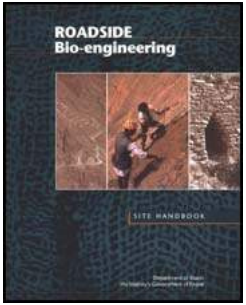

Roadside Bio-Engineering - Site Handbook (DFID, 1999, 160 p.)

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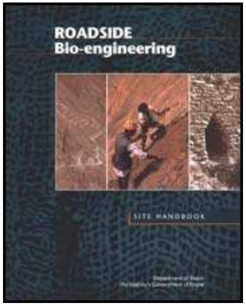

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Department of Roads
His Majesty's Government of Nepal

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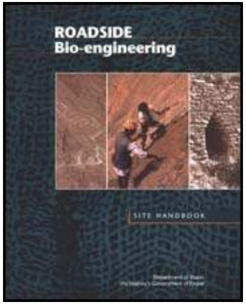


Annex A - Site assessment pro forma

Complete one pro forma per site. Use additional forms if there are more than three segments on the site

Site location and chainage:

Date of assessment: Assessor's name:

Sketch of site [Label segments]

Scale: Orientation:

Segment number	(1)	(2)	(3)

Segment number	(1)	(2)	(3)
(a) Erosion and failure processes			
(b) Other factors			
(c) Slope angle(s)			
(d) Slope length			
(e) Material drainage			
(f) Segment moisture			
(g) Altitude			

Assessment criteria. See *Roadside Bio-engineering Site Handbook,* Annex A, pages 127-129 for details

(a) Erosion and failure processes.	List the erosion or failure processes. State their size and severity.
(b) Other factors.	List any physical factors that might affect the site. State their size and severity.
(c) Slope angle(s).	Measure and place in one of 3 classes: <30°, 30 - 45°, or >45°.
(d) Slope length.	Measure and place in one of 2 classes: <15 metres or >15 metres.
(e) Material drainage.	Assess and place in one of 2 classes: good or poor.
(f) Segment moisture.	Assess and place in one of 4 classes: wet, moist, dry or very dry.
(g) Altitude.	Determine: ± 100 metres. Use an altimeter, map or site drawing.

Figure A1: The main erosion and failure processes

MECHANISM	DESCRIPTION
Erosion on the surface	Rills and small gullies form in weak, unprotected surfaces. Erosion should also be expected on bare or freshly prepared slopes.
Gully	Gullies that are established in the slope continue to develop and grow bigger. Large

Gully erosion	Gullies that are established in the slope continue to develop and grow bigger. Large gullies often have small landslides along the sides.
Planar sliding (translational landslide or debris slide)	Mass slope failure on a shallow slip plane parallel to the surface. This is the most common type of landslide, slip or debris fall. The plane of failure is usually visible but may not be straight, depending on site conditions. It may occur on any scale.
Shear failure (rotational landslide)	Mass slope failure on a deep, curved slip plane. Many small, deep landslides are the result of this process. Large areas of subsidence may also be due to these.
Slumping or flow of material when very wet	Slumping or flow where material is poorly drained or has low cohesion between particles and liquefaction is reached. These sometimes appear afterwards like planar slides, but are due to flow rather than sliding. The resulting debris normally has a rounded profile.
Debris fall or collapse	Collapse due to failure of the supporting material. This normally takes the form of a rock fall where a weaker band of material has eroded to undermine a harder band above. These are very common in mixed Churia strata.
Debris flow	In gullies and small, steep river channels (bed gradient usually more than 15°), debris flows can occur following intensive rain storms. This takes the form of a rapid but viscous flow of liquefied mud and debris.

(a) Erosion and failure processes

A number of erosion and failure processes are to be found. The types of erosion and slope failure found in Nepal are given in Figure A1. All sites have a combination of these mechanisms at work on them. During site assessment, you should check for these.

Figure A2: The main physical factors affecting slopes

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

activities	excavations, or surcharging through spoil disposal in the wrong places.

(b) Other factors

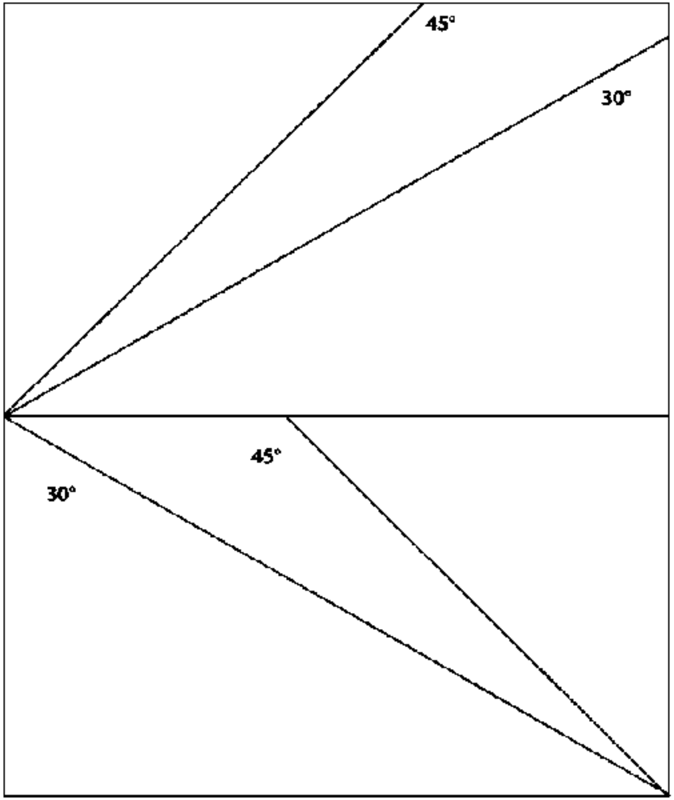
In addition to erosion and failure mechanisms, other factors may affect the site. Some are internal (e.g. springs) while others are external (e.g. river undercutting). During site assessment, you must check for signs of any of the potential damaging factors listed in Figure A2.

(c) Slope angle(s)

Measure the average slope angle of the slope segment and place it in one of three classes:

< 30º,
30 - 45°, or
> 45°.

If there is more than one dominant slope, record all main slope angles.



Figure

(d) Slope length

Measure the average length of the slope segment and place it in one of two classes:

< 15 metres or
> 15 metres.

Figure A3: Common features indicating soil drainage characteristics

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

(e) Material drainage

Assess and place in one of two classes: good or poor (see Figure A3).

Figure A4: Environmental factors determining site moisture

SITE MOISTURE FACTOR	TENDENCY TOWARDS DAMP SITES	TENDENCY TOWARDS DRY SITES

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

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

(f) Segment moisture

Assess and place in one of four classes:

Wet: permanently damp sites (*e.g.* north-facing gully sites).
Moist: sites that are reasonably well shaded or moist for some other reason.
Dry: generally dry sites.

Dry: generally dry sites.

Very dry: sites that are very dry; these are usually quite hot as well (*e.g.* south-facing cut slopes at low altitudes).

See Figure A4.

(g) Altitude

Determine: ±100 metres. Use an altimeter, map or site drawing.

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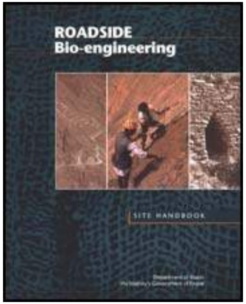


Annex B - Full lists of species for bio-engineering in the road sector

B1: FULL LISTS OF SPECIES FOR BIO-ENGINEERING IN THE ROAD SECTOR

GRASSES FOR BIO-ENGINEERING IN THE ROAD SECTOR (including small legumes)

Local name	स्थानिय नाम	**Botanical name**	**Rec**	**Character**	**Altitude**	**Sites**	**Best propagation**	**Seed collecti**
Amliso	अमलीसो	***Thysanolaena maxima***	✓	**Large clumping**	**Terai - 2000 m**	**Varied**	**Slip cuttings**	Mar-Apr
Babiyo	बाबियो	***Eulaliopsis binata***	✓	**Medium-sized clumping**	**Terai - 1500 m**	**Hot and dry**	**Slip cuttings/seeds**	Jan-Feb
Bansko ghans	बांसको घांस	*Eragrostis tenella*		Large spreading	500 - 1800 m	Varied	Slip cuttings/seeds	Dec-Jan
Blue panic grass	ब्लु पैनिक घांस	*Panicum antidotate*		Medium-sized spreading	500 - 1800 m	Varied and dry	Slip cuttings	Use cuttings
Buffalo grass	भैसी घांस	*Cenchrus ciliaria*		Medium-sized spreading (exotic)	500 - 1800 m	Varied and dry	Slip cuttings	Use cuttings
Clover	क्लोभर	*Trifolium species*		Small spreading	Terai - 2000 m	Varied; moist	Stem cuttings/seeds	Use cuttings

				legume (exotic)				
Dangre khar	डंग्री खर	*Cymbopogon pendulus*		Large clumping	Terai - 1200 m	Varied	Seeds	Dec-Jan
Desmodium	डेसमोडियम	*Desmodium distortum*		Spreading legume (exotic)	Terai - 1800 m	Varied	Stem/slip cuttings	Use cuttings
Desmodium greenleaf	डेसमोडियम हरियोपात	*Desmodium intortum*		Spreading legume (exotic)	Terai - 2000 m	Varied and dry	Stem/slip cuttings	Use cuttings
Dhonde	ढोन्डे	***Neyraudia reynaudiana***	✔	**Large clumping**	**Terai - 1500 m**	**Hot and dry**	**Stem/slip cuttings/seeds**	Dec-Jan
Dubo	दुबो	*Cynodon dactylon*		Small creeping	Terai - 1800 m	Varied	Stem cuttings	Use cuttings
Dhungre	ढुंग्री	Unknown		Large clumping	1500 - 2500 m	Damp or shady	Large slip cuttings	Dec-Jan
Dhus	धुस	Unknown		Large clumping	1500 - 2500 m	Varied, dry to moist	Slip/stem cuttings	Dec-Jan
Jaughans	जौघांस	Unknown		Medium-large spreading	1600 - 3000 m	Varied	Slip cuttings/seeds	May-Jun

Kagati ghans	कागती घाँस	*Cymbopogon citratus*		Medium-large clumping	Terai - 1500 m	Varied	Slip cuttings/seeds	Nov-Dec
Kans	कांस	***Saccharum spontaneum***	✔	**Large clumping and large spreading**	**Terai - 2000 m**	**Hot and dry to moist**	**Slip cuttings**	Nov-Dec
Katara khar	कटरा खर	***Themeda* species**	✔	**Large clumping**	**Terai - 2000 m**	**Varied**	**Slip cuttings/seeds**	Oct-Nov
Khar	खर	***Cymbopogon microtheca***	✔	**Medium-large clumping**	**500 - 2000 m**	**Hot and dry; varied**	**Slip cuttings/seeds**	Dec-Jan
Khus	खस	***Vetiveria lawsoni***	✔	**Medium-large clumping**	**Terai - 1500 m**	**Varied**	**Slip cuttings**	Sep-Nov
Kikiyu, thulo dubo	किकियु, ठूलो दुबो	*Pennisetum clandestinum*		Small creeping (exotic)	Terai - 1800 m	Varied	Stem/slip cuttings	Use cuttings
Kudzu	कूडजू	*Pueraria lobata*		Spreading legume (exotic)	500 - 1500 m	Varied	Stem/slip cuttings	Use cuttings
Molasses	मोलासेस	*Melinis minutiflora*		Medium-large spreading (exotic)	Terai - 1800 m	Varied to dry	Slip cuttings/seeds	Use cuttings

