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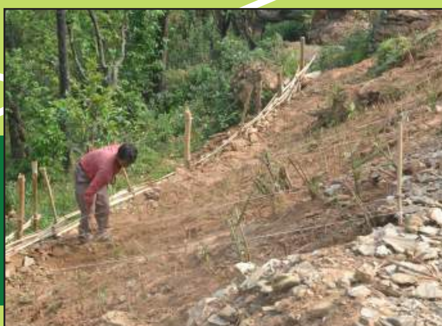
COMMUNITY-BASED BIO-ENGINEERING FOR ECO-SAFE ROADSIDES IN NEPAL



PREFACE

BY DEPARTMENT OF SOIL CONSERVATION AND WATERSHED MANAGEMENT, GOVERNMENT OF NEPAL

Roads are critical lifelines, connecting our rural population with other villages and urban centers for transporting goods to markets, schools, health centers. They form the basis of our country's economic development and social mobility. Over the past decade, the number of roads has increased exponentially from 7330 km in 1990 to 51,000 km in 2013 (DoR, 2013). The total amount spent on rural road construction amounts to NPR 56 billion annually, with communities contributing an estimated 12 % of this total amount (Government of Nepal, 2012). The high amount demonstrates the significance and priority given to connectivity.

The Government of Nepal plan is to expand the road network from 9 km to 15 km per 10,000 people (DoR, 2013). A majority of these roads are constructed using heavy construction equipment with little technical expertise or design. Such roads are commonly wiped out during heavy monsoon rains, requiring costly clearing with heavy equipment. Less known are the environmental, economic and social costs of the " conventionally constructed roads ", using bulldozers with few or no protection or drainage measures. The environmental costs include accelerated sedimentation of river ways and lakes, reducing water quality ; the economic costs are due to the high loss of agricultural land and damage to infrastructure ; and the social costs ensue directly from families losing their agricultural lands. These costs could be significantly reduced by constructing roads using low-cost eco-engineering technology, which combines simple civil engineering structures with the use of locally available deep-rooted grasses and shrubs. Savings from improved rural earthen roads could instead be used for education or livelihoods improvements. However, the bottom line fact is that most community people have little access to knowledge about low-cost bio-engineering practices in rural areas.
The Department of Watershed Management and Soil Conservation has over three decades of expertise and experience with bio-engineering practices in Nepal. Our District Soil Conservation Offices (DSCO) are important extension agents for transmitting this expertise to rural communities. Every year, our District Soil Conservation Offices organize local workshops, training hundreds of community people on how to better manage the negative effects of rural road construction and best practices for soil conservation. This publication, " Community-based Bio-Engineering for Eco-Safe Roads in Nepal " is an important contribution to explaining low cost bio-engineering practices for communities, roads committees and citizen groups. It will be used to support our DSCO officers' on-going extension work to improve the safety and quality of rural earthen roads in Nepal. We are convinced that it will be a well-read addition to our expanding extension materials in this field.

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4

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Layout, design and illustrations :
Sandrine Eberle, University of Lausanne, Switzerland

5

Figure 1

Phewa Lake, Kaski District. The lake is threatened due to high rates of sedimentation which have considerably reduced the lake's surface area.
Photo credit : K. Sudmeier-Rieux, 2013.

Table of contents

Acknowledgements

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1. About the manual

This manual provides guidance to communities and local government agencies on the occurrence, assessment and mitigation of road construction-induced landslides and erosion. By better understanding the interaction between human activity and natural phenomena we are better able to find solutions and increase our coping capacities to face threats. In Nepal, the number of rural roads has quadrupled over the past two decades as many communities are prioritizing access to markets, health care and education. We know that haphazard rural road construction in Nepal is one of the leading causes of slope instabilities and severe erosion, leading to the destruction of agricultural land, loss of lives and property. The current way of building roads requires frequent clearing of roads

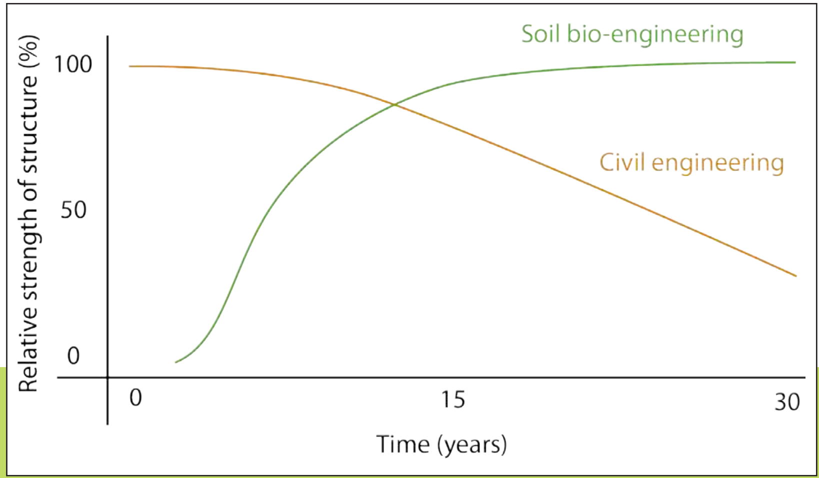


Figure 1A

Comparison of relative strength of civil engineering versus soil bio-engineering structures for slope stabilisation. Modified from Cesvi, 2013.

