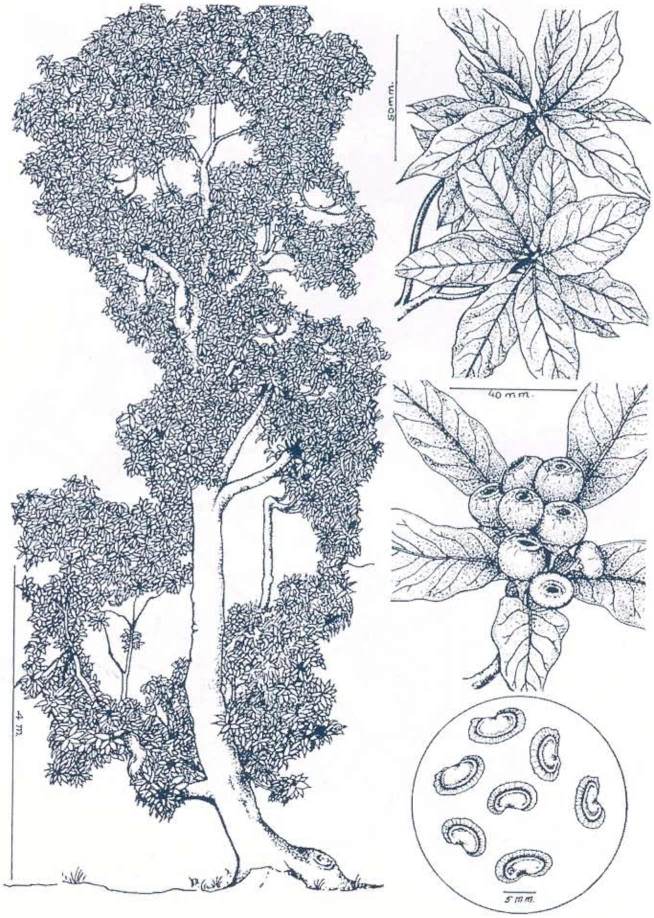
Cultivation and maintenance
Depending on the site, bakaino may require the following:
- weeding (in the first growing season only);
- protection from grazing (until it gets out of the reach of animals).

Thinning should be carried out when the plantation gets too dense. Bakaino can be lopped heavily, and once the tree is established, thinning can be achieved by full coppicing or pollarding.

Uses (other than bio-engineering)
Timber, firewood.

CHILAUNE

Schima wallichii



Character
Large deciduous tree.

Role in bio-engineering
Large tree planting.

Description
Leaves are relatively large, with a serrated edge and shiny top. The bark is thick and covered in hairs that are very itchy. The flower buds are rounded and white, but open to reveal a bright yellow centre. The fruit forms a hard spherical coat and, when dried, opens into four equal divisions. The seeds are white with thin platy wings.

Sites
900 – 2000 m

Chilaune, with various species of katus (*Castanopsis*), forms the dominant forest on northern aspects in its altitude range. It grows best on moist sites and is usually found on south-facing slopes only in areas of high rainfall. However, it can survive a certain amount of drought. It can tolerate shade, and often starts to appear in plantations of other species, particularly of salla and utis. Chilaune can also regenerate very well.

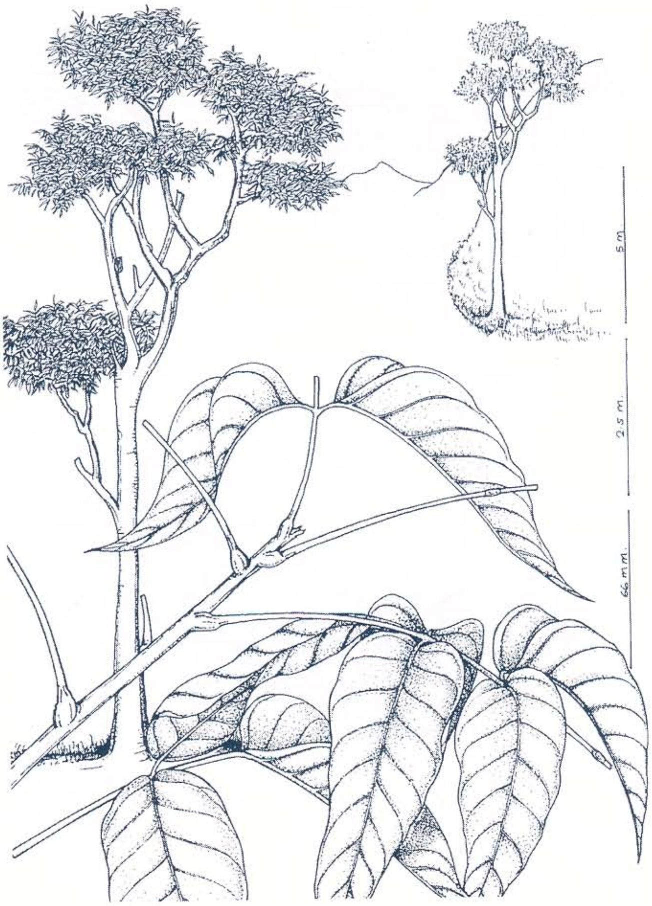
Propagation
Propagation is by polypot seedlings raised from seed in a nursery. There are 160,000 seeds per kg, collected between Magh and Chaitra (January to April). They remain viable only for about 6 months.

Cultivation and maintenance
Depending on the site, chilaune may require the following:

- weeding (in the first growing season only);
- protection from grazing (until it gets out of the reach of animals).

Thinning should be carried out when the plantation gets too dense. Chilaune can be lopped heavily, but should not be coppiced or pollarded.

Uses (other than bio-engineering)
Firewood, timber.



DABDABE

Garuga pinnata

Character

Large deciduous tree.

Role in bio-engineering

Large hardwood cuttings (truncheon cuttings) are used as part of live check dams.

Description

A common fodder tree. The trunk is usually straight, white and has relatively rough bark. The leaves are regular and grow opposite each other. The leaves are large, long and pointed.

Sites

Terai – 1300 m

Dabdabe is associated with sal (*Shorea*) and banghi (*Anogeissus*) forests. It does grow on stony and fairly dry sites, but is much better in damp situations and often occurs near streams.

Propagation

For bio-engineering purposes it is normally propagated as a large hardwood cutting or truncheon cutting: these are typically 2 metres in length. However, it can also be propagated from seed and raised in polypots in the nursery. There are 4,000 seeds per kg and they are collected between Ashad and Bhadra (June to September). They remain viable for about 12 months.

Cultivation and maintenance

Depending on the site, dabdabe may require the following:

- weeding;
- protection from grazing.

Thinning should be carried out when the plantation gets too dense. Dabdabe can be lopped heavily, and thinning can be achieved by full coppicing or pollarding.

Uses (other than bio-engineering)

Timber, fodder.

GOBRE SALLA

Pinus wallichiana, Blue pine

Character

Large coniferous tree.

Role in bio-engineering

Large tree planting. Can also be sown directly on site (direct seeding or broadcasting).

Description

The higher-altitude pine. Above about 1900 metres, it is likely to be the only pine found. It has long (about 200 mm) bluish needles, which occur in clusters of five. The bark is smooth (chillo) and shiny.

Sites

1800 – 3000 m

Gobre salla has a natural tendency towards warm, dry sites and within its altitude range grows on most of the driest sites. It occurs at higher altitudes in the drier inner valleys. It is also found in north-facing gullies, but in general does poorly in damp sites.

Propagation

Propagation is by polypot seedlings raised from seed in a nursery. There are 22,500 seeds per kg, collected between Aswin and Mangsir (October to November). They remain viable for about 12 months.

Cultivation and maintenance

Depending on the site, gobre salla may require:

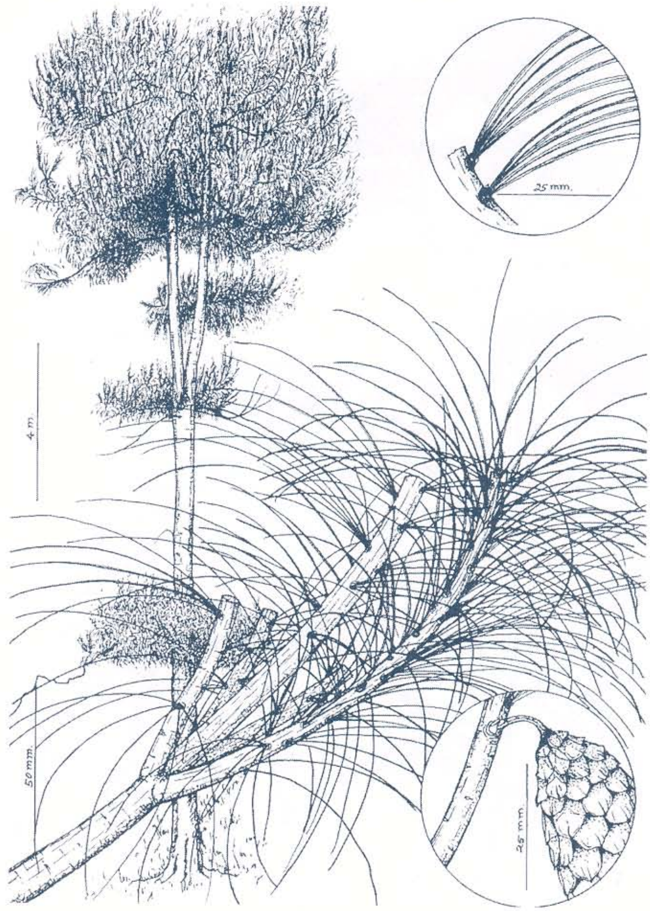
- weeding (in the first two or three growing seasons: dense grass around the trunk is particularly harmful);
- protection from grazing (until it gets out of the reach of animals).

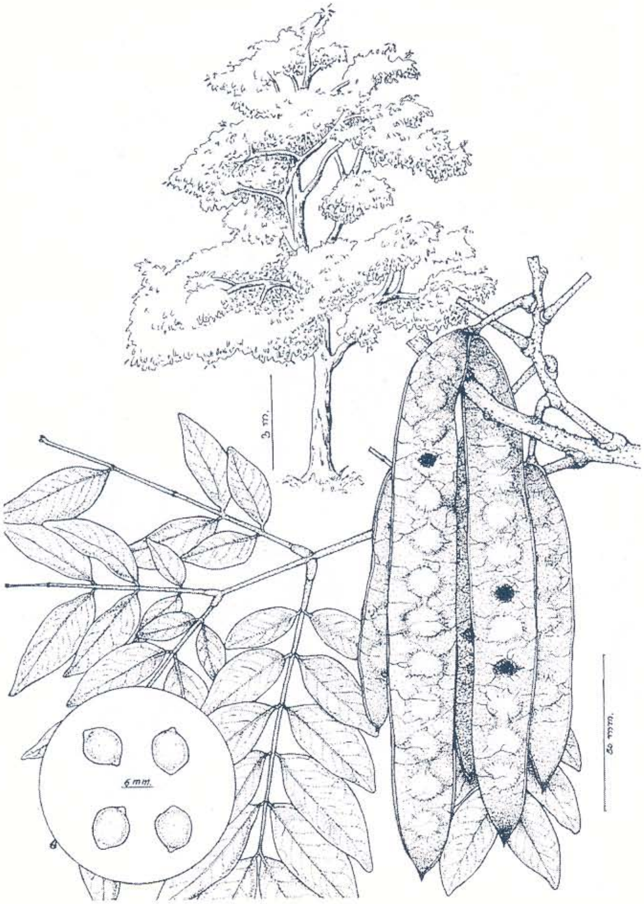
Dense plantations should be thinned. Small branches can be lopped, but pine trees should not be coppiced or pollarded.

Since gobre salla is a pioneer species, it should not be grown as the main species on a site for more than about five years. Vegetation enrichment should be used to grow up other species between the pine trees, with the aim of removing all pines by 10 years after the first planting.

Uses (other than bio-engineering)

Timber, firewood.





KALO SIRIS

Albizia lebbeck

Character

Medium-sized deciduous tree.

Role in bio-engineering

Large tree planting.

Description

A medium-sized tree commonly used for firewood. The trunk is normally straight. Leaves are oval with a slight point, and grow in even numbers (*i.e.* there are always 2, 4, 6 or 8). The stems of young trees are brittle, and usually covered in yellowish-brown spots.

Sites

Terai – 1200 m

Kalo siris grows naturally in harsh sites, since it is a constituent of the sissoo-khayer riverine forest and the sal-saaj forest in the Siwaliks. It is tolerant of droughts and grows on infertile soils. It has been used extensively in India for erosion control. It does not withstand waterlogging, and so should not be planted where drainage is a problem.