Musekharuki	मुसेखरुकी	*Pogonatherum paniceum (?)*		Small spreading	Terai - 2500 m	Varied	Slip cuttings	Use cuttings
Napier	नेपियर	*Pennisetum purpureum*		Large semi clumping (exotic)	Terai - 1750 m	Varied; needs fertile soil	Stem cuttings	Use cuttings
Narkat	नरकट	***Arundo clonax***	✓	**Large clumping and spreading**	**Terai - 1500 m**	**Hot and dry; varied**	**Stem/slip cuttings**	Nov-Jan
NB21	एनबी२१	*P. Purpureum x typhoides*		Spreading (exotic)	Terai - 1750 m	Varied	Stem cuttings	Use cuttings
Padang bans	पन्याङ्ग बांस	***Himalayacalamus hookerianus***	✓	**Large clumping (small-stature bamboo)**	**1500 - 2500 m**	**Moist**	**Large slip cuttings**	Use cuttings
Phurke	फुर्केघांस	***Arunduella nepalensis***	✓	**Medium-sized clumping**	**700 - 2000 m**	**Varied; stony**	**Slip cuttings/seeds**	Dec-Jan
Rato kans	रातो कांस	*Frianthus rufipilus*		Medium-sized clumping	900 - 2200 m	Varied	Slip cuttings/seeds	Dec-Jan
Salimo khar	सालिमा खर	*Chrysopogon gryllus*		Medium-large clumping	800 - 2000 m	Varied	Slip cuttings/seeds	Dec-Jan
Setaria	सेतारिया	*Setaria anceps*		Medium-	500 -	Varied	Slip	Jul-Aug

Setaria	[illegible]	*Setaria anceps*		Medium-large spreading (exotic)	500 - 2500 m	Varied to dry	Slip cuttings/seeds	Jul-Aug
Sito	सिटो	***Neyraudia arundinacea***	✓	**Large clumping**	**Terai - 1500 m**	**Varied**	**Slip cuttings/seeds**	Dec-Jan
Stylo	स्टायलो	*Stylosanthes guianensis*		Spreading legume (exotic)	500 - 1500 m	Varied	Stem/slip cuttings	Use cuttings
Thulo kharuki	ठूलो खरुकी	*Capipedium assimile (?)*		Medium-large clumping	600 - 2000 m	Varied	Slip cuttings/seeds	Dec-Jan
Tite nigalo bans	तिते निगालो बाँस	***Drepanostachyum intermedium***	✓	**Large clumping (small stature bamboo)**	**1000 - 2500 m**	**Varied**	**Large slip cuttings**	Use cuttings

Rec: ✓ = particularly recommended for roadside areas.

B2: FULL LISTS OF SPECIES FOR BIO-ENGINEERING IN THE ROAD SECTOR

SHRUBS; SMALL TREES FOR BIO-ENGINEERING IN THE ROAD SECTOR

Local name	स्थानिय नाम	Botanical	Rec	Character	Altitude	Sites	Best	Se

		name					propagation	co
Aak	आँक	*Calatropha giganteum*		Small shrub, large fleshy leaves	Terai - 1000 m	Hot and dry; harsh	Seeds/polypots	Fel
Ainselu	ऐंसेलु	*Rubus ellipticus*		Thorny shrub up to 2 m high	1000 - 2500 m	Varied	Seeds/root cuttings	No
Alainchi	अलैंची	*Elettaria cardomomum*		Herb up to 2 m high	1000 - 2000 m	Moist	Seeds/polypots	?
Amala	अमला	*Phyllanthus emblica*		Small tree	Terai - 1500 m	Hot and dry; harsh	Seeds/polypots	Se
Amba/ambak	अम्बा	*Psidium guajava*		Small tree, up to 5 m	Terai- 2000 m	Varied and dry	Seeds/polypots	Au
Aparajita	अपराजिता	*Clitoria ternatea*		Climbing shrub (exotic)	Terai - 1500 m	Varied and dry	Seeds	?
Areri	अरेरी	***Acacia pennata***	✔	**Small thorny tree, up to 5 m**	**500 - 1500 m**	**Hot and dry; harsh**	**Seeds/polypots**	No
Argali	अर्गाली	Unknown		Shrub up to 3 m high	1500 - 2500 m	Varied, dry to moist	Hardwood cuttings	Us cut
Arile kanda	अरिले कांडा	*Caesalpinia decapetala*		Thorny climber (exotic)	Terai - 1500 m	Varied	Seeds/stem cuttings	?

Armalito, seabuckthorn	अर्मालितो	*Hippophae salicifolia*		Small thorny tree	1000 - 2500 m	Varied and dry	Seeds/polypots	Au
Asuro	असुरो	***Adhatoda vasica***	✔	**Shrub up to 3 m high**	**Terai - 1000 m**	**Varied**	**Hardwood cuttings**	Us cut
Bains	बैंस	***Salix tetrasperma***	✔	**Tree up to 15m high**	**Terai- 2700 m**	**Moist**	**Hardwood cuttings**	Us cut
Bains	बैंस	Unknown; not *Salix*		Shrub up to 5 m high	1300 - 2000 m	Varied to moist; bears shade	Hardwood cuttings	Us cut
Baganbeli/ baramase phul	बगानबेली बाह्रमासे फुल	*Bougainvillea spectabilis*		Thorny climber (exotic)	Terai - 1500 m	Varied and dry	Stem cuttings	Us cut
Ban chutro	बन चुत्रो	*Berberis aristata*		Thorny shrub up to 2 m high	1500 - 3000 m	Varied and dry	Seeds/polypots	?
Ban silam	बन सिलाम	*Elsholtzia blanda*		Shrub	Terai - 1500 m	Varied	?	?
Bayer	बयर	*Zizyphus*		Thorny	Terai -	Hot and dry;	Seeds/polypots	De

		mauritiana		shrub up to 4 m high	1200 m	harsh		
Bhimsenpati	भिमसेन पाती	*Buddleja asiatica*		Shrub up to 4 m high	600 - 1800 m	Hot and dry; harsh	Seeds/hardwood cuttings	Us cut
Bhui katahar	भुईंकटहर	*Ananas comosus*		Thorny herb up to 1 m high	Terai - 1600 m	Hot and dry; harsh	Stem cuttings	Us cut
Bhujetro	भुजेत्रो	***Butea minor***	✓	**Shrub up to 4 m high**	**500-1500 m**	**Hot and dry; harsh**	**Direct seeding**	No
Bilaune	बिलाउनी	*Maesa chisia*		Shrub	Terai-2000 m	Varied	?	?
Bokshi ghans	बोक्सी घास	*Mimosa rubicaulis*		Shrub up to 3 m high	500 - 1700 m	Varied	Hardwood cuttings/seeds	Us cut
Chiya	चिया	*Camellia sinensis* (and other species)		Shrub up to 4 m high	Terai-2000 m	Varied and moist	Hardwood cuttings	Us cut
Chutro	चुत्रो	*Berberis asiatica*		Thorny shrub up to 2 m high	1000 - 2500 m	Varied and dry	Seeds/polypots	Ma
Coffee	कफि	*Coffea arabica*		Shrub up to 2 m high	Terai-2000 m	Varied	Seeds/polypots	Au
Dhanyero	धंएरो	***Woodfordia***	✓	**Shrub up**	**Terai -**	**Hot and dry;**	**Seeds/polypots**	Ma

		fruticosa		**to 3 m high**	**1500 m**	**harsh**		
Dhusun	धुसुन	***Colebrookea oppositifolia***	✓	**Shrub up to 3 m high**	**Terai - 1000 m**	**Hot and dry; harsh**	**Seeds/polypots**	Ma
Gahate	गहते	*Desmodium species*		Shrub up to 4 m high	400 - 1500 m	Varied	Seeds/polypots	?
Ghangaru	घंगारु	*Pyracantha crenulata*		Shrub up to 2m high	1500 - 2500 m	Varied	Hardwood cuttings (?)	Us cut
Ghurmiso	घुर्मिसो / घुर्मिस	*Leucosceptrum canum*		Tree up to 8 m high	1000 - 2500 m	Varied	Hardwood cuttings/seeds	Us cut
Hasna/hasua	हसना / हासु	*Cestrum nocturnum*		Shrub	Terai - 1500 m	Varied	?	?
Imali	इमली	*Rumex hastatus*		Herb up to 1 m high	600-2000 m	Hot and dry; harsh	Seeds	Ma
Kanda phul	कांडा फुल	***Lantana camara***	✓	**Shrub up to 2 m high**	**Terai - 1750 m**	**Hot and dry**	**Hardwood cuttings**	Us cut
Kera	केरा	*Musa paradisiaca*		Tree up to 5 m high	Terai - 1300 m	Varied and dry	Root suckers	Us su
Kettuke	केतुके	***Agave americana***	✓	**Large cactus;**	**Terai 2400 m**	**Hot and dry**	**Root suckers**	Us cut

				sub-species with and without thorns				
Keraukose	केराउकोशे	***Indigofera atroturpurea***	✓	**Tree up to 8 m high**	**Terai-2000 m**	**Hot and dry; harsh**	**Seeds/polypots**	No
Khirro	खिरो	*Sepium insegne*		Small tree	800 - 1500 m	Varied and dry	Hardwood cuttings/seeds	Us cut
Kimbu	किम्बु	*Morus alba*		Small tree	Terai-2000 m	Varied and dry	Hardwood cuttings/seeds	Us cut
Kunyelo	कुन्यलो	*Trema orientalis*		Small tree, up to 6 m high	Terai - 1500 m	Stony and dry	Hardwood cuttings/seeds	Us cut
Lalupate	लालुपाते	*Poinsettia pulcherrima*		Shrub up to 5 m high	Terai - 1500 m	Varied	Hardwood cuttings/seeds	Us cut
Mesquite	मेसक्युते	*Prosopis juliflora*		Small thorny tree (exotic)	Terai - 1000 m	Hot and dry; harsh	Seeds/polypots	Ma
Namdi phul	नाम्दी फुल	***Colquhounia coccinea***	✓	**Shrub up to 3 m high**	**1000-2000 m**	**Varied**	**Hardwood cuttings**	**Us cu**
Nil kanda	निलकांडा	*Duranta repens*		Thorny shrub	Terai - 1500 m	Varied and dry	Hardwood cuttings/seeds	Us cut

Pate siuli	पाटे सिउली	*Opuntia ficus indica*		Large thorny cactus, up to 4 m high	Terai - 1800 m	Varied and dry	Stem cuttings	?
Rahar	रहर	*Cajanus cajan*		Shrub up to 4 m high (exotic)	Terai - 1500 m	Varied and dry	Seeds	?
Rato chulsi	रातो चुल्सी	*Osbeckia stellata*		Shrub	Terai - 1500 m	Varied	?	?
Saruwa/bihaya	सरुवा / विहाय	***Ipomoea fistulosa***	✔	**Recumbent shrub**	**Terai - 1500 m**	**Varied; sunny sites; stands waterlogging**	**Hardwood cuttings**	Us cut
Sajiwan (kadam in the Terai)	साजिवन / कदम	*Jatropha curcas*		Shrub up to 4 m high	Terai - 1000 m	Varied	Hardwood cuttings	Us cut
Simali	सिमाली	***Vitex negundo***	✔	**Small tree, up to 6 m high**	**Terai - 1750 m**	**Hot and dry; varied**	**Hardwood cuttings**	Us cut
Sisal	सिसाल	*Agava sisalana*		Cactus	Terai - 1000 m	Hot and dry; varied	Root cuttings (?)	Us cut
Siuli/sihundi	सिउँली / सिहुँडी	*Euphorbia royleana*		Shrub	900 - 1800 m	Varied	?	?
Tara phul/kochu	तारा फुल / कोच	*Helianthus*		Spreading	800 -	Varied	Root cuttings	Us

Tara phul/kochu	[illegible]	*Helianthus tuberosus*		Spreading herb	800 - 1500 m	Varied	Root cuttings	Us cut
Thakal	थाकल	*Phoenix humilis*		Small stature palm tree	Terai - 1000 m	Hot and dry; needs shade	Direct seeding on site	Fel
Tilka	तिल्का	**Wendlandia puberula**	✓	**Tree up to 10 m high**	**Terai - 1500 m**	**Hot and dry; harsh**	**Seeds/polypots**	Fel
Udalo	उडालो	*Hypericum cordifolium*		Shrub up to 1.5 m high	1200 - 2500 m	Varied; dry to moist	Seeds/polypots	Ma

Rec: ✓ = particularly recommended for roadside areas.