after each monsoon and is much less cost-effective as compared to a road constructed with proper drainage and low-cost vegetative stabilisation, or bio-engineering. It is true that bio-engineering alone may not suffice to stabilise certain road side failures, while civil engineering alone and especially - improper civil engineering - may also be prone to failure. For small failures, appropriately-scaled civil engineering structures may be required as reinforcement to vegetative stabilization to anchor the soil (e.g. stone walls for reinforcing slope toes with vegetation on slopes). The two are most often very complementary since civil engineering structures often need to be replaced or strengthened after 10 - 15 years, while bio-engineering benefits accrue over time. This manual will only consider small slope failures along roadsides as large failures require large and costly civil engineering structures, which fall outside the scope of community-based stabilisation possibilities.
The practice of bio-engineering is not new in Nepal and in fact many very good manuals exist on this topic [1, 2, 3]. This manual is however intended for local stakeholders,

Figure 1B

Bulging gabion walls six months after construction. Dolakha District. Photo credit : K. Sudmeier-Rieux, 2010.

including communities, civil society groups, NGOs and local government actors and those who are involved in or initiating rural road construction in Nepal. Its purpose is to better understand the processes and factors leading to common, small slope instabilities caused by road construction and low-cost and appropriate solutions. This manual is intended as a " how to guide " to resolving common small-scale slope failures, using a combination of vegetation and simple civil engineering, or bio-engineering alone. The manual will answer the following questions :

- What are common slope-stability problems linked to road construction ?
- What locally appropriate bio-engineering solutions are available for reducing the negative impacts of rural road construction ?

These are questions that we intend to answer in an easy-to-read language, focusing mostly on visual content. We have developed a useful roadside slope failure diagnosis tool and bio-engineering checklist (see Annex I) that can be used by local government and communities for better understanding roadside failure issues and possible, locally appropriate solutions.

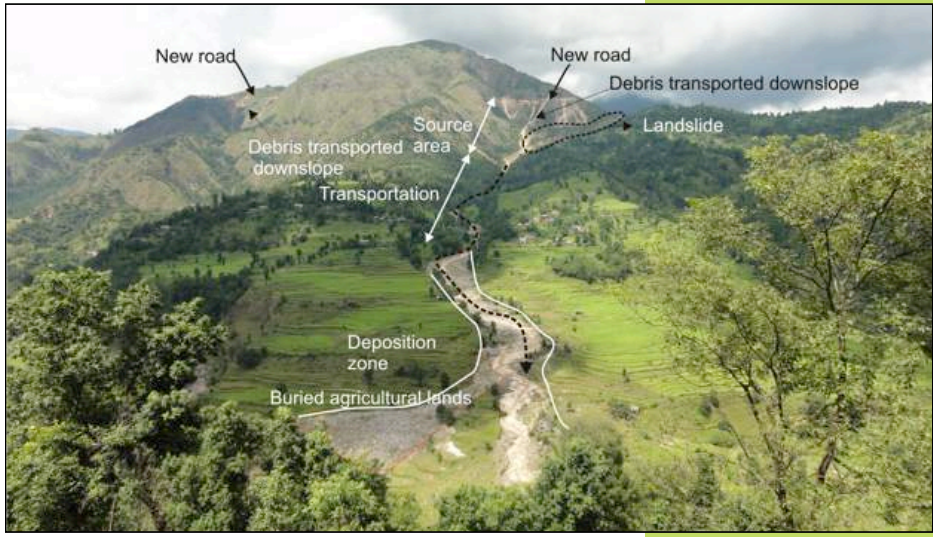
2. INTRODUCTION

ROAD CONSTRUCTION - HUMAN ACTIVITY IN A FRAGILE LANDSCAPE

Steep slopes and weak rocks are subject to erosion and landslides that degrade land and are often caused by heavy rainfall and aggravated by human activities, such as improper terrace building or road construction. The direct effects might be the creation of landslides and gullying, and secondary effects, such as an increase in sediments transported down slopes and in streams should not be neglected (Figure 2). The consequence on water quality of surface reservoirs and on the effectiveness of hydropower plants can be considerable in the near future (e.g. siltation, fish habitats degradation) (Figure 3). Therefore, these problems should not be considered isolated, but need to be part of integrated watershed management strategies.

Figure 2

Landscape view of a rural road construction causing significant slope destablization and reactivation of former slope instabilities. This is leading to debris transported downslope and burying agricultural land in Syangja District, Nepal. Photo credit : I. Penna, 2013.



In the following pages we provide information regarding the most common erosive processes related to road construction in Nepal, the diagnostic features for identifying them, and also a review of sustainable measures to mitigate them. In the last section of the manual, we suggest a field form to easily carry out a first assessment of processes driving erosion, which can be undertaken both by specialist or community members.