Propagation

Propagation is by polypot seedlings raised from seed in a nursery. There are 5,000 seeds per kg, collected between Mangsir and Magh (November to January). They remain viable for at least five years.

Cultivation and maintenance

Depending on the site, kalo siris may require the following:

- weeding (in the first growing season only);
- protection from grazing (until it gets out of the reach of animals).

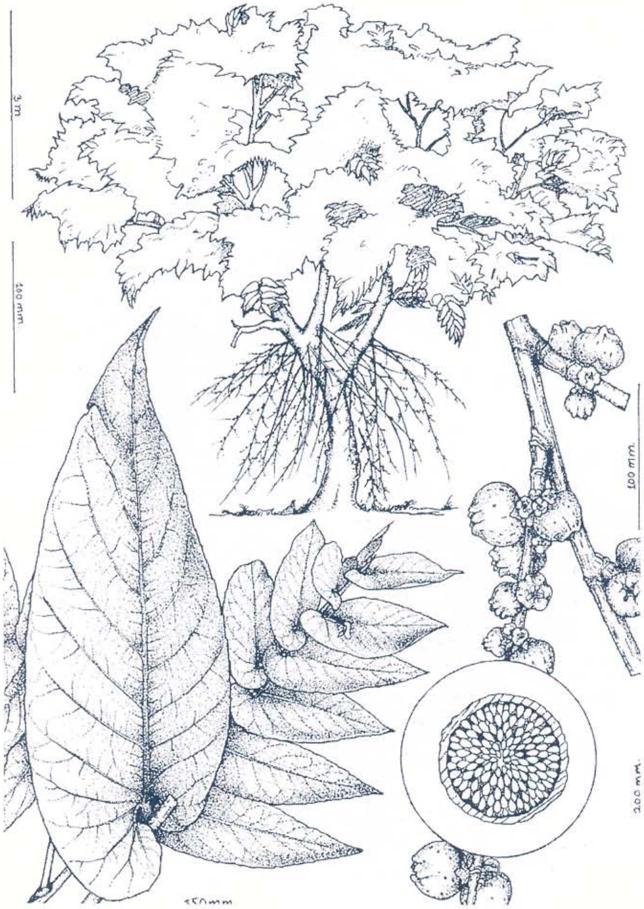
Thinning should be carried out when the plantation gets too dense. Kalo siris can be lopped heavily, and once the tree is established, thinning can be achieved by full coppicing or pollarding.

Uses (other than bio-engineering)

Timber, firewood, fodder.

KHANYU (KHOSRO)

Ficus semicordata
Fig



Character
Small stature, heavy branching.

Role in bio-engineering
Large tree planting. Can also be sown directly on site (broadcasting only).

Description
A medium stature tree with distinctive semicordate leaves. The fruits grow from the trunk on aerial roots. It is distinguished from var. *montana* (rai khanyu) by its coarser leaves and white (rather than red) leaf veins.

Sites
Terai – 2000 m
A natural coloniser of bare and often very rocky sites. Khanyu is often the first tree species to appear on disturbed ground. It can withstand considerable drought, but also grows well in damp sites. Like most colonisers, full light is required, and it cannot tolerate shade. It is one of the most versatile trees for bio-engineering.

Propagation
Propagation is normally by polypot seedlings raised from seed in a nursery. There are 1,500,000 seeds per kg, collected between Shrawan and Aswin (July to October). They remain viable for only about 6 months.

Cultivation and maintenance
Depending on the site, khosro khanyu may require the following:

- weeding (in the first growing season only);
- protection from grazing (until it gets out of the reach of animals).

Thinning should be carried out when the plantation gets too dense. Khosro khanyu can be lopped heavily, and once the tree is established, thinning can be achieved by full coppicing or pollarding.

Uses (other than bio-engineering)
Fodder.

KHAYER

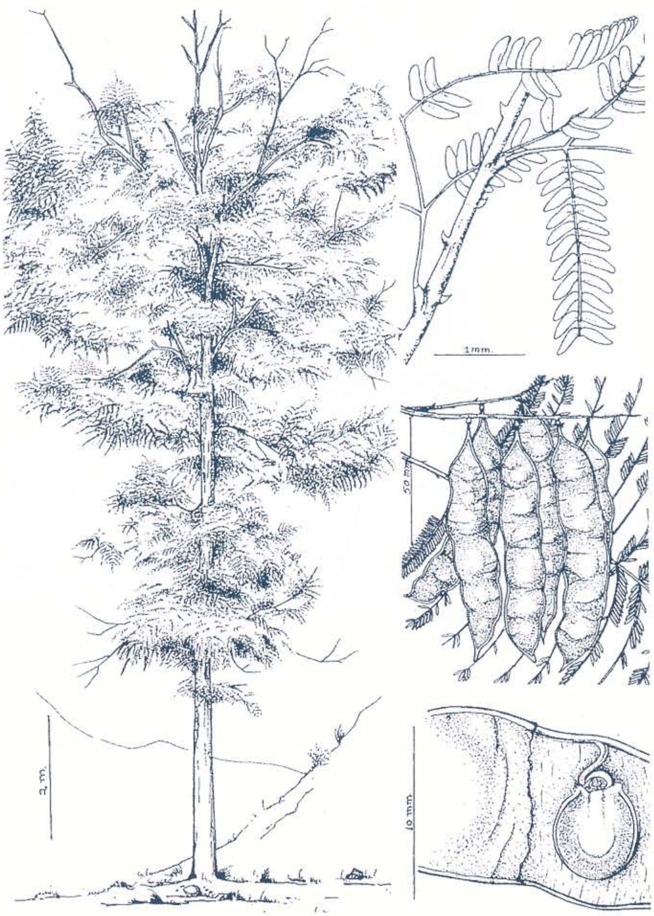
Acacia catechu

Character

Large, thorny tree.

Role in bio-engineering

Large tree planting. Can also be sown directly on site (direct seeding or broadcasting).



Description

A full stature tree with thorny branches and small, composite leaves. The trunk is never straight. Leaves are small (< 10 mm), arranged opposite each other. The thorns curve backwards.

Sites

Terai – 1000 m

Of any common tree found in Nepal, khayer is the most tolerant of excessively hot, dry sites. It needs full sunlight and does not grow in shady locations. But it will grow in any stony or gravelly soil, however dry, or in hard, clayey or calcareous residual soils. It withstands waterlogging and, as a major constituent of riverine forests, it can tolerate deep inundation. Away from the Terai and Siwalik river fringes, khayer grows in almost pure stands on dry, south-facing slopes in deep river valleys and other rain shadow areas: in all sites where it grows naturally, it is an indicator of low rainfall and hot summer temperatures.

Propagation

Propagation is by polypot seedlings raised from seed in a nursery. There are 30,000 seeds per kg, collected between Poush and Falgun (January to February). They remain viable for about 2 years.

Cultivation and maintenance

Depending on the site, khayer may require the following:

- weeding (in the first growing season only);
- protection from grazing (until it gets out of the reach of animals).

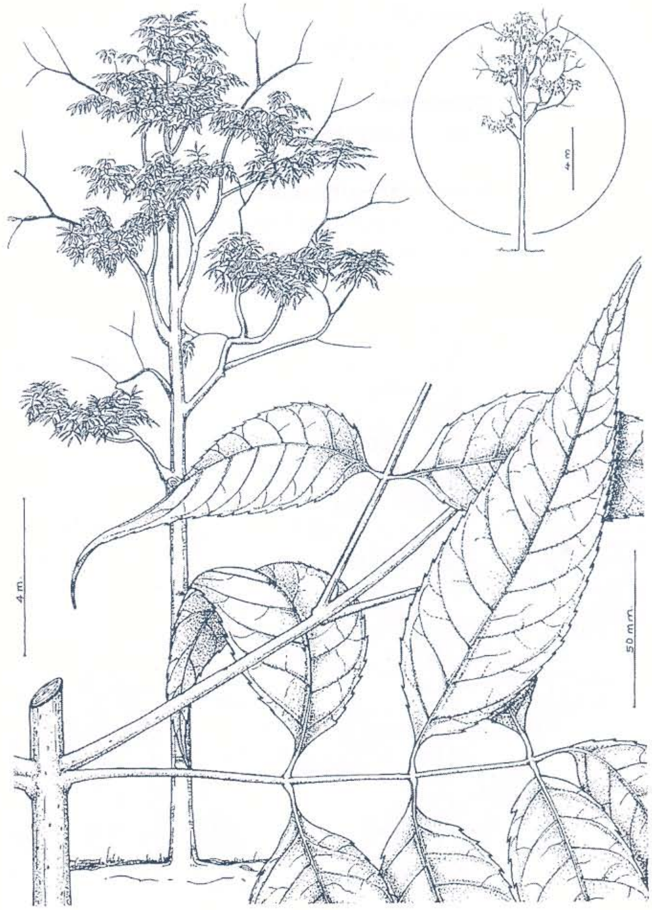
Thinning should be carried out when the plantation gets too dense. Khayer can be lopped, and once the tree is established, thinning can be achieved by coppicing; however, it will not re-grow if the shoots are shaded by other plants.

Uses (other than bio-engineering)

Firewood, fodder, extracts.

LANKURI

Fraxinus floribunda
Ash



Character
Large deciduous tree.

Role in bio-engineering
Large tree planting.

Description
A large tree with a straight, white trunk. The flowers are white and the leaf form in groups of three.

Sites
1200 – 2700 m
Lankuri grows on a wide range of sites and is one of the best survivors on poor materials. It tolerates limestone as well as acidic soils. Young seedlings need full light, and will not grow in shady locations.

Propagation
Propagation is by polypot seedlings raised from seed in a nursery. There are 60,000 seeds per kg, collected between Aswin and Poush (September to January). Green seed should be kept moist and sown immediately. If the seed is brown when collected, or if green seed dries out, it will not germinate until the spring after the next monsoon, but remains viable for three years.

Cultivation and maintenance
Depending on the site, lankuri may require the following:

- weeding (in the first growing season only);
- protection from grazing (until it gets out of the reach of animals).

Thinning should be carried out when the plantation gets too dense. Lankuri can be lopped, and once the tree is established, thinning can be achieved by coppicing or pollarding.

Uses (other than bio-engineering)
Timber, fodder.

PAINYU

Prunus cerasoides
Cherry

Character

Medium-sized flowering tree.

Role in bio-engineering

Large tree planting.

Description

A medium-sized fodder tree. The leaves are pointed, have serrated edges and grow densely on the stems. When young, the stems have a bluish colour, but become pink with shiny bark when older, with white spots left from the leaf buds. The outer skin of the bark tends to peel off naturally.

Sites

500 – 2400 m

Painyu is very tolerant of poor soil conditions; in fact, it is the most tolerant broadleaf tree in the middle hills, growing on stony and sandy materials in sites drier than utis can tolerate. Young trees will grow under moderate shade, and so it can be grown under pioneer plantations of pines and utis, eventually replacing them as the long-term species.

Propagation

Propagation is by polypot seedlings raised from seed in a nursery. There are 2,500 seeds per kg, collected between Aswin and Mangsir (October to November). They remain viable for about 9 months.

Cultivation and maintenance

Depending on the site, painyu may require the following:

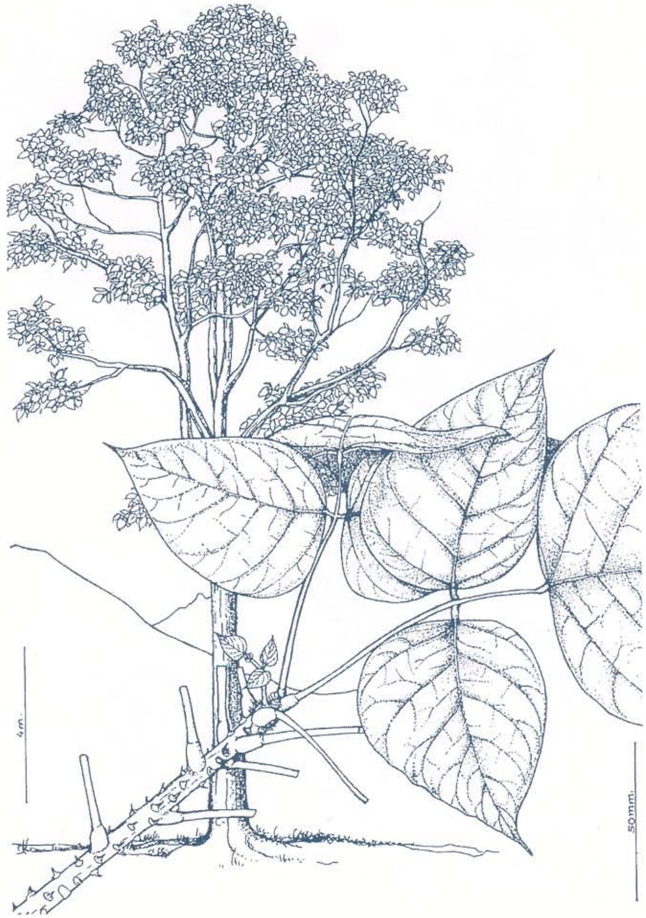
- weeding (in the first growing season only);
- protection from grazing (until it gets out of the reach of animals).