B3: FULL LISTS OF SPECIES FOR BIO-ENGINEERING IN THE ROAD SECTOR

LARGE CLUMPING BAMBOOS FOR BIO-ENGINEERING IN THE ROAD SECTOR

Local name	**स्थानिय नाम**	**Botanical name**	**Character**	**Altitude**	**Sites**	**Best propagation**	**Comments**
Choya/tama bans	चोया/तामा बांस	*Dendrocalamus hamiltonii*	Thin culm, heavy branching	300-2000 m	Moist	Culm cuttings	
Dhanu bans	धनु बांस	*Bambusa balcooa*	Thick culm, heavy branching	Terai - 1600 m	Varied	Culm cuttings	
Kalo bans	कालो बांस	*Dendrocalamus hookeri*	Heavy branching, brown hairs	1200 - 2500 m	Varied	Culm cuttings	

Mal bans	माल बांस	*Bambusa nutans*	Strong, straight culms	Terai - 1500 m	Dry/varied	Traditional method	Subspecies *cupulata*
Nibha/ghopi/lyas bans	निभा बांस	*Ampelocalamus patellaris*	Smaller, bluish culms	1200 - 2000 m	Varied	Traditional method	
Tharu bans	थारु बांस	*Bambusa nutans*	Strong, straight culms	Terai - 1500 m	Varied	Traditional method	Subspecies *nutans*

Rec: ✓ = particularly recommended for roadside areas.

B4: FULL LISTS OF SPECIES FOR BIO-ENGINEERING IN THE ROAD SECTOR

LARGE TREES FOR BIO-ENGINEERING IN THE ROAD SECTOR

Local name	स्थानिय नाम	**Botanical name**	**Rec**	**Character**	**Altitude**	**Sites**	**Light**	**Coppicing**	**Best propag**
Acacia	अष्ट्रेलियन खयर	*Acacia auriculiformis*		Small non-thorny tree (exotic)	Terai - 1000 m	Hot and dry; harsh	Full light	Pollards well	Seeds/p
Amp/aap	आंप	*Mangifera indica*		Medium-sized fruit tree	Terai - 1200 m	Hot and dry but not stony	Full light	Can be lopped	Seeds/p
Ashare	असारे फुल	*Lagerstroemia*		Medium to	Terai -	Varied to	?	?	Seeds/p

[illegible] phul		*[illegible] parviflora*		[illegible] large tree	[illegible] 1200 m	[illegible] dry	[illegible]	[illegible]	[illegible]
Babul/kikar	बबुल/किकार	*Acacia nilotica*		Medium-sized thorny tree (exotic)	Terai - 1000 m	Hot and dry; harsh	Full light	Coppices poorly	Seeds/p
Badahar	बडहर	*Artocarpus lakoocha*		Medium to large deciduous tree	Terai - 1300 m	Varied and moist	Bears shade	Can be lopped	Seeds/p
Bakaino	**बकाइनु/बकाइनो**	*Melia azedarach*	✓	**Medium to large deciduous tree**	**Terai - 1800 m**	**Hot and dry; harsh**	**Demands light**	**Coppices well**	**Seeds/**
Bange kath	बांगे काठ	*Populus ciliata*		Large deciduous tree	2000 - 3000 m	Dry to moist	Full light	Pollards well	Hardwoo
Banghi	बांघी	*Anogeissus latifolia*		Large deciduous tree, drooping branches	Terai - 1700 m	Hot and dry	Full light	Coppices well	Seeds/p
Birendra phul	बिरेन्द्र फुल	*Jacaranda mimosifolia*		Medium-sized exotic, deciduous ornamental	Terai - 1600 m	Varied to dry	Light	Does not coppice	Seeds/p
Champ	चांप	*Michelia [illegible]*		Large [illegible]	500 - [illegible]	Varied to [illegible]	Light or [illegible]	Coppices [illegible]	Seeds/p

		champaca		evergreen tree	1500 m	moist	shade	well	
Chilaune	चिलाउने	***Schima wallichii***	✓	**Large evergreen tree**	**900 - 2000 m**	**Varied; dry to moist**	**Bears shade**	**Can be lopped**	**Seeds/**
Chiuri	चिउरी	*Aesandra butyracea*		Large tree	Terai - 1700 m	Varied and poor	Demands light	Withstands lopping	Seeds/p
Chuletro	चुलेत्रो	*Brassaiopsis hainla*		Small prickly evergreen tree	800 - 2000 m	Varied	?	Can be lopped	Seed/ha cuttings
Dabdabe	दबदबे	***Garuga pinnata***	✓	**Large deciduous tree**	**Terai - 1300 m**	**Varied and dry**	**Full light**	**Coppices well**	**Seed/h cutting: m**
Dar/githi	दार / गिथी	*Boehmeria rugulosa*		Small to medium tree	300 - 1700 m	Varied	Light or shade	Stands heavy lopping	Seeds/h cuttings
Deshi katus	देशी कटुस	*Castanea sativa*		Large tree (exotic)	1000 - 2000 m	Varied	Light or shade	Coppices well	Seeds/p
Dhale katus	धाले कटुस	*Castanopsis indica*		Large tree	900 - 2900 m	Varied	Light or shade	Coppices	Seeds/p
Dhupi salla	धुपी सल्ला	*Cryptomeria japonica*		Large evergreen	1200 - 2500 m	Varied but not	Bears shade	?	Seeds/p

				tree (exotic)		hot or dry			
Dudhilo	दुधिलो	*Ficus neriifolia*		Small deciduous fodder tree	900 - 2200 m	Varied and dry	Bears shade	Can be lopped	Seeds/p
Gobre salla	गोब्रे सल्ला	***Pinus wallichiana***	✓	**Large coniferous tree**	**1800 - 3000 m**	**Dry; varied**	**Full light**	**Can be lopped**	**Seeds/**
Gliricidia	ग्लीरीसिडिया	*Gliricidia sepium*		Small leguminous tree (exotic)	Terai - 500 m	Hot, not too dry; free draining	Full light	Coppices and pollards well	Seeds/h cuttings
Gogan	गोगन	*Saurauia nepaulensis*		Medium-sized fodder tree	750 - 2100 m	Varied	Bears shade	Can be lopped	Seeds/p
Golainchi/ goila	गोलैंची/ गोइला	*Plumeria acuminata*		Ornamental tree	500 - 1500 m	Varied and dry	Bears shade	?	Seeds/p
Gulmohar	गुलमोहर	*Delonix regia*		Medium-sized ornamental tree	Terai - 1000 m	Varied and dry	Full light	Can be lopped	Seeds/p
Ipil ipil	इपिल इपिल	*Leucaena* species		Several species of	Terai - 1500 m	Varied and dry	Full light	Coppices and	Seeds/p

				small fodder trees				pollards well	
Jamun	जामुन	*Syzygium cumini*		Medium-sized evergreen tree	Terai - 1600 m	Moist	Bears shade	Coppices well	Seeds/p
Kadam	कदम	*Anthocephalus chinensis*		Large deciduous tree; horizontal branches	Terai - 1000 m	Varied and moist	Bears shade	Coppices well	Seeds/p
Kagati	कागती	*Citrus aurantifolia*		Small fruit tree	500 - 1500 m	Varied	?	?	Hardwoo
Kaju	काजु	*Anacardium occidentale*		Small nut tree	Terai - 1600 m	Varied and poor	?	?	Grows ir rocky sit
Kalki phul/ bottlebrush	कल्की फुल/ बोटलब्रुश	*Callistemon citrinus*		Small ornamental tree (exotic)	Terai - 1800 m	Varied; tolerates swampy sites	Full light	Can be lopped	Seeds/h cuttings
Kalo siris	**कालो सिरीस**	***Albizia lebbeck***	✓	**Medium-sized deciduous tree**	**Terai - 1200 m**	**Hot and dry; harsh**	**Full light**	**Coppices well**	**Seeds/**
Kangiyo	काँगियो	*Grevillea robusta*		Large exotic, straight-	Terai - 1600 m	Varied; avoid windy	Full light	Can be pollarded	Seeds/p

				stemmed ornamental		sites			
Kapur	कपूर	*Cinnamomum camphora*		Evergreen tree (exotic)	Terai - 2000 m	Prefers moist sites	?	Coppices well	Seeds/p
Kavro	काभ्रो	*Ficus lacor*		Small, nearly evergreen fodder tree	Terai - 1600 m	Varied	Full light	Can be lopped	Hardwoo cuttings
Khanyu (khosro)	खन्यु / खोस्रो	***Ficus semicordata***	✓	**Small stature, heavy branching**	**Terai - 2000 m**	**Hot and dry; varied**	**Full light**	**Coppices well**	**Seeds/**
Khari	खरि	*Celtis australis*		Medium-sized deciduous tree	700 - 2400 m	Varied	Bears shade	Coppices and pollards well	Seeds/p
Khasru	खसु	*Quercus semecarpifolia*		Large forest tree	1700 - 3800 m	Varied	Full light	Coppices and pollards well	Seeds/p
Khayer	खयर	***Acacia catechu***	✓	**Large, thorny tree**	**Terai - 1000 m**	**Hot and dry; harsh**	**Full light**	**Coppices well**	**Seeds/**
Koiralo	कोइरालो	*Bauhinia variegata*		Medium-sized fodder tree	Terai - 1900 m	Varied and dry	Full light	Coppices well	Seeds/p

Kutmero	कुटमिरो	*Litsea monopetala*		Medium-sized evergreen fodder tree	Terai - 1600 m	Varied to stony and dry	Light or shade	Can be lopped	Seeds/p
Lahare pipal	लहरे पिपल	*Populus x euramerica*		Large deciduous varieties (exotics)	Terai - 1700 m	Moist	Full light	Coppices and pollards well	Hardwoo
Lankuri	लाँकुरे	***Fraxinus floribunda***	✓	**Large deciduous tree**	**1200 - 2700 m**	**Varied; best in moist sites**	**Prefers light**	**Coppices well**	**Seeds/**
Lapsi	लप्सी	*Choerospondias axillaris*		Medium to large deciduous tree	950 - 1900 m	Varied and dry	Strong light	Can be lopped	Seeds/p
Makadamia	मकदमिया	*Macadamia tetraphylla*		Exotic nut tree	Terai - 1600 m	Hot and dry; harsh	?	?	Seeds/p
Mashala	मसला	*Eucalyptus camaldulensis*		Large tree with a thin crown	Terai - 1800 m	Hot and dry; harsh	Full light	Coppices well	Seeds/p
Mayal/mel	मयल / मेल	*Pyrus pashia*		Small tree, often spiny	1500 - 2500 m	Varied	?	?	Seeds/h cuttings

Musure katus	मुसुरे कटुस	*Castanopsis tribuloides*		Large deciduous tree	500 - 2300 m	Varied and dry	Lighter shade	Coppices well	Seeds/p
Nebharo	नेभारो	*Ficus auriculata*		Medium-sized fodder tree	Terai - 2000 m	Varied and dry	Full light	Coppices and pollards well	Seeds/h cuttings
Neem	निम	*Azadirachta indica*		Large evergreen tree	Terai - 900 m	Hot and dry	Full light	Coppices well	Seeds/p
Okhar	ओखर	*Juglans regia*		Medium-sized nut tree	1200 - 2800 m	Varied and moist	Full light	Coppices well	Seeds/g
Painyu	पैन्यु	***Prunus cerasoides***	✓	**Medium-sized flowering tree**	**500 - 2400 m**	**Varied and dry; stony**	**Bears shade**	**Coppices**	**Seeds/**
Patle katus	पात्ले कटुस	*Castanopsis hystrix*		Large evergreen tree	1000 - 2500 m	Varied	Bears shade	Coppices well	Seeds/p
Phalant	फलाट	*Quercus lamellosa*		Large forest tree	1600 - 2800 m	Moist sites preferred	Bears shade	Coppices well	Seeds/p
Phaledo	फलेदो	***Erythrina species***	✓	**Three fodder**	**900 - 3000 m**	**Varied**	**Light**	**Can be lopped**	**Seeds/ cutting**