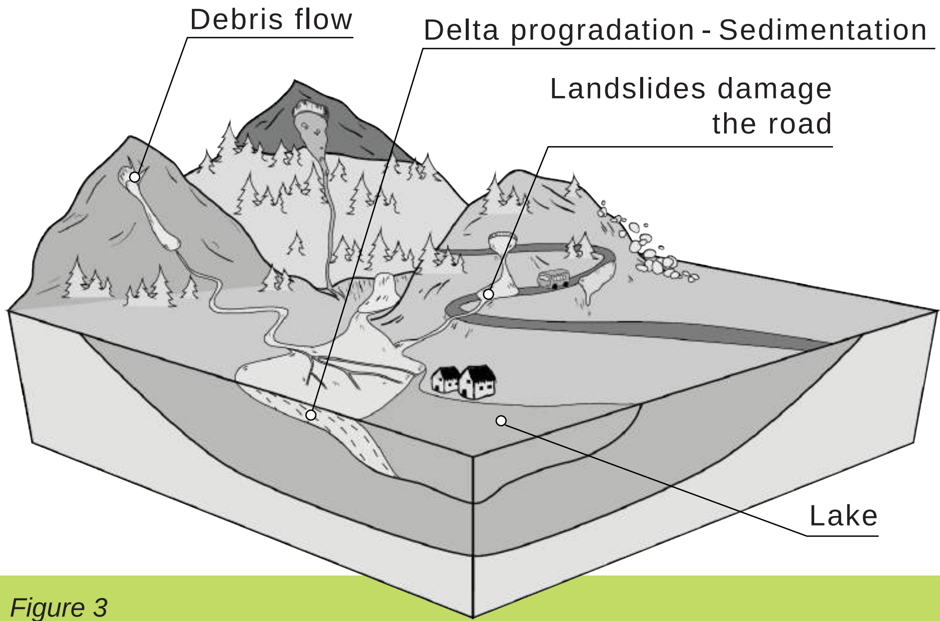


Figure 3

Schematic example of watershed including natural and road-induced processes affecting infrastructure, carrying debris downstream and sediments gradually filling up the lake.
Credit : S. Eberle. Modified from 3rd report on Disaster Management, Government of India.

2.1 Cost of building rural earthen roads : the conventional way versus " eco-safe roads "

The total amount spent on rural road construction amounts to NPR 56 billion annually, with communities contributing an estimated 12 % of this total amount [4]. The high amount demonstrates the significance and priority given to connectivity. Less known are the environmental, economic and social costs of the " conventionally constructed " earthen rural roads, meaning with the use of bulldozers with no consideration for simple bio-engineering techniques.
Over 20 years, the maintenance costs of such roads make their construction more expensive than eco-safe roads, not including the additional damage to agricultural lands by roadsides, which has not been included in this calculation. Table 1 gives average costs of a conventionally constructed earthen road versus an eco-safe road in the middle hills of Nepal, assuming not very rocky soils.

Table 1

Average cost of conventionally constructed rural earthen roads versus eco-safe roads over 20 years in Nepal Middle Hills. Assuming NPR 2013 rates. 1 USD = 97.00 NPR (2013). Based on calculations from UNDP, 2011.

Average cost NPRs per km	Conventional earthen roads	Eco-safe roads
Initial construction	800,000 - 1,500,000	1,500,000 - 2,000,000
Annual maintenance in normal monsoon year	175,000 - 300,000	50,000 - 75,000
Annual maintenance with heavy monsoon conditions	300,000 - 500,000	100,000 - 200,000
20 year (maintenance cost) [1]	4,125,000 - 7,000,000	1,250,000 - 4,000,000
Total (initial costs + 20 year maintenance costs)	4,925,000 - 8,500,000	2,750,000 - 6,000,000

[1] For estimate - out of 20 years it is assumed 5 years of extreme monsoon and the cost has been generalized to fit in all conditions in Nepal

2.2 Identifying problems related to road construction on slopes

The following section will focus on diagnosing the cause of the roadside slope failure, which should follow these main steps (Box 1).

Box 1 : Steps for diagnosis of roadside slope failures and identifying solutions

I. Diagnose the problem

1. Does the road traverse a landslide area ? If there are signs of slope movement, STOP and seek expertise ! Bio-engineering methods described in this manual may not suffice !

2. Is it hill road or valley road ?
- bio-engineering methods can be considered useful for both hill and valley roads that are prone to erosion, keep reading !

3. How was the road constructed ? What is the road gradient ? How steep and how long is it ?
- if it is considered prone to erosion, then you need to consider bio-engineering methods, keep reading !

4. What is the land-use of the area where the road runs through ?
- if there are houses or fields nearby, that can be damaged by erosion, then you need to consider bio-engineering methods, keep reading !

II. Do a site assessment

5. How deep are the soils ? What is the soil moisture ?
- if very deep and moist, your road may be especially subject to failure, keep reading !

6. Are there any water sources (springs, streams, seepage water, etc.) along the road ?
- if yes, they need to be checked in case they cause erosion, keep reading !

7. Is there any road side drainage system ? Where does the drainage go ?
- if no, then lack of drainage can cause many problems, keep reading !

8. Does the road pass through old landslide or visible unstable location (bent trees, cracks in ground) ?
- if yes, your road may be especially subject to failure, keep reading !

III. Identifying solutions

9. Have any road side protection measures been applied ?
- if no protection measures have been applied but you observe any of the above problems, keep reading, we have designed this manual to address many of the above issues.

3. Diagnosing the problem

Natural processes aggravated by road construction

“ 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 field workers 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. 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. These erosion and failure processes must be identified before remedial work can be started ” [1].

Road construction can have a number of (geomorphic) problems and impacts :

• Slope destabilisation : slope cuts which make the slope weaker and create free faces. Removing material from the toe of a past landslide or a creeping area might lead to reactivations or accelerate instabilities.

• Increase of sediment loads downstream : Resulting from materials caused from landslides or erosion, but also because of materials removed during the slope cut, deposited down slope, and wash-out of road fills.

• Increase of run-off : Due to removal of vegetation during road construction.

• Creation of new drainage : Road cutting of a slope might act as new waterway by trapping the run-off and diverting drainage from its natural path. Gully erosion can result from this drainage alteration.