Thinning should be carried out when the plantation gets too dense. Painyu can be lopped, and once the tree is established, thinning can be achieved by coppicing or pollarding.

Uses (other than bio-engineering)
Firewood, fodder, timber.

PHALEDO

Erythrina species



Character

Three large fodder species.

Role in bio-engineering

Large hardwood cuttings (truncheon cuttings) are used as part of live check dams.

Description

A genus of large fodder trees. When young, there are thick thorns on the branches, but these disappear as the tree gets older. The flowers are a brilliant red. The leaves are broad, usually in a group of three.

Sites

900 – 3000 m

Phaledo tolerates a wide range of sites, but should not be planted in dry locations. Good growth can only be expected in reasonably moist sites with soil that is not too stony.

Propagation

For bio-engineering purposes it is normally propagated as a large hardwood cutting or truncheon cutting: these are typically 2 metres in length. The tree can also be grown from small cuttings (ideally 150 mm long and as thick as a pencil), but these would normally need to be grown on in a nursery. It can also be propagated from seed and raised in polypots in the nursery. There are 2,000 seeds per kg and they are collected between Mangsir and Falgun (November to March). They remain viable for about 5 years.

Cultivation and maintenance

Depending on the site, phaledo may require the following:

- weeding;
- protection from grazing.

Thinning should be carried out when the plantation gets too dense. Phaledo can be lopped heavily, and thinning can be achieved by full coppicing or pollarding.

Uses (other than bio-engineering)

Fodder.

RANI (KHOTE) SALLA

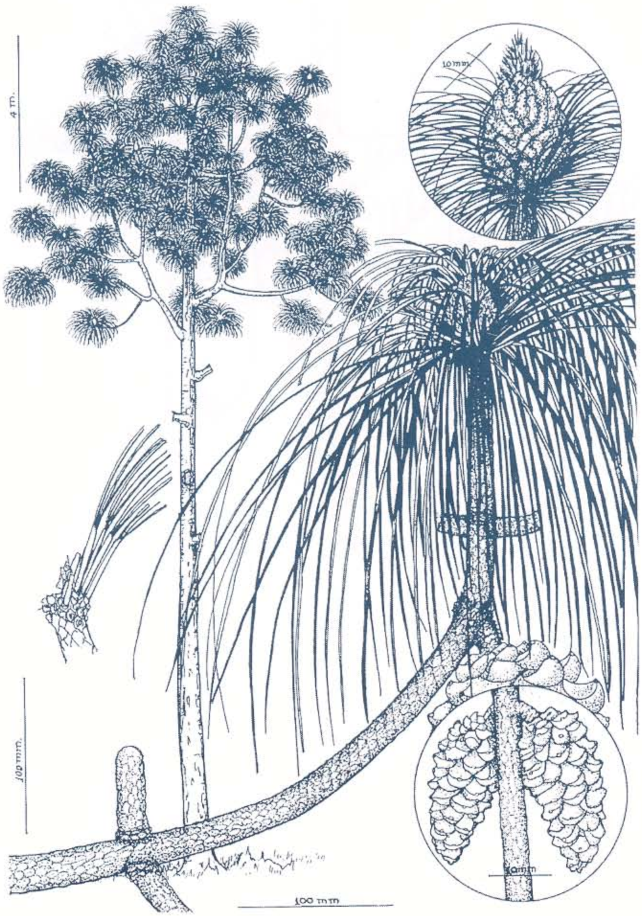
Pinus roxburghii
Chir pine

Character

Large coniferous tree.

Role in bio-engineering

Large tree planting. Can also be sown directly on site (direct seeding or broadcasting).



Description

A large-stature tree, usually with a very straight trunk. Needles are long (about 300 mm) and characteristically occur in clusters of three. Below about 1800 metres, it is the only pine except in areas of old soil-conservation planting (where introduced pines are sometimes found).

Sites

500 – 1950 m
The indigenous low-altitude pine. Rani salla grows naturally on sites that are ecologically or climatically dry, and therefore is an indicator of rain shadow areas and other dry locations. Like most pines, it is a pioneer species and needs full light to grow. It is tolerant of exposed south-facing slopes, hot, dry sites and poor, stony soils. However, it does not grow down to the Terai and unlike khayer it performs badly on poorly drained materials.

Propagation

Propagation is by polypot seedlings raised from seed in a nursery. There are 8,000 seeds per kg, collected between Magh and Falgun (January to March). They remain viable for about 12 months.

Cultivation and maintenance

Depending on the site, rani salla may require the following:

- weeding (in the first two or three growing seasons: dense grass around the trunk is particularly harmful);
- protection from grazing (until it gets out of the reach of animals).

Thinning should be carried out when the plantation gets too dense. Small branches can be lopped, but pine trees should not be coppiced or pollarded.
Since rani salla is a pioneer species, it should not be grown as the main species on a site for more than about five years. Vegetation enrichment should be used to grow up other species between the pine trees, with the aim of changing the mixture and removing all pines by 10 years after the first planting.

Uses (other than bio-engineering)
Timber, firewood.

RATO SIRIS

Albizia julibrissin

Character

Medium-sized deciduous tree.

Role in bio-engineering

Large tree planting.

Description

A large tree, usually with a straight stem. The leaves are feathery in appearance;, they take a herringbone form, being small and thin, and growing opposite each other along the branches. The young leaves are red and, at this stage, are poisonous.

Sites

500 – 2500 m

Rato siris is the best of the siris trees on poor sites, and sometimes colonises landslides naturally. Like most trees, it prefers a fertile, loamy soil; but it can grow relatively quickly on poor, stony sites. It seems to have a low drought tolerance and naturally it occurs mainly in moist locations, such as near streams. Like utis, rato siris should, therefore, be planted in wetter sites.

Propagation

Propagation is by polypot seedlings raised from seed in a nursery. There are 24,000 seeds per kg, collected between Aswin and Magh (September to February). They remain viable for about 5 years.

Cultivation and maintenance

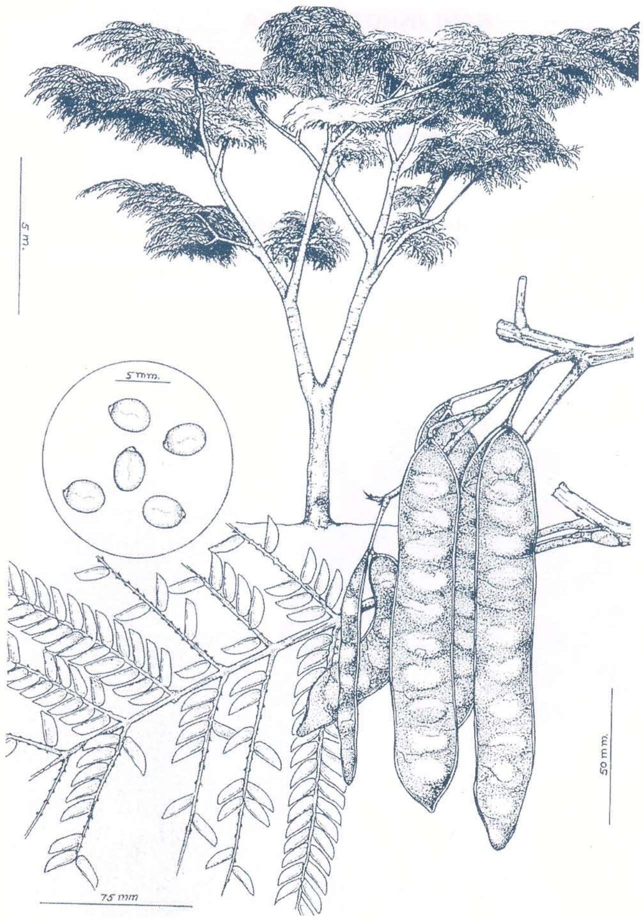
Depending on the site, rato siris may require the following:

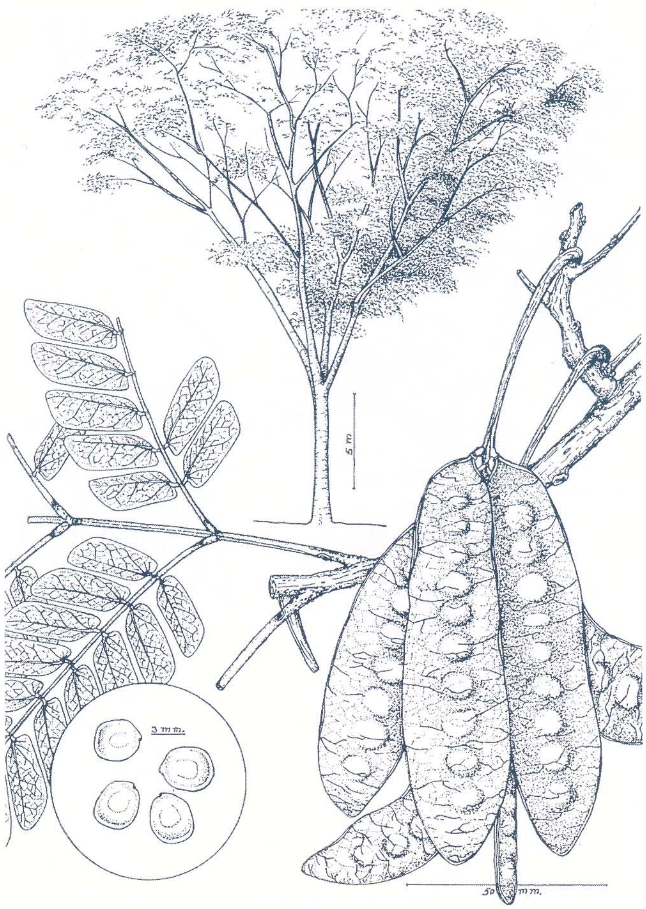
- weeding (in the first growing season only);
- protection from grazing (until it gets out of the reach of animals).

Thinning should be carried out when the plantation gets too dense. Rato siris can be lopped, and once the tree is established, thinning can be achieved by coppicing or pollarding.

Uses (other than bio-engineering)

Timber, fodder.





SETO SIRIS

Albizia procera

Character

Medium-sized deciduous tree.

Role in bio-engineering

Large tree planting.

Description

This tree has branches that are brittle and give off a strong smell when broken. Leaves are of a medium size and grow opposite each other in pairs. The stems are covered in brown spots. The seeds hang down in distinctive pods, 100 to 150 mm long.

Sites

Terai – 1350 m

A tree that grows best in damp and even waterlogged conditions, such as poorly drained clays. It grows poorly in dry sites. It prefers full light, but seedlings can tolerate some shade.

Propagation

Propagation is by polypot seedlings raised from seed in a nursery. There are 18,000 seeds per kg, collected between Poush and Jestha (December to June). They remain viable for about 5 years.

Cultivation and maintenance

Depending on the site, seto siris may require the following:

- weeding (in the first two growing seasons, as grass competition is bad for seedlings);
- protection from grazing (until it grows out of the reach of animals).

Thinning should be carried out when the plantation gets too dense. Seto siris can be lopped, and once the tree is established, thinning can be achieved by coppicing or pollarding.