				species					**m**
Rajbriksha/ amaltas	राजवृक्ष / अमलताश	*Cassia fistula*		Medium-sized ornamental tree	Terai - 1400 m	Varied and dry	Light or shade	?	Seeds/p
Rani (khote) salla	**रानी (खोटे) सल्ला**	***Pinus roxburghii***	✓	**Large coniferous tree**	**500 - 1950 m**	**Hot and dry; varied**	**Full light**	**Can be lopped**	**Seeds/**
Rato siris	**रातो सिरिस**	***Albizia julibrissin***	✓	**Medium-sized deciduous tree**	**800 - 3000 m**	**Varied and moist**	**Light or shade**	**Coppices well**	**Seeds/**
Ritha	रिट्ठा	*Sapindus mukorossi*		Large tree	700 - 2000 m	Varied	?	?	Seeds/p
Sahinjan/ shobhanjan	सहिजन / शोभान्जन	*Moringa oleifera*		Small ornamental tree	Terai - 1000 m	Hot and dry; varied	Light or shade	Coppices and pollards well	Hardwoo up to 2
Sal	साल	*Shorea robusta*		Large forest tree	Terai - 1000 m	Varied; dry to moist	Light or shade	Coppices well	Seeds/p
Saur	सौर	*Betula alnoides*		Small tree	1200 - 3000 m	Varied to moist	Full light	?	Seeds/p
Seto siris	**सेतो सिरीस**	***Albizia***	✓	**Medium-**	**Terai -**	**Moist**	**Full light**	**Can be**	**Seeds/**

		procera		**sized deciduous tree**	**1350 m**			**lopped**	
Sisau	सिसौ	***Dalbergia sissoo***	✓	**Large broad-leaved tree**	**Terai - 1400 m**	**Varied**	**Full light**	**Coppices and pollards well**	**Seeds/ stump**
Suntala	सुन्तला	*Citrus chyracarpa*		Small fruit tree	500 - 1500 m	Varied	Full light	?	Hardwo
Tanki	टांकी	*Bauhinia purpurea*		Medium-sized deciduous fodder tree	Terai - 1600 m	Varied and dry	Needs light	Can be lopped	Seeds/p
Tendu	तेन्दु	*Diospyros malabarica*		Medium-sized evergreen tree	Terai - 1500 m	Moist sites and good soils	Bears shade	Can be lopped	Seeds/p
Tooni	तूनी	*Toona ciliata*		Large deciduous tree	Terai - 1700 m	Moist sites and good soils	Light or shade	?	Seeds/p
Utis	उतिस	***Alnus nepalensis***	✓	**Large broad-leaved tree**	**900 - 2700 m**	**Varied and moist**	**Full light**	**Probably does not coppice**	**Seeds/**

Rec: ✓ = particularly recommended for roadside areas.

B5: PLANTS THAT ARE DIFFICULT OR POTENTIALLY DAMAGING

THESE PLANTS SHOULD NEVER BE USED FOR BIO ENGINEERING

LOCAL NAME	BOTANICAL NAME	REASON FOR NOT USING AS A BIO-ENGINEERING SPECIES
Ban mara	*Eupatorium adenophorum*	Very shallow rooting; stifles other plants; has become a damaging weed
Tite pate	*Artemisia vulgaris*	Very shallow rooting; stifles other plants; has become a damaging weed
Annual grasses	Various	Too short lived
Cassia (exotic)	*Cassia siamea*	Suffers from grass competition; creates heavy shade when canopy closes; competes heavily with other species
Patula salla	*Pinus patula*	Frequently suffers from either drought or nutritional problems in Nepal hill plantations
Sagawan (teak)	*Tectona grandis*	This tree tends to suppress all undergrowth and is known to give rise to conditions allowing extensive erosion below its canopy

THESE PLANTS SHOULD BE USED WITH CARE

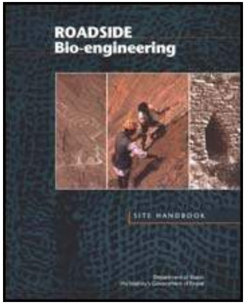
LOCAL NAME	BOTANICAL NAME	REASON FOR CAUTION	BEST WAY TO USE
Gobre salla	*Pinus wallichiana*	Tends to stifle nearby plants and, in particular, prevents the development	Plant as a 50% mix with other species. Once the trees are established,
gradually		of a good ground cover. However,	eliminate the pines in subsequent

		it is a good pioneer species and in a mixture can show excellent results	thinning, leaving only other species
Ipil Ipil	*Leucaena leucocephala*	Growth has been severely hampered by attacks of the insect psyllid throughout Nepal	Use only if you can see ipil ipil growing well nearby. Plant in a mixture with other species, with never more than 50% of ipil ipil
Mashala gradually	*Eucalyptus camaldulensis*	Tends to stifle nearby plants and in particular, prevents the development	Plant as a 50% mix with other species. Once the trees are established,
		of a good ground cover. However, it grows well on dry sites and in a mixture can show excellent results	eliminate the eucalypts in subsequent thinning, leaving only other species
Rani (khote) salla	*Pinus roxburghii*	Tends to stifle nearby plants and in particular, prevents the development	Plant as a 50% mix with other species. Once the trees are established,
gradually		of a good ground cover. However, it is a good pioneer species and in a mixture can show excellent results	eliminate the pines in subsequent thinning, leaving only other species

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Roadside Bio-Engineering - Site Handbook (DFID, 1999, 160 p.)

(introduction...)



Annex C - Nursery registers

GRASS SLIP/HARDWOOD CUTTING REGISTER **Name of nursery:** ____________ **Division/Project:** ____________ **Species:** ____________ **Identity no:** ____________ **Planting date:** ____________ Bed no: ____________ Number planted: ____________ **Source of slips/cuttings:** ____________	
Shoots starting	Date started: ____________ Approx. percentage: ____________
Re-spacing (1)	Date started: ____________ Approx. number: ____________
	Bed nos.:

Re-spacing (2)	Date started: ________________________ Approx. number:____________
	Bed nos.: __________________________
Diseases/pests ____ **Other notes** ____	

Distribution record			
Date	Number	Location	Notes

SEEDLING REGISTER

Name of nursery: _________________________ **Division/Project:** ____________________
Species: __________________ **Identity no:** _______________ **Sowing date:** ___________
Bed no: ____ Amount sown: ______________
Pre-treatment: ____

Germination	Date started: Approx. number:

Pricking out (transplanting)	Date carried out: ______________________________ Number: __________ Bed no.: ____
Root pruning	Dates: ____
Spacing out	Date: ____
Diseases/pests	____
Other notes	____

Distribution record			
Date	Number	Location	Notes

SEED IDENTIFICATION REGISTER

Name of nursery: __________________________ Division/Project: ________________________

Date	Identity	Species	Quantity	Source: location	Supplier	Date

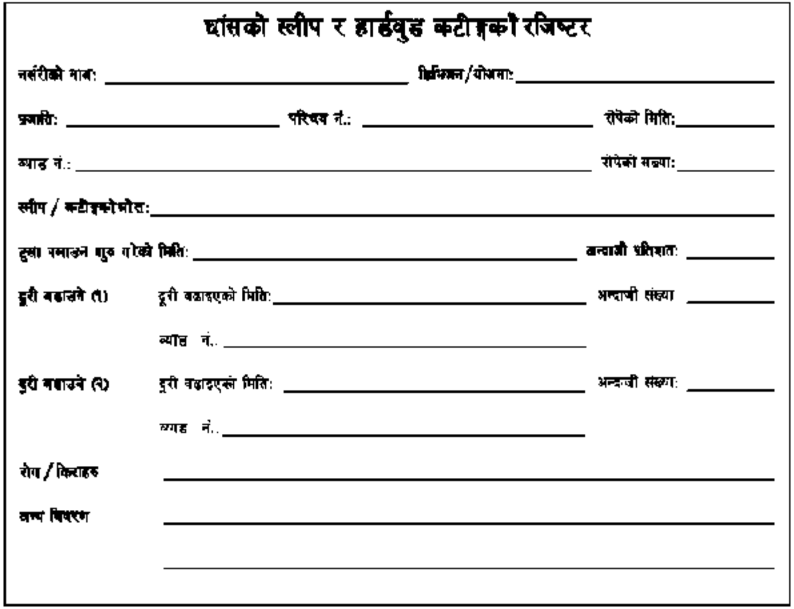
supplied	number		(g or kg)	and seedlot		collected

SEED COLLECTION CALENDAR

Name of nursery: _______________________ Division/Project: _____________________

Month	Seeds to collect	Locations
Shrawan (July-August)		
Bhadra (August-September)		
Aswin (September-October)		
Kartik (October-November)		
Mangsir (November-December)		
Poush (December-January)		
Magh (January-February)		
Falgun (February-March)		
Chaitra (March-April)		
Baisakh (April-May)		
Jestha (May-June)		
Ashad		

(June-July)		



घांसको स्लीप र हार्डवुड कटीङ्गको रजिष्टर

नर्सरीको नाम: ______ डिभिजन/योजना: ______

प्रजाति: ______ परिचय नं.: ______ रोपेको मिति: ______

ब्याड नं.: ______ रोपेको संख्या: ______

स्लीप / कटीङ्गको स्रोत: ______

टुसा पलाउन शुरु गरेको मिति: ______ अन्दाजी प्रतिशत: ______

दूरी बढाउने (१) दूरी बढाइएको मिति: ______ अन्दाजी संख्या ______

ब्याड नं.: ______

दूरी बढाउने (२) दूरी बढाइएको मिति: ______ अन्दाजी संख्या: ______

ब्याड नं.: ______

रोग / किराहरु ______

अन्य विवरण ______

Figure

वितरण रेकार्ड			
तिथि	संख्या	स्थान	कैफियत

Figure

नर्सरी बिरुवाको रजिष्टर

नर्सरीको नाम: ______________________ डिभिजन/योजना: ______________________

प्रजाति: ______________ परिचय नं.: ______________ बिउ छरेको मिति: __________

ब्याड नं.: __________________________________ छरेको परिमाण: __________

पूर्व उपचार: ____

उम्रन शुरु गरेको मिति: ______________________________ अन्दाजी संख्या: __________

सार्ने काम: सारेको मिति: ______________________________ संख्या: __________

ब्याड नं. ______________________________

जरा छाँट्ने काम: छाँटेको मिति: ______________________________

दूरी बढाइएको: मिति: ______________________________

रोग / किराहरु ____

अन्य विवरण ____

____

Figure

वितरण रेकर्ड			
मिति	संख्या	स्थान	कैफियत

Figure

बिउको रजिष्टर

नर्सरीको नाम: ______________ डिभिजन/योजना: ______________

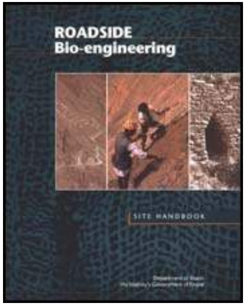
प्राप्त मिति	परिचय नं.	प्रजाति	परिमाण कि.ग्रा/ग्रा	बिउको लट नं. र स्रोत	सप्लायर	संकलन मिति

Figure

बिउ संकलन तालिका		
नर्सरीको नाम:	डिभिजन/योजना:	
महिना	संकलन गर्नु पर्ने बिउ	स्थान
श्रावण		

भाद्र		
आश्विन		
कार्तिक		
मंसिर		
पौष		
माघ		
फाल्गुन		
चैत्र		
वैशाख		
जेष्ठ		
आषाढ		

Figure



Glossary

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.*

Bedding The layers of sedimentary rocks, as they were laid down. The layers are separated by 'bedding planes'.

Bio-engineering The use of living plants for engineering purposes.

Bolster A tube, usually of small-mesh gabion wire, containing stones. They are installed as scour checks or french drains, or both.

Botanical name The international system for the scientific naming of plants. These normally 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.

Brash 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 or drains. It is a form of localised diagonal grass planting.

Clay Mineral material < 2 µm. Also applied to a class of soil texture, and used to describe the silicate clay 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.

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.

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, Hardwood cutting* and *Slip cutting.*

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.*

Erosion The gradual wearing away of soil (or other material) and its loss, particle by particle.

Evaporation The loss of water from the soil or another surface into the air in the form of water vapour.

Evapotranspiration The total loss of water from the soil in the form of water vapour, either by direct evaporation or from plants by transpiration.

Exotic Of a plant that has been introduced from another area.

Fallow Where land is cultivated but left unplanted to restore its fertility.

Fascine Bundles of branches laid along shallow trenches and buried completely. They send up shoots and can be used to form a thick hedge and erosion barrier across the slope, or a living subsoil drain.

Fault A fracture in the Earth's crust along which movement has taken place, and where the rock strata on the two sides therefore do not match. The movement can be in any direction, but in the Himalaya the main faults are all thrust faults: this is where two rock masses have been pushed together and one has ridden over the other. In places this occurs when the rocks fracture as a result of extreme folding.