3.1 Landslides

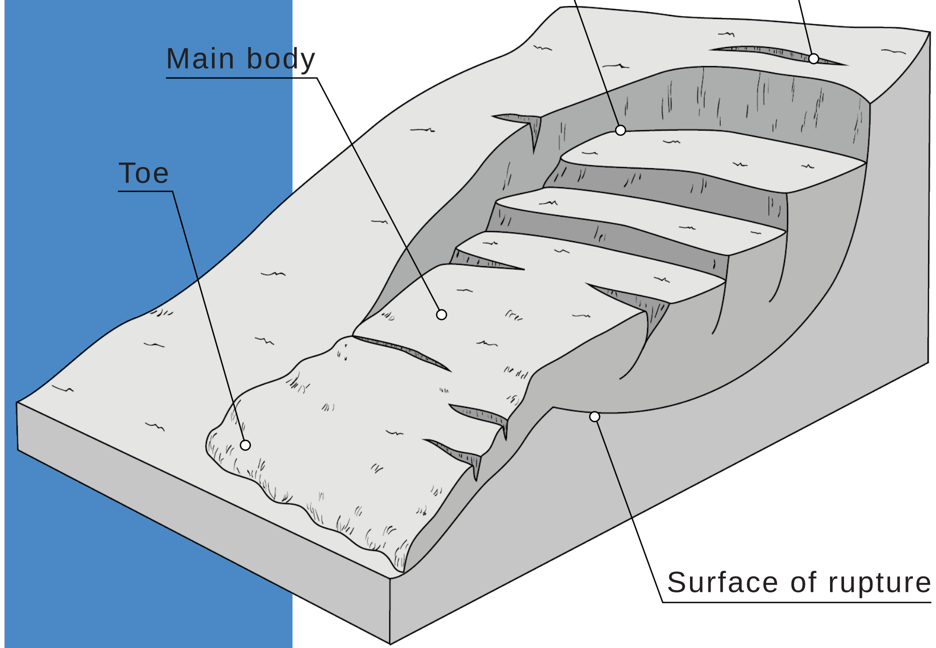
Landslides are downslope movements of rock, debris or soil, moving up to tens of meters per second, and involving from a single boulder up to thousands of cubic metersof materials [5]. They are commonly triggered by prolonged or intense rainfall, snow melting or earthquakes, but human activities also contribute to their occurrence by changing slope gradients such as when we construct a road or deforesting areas for house construction [6, 7]. Landslides can be deep-seated or shallow. Deep-seated landslides require much more structural engineering to be stabilized [6] and will not be covered by this manual (Figure 4A and B).

Figure 4A

Khariswara landslide, triggered by high rainfall event in Dolakha District, Nepal
Photo credit: S. Devkota, 2011.

Figure 4B

Schematic illustration of deep-seated slump-earth flow landslide.
Credit: S. Eberle. Modified from Cruden and Varnes, 1996 [5].



3.2 Shallow landslides - earthflows

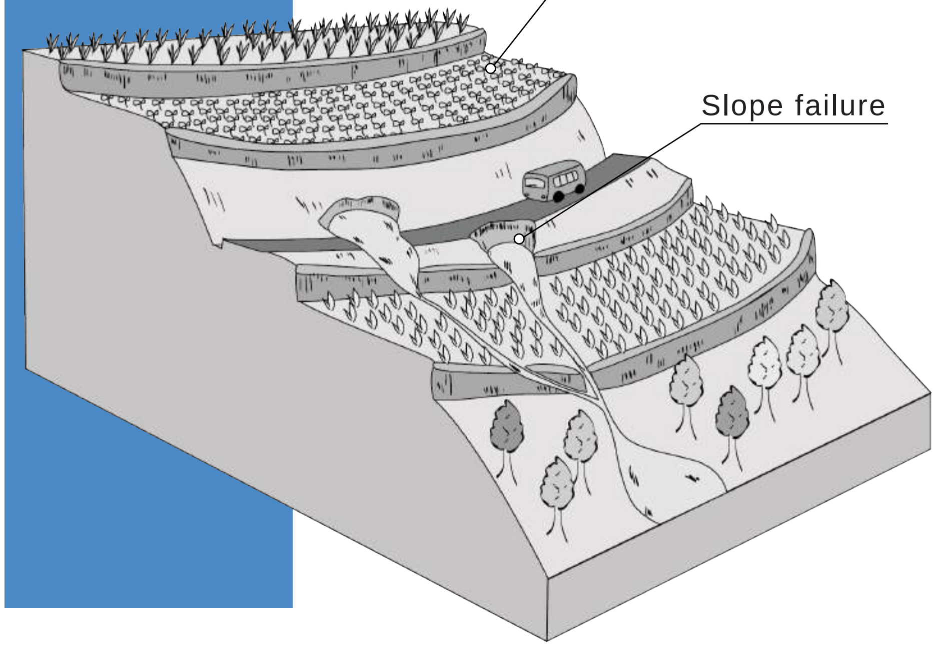
Shallow landslides, involving the first 2 m [8] below the surface (commonly soil or the weathering area of outcrops), are very frequent phenomena in the hillslopes of Nepal. They are mostly triggered by heavy and prolonged rainfall events, [6, 9] and often have additionally been aggravated by some human activity which further fragilised the slope [7, 10]. Initial signs of instability are marked by cracks in the soil or a spring [11, 12, 13]. They can be identified by the presence of a headscarp in the upper part where materials are detached, cracks in the area of transport and a bulge form in the toe of the deposit (Figure 5A and B).

Figure 5A

Roadside instabilities along rural road in Basantapur, Tehrathum District, Nepal.
Photo credit: K. Sudmeier-Rieux, 2009.