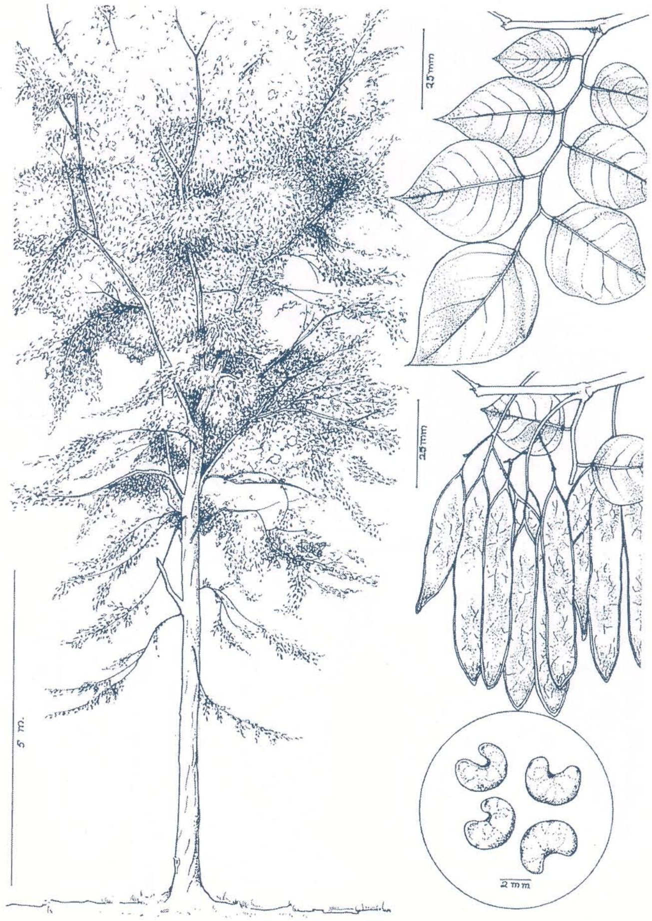
Uses (other than bio-engineering)

Firewood, timber, fodder.

SISAU

Dalbergia sissoo

Sissoo (a type of rosewood)



Character

Large broad-leaved tree.

Role in bio-engineering

Large tree planting. Can also be sown directly on site (direct seeding or broadcasting).

Description

The common low-altitude plantation tree. It is a full-stature tree with a slender, rarely straight stem. Leaves are round, but with a slight point, and generally less than 50 mm long.

Sites

Terai – 1400 m

One of the most versatile low-altitude trees. It occurs naturally in riverine sites, and so is tolerant both of long droughts on stony and gravelly materials, and of waterlogging and flooding. It grows slowly on very dry sites, but rarely dies completely. In fact, its rapid growth depends entirely on it being planted on a well drained, fertile soil with access to a reliable water table. But sisau is so robust that it will grow almost anywhere in its altitudinal range, even if very slowly. For bio-engineering purposes, it should not be planted on very hot, dry sites, where khayer performs better.

Propagation

Propagation is by polypot seedlings raised from seed in a nursery. There are 33,000 seeds per kg, collected between Falgun and Baisakh (February to May). They remain viable for about 12 months.

Cultivation and maintenance

Depending on the site, sisau may require the following:

- weeding (in the first growing seasons only);
- protection from grazing (until it grows out of the reach of animals).

Thinning should be carried out when the plantation gets too dense. Sisau can be lopped, and once the tree is established, thinning can be achieved by coppicing or pollarding.

Uses (other than bio-engineering)

Timber, firewood, fodder.

UTIS

Alnus nepalensis
Nepalese alder

Character

Large broad-leaved tree.

Role in bio-engineering

Large tree planting. Can also be sown directly on site (broadcasting only).

Description

A large-stature tree with a straight stem. Leaves are usually dark green in colour, rounded at the sides but with a point. They are about 50 mm wide and 80 mm long. Groups of utis trees usually have noisy insect colonies and the leaves are often full of holes from insect attacks.

Sites

900 – 2700 m
Utis is a well known natural coloniser of landslides and gullies in the middle hills. It needs damp or shady conditions, but then will tolerate the poorest and stoniest of materials. Soils should be permeable rather than hard or massive. Although it grows best in damp locations, it avoids waterlogged areas.

Propagation

Propagation is by polypot seedlings raised from seed in a nursery. There are 500,000 seeds per kg, collected between Mangsir and Falgun (November to March). They remain viable for about 18 months.

Cultivation and maintenance

Depending on the site, utis may require the following:

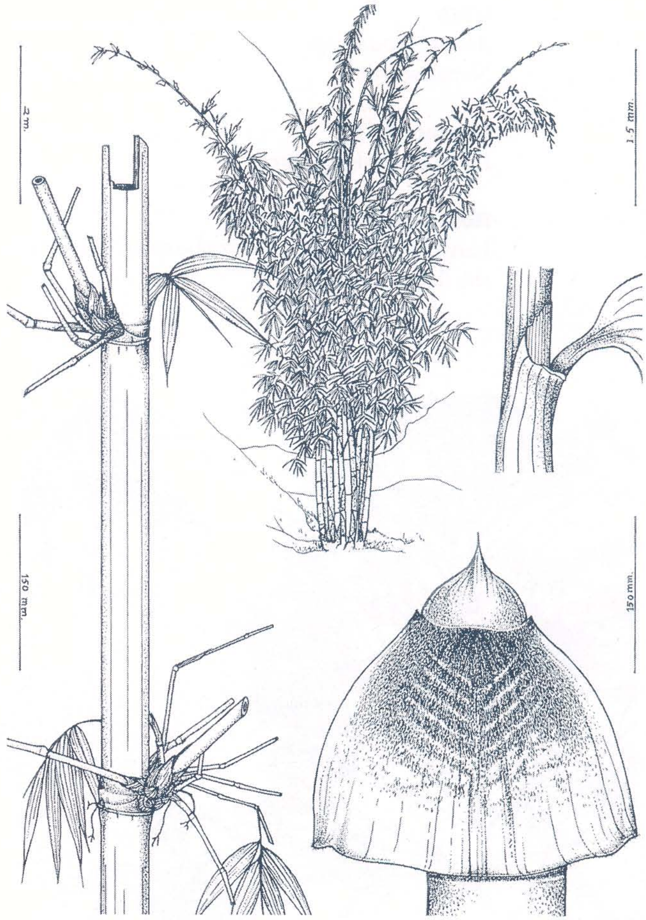
- weeding (in the first two or three growing seasons: dense grass around the trunk impedes growth significantly);
- protection from grazing (until it gets out of the reach of animals).

Thinning should be carried out when the plantation gets too dense. Branches can be lopped, but utis trees should not be coppiced or pollarded except in very good growing sites.
Since utis is a pioneer species, it should not be grown as the main species on a site for more than about five years. Vegetation enrichment should be used to grow up other species between the utis trees, with the aim of changing the mixture and removing all utis by 10 years after the first planting.

Uses (other than bio-engineering)
Firewood, timber, fodder.

LARGE CLUMPING BAMBOOS

CHOYA/TAMA BANS
Dendrocalamus hamiltonii



Character
Large clumping bamboo.

Role in bio-engineering
Large bamboo planting.

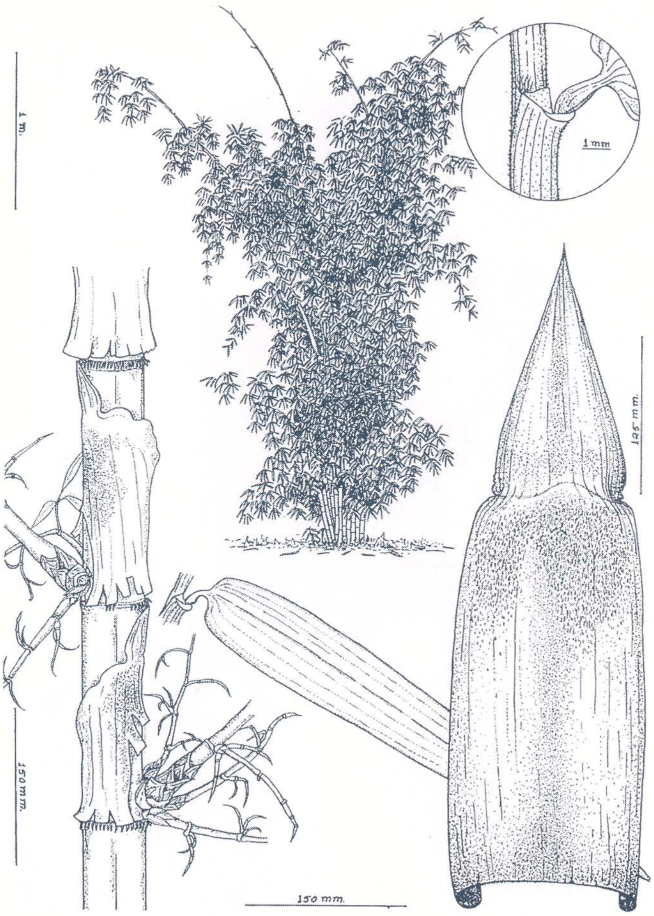
Description
A large-stature bamboo with larger leaves than most other species. It has thin culms and heavy branching. The culm splits easily between the nodes, to give soft, flexible sections.

Sites
300 – 2000 m
This is the most widely cultivated of all the bamboos. As with all large bamboos, it grows best in moist, shady sites. It should not be planted on south-facing slopes below 1200 metres. Survival is much better on permeable materials and in debris and fill sites than on cut slopes and hard original ground.

Propagation
Choya bans is the easiest of the large bamboos to propagate. It has heavy branching from the nodes, and so can be propagated from single node culm cuttings raised in a nursery. It can also be planted directly on site using the traditional method of a large section of rhizome and culm about 2 metres long. It flowers relatively often for a bamboo, and so seeds can be obtained quite often. They are viable for at least one year.

Cultivation and maintenance
Depending on the site, choya bans may require the following:
- watering (in the first season only, before the monsoon rains start);
- mulching and weeding (in the first two or three growing seasons);
- protection from grazing (until large shoots have grown out of the reach of animals).

Uses (other than bio-engineering)
Weaving, fodder, edible shoots.



DHANU BANS

Bambusa balcooa

Character

Large clumping bamboo with a thin culm and heavy branching.

Role in bio-engineering

Large bamboo planting.

Description

A very large-stature bamboo with characteristically bowed culms. Branching is heavy and, lower down, fairly thorny. The culms are often topless, since they are very brittle when young and can be broken by the weight of a bird.

Sites

Terai – 1600 m

Grows on south-facing sites between 1400 and 1800 metres. Dhanu bans tolerates dry conditions better than any of the other large bamboos, but it still grows much better in shady gullies than on dry slopes. Survival is much better on permeable materials and in debris and fill sites than on cut slopes and hard original ground.

Propagation

Dhanu bans is one of the easier of the large bamboos to propagate. It has heavy branching from the nodes, and so can be propagated from single-node culm cuttings raised in a nursery. It can also be planted directly on site using the traditional method of a large section of rhizome and culm about 2 metres long.

Cultivation and maintenance

Depending on the site, dhanu bans may require the following:

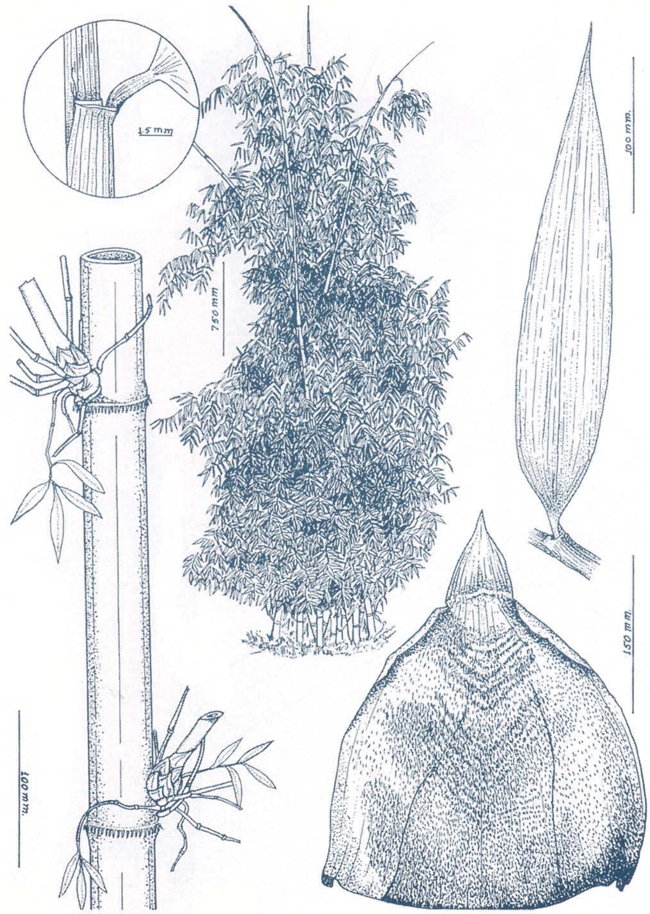
- watering (in the first season only, before the monsoon rains start);
- mulching and weeding (in the first two or three growing seasons);
- protection from grazing (until large shoots have grown out of the reach of animals).

Uses (other than bio-engineering)

House construction (poles, *etc.*) and scaffolding.

KALO BANS

Dendrocalamus hookeri



Character

Large clumping bamboo with heavy branching, brown hairs.

Role in bio-engineering

Large bamboo planting.