Field capacity The total amount of water remaining in a freely draining soil after the

excess has flowed into the underlying unsaturated soil.

Fold A bend in rock strata caused by movements in the Earth's crust. The strata are bent into a series of arches (anticlines) and troughs (synclines).

Frankia **Actinomycetes (micro-organisms) that form a symbiotic relationship with the roots of certain species, and which fix nitrogen.**

Friable A term applied to soils that when either wet or dry crumble easily between the fingers.

Gondwanaland The southerly of the two ancient continents which once comprised the Earth's two big land masses (the other was Laurasia). The continents broke apart and, through the process of continental drift, have re-formed into the land masses seen today. The Indian Shield continental plate was once part of Gondwanaland.

Grass A plant of the family Gramineae, characterised by long, 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 more-or-less stable level of the fraction of soil organic matter remaining after the major portion of added plant and animal residues have decomposed.

Igneous rocks Rocks that have solidified from molten or partly molten material originating from magma

Isostasy The state of equilibrium that is thought to exist in the Earth's crust, where equal masses of matter underlie equal areas, whether of continental or oceanic crust rocks, to a level of hydrostatic compensation. An analogy is in wooden blocks floating in water: the bigger the block, the higher it rises above the surface and the deeper it goes below the surface: the thicker continental plates rise 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).

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.

Metamorphic rocks Any rocks derived from pre-existing rocks by mineralogical, chemical or structural change, especially in the solid state, in response to marked changes in temperature, pressure and the chemical environment at depth in the Earth's crust; that is, below the zone of weathering and cementation. Metamorphosis may be from contact (usually with a hot magma), where changes are usually at high temperature but low pressure; or dislocation, where changes occur under high pressure but low temperature. Changes due to both high temperature and high pressure are known as regional metamorphism. Most metamorphism in the Himalayas is dislocation metamorphism.

Minerals The naturally occurring crystalline chemical compounds found in rocks. Rocks are composed of aggregations of minerals.

Molasse A Swiss geological term to describe certain depositional materials found in fold mountain belts. Molasses are a continental (*i.e.* non-marine) deposit formed in marginal troughs and inter-montane basins during and after major tectonic movements. They are often cemented with calcareous and clay-rich materials. These materials are common in the Churia range.

Monsoon The name is derived from the Arabic word *mausim,* meaning season, which explains its application to a climate with large-scale seasonal reversals of the wind regime. In Nepal, 'monsoon' is usually used to describe the period of the south-west monsoon rains, which occur between June and September.

Mulch A layer of 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 Mountains, hills and ridges, or effects resulting from them. Orographic rain is caused by mountains in the path of moisture-laden air: the air is forced to rise, which cools it and causes the moisture to condense and precipitate.

Orthodox Seeds which need to be dried and kept dry during storage.

Palisade The placing of cuttings or seedlings across a slope to form a barrier against soil movement.

Perennial Of plants which grow and reproduce for many years.

Phraetophyte A plant with a high rate of water usage.

Physiography The study of the physical features of the earth, their causes and their relation to one another. Generally taken to be the same as geomorphology.

Piedmont Literally, 'the foot of the mountain'. Usually used to describe the piedmont alluvial plain (in Nepal the Bhabar and Terai).

Pioneer species The first plants to colonise bare ground.

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

Planting drill When grasses are propagated using vegetative parts, the planting drill consists of one or more grass slips or cuttings. (see also *Drill.*)

Pollard A treatment in which the main trunk of a tree is cut off, usually two to three metres above the ground, to allow new, smaller, shoots to grow.

Precipitation In meteorology, the deposits of water, as rain, hail or snow, which reach the Earth from the atmosphere.

Prop wall A wall provided in a weaker portion of soil to give support to a stable portion above.

Prune To cut branches carefully in order to improve the shape of a plant or allow more light to penetrate.

Rato mato A red soil, normally of clay loam texture, formed from prolonged weathering (probably >100,000 years). It can be considered semi-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.

***Rhizobia* The nitrogen-fixing bacteria that form nodules on the roots of many leguminous species.**

Rhizome An underground stem that produces shoots and roots. Grasses naturally use rhizomes and stolons for vegetative propagation. Roots and shoots appear from the nodes on each and eventually they become individual 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.

Scour The physical removal of soil from the surface by erosion. In some text books it is used to describe erosion in broad, shallow rills which can coalesce to give sheet erosion.

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

Seedling Any plant raised from seed.

Shoot The general name for any stem above the ground.

Shrub A small woody perennial plant with branches from ground level upwards.

Silt Mineral particles in the diameter range of 0.02 to 0.002 mm (20 to 2 µm). Also used loosely to describe any accumulation of fine material, and applied to a class of soil texture

Slip cutting A cutting made from a grass that has fibrous roots but no rhizome system. See also *Grass slip.*

Slumping A form of saturated flow of soil or debris. It occurs mostly in weak, poorly drained materials, when a point of liquefaction is reached following heavy rain. In effect, the addition of water to the material causes a reduction in cohesion to a point of limited friction. It is usually 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 sedimentary rocks, but some metamorphic rocks also have visible strata.

Strike The horizontal line contained in the plane of bedding, foliation, or jointing of rock. It is perpendicular to the dip, just as a contour is to the maximum slope of the ground. It is always expressed as a reading less than 180°.

Subsoil In a moderately or well developed soil, the layer(s) or horizon(s) below the topsoil. It is usually made up almost entirely of mineral constituents, and is less fertile than the topsoil. It is distinguished from weathered parent material by the absence of any

structural characteristics of the parent material.

Sward An area of vegetation consisting mainly of grasses; a low, dense mass of ground-covering vegetation.

Syncline The trough or inverted arch of a fold in rock strata.

Synclinorium A huge trough, in form resembling a syncline, each limb of which consists of a number of small folds.

Tethys The ancient sea which separated two ancient continents. Marine deposits laid down in the Tethys Sea now form part of the Tibetan Plateau.

Texture In soils, the 'feel' of moist soil resulting from the mixture of different particle sizes and organic matter. Texture is classified into groups of soils with similar properties on the basis of the mineral component. For example, clay loam contains 27 to 40 percent clay, 15 to 55 percent silt and 20 to 45 percent sand.

Thin The removal of a proportion of the plants in a given area, to allow the others to grow bigger. This is a standard nursery and forestry procedure.

Thrust or thrust fault See under fault.

Toe wall A wall of low height provided to protect the toe of a soil mass.

Topography A detailed description or representation of the features, both natural and artificial, of an area, often with special reference to the relief (differences of altitude).

Topsoil In a moderately or well developed soil, the darker, more fertile and organically rich upper layer or horizon of soil. In a cultivated soil, it is often the plough layer.

Transpiration The process by which 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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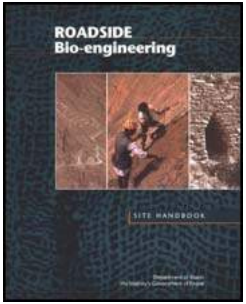
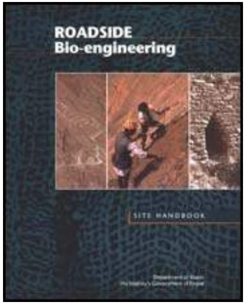


Back cover

This handbook provides the information needed to design, plan, implement and maintain bio-engineering works on steep slopes, with specific reference to roadside areas. It also covers the establishment and operation of bio-engineering nurseries.

It is intended that the handbook cover all subjects that an engineer would need on site. The companion Reference Manual provides background and supporting information and is intended for office use.



Acknowledgements

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.

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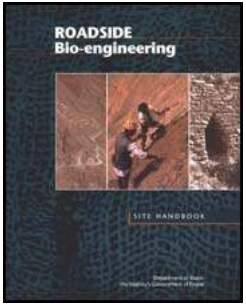

Introduction

Figure

The nature and scope of bio-engineering

USING THE *SITE HANDBOOK*

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

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

Words that appear in the glossary have been highlighted in orange.

THE NATURE AND SCOPE OF ROADSIDE BIO-ENGINEERING

What is this handbook for?

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

What is bio-engineering?

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

Placing jute netting on a steep cut slope

What does bio-engineering do?

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

[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).

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

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

How does bio-engineering work?

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

Where should bio-engineering be used?

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

- all areas of bare soil on embankment and cut-face slopes;
- wherever there is a risk of gullying;
- all slopes where there is a risk of shallow slumps or planar slips of less than 500

mm depth;

- **any slope segment in which civil engineering structures are planned or have been built, and the surface remains bare;**

- **any area that has failed and needs to be restored, other than rock slopes;**

- **any area, such as tipping and quarry sites, or camp compounds, that requires rehabilitation.**

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

How is bio-engineering done?

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

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

When is bio-engineering done?

Bio-engineering works are planned in the same way as other works, following the annual pattern of planning, budget estimation and submission, detailed site assessment,

estimation and implementation. However, some differences exist: the need to establish and maintain nurseries, for example, and the fact that timing is controlled by seasons.

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

FUNCTION*	CIVIL ENGINEERING TECHNIQUE	BIO-ENGINEERING TECHNIQUE	COMBINATION OF BOTH
Catch	Catch walls	Contour grass lines	Catch wall with bamboos above
Armour	Revetments	Grass carpet	Vegetated stone pitching
Reinforce	Reinforced earth	Densely rooting grasses	Jute netting with planted grass
Anchor	Soil anchors	Deeply rooting trees	Combination of anchors and trees
Support	Retaining walls	Large trees and large bamboos	Retaining wall with bamboos above
Drain	Surface or sub-surface drains	Downslope vegetation lines	French drains and angled grass lines

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

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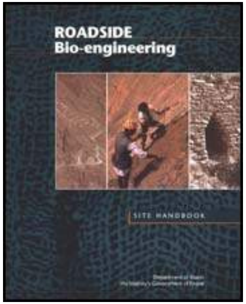
Roadside Bio-Engineering - Site Handbook (DFID, 1999, 160 p.)



Safety Code of Practice for Working on Slopes

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

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

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

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

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

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

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

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

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

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

11. If there is any potential hazard to personnel below where the slope work is taking place,

adequate temporary warning notices, barriers and a 'look out' person shall be employed. Where appropriate, standard traffic warning and control measures must be taken.

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

How safe are the working practices in your area?

Site safety

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

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

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

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

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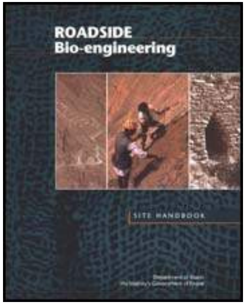


Roadside Bio-Engineering - Site Handbook (DFID, 1999, 160 p.)

Section One - Stabilising slopes with civil and bio-engineering

Figure

This section provides:

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

1.1 Problems of slopes and their solutions

Ideally, the causes of slope instability would be well understood and appropriate solutions would be easy to select. However, this is rarely the case and engineers must make assumptions about the causes of slope instability, based on their knowledge and experience of the terrain. This is particularly true in Nepal, where slopes tend to be long and steep, and the climatic variables are as yet poorly understood. Attaining a desired

factor of safety may not be feasible.