Figure 5B

Schematic illustration of shallow landslide caused by road construction.
Credit: S. Eberle



3.3 Rock falls

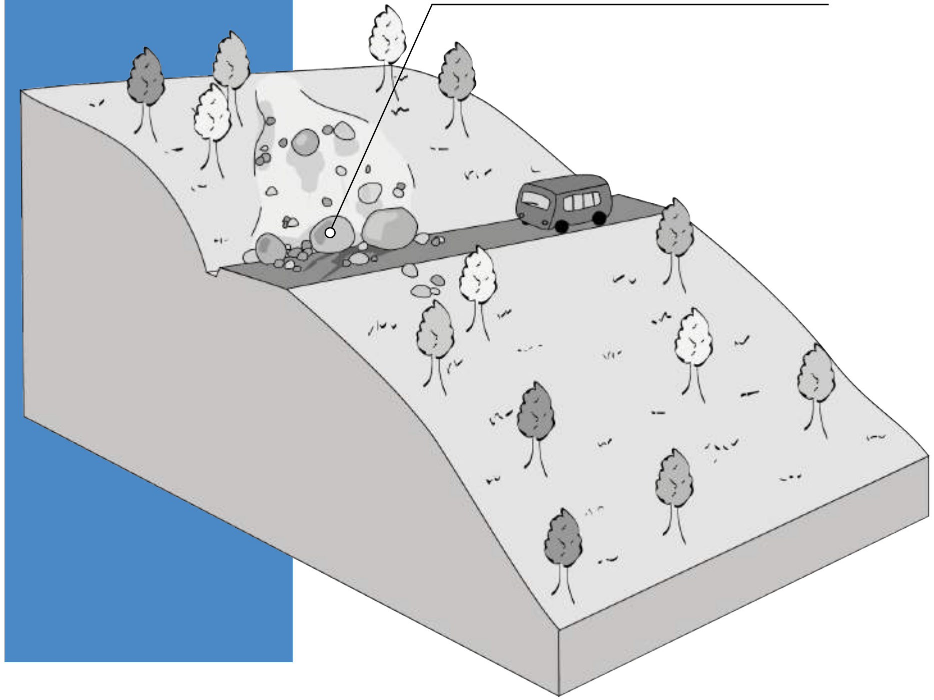
Rock fall involves the detachment from a steep wall of rocks, or slopearea. Preceding the detachment, fractures bounding the blocks start to open, and small blocks might also detach until a major failure occurs [7]. Once the blocks are detached, they move rapidly downslope due to free fall, but also bouncing and rolling [7, 14]. Fractured or block deposits with free faces or "hanging blocks" can be areas of potential rock falls (Figure 6A and B).

Figure 6A

Boulders rolling down from the steep slope, Jiri-Namadi Road, Ramechhap District Nepal.
Photo credit: S. Devkota, 2013.

Figure 6B

Schematic illustration of Boulder/Rock fall
Credit: S. Eberle



3.4 Debris flows

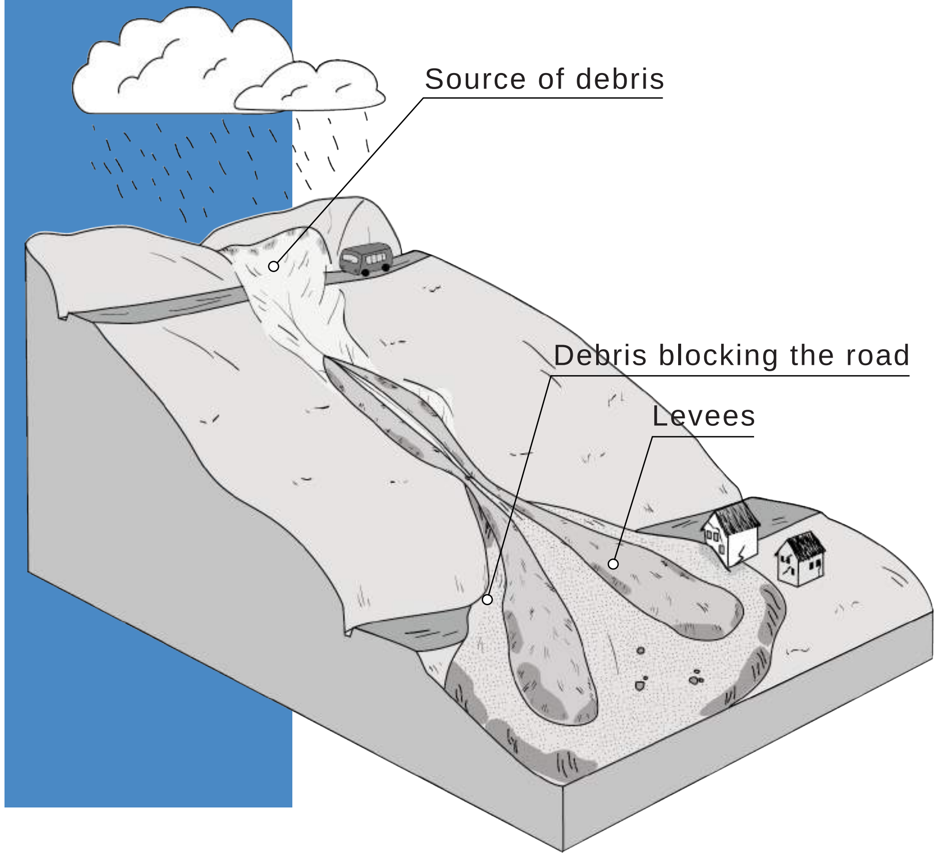
Debris flow involve downslope movements at very high velocities (channelized or not) of debris and water [5, 7]. They occur due to the accumulation of sediments in a source area, which are later remobilized during strong or prolonged rainfall events [15]. They commonly trap material during displacements, for which it is common also to find of the remains of trees in their deposit. They are highly destructive and damages occur due to erosion and burial due to depositional [15]. A debris flow prone area can be recognized by observing how sediments have accumulated, such as a bulge, and whether there are landforms such as lateral levees along channels or rugged fans (Figure 7A and B).