Description

Very similar in appearance to dhanu bans, but with thinner culm walls and no low branching. Culms and culm sheaths are often covered in brown hairs, and are dark green to black in colour. This species tends to flower more quickly than other species of bamboo, although this is still quite rare.

Sites

1200 – 2500 m

A bamboo commonly cultivated in eastern Nepal. It is the most frost resistant of the large bamboos, and so can be used to the highest extent of the main road network. It grows best in cool, shady gullies and on north-facing slopes. Survival is much better on permeable materials and in debris and fill sites than on cut slopes and hard original ground.

Propagation

Kalo bans is one of the easier of the large bamboos to propagate. It has heavy branching from the nodes, and so can be propagated from single node culm cuttings raised in a nursery. It can also be planted directly on site using the traditional method of a large section of rhizome and culm about 2 metres long. Seeds are available in most years and so plants can be raised as polypot seedlings in a nursery as well.

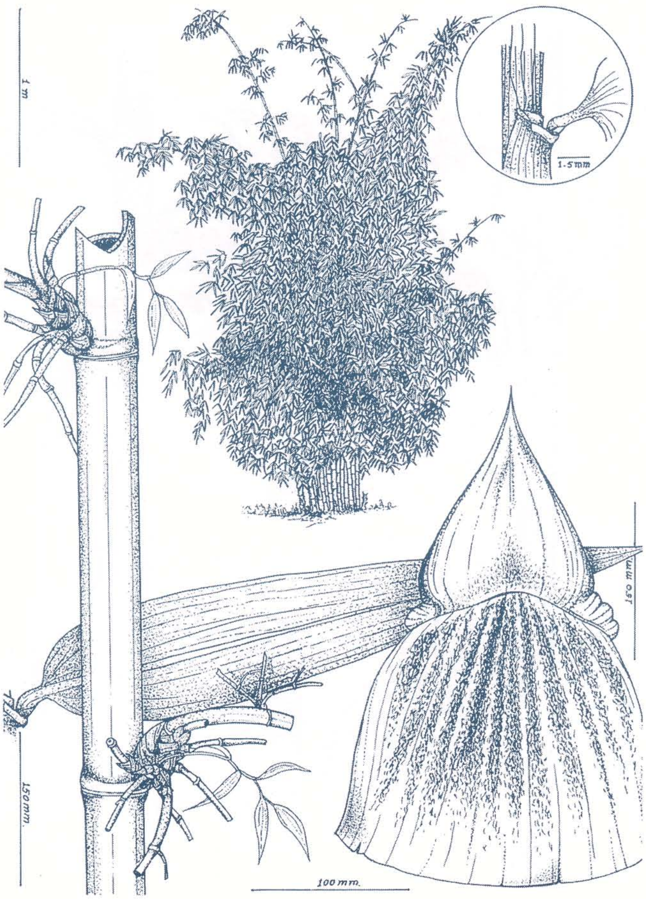
Cultivation and maintenance

Depending on the site, kalo bans may require the following:

- watering (in the first season only, before the monsoon rains start);
- mulching and weeding (in the first two or three growing seasons);
- protection from grazing (until large shoots have grown out of the reach of animals).

Uses (other than bio-engineering)

Construction, fodder.



MAL BANS

Bambusa nutans subspecies *cupulata*

Character

Large clumping bamboo with strong, straight culms.

Role in bio-engineering

Large bamboo planting.

Description

A large-stature bamboo with round, straight culms. The distance between the nodes is greater than for almost all other bamboos. The culms have many small branches from almost every node. The culms are used very widely for construction.

Sites

Terai – 1500 m

Mal bans is relatively tolerant of dry conditions for a bamboo, but as with all the large bamboos, grows best in damper sites and gullies. Survival is much better on permeable materials and in debris and fill sites than on cut slopes and hard original ground.

Propagation

Mal bans should be planted directly on site using the traditional method of a large section of rhizome and culm about 2 metres long.

Cultivation and maintenance

Depending on the site, mal bans may require the following:

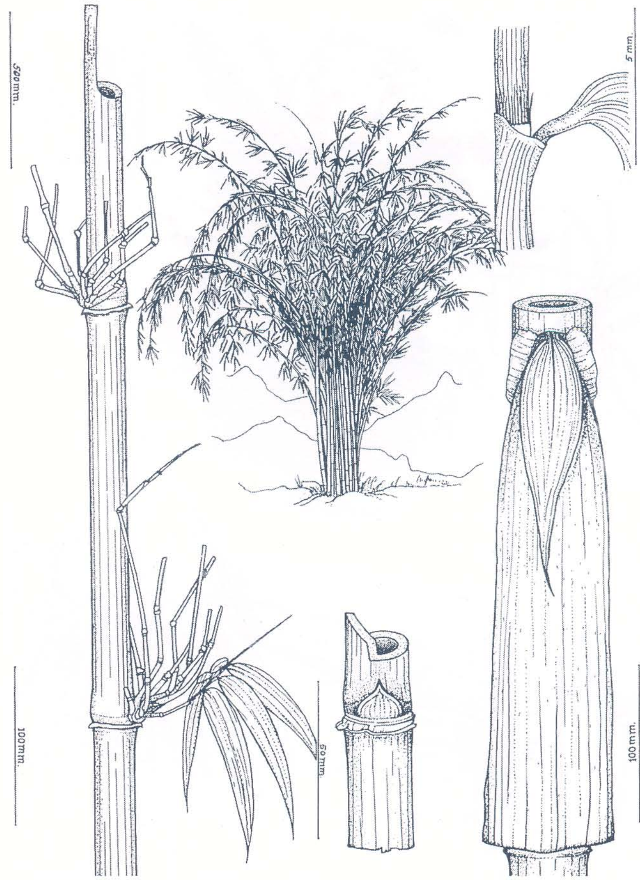
- watering (in the first season only, before the monsoon rains start);
- mulching and weeding (in the first two or three growing seasons);
- protection from grazing (until large shoots have grown out of the reach of animals).

Uses (other than bio-engineering)

Construction, fodder.

NIBHA/GHOPI/LYAS BANS

Ampelocalamus patellaris



Character

Large clumping bamboo with smaller, bluish culms.

Role in bio-engineering

Large bamboo planting.

Description

A small stature bamboo with culms that are nearly blue. The culms are usually less than 20 mm in diameter. Nodes have a woody ring immediately below them. If the culm is more than 2 years old, roots and heavy branches emerge from the nodes. In the wettest sites, clumps grow to a diameter of 2.5 metres.

Sites

1200 – 2000 m

This species tends to grow only in very wet sites. It is most common in the higher rainfall areas (such as Ilam and Taplejung, and Kaski and Palpa). Survival is much better on permeable materials and in debris and fill sites than on cut slopes and hard original ground.

Propagation

Nibha bans should be planted directly on site using the traditional method of a large section of rhizome and culm about 2 metres long. If aerial roots have formed from a node, it should be possible to propagate it from single-node culm cuttings raised in a nursery.

Cultivation and maintenance

Depending on the site, nibha bans may require the following:

- watering (in the first season only, before the monsoon rains start);
- mulching and weeding (in the first two or three growing seasons);
- protection from grazing (until large shoots have grown out of the reach of animals).

Uses (other than bio-engineering)

Weaving, fodder.

THARU BANS

Bambusa nutans subspecies *nutans*

Character

Large clumping bamboo with strong, straight culms.

Role in bio-engineering

Large bamboo planting.

Description

The central Nepal equivalent to mal bans and very similar in appearance, having round, straight culms and many branches from the nodes. Branching is stronger than mal bans; the clumps are denser and the culms have minor differences.

Sites

Terai – 1500 m

Tharu bans is relatively tolerant of dry conditions for a bamboo, but as with all the large bamboos, grows best in damper sites and gullies. Survival is much better on permeable materials and in debris and fill sites than on cut slopes and hard original ground.

Propagation

Tharu bans should be planted directly on site using the traditional method of a large section of rhizome and culm about 2 metres long.

Cultivation and maintenance

Depending on the site, tharu bans may require the following:

- watering (in the first season only, before the monsoon rains start);
- mulching and weeding (in the first two or three growing seasons);
- protection from grazing (until large shoots have grown out of the reach of animals).

Tharu bans can lose most of its leaves in the spring drought, without any harm.

Uses (other than bio-engineering)

Construction, lych poles, rough weaving.

PRODUCTION OF JUTE NETTING

Spinning raw jute into yarn for the production of jute netting

This annex describes the procedure for the purchase of raw jute, its spinning into yarn and weaving into the two types of netting used in roadside bio-engineering.

Jute supply

Raw jute should be purchased from merchants in the eastern Terai as soon as the harvest is under way and the price has dropped to its market low for the year. The harvest takes place in August and September, but early products are not usually high quality. Purchasing should be done in September as, by October, the price begins to rise.

Jute is produced regionally in the eastern Nepal and Indian Terai, and in Bangladesh. Since the late 1980s, there has been an increasing shortfall in supply. This appears to be due to increasing pressure for rice cultivation, and the rise in the number of sugar mills and cigarette factories offering better value for cash crops. Most of the jute produced in Nepal is exported. Although the market value of raw jute in villages in the Nepal Terai is often fairly low, the value in India may be twice this or more. Therefore the dealers use this to force up the price in sales of large quantities. There is not usually any discount for bulk purchases.

The material is available in a number of grades: middle grades are acceptable for weaving into netting, though it is preferred to buy tosa, a more expensive higher grade.

Jute purchased in September may not be fully dry, so it should be stored in an airy place and turned every few weeks until it is safely dry. It is extremely inflammable, and smoking must be banned from the area around its storage, as for fuel store.

Raw jute more than 12 months old should never be used to make netting. Old netting stocks unused through the monsoon after manufacture should be tested carefully to ensure that the strength is adequate. The general rule is that it should not be possible to break a single strand of standard yarn when pulled between the hands as hard as possible (a breaking strain of approximately 100 kg); if it can be broken, the netting should be composted or used as mulch.

In parts of Nepal far from sources of jute, it may be more cost effective to use other materials. One in the hills, which shows potential, is allo or sisnu (*Girardinia palmata*). There are others, but few have the fine, high-quality fibres that make jute such a good geotextile.

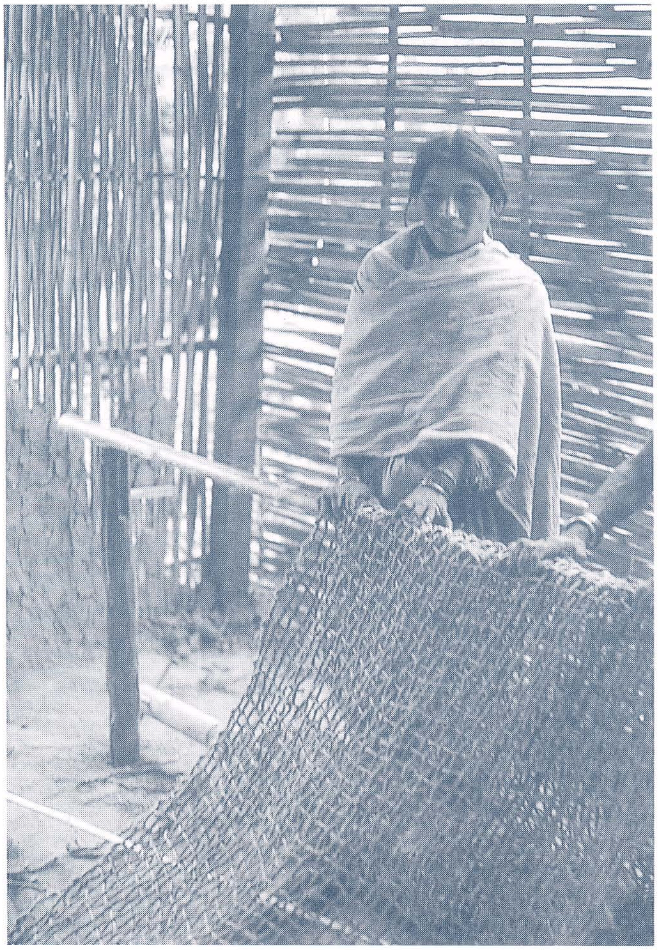
The manufacturing process

The process involves spinning raw jute into yarn and weaving the yarn into lengths of netting, which are similar to a simple, loose-weave cloth.

The equipment required is a rain/sun shelter, a loom, weaving frame and shuttles. Some smaller tools, such as khukuris or chulesis, and sticks, are also required.

Raw jute fibres are teased out and then spun into yarn. Spinning is a simple hand process, twisting the fibres together into an even yarn, which is then wound on to sticks to form rolls. For standard netting, the yarn should be spun so that it is no less than 5 mm and no more than 8 mm in diameter when tightly wound. Loose yarn would be larger but it must be tight enough to have maximum strength. For wide mesh netting, the yarn should be between 3 and 5 mm in diameter.