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

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

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

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

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

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

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

Figure 1.1: Common types of erosion and slope failure

DESCRIPTION	**DEPTH**	**MECHANISM***	**FUNCTION REQUIRED**
Rills and gullies form in weak, unprotected surfaces. Erosion should also be expected on bare or freshly prepared slopes.	Usually in the top 0.5 metre, but can become deeper if not controlled.	**Erosion on the surface.**	Armour, Reinforce, Catch.
Mass slope failure on a shallow slip plane parallel to the surface. This is the most common type of landslide, slip or debris fall. The plane of failure is	Frequently 0.5 metres or less below surface	**Planar sliding (translational landslide or**	Reinforce, Anchor, Catch,

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

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

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

FUNCTION*	CIVIL ENGINEERING TECHNIQUE	BIO-ENGINEERING TECHNIQUE	COMBINATION OF BOTH
Catch	Catch walls	Contour grass lines or brush layers	Catch wall with densely planted shrubs

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

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

PHASE	STEP	ACTION TO BE TAKEN	LOCATION
PLANNING	1	Make an initial plan of the year's works	Office

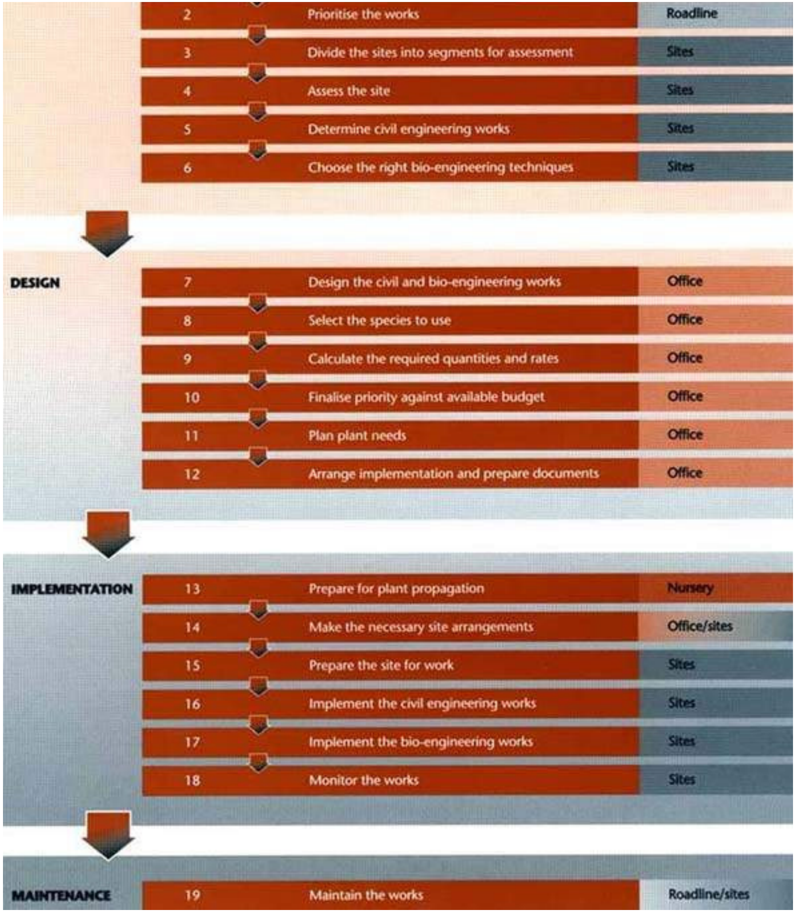


Figure 1.3: Flow chart to show the progression of the steps for slope stabilisation

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

1.2 Steps for the stabilisation of slopes

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

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

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

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

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

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

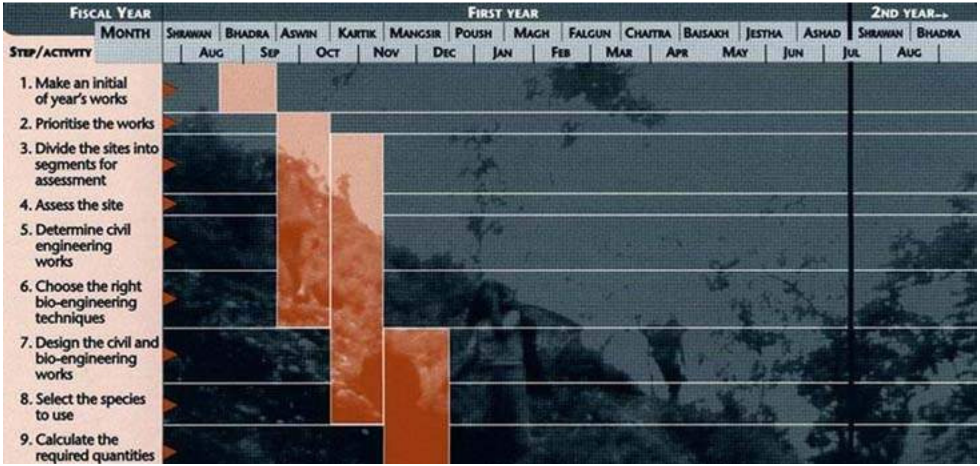
Support a soil mass by buttressing. On a large scale, a retaining wall or the roots of large plants (and their stems once they have caught some debris) such as big bamboo clumps

can buttress a soil mass. On a micro scale individual large stones or smaller vegetation perform this function.

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

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

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



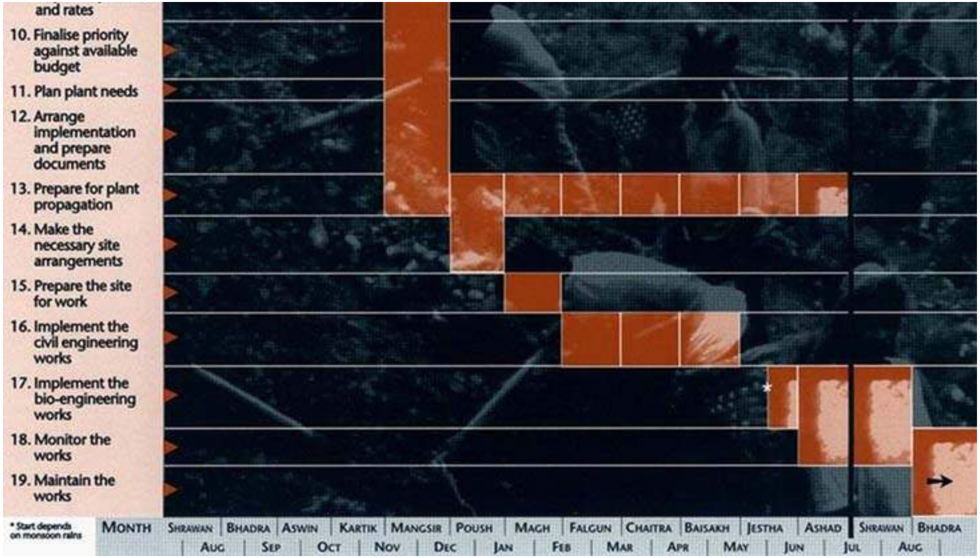


Figure 1.4: Summary calendar of civil and bio-engineering works

Step 1: Make an initial plan

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

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

- **seed collection, which starts in Mangsir for many species;**
- **civil engineering works, which must be complete before the rains start in Jestha;**

and

- **site planting, which usually starts in late Jestha or Ashad, as soon as the rains are reliable.**

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

Step 2: Prioritise the works

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

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

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

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

EXPECTED CONSEQUENCE IF THE SITE IS NOT TREATED	PRIORITY RATING
Slope movement threatens houses	Priority 1 (i.e. very high priority)
Slope movement threatens complete loss of road	Priority 2
Slope movement threatens partial loss of road	Priority 3

Slope movement threatens complete road blockage	Priority 3
Debris may fall on top of pedestrians or vehicles and cause injury	Priority 3
Slope movement threatens loss of productive farmland	Priority 4
Slope movement threatens blockage of drains	Priority 4

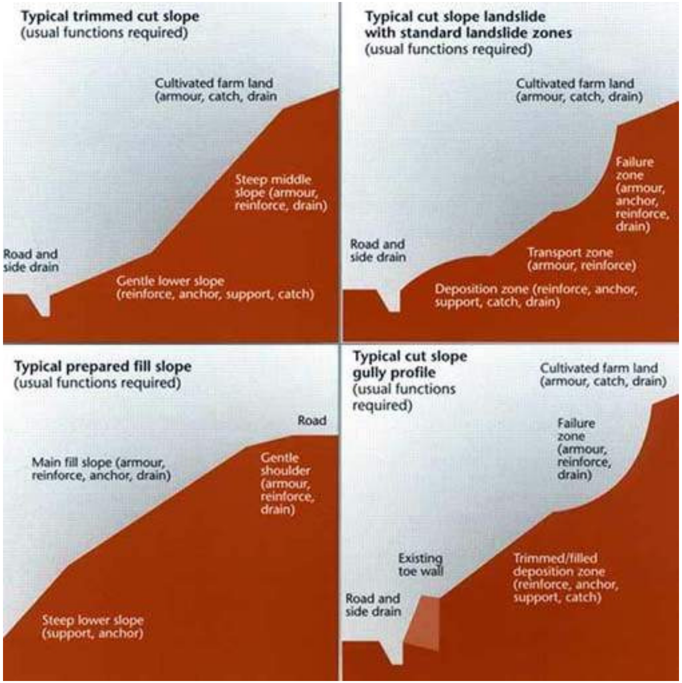


Figure 1.6: Typical slope segments, showing patterns of material movement

Step 3: Divide the site or slope into segments

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

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

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

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

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

Careful site inspection Is essential for successful stabilisation

Figure 1.7: Common types of erosion and slope failure

MECHANISM*	DESCRIPTION	DEPTH
Erosion on the surface.	**Rills** and gullies form in weak, unprotected surfaces. **Erosion** should also be expected on bare or freshly prepared slopes.	Usually in the top 0.1 metre, but can become deeper if not controlled.
Gully erosion	Gullies that are established in the slope continue to develop and grow bigger. Large gullies often have small landslides along the sides.	Usually in the top 0.5 metre, but can become deeper if not controlled.
Planar sliding (translational landslide or	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	Frequently 0.5 metre or less below surface (or

debris slide).	straight, depending on site conditions. It may occur on any scale.	along a local discontinuity).
Shear failure (rotational landslide).	Mass slope failure on a deep, curved slip plane. Many small, deep landslides are the result of this process. Large areas of subsidence may also be due to these.	Usually > 1.5 metres deep.
Slumping or flow of material when very wet.	**Slumping** or flow where material is poorly drained or has low cohesion between particles and liquefaction is reached. These sometimes appear afterwards like planar slides, but are due to flow rather than sliding. The resulting debris normally has a rounded profile.	Frequently 0.5 metre or less below surface.
Debris fall or collapse.	Collapse due to failure of the supporting material. This normally takes the form of a rock fall where a weaker band of material has eroded to undermine a harder band above. These are very common in mixed Churia strata.	0.5 to 2 metres in road cuts; deeper in natural cliffs.
Debris flow	In gullies and small, steep river channels (bed gradient usually more than 15°), debris flows can occur following intensive rain storms. This takes the form of a rapid but viscous flow of liquefied mud and debris.	The flow depth is usually 1 to 2 metres deep.

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

Step 4: Assess the site

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

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

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

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

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

Figure 1.8: The main physical factors affecting slopes

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

Erosion and failure processes

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

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

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

Other factors

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

Slope angle(s)

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

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

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

Slope length

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

Material drainage

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

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

Segment moisture

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

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

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

Altitude

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

Figure 1.10: Environmental factors indicating site moisture characteristics

SITE MOISTURE FACTOR	TENDENCY TOWARDS DAMP SITES	TENDENCY TOWARDS DRY SITES
Aspect	Facing N, NW, NE and E	Facing S, SW, SE and W
Altitude	Above 1 500 metres; particularly above 1 800 metres	Below 1 500 metres; deep river valleys surrounded by ridges
Topographical location	Gullies; lower slopes; moisture accumulation and seepage areas	Upper slopes; spurs and ridges; steep rocky slopes
Regional rain effects	Eastern Nepal in general; the southern flanks of the Annapurna Himal	Most of Mid Western and Far Western Nepal
Rain shadow effect	Sides of major ridges exposed to the monsoon rain-bearing wind	Deep inner valleys; slopes sheltered from the monsoon by higher ridges to the south
Stoniness and soil moisture holding capacity	Few stones; deep loamy* and silty soils	Materials with a high percentage volume of stones; sandy soils and gravels
Winds	Sites not exposed to winds	Large river valleys and the Terai
Dominant vegetation	*e.g.* amliso, nigalo, bans, chilaune, katus, lali gurans, utis	*e.g.* babiyo, khar, dhanyero, imili, kettuke, khayer, salla

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

Figure 1.11: Assessing the requirements for civil engineering treatments

QUESTION	FUNCTIONAL IMPLICATION	ACTION IF THE ANSWER IS "YES"	USE OF BIO-ENGINEERING
Is the slope segment or the whole site subject to a deep-seated (>1 metre depth) shear (rotational) failure?	Major reinforcing, anchoring or physical support required.	If the failure plane can be identified, use conventional civil retaining walls to support the toe. Alternatively, it may be possible to remove weight from higher up on the slope by heavy trimming.	Bio-engineering measures will mainly be used to armour backfill and foundation areas. If trimming is carried out, bio-engineering measures will be needed to armour the new bare surfaces.
Is the slope segment very long (greater than about 30 metres), steep and in danger of a mass failure below the surface?	Reinforcing or physical support is required. Armouring is also required. Bio-engineering measures alone may be adequate, but where a large volume of surface runoff is possible, physical structures are also necessary.	If suitable foundations are available, use retaining walls to break the slope into smaller, more stable lengths. Some other kind of physical scour check should be used, such as wire	Bio-engineering measures must be designed to reinforce and armour the slope between the physical structures.