Figure 7A

View of debris flow on steep slope Sindhupalchok District Nepal. Photo credit: S. Devkota, 2013.

Figure 7B

Schematic illustration of debris flow. Credit: S. Eberle



3.5 Water induced (fluvial) erosion

3.5.1 Gullying

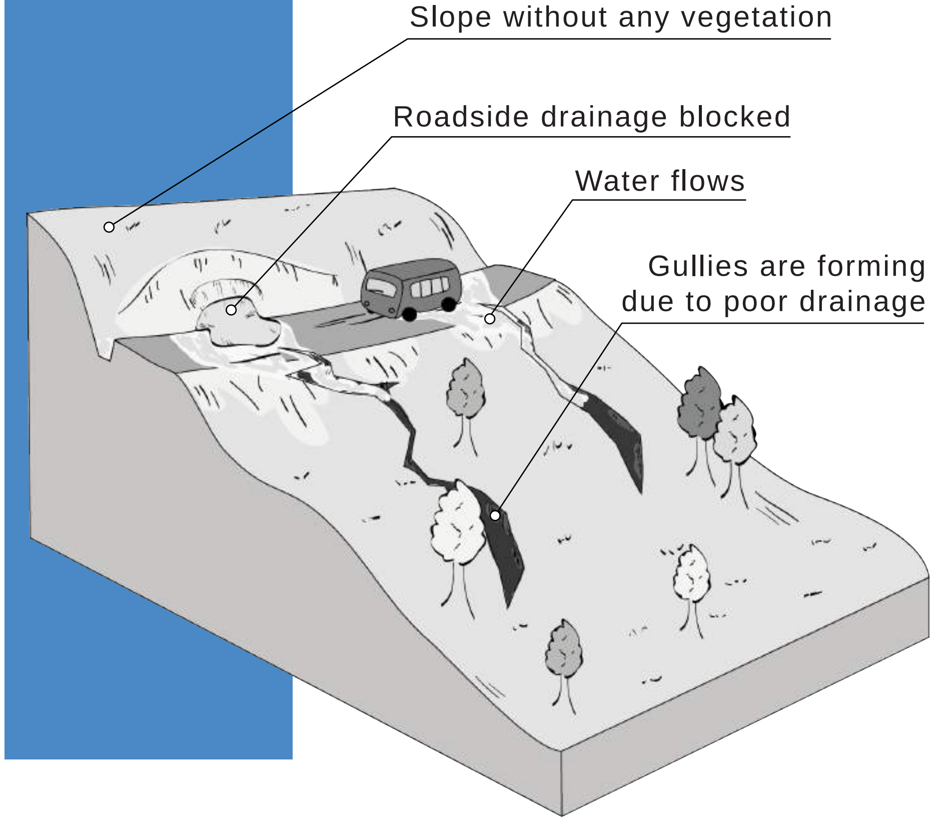
Concentration of run-off on a surface promotes the development of drainage lines called rills. Evolution of erosion along rills gives place to gullies. Generally they show a sharp V- to U-shape profile [16]. The sides of roads and culvert outlets can concentrate large amounts of water leading to gullies if they are not well-designed (Figure 8A and B).

Figure 8A

Gully erosion in Syangja District, Nepal.
Photo credit: S. Devkota, 2014.

Figure 8B

Schematic illustration of road side gully erosion.
Credit: S. Eberle



3.6 Secondary impacts to waterways

3.6.1 River bank erosion

When there is higher rainfall and more sediment flowing down, a stream has to adjust to new conditions. One of the adjustments involves the increase of channel width, which may impact agricultural land. River bankerosion therefore should be controlled (Figure 9A and B).