A length of completed jute netting is removed from the loom



The weaving loom consists of two parallel horizontal beams about 1.5 metres long and placed 12 metres apart. When the yarn has been prepared, it is placed on the loom to form the warp (the length-ways threads). For standard netting there should be 32 strands of warp, wound from end to end of the loom and passing through the weaving frame. For wide mesh netting there are 10 strands of warp.

The weaving frame is a rectangular wooden frame 1250 mm long by 500 mm wide. Across it are placed 16 wires at regular intervals, each wire with a loop in the middle. Alternate strands of warp pass either through a loop or between two wires.

Once the warp is on the loom, it is tightened so that each strand is an equal distance (30 to 40 mm for standard and 150 mm for wide mesh netting) apart. Then the weaving of the weft (cross threads) can begin. Yarn wound on to a shuttle (a simple H-shaped board) is passed repeatedly backwards and forwards through the warp. With each pass, the frame is alternately raised and lowered so that the weft crosses the warp on alternate sides. Behind the shuttle, the weft threads are pushed up the warp by hand until they are evenly spaced 30 to 40 mm apart (500 mm apart for wide mesh netting. There should be 20 to 24 strands of weft per metre for standard netting, and 2 strands for wide mesh netting.

Once the end of the warp is reached, the net is complete. It is cut off the loom and the cut ends tied to prevent fraying. Each piece of woven netting should be not less than 1.10 metres and not more than 1.20 metres in width. It should be at least 10 metres in length but no more than 11.50 metres.

Experience has shown that a profit-shared contract employing five women weavers can be expected to produce 2 lengths of standard mesh jute netting per day, or between 24 and 28 lengths per fortnight. Experiments with other arrangements of weavers have not been so productive.

Detailed specifications

The detailed specifications for standard jute netting are as follows. Standard jute netting is used for placing on bare slopes and is normally planted with grasses. [Note: warp ends are the length-ways threads and weft strands are the cross-ways threads]

(i)	Material:	High quality, 100 percent natural jute fibre from the latest harvest, properly treated and dried.
(ii)	Yarn:	Handspun 5 to 8 mm.
(iii)	Strip size:	minimum 1.0 × 10.0 metres; maximum 1.5 × 11.5 metres.
(iv)	Warp ends:	27 ends per 1000 mm.
(v)	Weft strands:	20 to 24 strands per 1000 mm.
(vi)	Mesh size:	40 mm square mesh holes.
(vii)	Weight:	0.8 to 1.2 kg per square metre.

The detailed specifications for wide mesh jute netting are as follows. Wide mesh jute netting is used for holding mulch on to slopes that have been sown with grass seed.

(i)	Material:	High quality, 100 percent natural jute fibre from the latest harvest, properly treated and dried.
(ii)	Yarn:	Handspun 3 to 5 mm.
(iii)	Strip size:	minimum 1.0 × 10.0 metres; maximum 1.5 × 11.5 metres.
(iv)	Warp ends:	7 ends per 1000 mm.
(v)	Weft strands:	2 strands per 1000 mm.
(vi)	Mesh size:	150 × 500 mm rectangular mesh.
(vii)	Weight:	0.2 kg per square metre.

Bitumenised jute netting

If jute netting is required to retain its strength for more than one year, it should be preserved by soaking in a solution of bitumen diluted with kerosene: this will preserve it sufficiently to retain its strength for about 3 years, or perhaps longer on hot, dry sites.

A large vat is filled with a mixture of 60:40 bitumen:kerosene. Rolls of new jute net are lowered into it from a bamboo tripod to soak for 30 minutes, then raised and allowed to drain. Once most of the surplus has run off, the netting is rolled in sand to reduce its stickiness. It can then be used in the normal way.

A bitumen:kerosene mixture gives better preservation than bitumen emulsion.

Other sources of jute netting

A number of slopes have been stabilised using products imported from jute mills in West Bengal. None of these have met the specifications described above, and therefore have not conformed to the standards of the Department of Roads. There appears to be no reason why any source cannot be used to provide jute netting, however, as long as quality control is strict.

The specifications given here, which are those adopted by the Department of Roads, are necessary to serve the functions required of jute netting. In the case of standard netting, the thickness and loose weave of yarn is essential to provide adequate surface armouring at the micro scale. Finer, more tightly spun yarns do not serve the function of the netting specified here.

LOW-COST TECHNIQUES THAT DO NOT WORK

Inert wattle fences are often too weak to support the weight of wet soil; erosion can just take place underneath

In the process of the experimentation that led to the production of this manual, a number of low-cost techniques were tried in the search for better solutions to the problems of slope instability and erosion that were encountered. Some of these were found not to work, or to work only in very limited situations. They have not been included in the *Site Handbook* for this reason. They are described here to provide a record, and to warn others against wasting resources using these methods.

Covering slopes with fine-mesh wire netting

Experiments with fine, small-mesh wire netting (as a possible alternative to jute netting) proved ineffective. It is virtually impossible to make it hug the surface as jute net or other, more flexible, geotextiles will. Even if it is touching the surface, it does not affect the rate of erosion and the slope will degrade just as fast. It adds nothing to the slope and therefore is not worth the expense.

Waterproof slope covers

This technique was mostly used on the brow of a slope to reduce continued failure. The slope is covered in a waterproof material (such as polythene or tar felt) to stop water infiltration and erosion. Although some materials will last for five years or more on some sites, this is only a temporary measure because the covering prevents the development of a long-term vegetation cover of the slope.

It is, however, very useful in emergencies for failures immediately below the road, where the road itself is in danger of collapse; and in certain situations on busy roads where failures on the slopes above threaten to block the carriageway. In these situations, waterproof coverings can be applied quickly during the monsoon. They must be removed soon after the rains stop and a permanent solution installed.

Other materials were also tried for slope covers, including bitumenised hessian and steel sheets. These tended to be subject to fires and theft respectively.

A further problem is that all waterproof slope covers tend to concentrate runoff into the slope section immediately below them, so that underscour takes place.

Hessian and jute bolsters

Bolsters, which are tubes of hessian or jute netting filled with stone, were placed along the contour. They were intended to act as scour checks and to reduce the surface movement of debris while a vegetation cover is established.

They are similar to gabion bolster cylinders but not nearly as strong. Although they were used on a number of sites, bolsters made using a skin of either hessian sheeting or jute netting either failed or at the very least simply disappeared when the skin material rotted away. They may have some application as a temporary measure and if made carefully might be expected to last for up to 18 months on gentle sites. Whichever skin material is used, it should first be strengthened by dipping it in bitumen emulsion. The construction technique was the same as for contour gabion bolster cylinders.

Dead wattle fences

Low fences are built along the contour to trap debris moving down the slope and to armour against surface scour. They can be made using wire or bamboo (or other plant material), but only those using steel have been found to be effective on most sites. Those using plant materials, which are the most common type of wattle fences, are usually only temporary measures. If they are to be used at all, wattle fences should be used only on slopes less than 35° with a restricted debris supply and composed of coarse, well-drained material. Fences made from bamboo or other plant materials should be restricted to very small and gentle sites, or where only a temporary measure is required.

The main problems with wattle fences are that they accumulate debris behind them over a period of one or two monsoons, during which time the structure decomposes; eventually the weight of debris is too much for the fence and it collapses. In fine-textured materials, the fences can give rise to an accumulation of weak, unconsolidated debris and an increase in the rate of infiltration. Under heavy rain this can lead to liquefied flow, which either pushes the fence over or simply flows underneath it. In weak sandy soils, gullies continue to develop underneath wattle fences because they do not interrupt the surface properly (unlike gabion bolster cylinders).

This technique has rarely been successful under Nepalese conditions. It is no match in terms of strength for many of the techniques described in the Site *H*andbook. Wattle fences do not have the flexibility of planted grass lines or the strength of gabion bolster cylinders. They should not be used except as a temporary measure in emergencies.

Sprayed bitumen

Bitumen was sprayed on to the slope surface to waterproof it and protect it from scour. The use of this technique assumed that there is no vegetation cover and that the surface being sprayed was clean and firm, and that it was best to remain in the same state. It was thought to hold potential on steep (> 50°) cut slopes less than 8 metres in height, particularly where climatic and rooting conditions were extremely poor for grass establishment.

This technique was not found successful and cannot be recommended. Trials showed that although it works well over very limited areas, it is not good except on perfectly homogeneous materials already resistant to weathering. Only a slight flaw is necessary to allow water to penetrate the bitumen skin and soften the material below. Even without this, weakening of the material seems to continue behind the bitumen, causing it to flake off with the material it is stuck to. Water can seep in from higher up the slope and then be trapped behind the surface, even when drainage measures are taken to reduce the effect of this. Hence it seems to be a temporary measure with limited applications. It may be useful to help stick seeds to the surface of fractured rocky materials.

Algal surface protection

A protective skin made up of algae and associated plants covers the surface of the soil or rock and acts in the same way as sprayed bitumen. Scour by runoff on the surface is prevented. This may hold potential on steep (> 50°) cut slopes less than about 5 metres in height.

This has not actually been applied as a stabilisation technique in practice. It is mentioned here because of the prevalence of algal growths over many road cut-slope surfaces. These occur in many parts of Nepal, from the Terai to at least 2,500 metres altitude. They seem to occur most widely on highly micaceous rocks, but there is not necessarily a link. In many cases the disadvantages are the same as for sprayed bitumen, and weakening still continues under the algal crust.

Mycologists have variously identified the organisms present in samples but they seem to be green algae, or members of the phylum Chlorophyta. The matter has not been pursued on account of the technical difficulties of cultivating pure cultures of algae (which are considerable on a large scale).

ANNEX E: RATE ANALYSIS NORMS FOR BIO-ENGINEERING

In January 1996, the Geo-Environmental Unit of the Department of Roads first published the rate analysis norms, which are reprinted here (with minor corrections). These norms were approved by His Majesty's Government, Ministry of Works and Transport (at Minister level) on 25 December 1995. At the time of the publication of this manual, they were the most up to date norms on bio-engineering.

Before using these norms, the reader should check for updates. These will normally be available either as part of the complete norms of the Ministry of Works and Transport, or as part of a revision published by the Department of Roads or the Geo-Environmental Unit.

A Nepali version of these norms has been published by the Geo-Environmental Unit and is available from the Department of Roads on request.

RATE ANALYSIS NORMS

S No	WORK DESCRIPTION	UNIT	LEVEL	LABOUR UNIT	QUANTITY
27	**(1) Collection and preparation of seeds** [a] Collection of grass seeds from sources within 1 km of the road, including separating and preparing seed for storage, and drying seed in the sun.	kg	Unskilled	nos	1.50
	[b] Collection of large shrub seeds (*e.g.* bhujetro) from sources within 1 km of the road including seed preparation for storage after drying.	kg	Unskilled	nos	0.45
	[c] Collection of medium-sized shrub seeds (*e.g.* keraukose) from sources within 1 km of the road, including seed preparation for storage after drying.	kg	Unskilled	nos	0.75
	[d] Collection of medium-sized shrub and tree seeds (*e.g.* areri, khayer, ghobre and rani salla, sisau) from sources within 1 km of the road, including seed preparation for storage after drying.	kg	Unskilled	nos	0.95
	[e] Collection of small shrub and tree seeds (*e.g.* dhanyero, dhusun, tilka, utis) from sources within 1 km of the road, including seed preparation for storage after drying.	kg	Unskilled	nos	2.50
	(2) Collection of grass and hardwood cuttings for vegetative propagation				
	[a] Collection of grass clumps (*e.g.* amliso, kans, khar) from sources within 1 km of the road, to make slips for multiplication in the nursery.	1000 slips	Unskilled	nos	1.50
	[b] Collection of cuttings of small bamboos (*e.g.* padang bans, tite nigalo bans), suitable for traditional planting, from sources within 1 km of the road. Material minimum 10 cm of rooted rhizome and 90 cm of culm	1000 nos	Unskilled	nos	3.00
	[c] Collection of hardwood cuttings (e.g. assuro, bains, kanda phul, namdi phul, saruwa, simali) from sources within 1 km of the road. Material minimum 30 cm in length and 2 cm in diameter.	1000 nos	Unskilled	nos	0.85