		bolster cylinders.	
Is the foot of the slope undermined, threatening higher segments or the whole Slope above?	Strong physical support is required. Bio-engineering measures will enhance civil structures.	Investigate the necessity of building revetment, toe or prop walls.	Bio-engineering measures will mainly be used to armour backfill and foundation areas.
Is there a distinct overhang or are there large boulders poorly supported by a soft, eroding band?	Localised physical support or anchoring are required. Support can be given using a civil structure.	Consider prop walls or **dentition** to support the overhang.	The direct seeding of shrubs on fragmented rocky slopes can provide anchorage.
Does the slope segment have a rough surface; or is it covered in loose debris; or is it a fractured rocky slope; or does it have any very steep or overhanging sections, however small?	Armouring is required, but only after the slope has been altered to stop it shedding loose material.	Trim the slope as far as possible to attain a smooth, clean surface with a straight profile in cross-section.	The trimmed slope will need to be armoured afterwards by the appropriate bio-engineering measure.
Is there water seepage, a spring or groundwater on the site, or a danger of mass slumping after heavy rain?	Deep drainage is required.	Investigate the need for a drainage system involving french or other sub-surface drains, depending on site conditions.	Deep drains can be enhanced by surface bio-engineering systems (*e.g.* downslope planted grass lines).
Is the slope made up of poorly	Techniques used on this sort	There is a danger	An appropriate

drained material, with a high clay content?	of material must be designed to drain rather than accumulate moisture.	of shallow slumping. Investigate the need for a surface drainage system.	bio-engineering system (*e.g.* downslope planted grass lines) is often adequate on its own.
Is the site a major gully, subject to occasional erosive torrents of water?	Major drainage is already present; heavy armouring is required.	Use masonry check dams to reduce the **scouring** effect.	Between the check dams, use large bamboo planting, live check dams or vegetated stone pitching.

Step 5: Determine civil engineering works

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

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

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

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

How to use the flow chart in Figure 1:12 **There are two methods: either** **1. Use it as a prescriptive system to determine the treatments required, based on the site assessment described in step 4; or** **2. If you have already determined a treatment, use it to check that your choice is suitable against normal practice.**

Step 6: choose the right bio-engineering techniques

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

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

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

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

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

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

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

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

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

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

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

Figure 1.12: Choosing a bio-engineering technique

START (a) SLOPE ANGLE	**→(b) SLOPE LENGTH**	**→ (c) MATERIAL DRAINAGE**	**→ (d) SITE MOISTURE**	**→ (e) PREVIOUS/POTENTIAL PROBLEMS ‡**	**→(f) FUNCTIONS REQUIRED**	**→ (g) TECHNIQUE(S)**
> 45°	> 15 metres	Good	Damp	Erosion slumping	Armour, reinforce drain	**Diagonal grass lines**
			Dry	Erosion	Armour, reinforce	**Contour grass lines**
		Poor	Damp	Slumping, erosion	Drain, armour, reinforce	**1 Downslope grass lines and vegetated stone pitched rills** or 2 Chevron grass lines and vegetated stone pitched rills
			Dry	Erosion, slumping	Armour, reinforce dram	**Diagonal grass lines**
	<15 metres	Good	Any	Erosion	Armour, reinforce	**1 Diagonal grass lines** or

						2 Jute netting and randomly planted grass
		Poor	Damp	Slumping, erosion	Drain, armour, reinforce	**1 Downslope grass lines** or 2 Diagonal grass lines
			Dry	Erosion, slumping	Armour reinforce drain	**1 Jute netting and randomly planted grass** or 2 Contour grass tines or 3 Diagonal grass lines
30° - 45°	>15 metres	Good	Any	Erosion	Armour, reinforce, catch	**1 Horizontal bolster cylinders and shrub/tree planting** or 2 Downslope grass lines and vegetated stone pitched rills or 3 Site grass seeding, mulch and wide mesh jute netting

		Poor	Any	Slumping, erosion	Dram, armour, reinforce	**1 Herringbone bolster cylinders & shrub/tree planting** or 2 Another drainage system and shrub/tree planting
	<15 metres	Good	Any	Erosion	Armour, reinforce, catch	**1 Brush layers of woody cuttings** or 2 Contour grass lines or 3 Contour fascines or 4 Palisades of woody cuttings or 5 Site grass seeding, mulch and wide mesh jute netting
		Poor	Any	Slumping, erosion	Dram, armour, reinforce	**1 Diagonal grass lines** or 2 Diagonal brush layers or

						3 Herringbone fascines and shrub/tree planting or 4 Herringbone bolster cylinders & shrub/tree planting or 5 Another drainage system and shrub/tree planting
< 30°	Any	Good	Any	Erosion	Armour, catch	**1 Site seeding of grass and shrub/tree planting** or 2 Shrub/tree planting
		Poor	Any	Slumping, erosion	Drain, armour, catch	**1 Diagonal lines of grass and shrubs/trees** or 2 Shrub/tree planting
	<15 metres	Any		Erosion	Armour catch	**Turfing and shrub/tree planting**
	Base of any slope			Planar sliding or	Support	**1 Large**

	Base of any slope	Planar sliding or shear failure	Support, anchor, catch	**1 Large bamboo planting** or 2 Large tree planting

Special conditions

Any *	Any*	Any*	Any*	Planar sliding, ear failure	Reinforce, anchor	**Site seeding of shrubs/small trees †**
> 30°	Any	**Any rocky material**		Debris fall	Reinforce, anchor	**Site seeding of shrubs/small trees**
Any loose sand		Good	Any	Erosion	Armour	**Jute netting and randomly planted grass**
Any rato mato		Poor	Any	Erosion, slumping	Armour, drain	**Diagonal lines of grass and shrubs/trees**
Gullies < 45°	**Any gully**			Erosion (major)	Armour, reinforce, catch	**1 Large bamboo planting** or 2 Live check dams or 3 Vegetated stone pitching

*** Possible overlap with parameters described in the rows above. † May be required in combination with other techniques listed on the rows above. ‡ Only the common potential problems listed in Figure 1.7 are given here. 'Any rocky material' is defined as material into which rooted plants cannot be planted, but seeds can be inserted in holes made with a steel bar. 'Any loose sand' is defined as any slope in a weak, unconsolidated sandy material. Such materials are normally river deposits of recent geological origin. 'Any rato mato' is defined as a red soil with a high clay**

content. It is normally of clay loam texture, and formed from prolonged weathering. It can be considered semi-lateritic. Techniques in bold type are preferred. Chevron pattern: <<<<< (like a sergeant's stripes). Herringbone pattern: ←←←←← (like the bones of a fish).

(g) Techniques

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

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

Step 7: Design the civil and bio engineering works

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

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

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

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

Step 8: Select the species to use

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

Function/technique

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

Propagation

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

Site suitability

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

- **Temperature. This is very closely related to altitude for most of Nepal. In choosing the species, therefore, the site altitude measured in step 4 is used.**

- **Moisture. This is very difficult to quantify. It was assessed in step 4 for the site and classed as one of wet, moist, dry or very dry. This is now used to choose the species.**

- **Nutrients. The main species used in bio-engineering are all tolerant of very poor soils. Therefore the nutrition factor can be ignored at this stage.**

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

Figure 1.13: Bio-engineering techniques and appropriate plant classes

TECHNIQUES	**PLANT CLASS TO USE**	**PACE REFERENCE TO FIGURE 1.14**	
Planted grass lines (all configurations) and vegetated stone pitching gully beds	Grasses grown from slip/rhizome cuttings	page	28
Brush layers, palisades, live check dams, fascines and vegetated stone pitching walls	**Shrubs** */ small trees grown from hardwood cuttings	page	30
Large bamboo planting	Large bamboos	page	33
Site seeding with grass	Grasses grown from seed	page	29
Turfing	Small **sward** grasses	page	29
Site seeding with shrubs/small trees	Robust shrubs/small trees grown from seeds	page	32

Shrub/small tree planting	Shrubs/small trees (grown from seeds/polypots)	page	31
Large tree planting	Large trees (grown from seeds/polypots)	page	31

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

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

Planted grass lines (all configurations) and vegetated stone pitching gully beds
These grasses are grown from slip or rhizome cuttings

MOISTURE	WET	MOIST	DRY	VERY DRY
ALTITUDE		**Grasses**		
2500 - 2000 m	Padang bans	Padang bans	Tite nigalo bans	
	Tite nigalo bans	Phurke		
		Tite nigalo bans		
2000 - 1500 m	Amliso	Amliso	Amliso	Babiyo
	Kans	Babiyo	Babiyo	Kans
	Katara khar	Kans	Kans	Khar
	Padang bans	Katara khar	Katara khar	
	Phurke	Khar	Khar	
	Tite nigalo bans	Padang bans	Phurke	

		Phurke	Tite nigalo bans	
		Tite nigalo bans		
1500 - 1000 m	Amliso	Amliso	Amliso	Babiyo
	Kans	Babiyo	Babiyo	Dhonde
	Katara khar	Dhonde	Dhonde	Kans
	Khus	Kans	Kans	Khar
	Phurke	Katara khar	Katara khar	Narkat
	Sito	Khar	Khar	
	Tite nigalo bans	Khus	Khus	
		Narkat	Narkat	
		Phurke	Phurke	
		Sito	Sito	
		Tite nigalo bans		
1000 - 500 m	Amliso	Amliso	Amliso	Babiyo
	Kans	Babiyo	Babiyo	Dhonde
	Katara khar	Dhonde	Dhonde	Kans
	Khus	Kans	Kans	Khar
	Phurke	Katara khar	Katara khar	Narkat
	Sito	Khar	Khar	
		Khus	Khus	
		Narkat	Narkat	
		Phurke	Phurke	
		Sito	Sito	
500 m - Terai	Amliso	Amliso	Amliso	Babiyo

500 m - Terai	Amliso	Amliso	Amliso	Babiyo
	Kans	Babiyo	Babiyo	Dhonde
	Katara khar	Dhonde	Dhonde	Kans
	Khus	Kans	Kans	Khar
	Sito	Katara khar	Katara khar	Narkat
		Khar	Khar	
		Khus	Khus	
		Narkat	Narkat	
		Sito	Sito	

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

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

Species for grass seeding and turfing

Moisture	**Wet**		**Moist**		**Dry**		**Very dry**	
Altitude	**Clump grasses (for seeding)**	**Small sward grass (for turfing)**	**Clump grasses (for seeding)**	**Small sward grass (for turfing)**	**Clump grasses (for seeding)**	**Small sward grass (for turfing)**	**Clump grasses (for seeding)**	**Small sward grass (for turfing)**
2500 - 2000 m								
2000	Kans	Dubo	Babiyo	Dubo	Babiyo	Dubo	Babiyo	

2000 -	Kans	Dubo	Babiyo	Dubo	Babiyo	Dubo	Babiyo	
1500 m	Katara khar		Kans		Kans		Kans	
	Phurke		Katara khar		Katara khar		Khar	
			Khar		Khar			
			Phurke		Phurke			
1500-	Kans	Dubo	Babiyo	Dubo	Babiyo	Dubo	Babiyo	
1000m	Katara khar		Dhonde		Dhonde		Dhonde	
	Phurke		Kans		Kans		Kans	
	Sito		Katara khar		Katara khar		Khar	
			Khar		Khar			
			Phurke		Phurke			
			Sito		Sito			
1000 -	Kans	Dubo	Babiyo	Dubo	Babiyo	Dubo	Babiyo	
500 m	Katara khar		Dhonde		Dhonde		Dhonde	
	Phurke		Kans		Kans		Kans	
	Sito		Katara khar		Katara khar		Khar	
			Khar		Khar			
			Phurke		Phurke			
			Sito		Sito			