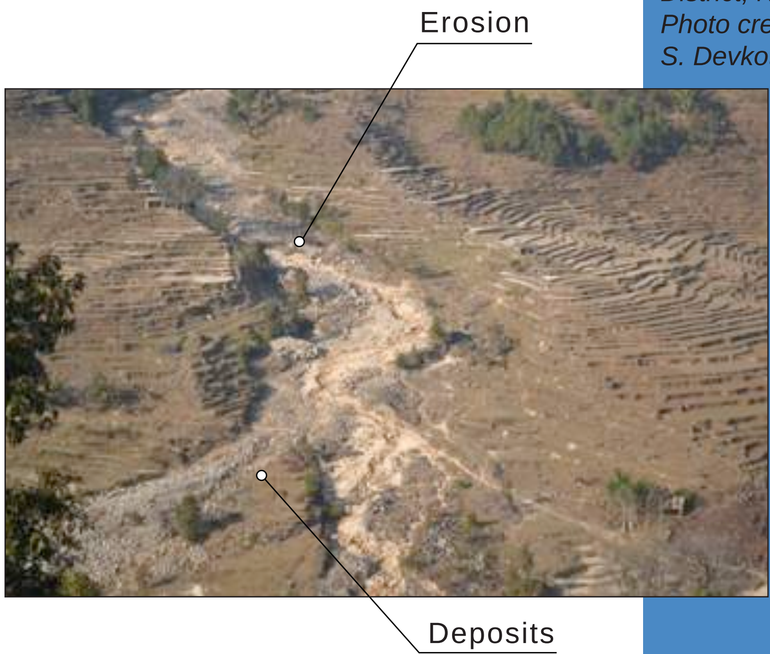
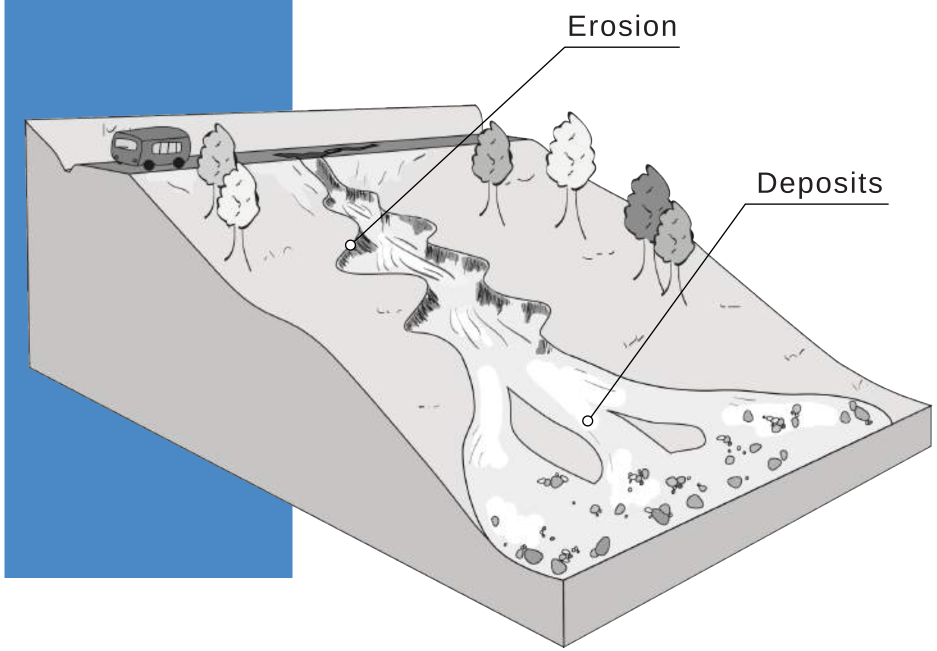


Figure 9A

Lateral erosion of a waterway partially due to road construction in Syangja District, Nepal. Photo credit: S. Devkota, 2014.

Figure 9B

Schematic illustration lateral erosion & fluvial process. Credit: S. Eberle



4. DETERMINING SOLUTIONS

DOING A SITE ASSESSMENT

Once you have identified the main problems creating the roadside failures the next step is to do a site assessment to better understand the following :

Box 2

a. Slope angle(s). 3 classes : < 30º, 30 – 45º, or > 45º.

b. Slope length. 2 classes : < 15 metres or > 15 metres.

c. Material drainage. 2 classes : good or poor.

d. Site moisture. 4 classes : wet, moist, dry or very dry.

e. Altitude. Determine : use an altimeter, map or site drawing.

Source : Modified from Howell, 1999

a. Slope angles. Record the slope angles and assign each segment to one of three classes : < 30º, 30 – 45º, or > 45º. Slopes of less than 30º will need only mild treatment. Those falling in the other two classes will require more substantial stabilization. As slope increases, instability also increases so the understanding of slope steepness is important. A soil slope which is less than 35° is mostly stable unless it is disturbed. However slopes above 35° need precaution and protection from failure. A 35° slope is a medium type slope where people and animal can walk easily. A 50° slope is quite steep as people cannot easily walk across such a steep slope.

b. Slope length can be measured using a tape measure or manually. Longer than 15 meters is considered long and prone to greater risks.

c. Material drainage. Soils with more clay and silts, mudflows (ratomato) slowly draining will be prone to poor drainage.

d. 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 (See Table 2).
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).

e. Altitude. This is an important determinant of temperature ranges for planting of various bio-engineering plant species in Nepal and should always be checked.

Source : Modified from Howell, 1999

See Figure 10 for an overview of the different determinants for deciding on which bio-engineering method to use. See also Annex I.