RESOURCES					
CONSTRUCTION MATERIALS			EQUIPMENT		
TYPE	UNIT	QUANTITY	TYPE	UNIT	QUANTITY
Sealed bag	nos	1.00	Khukuri	-	3% of labour cost
-	-	-	Khukuri	-	3% of labour cost
Sealed bag	nos	1.00	Nanglo	-	3% of labour cost
Sealed bag	nos	1.00	Nanglo	-	3% of labour cost
Sealed bag	nos	1.00	Nanglo	-	3% of labour cost
Adequate supply of appropriate clumps Hessian jute	- m²	- 5.00	Kodalo	-	3% of labour cost
Adequate supply of appropriate bamboos Hessian jute	- m²	- 10.00	Kodalo Khukuri	- -	3% of labour cost
Adequate supply of appropriate bushes Hessian jute	- m²	- 5.00	Khukuri	-	3% of labour cost

RATE ANALYSIS NORMS (continued)

S No	WORK DESCRIPTION	UNIT	LEVEL	LABOUR UNIT	QUANTITY
27-	**(3) Nursery operation and management (bed preparation)**				
	[a] Construction of seed beds for tree seedlings, including materials for beds and shades. Bed is 1 m wide × 17 cm high and made up of: 5 cm of washed gravel, 5 cm of unsieved forest soil, 5 cm of 1:3 mix of sieved forest soil and washed sand, 2 cm of washed, sieved and sterilised sand. [Add 5 % to the number of bricks to allow for normal wastage.]	5 m²	Skilled Unskilled	nos nos	1.50 2.00
	[b] Construction of stand out beds for tree seedlings in polypots, including materials for beds and shades. Bed is 100 cm wide × 15 cm high, with a 5 cm layer of gravel placed above the compacted ground. [Add 5 % to the number of bricks to allow for normal wastage.]	5 m²	Unskilled	nos	6.00
	[c] Construction of beds for grass seeds, grass slips (*i.e.* vegetative propagation) and tree stool cuttings, including materials and hessian cover. Bed is 100 cm wide × 25 cm high and made up of: 5 cm of washed gravel placed above the ground, 5 cm of 1:1 mix of sieved soil and compost, and topped with 15 cm of 3:1 mix of sieved forest topsoil and washed sand.	5 m²	Skilled Unskilled	nos nos	1.00 1.50
	[d] Construction of beds for propagation of bamboo culm cuttings, including materials and hessian cover. Bed is 100 cm wide × 30 cm high. The ground below the bed is dug to a depth of 30 cm. Bed is made with 10 cm unsieved soil and 20 cm sieved soil. A bund 10 cm high is formed around the edge.	5 m²	Unskilled	nos	2.00
27-	**(4) Nursery operation and management (seed sowing and transplanting; planting hardwood cuttings)**				
	[a] Tree seed sowing @ 10 grammes per m² (medium-sized seeds) or 2 grammes per m² (very fine seeds) into seed beds including pre-sowing seed treatment.	5 m²	Unskilled	nos	0.04
	[b] Preparing potting mix and filling polypots, including all materials for container seedlings. [Note. 1 kg of 200 gauge polypots (4' × 7' laid flat) = 464 bags; 200 gauge black polythene is preferred.]	1000nos	Unskilled	nos	10.00
	[c] Direct sowing of tree seeds into polypots including seed treatment, by sowing one seed in half the pots and two seeds in the other half.	1000 nos	Unskilled	nos	0.62
	[d] Pricking out young seedlings and transplanting into polypots.	100 nos	Unskilled	nos	0.18
	[e] Pricking out tree seedlings and transplanting into beds.	1000 nos	Unskilled	nos	0.12
	[f] Transplanting grass slips into beds, from clumps. Slips are planted at 10 cm centres in rows 25 cm apart.	m²	Unskilled	nos	0.12
	[g] Planting of hardwood cuttings of minimum 30 cm length to 20 cm depth into prepared beds. Cuttings spaced at 5 cm centres within rows, with 20 cm between rows.	1000 nos	Unskilled	nos	0.60

RESOURCES					
CONSTRUCTION MATERIALS			EQUIPMENT		
TYPE	UNIT	QUANTITY	TYPE	UNIT	QUANTITY
Bamboo poles	nos	9.00	Khanti	-	3% of labour cost
Polythene sheet	m²	9.00	Shovel	-	
Bricks	nos	96.00	Pick axe	-	
Gravel	m³	0.25	Screen mesh	-	
Unsieved soil	m³	0.10			
Line string	m	13.00			
Binding wire	kg	3.00			
Bamboo	nos	15.00	Khanti	-	3% of labour cost
Bricks	nos	96.00	Shovel	-	
Line string	m	13.00	Pick axe	-	
Binding wire	kg	3.00			
Gravel	m³	0.25			
Gravel	m³	0.38	Shovel	-	3% of labour cost
Forest soil	m³	1.46	Pick axe	-	
Compost	m³	0.38			
Washed sand	m³	0.46			
Hessian cover	m²	10.00			
Gravel	m³	0.38	Shovel	-	3% of labour cost
Forest soil	m³	1.46	Pick axe	-	
Compost	m³	0.38	Khukuri	-	
Bamboo poles	nos	6.00	Log saw	-	
Hessian jute	m²	25.00			
Seed	g	50.00	Bowl	-	3% of labour cost
			Trowel	-	
Polypot	nos	1050.00	Sieve	-	3% of labour cost
Sand	m³	0.46	Shovel	-	
Soil	m³	0.70			
Compost	m³	0.23			
Seed	nos	1500.00	Wooden peg	nos	1.00
-	-	-	Wooden peg	nos	1.00
			Tray	-	3% of labour cost
-	-	-	Wooden peg	nos	1.00
Hessian jute	m²	0.30	Khukuri	-	3% of labour cost
			Shovel	-	
Hardwood cuttings	nos	1000.00	Khanti	-	3% of labour cost

RATE ANALYSIS NORMS (continued)

S No	WORK DESCRIPTION	UNIT	LEVEL	LABOUR UNIT	QUANTITY
27-	**(5) Preparation of raised materials for extraction from the nursery**				
	[a] Grass culm cutting production from nursery stock; single or double node (*e.g.* napier).	1000 nos	Unskilled	nos	0.70
	[b] Uprooting and preparing grass slips ready for site planting from nursery seedlings.	1000 nos	Unskilled	nos	0.63
	[c] Uprooting and preparing grass slips ready for site planting from nursery grass clumps raised from slips by vegetative propagation.	1000 nos	Unskilled	nos	0.33
27-	**(6) Compost and mulch production**				
	[a] Mulch production by collection and cutting of weeds and other vegetation such as tite pati, banmara *etc*, within 1 km of the road, and stacking along roadside.	m^3	Unskilled	nos	1.20
	[b] Compost production by collection and cutting of weeds and other vegetation such as tite pati, banmara *etc*, within 1 km of the road, including fine cutting and filling compost pit.	m^3	Unskilled	nos	1.20
	[c] Turning compost once per month.	m^3	Unskilled	nos	0.10
27-	**(7) Direct seeding on site**				
	[a] Broadcasting grass seeds on slopes <40°, seeding rate 25 g per m^2.	100 m^2	Unskilled	nos	0.17
	[b] Broadcasting grass seeds on slopes <40°, including cover with long mulch, seeding rate 25 g per m^2.	100 m^2	Unskilled	nos	5.00
	[c] Broadcasting grass seeds on slopes < 40-45°, including cover with long mulch and jute netting of mesh size 300 mm × 500 mm. Seeding @ 25 g per m^2. Operation includes pegging with suitable live pegs or hardwood cuttings (*e.g.* simali) @ 1 m spacing, jute net of 6.75m × 1m size.	100 m^2	Unskilled	nos	6.25
	[d] Sowing shrub or tree seeds on all slopes, at 25 cm intervals, including digging planting holes to 5 cm depth and covering with soil. Two seeds per planting hole.	100 m^2	Unskilled	nos	1.00
27-	**(8) Planting grass cuttings on site**				
	[a] Planting single node culm cuttings of grass (*e.g.* napier) on fill slopes < 45° and embankment slopes in plain areas. Approx length 15-20 cm, including digging planting hole 10-20 cm depth using a metal rod or hardwood peg,	100 nos	Unskilled	nos	0.20
	[b] Planting single node culm cuttings of grass (*e.g.* napier) on hard cut slopes < 45°. Approx length 15-20 cm, including digging planting hole 10-20 cm depth using a metal rod or hardwood peg,	100 nos	Unskilled	nos	0.35
	[c] Planting single node culm cuttings of grass (*e.g.* napier) on hard cut slopes > 45°. Approx length 15-20 cm, including digging planting hole 10-20 cm depth using a metal rod or hardwood peg,	100 nos	Unskilled	nos	0.50
	[d] Planting rooted grass slips on embankment slopes in plain areas, at 10 cm spacings within the row. The first row is 0.75 m from the edge of the pavement and subsequent rows are spaced at 1 m intervals down the embankment.	m	Unskilled	nos	0.02

RESOURCES CONSTRUCTION MATERIALS			EQUIPMENT		
TYPE	UNIT	QUANTITY	TYPE	UNIT	QUANTITY
Hessian jute	m²	2.70	Khukuri	-	3% of labour cost
Hessian jute	m²	1.35	Fork Pick axe Khukuri	- - -	3% of labour cost
Hessian jute	m²	4.20	Shovel Khanti	- -	3% of labour cost
-	-	-	Hasiya Doko	- -	3% of labour cost
-	-	-	Doko	-	3% of labour cost
-	-	-	Shovel	-	3% of labour cost
Seed	kg	2.50	-	-	-
Seed Mulch	kg m³	2.50 5.00	-	-	-
Seed Mulch Jute net Live pegs	kg m³ m² nos	2.50 5.00 105.00 128.00	Khukuri Mallet (wooden hammer)	- -	3% of labour cost
Seeds	nos	3200.00	MS rod of 50 cm length	-	3% of labour cost
Grass cuttings Hessian jute	nos m²	100.00 0.27	MS rod or hardwood peg of 50 cm length	-	3% of labour cost
Grass cuttings Hessian jute	nos m²	100.00 0.27	MS rod or hardwood peg of 50 cm length	-	3% of labour cost
Grass cuttings Hessian jute	nos m²	100.00 0.27	MS rod or hardwood peg of 50 cm length	-	3% of labour cost
Grass slips Hessian jute Line string	nos of drills m² m	11.00 0.14 1.00	MS rod or hardwood peg of 50 cm length	-	3% of labour cost

RATE ANALYSIS NORMS (continued)

S No	WORK DESCRIPTION	UNIT	LEVEL	LABOUR UNIT	QUANTITY
	[e] Planting rooted grass slips on slopes <45° including preparation of slips on site. Operation includes digging planting hole to a max of 5 cm depth with metal rod or hardwood peg, depending on nature of soil. The planting drills should be spaced 10 cm apart.	m^2	Unskilled	nos	0.20
	[f] Planting rooted grass slips on slopes 45-60° including preparation of slips on site. Operation includes digging planting hole to a max of 5 cm depth with metal rod or hardwood peg, depending on nature of soil. The planting drills should be spaced 10 cm apart.	m^2	Unskilled	nos	0.30
	[g] Planting rooted grass slips on slopes >60° including preparation of slips on site. Operation includes digging planting hole to a max of 5 cm depth with metal rod or hardwood peg, depending on nature of soil. The planting drills should be spaced 10 cm apart.	m^2	Unskilled	nos	0.40
27-	**(9) Planting shrub and tree seedlings and cuttings on site**				
	[a] Planting containerised tree and shrub seedlings, including pitting, transplanting, composting and placing tree guards, on toe of embankment slopes in plain areas, not less than 8 m from the road centre line. Pit size 30 cm diameter × 30 cm depth. Compost volume ¼ of the volume of the pit, mixed with original soil.	10 nos	Unskilled	nos	0.25
	[b] Planting containerised tree and shrub seedlings, including pitting, transplanting, composting and mulching, on slopes < 30°. Pit size 30 cm diameter × 30 cm depth. Mix compost with soil and backfill into pit, to ¼ of pit volume.	10 nos	Unskilled	nos	0.33
	[c] Planting containerised tree and shrub seedlings, including pitting, transplanting, composting and mulching, on slopes 30-45°. Pit size 30 cm diameter × 30 cm depth. Mix compost with soil and backfill into pit, to ¼ of pit volume.	10 nos	Unskilled	nos	0.40
	[d] Planting rooted tree stump cuttings and bare root seedlings, including pitting, transplanting, composting and mulching on slopes <30°. Pit size 10 cm diameter × 20 cm depth. Compost volume ¼ of volume of the pit mixed with original soil.	10 nos	Unskilled	nos	0.17
	[e] Planting rooted tree stump cuttings and bare root seedlings, including pitting, transplanting, composting and mulching on slopes 30-45°. Pit size 10 cm diameter × 20 cm depth. Compost volume ¼ of volume of the pit mixed with original soil.	10 nos	Unskilled	nos	0.25
	[f] Planting tree stump and bare root seedlings, including pitting, transplanting, composting and mulching on slopes >45°. Pit size 10 cm diameter × 20 cm depth. Compost volume ¼ of volume of the pit mixed with original soil.	10 nos	Unskilled	nos	0.33
27-	**(10) Vegetative palisade construction, brush layering and fascines**				
	[a] Collection of hardwood cuttings for planting material (*e.g.* assuro, namdi phul, simali) from sources within 1 km of road. Material to be approx 1 m in length and minimum 5 cm in diameter.	1000 nos	Unskilled	nos	0.85