			Sito		Sito			
500m-	Kans	Dubo	Babiyo	Dubo	Babiyo	Dubo	Babiyo	
Terai	Katara khar		Dhonde		Dhonde		Dhonde	
	Sito		Kans		Kans		Kans	
			Katara khar		Katara khar		Khar	
			Khar		Khar			
			Sito		Sito			

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

Step 9: Calculate the required quantities and rates

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

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

Step 10: Finalise priority against available budget

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

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

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

Species for brush layers, palisades, live check dams, fascines and vegetated stone pitching walls
Shrubs/small trees grown from hardwood cuttings

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

	Kanda phul		Kanda phul		Saruwa/			
	Saruwa/		Saruwa/		bihaya			
	bihaya		bihaya		Simali			
	Simali		Simali					
500 m -	Assuro	Dabdabe	Assuro	Dabdabe	Assuro	Dabdabe	Kanda phul	
Terai	Bainsh		Bainsh		Kanda phul			
	Kanda phul		Kanda phul		Saruwa/			
	Saruwa/		Saruwa/		bihaya			
	bihaya		bihaya		Simali			
	Simali		Simali					

*** Required for live check dams only**

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

Step 11: Plan plant needs

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

It is standard practice when planning the growing of plants in a nursery to allow for

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

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

Species for shrub/small tree planting and large tree planting
Shrubs/small trees grown from seeds/polypots

Moisture	**Wet**		**Moist**		**Dry**		**Very dry**	
Altitude	**Shrubs/ small trees**	**Large trees**	**Shrubs/ small trees**	**Large trees**	**Shrubs/ small trees**	**Large trees**	**Shrubs/ small trees**	**Large trees**
2500 -		Lankuri		Gobre salla		Gobre salla		Gobre salla
2000 m		Painyu		Lankuri		Lankuri		
		Rato siris		Rato siris		Rato siris		
		Utis		Utis		Utis		
2000 -		Chilaune	Keraukose	Bakaino	Keraukose	Bakaino	Keraukose	Bakaino
1500 m		Khanyu		Chilaune		Chilaune		Gobre salla
		Lankuri		Gobre salla		Gobre salla		Khanyu
		Painyu		Khanyu		Khanyu		Rani

								salla
		Rato siris		Lankuri		Painyu		
		Utis		Painyu		Rani salla		
				Rani salla		Rato siris		
				Rato siris		Utis		
				Utis				
1500 -	Keraukose	Chilaune	Areri	Bakaino	Areri	Bakaino	Areri	Bakaino
1000 m		Khanyu	Dhanyero	Chilaune	Dhanyero	Chilaune	Dhanyero	Khanyu
		Lankuri	Kanda phul	Khanyu	Kanda phul	Khanyu	Kanda phul	Rani salla
		Painyu	Keraukose	Painyu	Keraukose	Painyu	Keraukose	
		Rato siris	Tilka	Rani salla	Tilka	Rani salla	Tilka	
		Seto siris		Rato siris		Rato siris		
		Utis		Seto siris				
				Sisau				
				Utis				
1000 -	Dhanyero	Khanyu	Areri	Bakaino	Areri	Bakaino	Areri	Bakaino
500 m	Dhusun	Painyu	Dhanyero	Kalo	Dhanyero	Kalo	Dhanyero	Kalo

				siris		siris		siris
	Keraukose	Rato siris	Dhusun	Khanyu	Dhusun	Khanyu	Dhusun	Khanyu
	Tilka	Seto siris	Kanda phul	Painyu	Kanda phul	Khayer	Keraukose	Khayer
		Sisau	Keraukose	Rani salla	Keraukose	Painyu	Tilka	Rani salla
		Utis	Tilka	Seto siris	Tilka	Rani salla		Sisau
				Sisau		Sisau		
500 m-	Dhanyero	Khanyu	Dhanyero	Bakaino	Dhanyero	Bakaino	Dhanyero	Bakaino
Terai	Dhusun	Seto siris	Dhusun	Kalo siris	Dhusun	Kalo siris	Dhusun	Kalo siris
	Keraukose	Sisau	Kanda phul	Khanyu	Kanda phul	Khanyu	Keraukose	Khanyu
	Tilka		Keraukose	Seto siris	Keraukose	Khayer	Tilka	Khayer
			Tilka	Sisau	Tilka	Sisau		

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

Step 12: Arrange implementation and prepare documents

In this step, the question as to whether the works are to be carried out by contract or

through a direct labour force is considered. Both have advantages in different situations. Small-scale works are normally best done through daily-rated labour. Both the government regulations and the private sector in Nepal provide considerable flexibility for either system.

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

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

Species for seeding (on site) with shrubs/small trees or large trees
Robust plants grown from seeds

Moisture	**Wet**		**Moist**		**Dry**		**Very dry**	
Altitude	**Shrubs/ small trees**	**Large trees**	**Shrubs/ small trees**	**Large trees**	**Shrubs/ small trees**	**Large trees**	**Shrubs/ small trees**	**Large trees**
2500 -		Utis*		Gobre salla		Gobre salla		Gobre salla
2000 m				Utis*		Utis*		
2000 -		Khanyu *	Keraukose	Bakaino	Keraukose	Bakaino	Keraukose	Bakaino
1500 m		Utis*		Gobre salla		Gobre salla		Gobre salla
				Khanyu		Khanyu		Khanyu

				Rani salla *		Rani salla *		Rani salla *
				Utis*		Utis*		
1500 -	Bhujetro	Khanyu *	Areri	Bakaino	Areri	Bakaino	Areri	Bakaino
1000 m	Keraukose	Utis *	Bhujetro	Khanyu *	Bhujetro	Khanyu *	Bhujetro	Khanyu *
			Keraukose	Rani salla	Keraukose	Rani salla	Keraukose	Rani salla
				Sisau				
				Utis*				
1000 -	Bhujetro	Khanyu *	Areri	Bakaino	Areri	Bakaino	Areri	Bakaino
500 m	Keraukose	Sisau	Bhujetro	Kalo siris	Bhujetro	Khanyu *	Bhujetro	Khanyu *
		Utis*	Keraukose	Khanyu *	Keraukose	Khayer	Keraukose	Khayer
				Rani salla		Rani salla		Rani salla
				Sisau		Sisau		Sisau
500 m -	Keraukose	Khanyu *	Keraukose	Bakaino	Keraukose	Bakaino	Keraukose	Bakaino
Terai		Sisau		Khanyu *		Khanyu *		Khanyu *

				Sisau		Khayer		Khayer
						Sisau		

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

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

Step 13: Prepare for plant propagation

There are three main considerations in producing plants.

- **Seeds must be collected for the grasses, shrubs and trees that are needed for the programme (step 11). Seed collection times for bio-engineering plants are given in Annex B. The timing of this operation is critical (for obvious biological reasons) and orders must be placed in time. The calculation of the required seed quantities is given in Section 4.**

- **Fill grass slip beds with stock to give sufficient of the right species of plants. Section 4 gives all the details of grass bed preparation and production in nurseries.**

- **Nurseries must be checked to make sure that they have all the resources necessary for the production season. Below about 1200 metres, nurseries should be prepared in Mangsir and Poush (mid November to mid January) for growth and** production to start in Falgun (February). Section 4 provides the details for nursery preparation and production.

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

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

Species for large bamboo planting

Moisture	Wet	Moist	Dry	Very dry
Altitude		**Large bamboos**		
2500 - 2000 m	Kalo bans	Kalo bans	Kalo bans	
2000-1500 m	Choya bans	Choya bans	Kalo bans	
	Kalo bans	Kalo bans	Nibha bans	
	Nibha bans	Nibha bans		
1500 - 1000 m	Choya bans	Choya bans	Mal bans	
	Dhanu bans	Dhanu bans	Nibha bans	
	Kalo bans	Kalo bans	Tharu bans	
	Mal bans	Mal bans		
	Nibha bans	Nibha bans		

	Tharu bans	Tharu bans		
1000 - 500 m	Choya bans	Choya bans	Mal bans	
	Dhanu bans	Dhanu bans	Tharu bans	
	Mal bans	Mal bans		
	Tharu bans	Tharu bans		
500 m - Terai	Dhanu bans	Dhanu bans	Mal bans	
	Mal bans	Mal bans	Tharu bans	
	Tharu bans	Tharu bans		

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Step 14: Make the necessary site arrangements

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

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

If contractors are being employed, it is also necessary to finalise the liability for defect repair if this has not already been established in the contract. It may be necessary to make

special arrangements if different civil engineering works and bio-engineering contractors are being used on the same sites.

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

Step 15: Prepare the site

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

Trim slopes to a straight profile, with a slope angle of between 30° and 60°. (In certain cases the angle will be steeper, but review this carefully in each case.) Never produce a pronounced convex or concave profile; these are prone to failure starting at a steep point. Trim off steep sections of slope, whether at the top or bottom. In particular, avoid convex profiles with an over-steep lower section, since a small failure at the toe can destabilise the whole slope above. Remove all small protrusions and unstable large rocks. Eradicate indentations that make the surrounding material unstable by trimming back the whole slope around them. If removing indentations would cause an unacceptably large amount of work, excavate them carefully and build a prop wall.

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

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

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

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

A carefully prepared site has more chance of reaching stability

Trimming slopes

To trim slopes effectively, follow these steps.

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

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

designed plan section; new retaining wall to be backfilled.

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

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

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

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

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

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

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

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

tidy up.

11 Dispose of excess spoil safely (see below).

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

Spoil disposal

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

- erosion of the spoil tip itself;

- the smothering or removal of natural vegetation. Once stripped of plant and soil cover, slopes usually take three to five years to re-vegetate, and as many as 10 years on steeper and more sterile slopes;

- instability within the spoil material itself, especially when infiltrated by water;

- overloading and resultant failure of the slope;

- **disruption of existing runoff patterns and siltation of water courses and drainage channels;**

- **disruption to agricultural practices.**

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

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

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

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

guidelines:

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

- **on completion, leave spoil benches in their required shape and plant them with grasses, shrubs and trees to encourage maximum stability and resistance to erosion.**

Do not permit the following:

- **tipping of spoil into stream channels other than major rivers, as the increased sediment load will lead to scour and siltation downstream;**

- **tipping of spoil on to slopes where road alignments, housing areas or farmland downslope might be affected;**

- **use of areas of past or active instability and erosion as tip sites, unless they are at least 50 metres from the road;**

- **the discharge of runoff over the loose front edge of a tip bench during or after construction;**

- **tipping of spoil in front of road retaining walls, where impeded drainage could soften the wall foundation.**

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

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

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

	Straight, according to specification.
Brush layers and palisades	Complete, with the right number of cuttings per running metre.
	The right distance between the lines, according to specification.
	Even, with no gaps or dead cuttings.
	Straight, according to specification.
Fascines (minor excavations needed to check)	Complete, with the right number of cuttings per running metre.
	The right distance between lines, according to specification.
	Straight, according to specification.

Step 16: Implement the civil engineering works

Dressing stone during the construction of dry stone dentition

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

(mid February to mid May).

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

Step 17: Implement the bio-engineering works

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

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

Step 18: Monitor the works

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

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

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

Step 19: Maintain the works

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

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

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

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

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

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

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

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

WHERE TO FIND MORE INFORMATION

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

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

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

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

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

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

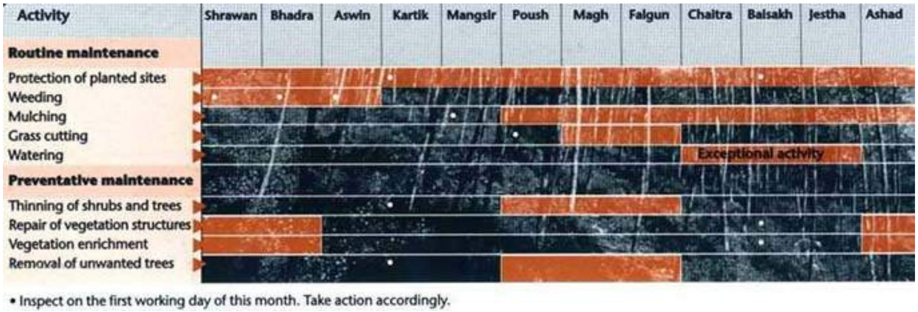

Figure 1.16: Calendar of bio-engineering maintenance operations