RESOURCES CONSTRUCTION MATERIALS TYPE	UNIT	QUANTITY	EQUIPMENT TYPE	UNIT	QUANTITY
Grass slips Hessian jute	nos of drills m^2	100.00 0.27	MS rod or hardwood peg of 50 cm length Khukuri	- -	3% of labour cost
Grass slips Hessian jute	nos of drills m^2	100.00 0.27	MS rod or hardwood peg of 50 cm length Khukuri	- -	3% of labour cost
Grass slips Hessian jute	nos of drills m^2	100.00 0.27	MS rod or hardwood peg of 50 cm length Khukuri	- -	3% of labour cost
Container seedling Compost Tree guard Green mulch	nos m^3 nos m^3	10.00 0.05 10.00 0.04	Khanti Mallet (wooden hammer) Doko	- - -	3% of labour cost
Seedlings Compost Green mulch	nos m^3 m^3	10.00 0.05 0.04	Khanti Doko	- -	3% of labour cost
Seedling Compost Green mulch	nos m^3 m^3	10.00 0.05 0.04	Khanti Doko	- -	3% of labour cost
Seedling Compost Green mulch	nos m^3 m^3	10.00 0.03 0.04	Khanti	-	3% of labour cost
Seedling Compost Green mulch	nos m^3 m^3	10.00 0.03 0.04	Khanti	-	3% of labour cost
Seedling Compost Green mulch	nos m^3 m^3	10.00 0.03 0.04	Khanti	-	3% of labour cost
Adequate supply of bushes	-	-	Khukuri	-	3% of labour cost

RATE ANALYSIS NORMS (continued)

S No	WORK DESCRIPTION	UNIT	LEVEL	LABOUR UNIT	QUANTITY
	[b] Preparation and planting of live pegs of selected species (*e.g.* assuro, namdi phul, simali) of minimum 1 m length to 0.5 m depth into hard ground. Pegs spaced at 5 cm centres within rows, with 5 - 20 cm between rows, and interwoven with vegetation.	m	Unskilled	nos	0.17
	[c] Preparation and planting of live cuttings of selected species (*e.g.* assuro, namdi phul, simali) of minimum 1 m length to 0.5 m into soft debris. Pegs spaced at 5 cm centres within rows, with 5 - 20 cm between rows, and interwoven with vegetation.	m	Unskilled	nos	0.12
	[d] Site preparation for fascine laying: earth works in excavation of trench to 20 cm depth.	m	Unskilled	nos	0.06
	[e] Laying of live fascines, using live hardwood cuttings of selected species (*e.g.* assuro, namdi phul, simali) of minimum 1 m length, placed in bundles to give 4 running metres of cuttings per metre of fascine, including backfilling of trench and careful compaction.	m	Unskilled	nos	0.17
27-	**(11) Jute netting works**				
	[a] Standard jute netting for bare slopes and under planting with slips. Spinning raw jute from 100% jute fibre into yarn and weaving the yarn into netting. Hand spun yarn 5 to 8 mm in diameter, width of net 1.20 metres, warp strands 27 nos per 100 cm, weft strands 20-24 nos per 100 cm, mesh size 30-40 mm square and 1.25 kg/m weight at 1.20 m widths. [Note. A tosro is the weaving shuttle, normally made from a split large bamboo culm.]	m^2	skilled	nos	0.36
	b] Wide mesh jute netting for holding mulch on slopes. Spinning raw jute from 100% jute fibre into yarn and weaving the yarn into netting. Hand spun yarn 3 to 5 mm diameter 1.20 metre side and 11.2 m long. Mesh size 150 mm × 500 mm rectangular mesh and 0.25 kg/m at 1.20 m width. [Note. A tosro is the weaving shuttle, normally made from a split large bamboo culm.]	m^2	skilled	nos	0.15
	[c] Placing 30-40 mm square mesh jute netting on bare slopes (for later underplanting with grass slips), including pegging with live hardwood cuttings or split bamboo pegs and loosening tension so that the net hugs the slope throughout.	m^2	Unskilled	nos	0.15
	[d] Placing 150 × 500 mm mesh jute netting to hold mulch on slopes, including application of mulch and pegging wih live hardwood cuttings or split bamboo pegs and loosening tension so that the net hugs the slope throughout.	m^2	Unskilled	nos	0.10
27-	**(12) Fabrication of gabion bolster cylinders**				
	[a] Site preparation for 30 cm diameter bolster: earth works in excavation of trench.	m	Unskilled	nos	0.085
	[b] Site preparation for 60 cm diameter bolster: earth works in excavation of trench.	m	Unskilled	nos	0.36
	[c] Manufacture of bolster panels: 70 × 100 mm hexagonal mesh wire construction (10 swg frame and 12 swg mesh).	m^2	skilled	nos	0.10
	[d] Construction of 30 cm bolster cylinder: placing, stretching wire mesh, filling with boulders, closing and backfilling.	m	Unskilled	nos	0.375

RESOURCES CONSTRUCTION MATERIALS TYPE	UNIT	QUANTITY	EQUIPMENT TYPE	UNIT	QUANTITY
Live pegs	nos	20.00	Crow bar	-	3% of labour cost
Live pegs	nos	20.00	Crow bar	-	3% of labour cost
-	-	-	Pick axe Shovel	- -	3% of labour cost
Hardwood cutting of at least 1 metre in lenght	m	8.00	Khukuri Shovel	- -	3% of labour cost
Raw jute	kg	1.25	Khukuri Bamboo sticks (10 nos) Weaving frame Tosro	- - - -	3% of labour cost
Raw jute	kg	0.26	Khukuri Bamboo sticks (10 nos) Weaving frame Tosro	- - - -	3% of labour cost
Woven jute net Hardwood cutting or split bamboo pegs	m² nos	1.00 5.00	MS rod of 50 cm length Mallet (wooden hammer)	- -	3% of labour cost
Cut mulch Woven jute net Hardwood cutting or split bamboo pegs	m³ m² nos	0.05 1.00 5.00	MS rod of 50 cm length Mallet (wooden hammer)	- -	3% of labour cost
-	-	-	Pick axe Shovel	- -	3% of labour cost
-	-	-	Pick axe Shovel	- -	3% of labour cost
GI wire	kg	2.00	Gabion frame and tools	- -	3% of labour cost
Boulders	m³	0.09	Gabion tools Doko	- -	3% of labour cost

RATE ANALYSIS NORMS (continued)

S No	WORK DESCRIPTION	UNIT	LEVEL	LABOUR UNIT	QUANTITY
	[e] Construction of 60 cm bolster cylinder: placing, stretching wire mesh, filling with boulders, closing and backfilling.	m	Unskilled	nos	0.75
	[f] Construction of 30 cm bolster cylinder: placing, stretching wire mesh over 20 gauge black polythene sheeting, filling with boulders, closing and backfilling.	m	Unskilled	nos	0.375
	[g] Construction of 60 cm bolster cylinder: placing, stretching wire mesh over 20 gauge black polythene sheeting, filling with boulders, closing and backfilling.	m	Unskilled	nos	0.75
	[h] Anchoring bolster: 12 mm diameter MS re-bar cut into 2 m lengths for anchorage and placed at 1 m intervals.	nos	Unskilled	nos	0.05
	[i] Laying of terram paper (geotextile).	m^2	Unskilled	nos	0.05
27-	**(13) Bamboo tree guards**				
	[a] Weaving bamboo tree guards using bamboo poles as uprights: 1.60 m in height; and weaving split bamboo with the outer wall intact around the posts. Dimensions of the guard are 0.60 m diameter × 1.30 m high.	nos	Unskilled	nos	0.25

RESOURCES CONSTRUCTION MATERIALS			EQUIPMENT		
TYPE	UNIT	QUANTITY	TYPE	UNIT	QUANTITY
Boulders	m^3	0.36	Gabion tools Doko	- -	3% of labour cost
Black polythene Boulders	m^2 m^3	0.40 0.09	Gabion tools Doko	- -	3% of labour cost
Black polythene Boulders	m^2 m^3	0.80 0.36	Gabion tools Doko	- -	3% of labour cost
MS rod	m	2.00	Sledge hammer	-	3% of labour cost
Terram paper	m^3	1.15	Khukuri	-	3% of labour cost
Bamboo	nos	2.20	Khukuri	-	3% of labour cost

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Alluvium Material, usually fine sand or silt with larger, rounded particles up to boulder size, deposited by a river, having been transported 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 strata.

Bamboo A perennial grass with woody culms from rhizomes. The term is used loosely to cover a number of genera other than just Bambusa.
Basement rocks Older rocks underlying a specified stratum.
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 always consist 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 considering 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 protruding. They are usually made to form a thick hedge and erosion 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 describe 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 of drains. It is a form of localised diagonal grass planting.
Clay Mineral material < 2 mm. Also applied to a class of soil texture, and used to describe the silicate clay minerals.
Climax community A plant community that has reached stability under the prevailing climate.
Cloche 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.
Colluvial slopes Slopes whose materials comprise mainly colluvium (see below).
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 material.
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 form of awareness-raising and the formation of user groups to manage common resources.
Conglomerates A sedimentary rock composed of rounded stones cemented together in a matrix of finer material.
Climax community 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. There will be no appreciable change in the mixture of species, although the individual plants will grow, die and be replaced.
Compost Decomposed 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 plant. The cotyledon often becomes the first photosynthetic (green, light -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.

Culm The stem of a grass.
Cutting Any part of a plant (stem, rhizome or root) that is used for vegetative propagation. See also **Grass slip** and **Slip cutting**.
Cyclonic rain Rain caused by a warm, moist air mass moving upwards over heavier, colder air.

Debris creep Gradual downward movement observed in unconsolidated debris masses on slopes (such as colluvium). It may range from a few millimetres to a few metres per year.
Deciduous Of plants which shed their leaves at least once a year and remain 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 first, 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.**

Ecology The study of organisms in relation to their environment.
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.

Geomorphology The study of the physical features of the earth and of the relationship between them and the geological structures that give rise to them.
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, thin 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 stable 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 higher 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 environmental 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 that 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).
Legumes Used loosely to refer to a large family of plants (Leguminosae) which bear their seeds in pods which split open along a line. Beans, lentils, peas, clovers and acacias all belong to this family. Strictly, the word 'legume' refers to the pod of seeds.
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) than the solid crust rocks above.
Material Used in the broad engineering sense to refer to any soil or accumulation of rock fragments.
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.

Mudstones A sedimentary rock composed of very fine (clay-sized) particles.

Mulch A layer of cut plant material 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 organisms 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, Orographic rain 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.

Plant community Any group of plants living together, either naturally or as a result of planting.

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.

Progression A regular movement by successive stages. In plant ecology, it refers to the development of repeated levels of plant communities, towards a climax. Regression is the return towards an earlier stage of development.

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-lateritic, 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.

Regression See **Progression.**

Rhizobia The nitrogen-fixing bacteria that form nodules on the roots of many leguminous species, including those listed here.

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 plants.

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.

Sandstones A sedimentary rock composed of sand-sized particles.

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.

Scrub Vegetation consisting of short trees and shrubs.

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 mm). 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 shallow (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 surfaces 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 s edimentary 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.

Talus deposits Materials deposited from upslope, and usually found on slopes below rock outcrops. They are characterised by angular debris, and are usually loose and unconsolidated. Other names are scree and colluvium.

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 contain 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 **fault.**

Toe wallA 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.

Translational landslide See **Planar sliding**

Transpiration The process by which plants, 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 100 mm, 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.

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ROADSIDE Bio-engineering

Reference Manual

This reference book provides the background information needed to understand the use of vegetation in engineering in Nepal, and the geological and geomorphological basis of site assessment for works on steep slopes.

It makes specific reference to roads. The manual also contains background information on the management of vegetation, including aspects of community participation and the law. The main bio-engineering species are described in detail. Standard specifications and rate analysis norms are also provided.

It is intended that the Reference Manual cover all subjects that an engineer would need in the office. The companion Site Handbook provides all the information required on site.