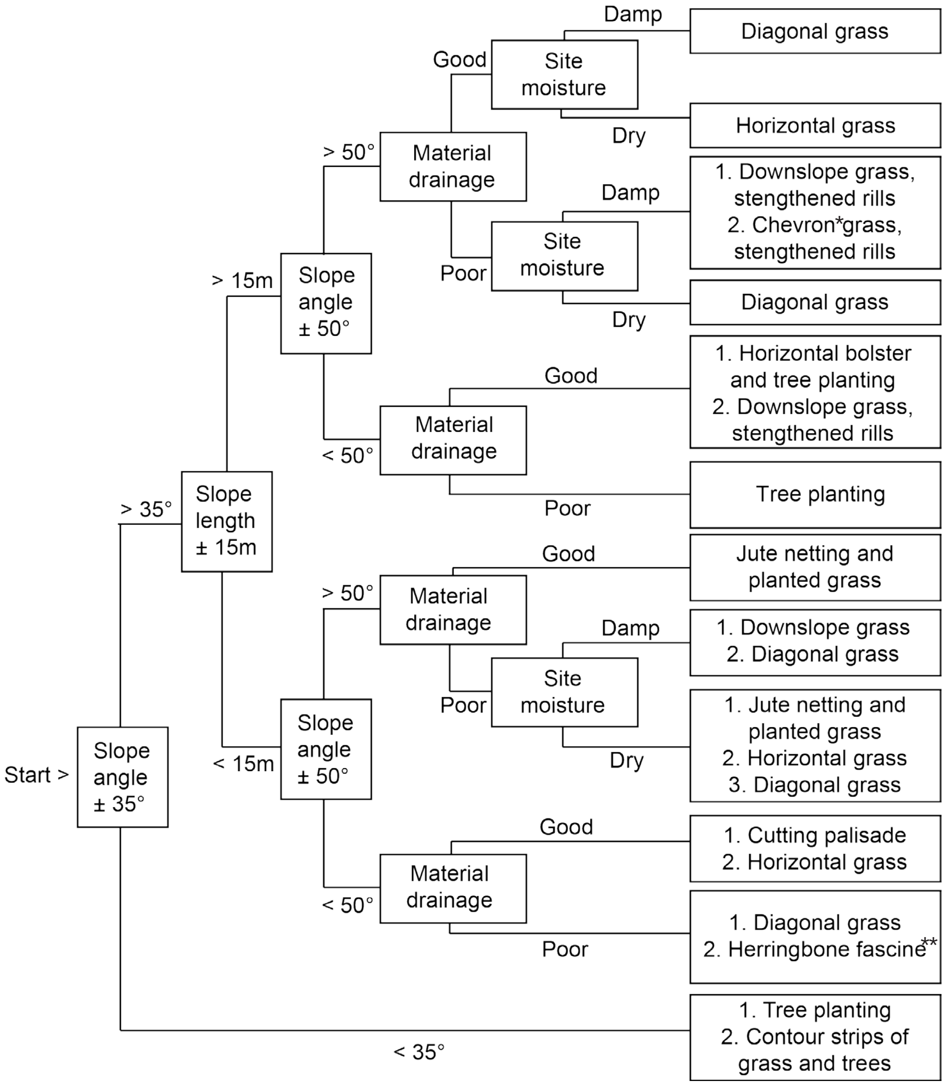


Figure 10

All the above techniques are described in section 5. Identifying solutions. (Source : Howell et al., 1999)
** Chevron is a zigzag pattern.*
*** Herringbone is a diagonal pattern.*

Table 2

Environmental factors indicating site moisture characteristics (Source : Howell, 1999)

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

5. Identifying solutions

Low cost community based solutions for roadside stabilization

5.1 Bio-engineering Techniques for Slope and Soil Protection

Bio-engineering, or the use of vegetation for slope stabilisation, and control of run off and their effects (soil erosion and transportation of sediments), is a cost-effective and locally adapted method along road side slopes, river banks or on cultivated terraces. Bio-engineering methods range from the very simple plantation of appropriate deep-rooted species, to a combination of vegetation and more elaborate civil engineering [17]. Examples include : planting grass lines along contours, vertically or diagonally, turfing, jute netting together with seedling, brush layering, fascines, palisades, wattling, live check dams, bamboo fencing and vegetated stone pitching. In addition to cost effectiveness, advantages beyond slope stabilisation include benefits obtained from vegetation for livelihoods, and inter-cropping. Some of the main requirements for successful bio-engineering include proper roadside drainage to divert heavy run-off from fragile slopes to a safer place, early plantation maintenance to keep weeds from competing with plants and keeping livestock away from slopes [17] (Figure 11A). As there are many different solutions to the various roadside slope failures or to control water run-off, we start by giving some general guidelines for finding solutions, followed by detailed steps for each solution below. If possible, it is best to construct a drainage dike that runs alongside the road while ensuring that the water accumulated here is disposed in a safe place such as a natural waterway (Figure 11B).

Figure 11A

Bio-engineering along roadside in Parbat District, Nepal. Photo credit : S. Devkota, 2014.

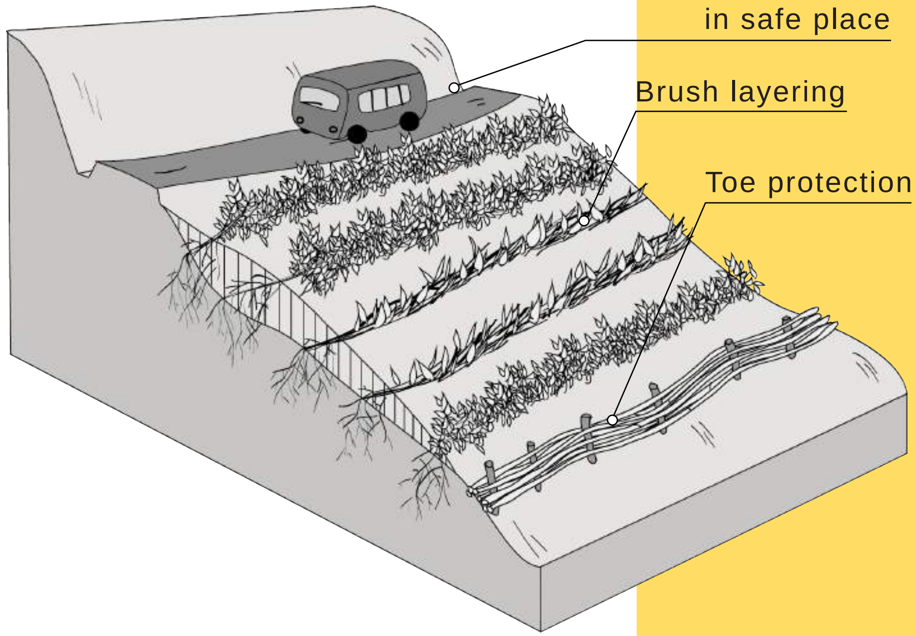


Figure 11B

Schematic illustration of brush layering. Credit : S. Eberle

Figure 12A and B illustrate two common and low cost methods for enabling safe disposal of drainage water. The Figure 12A shows how water can be diverted across the road when there is no possibility of creating drainage ditch along the roadside.The Figure 12B shows how water should be diverted away from a landslide area, or cracked area to avoid triggering the landslide or making it worse. This is known as a stone causeway.

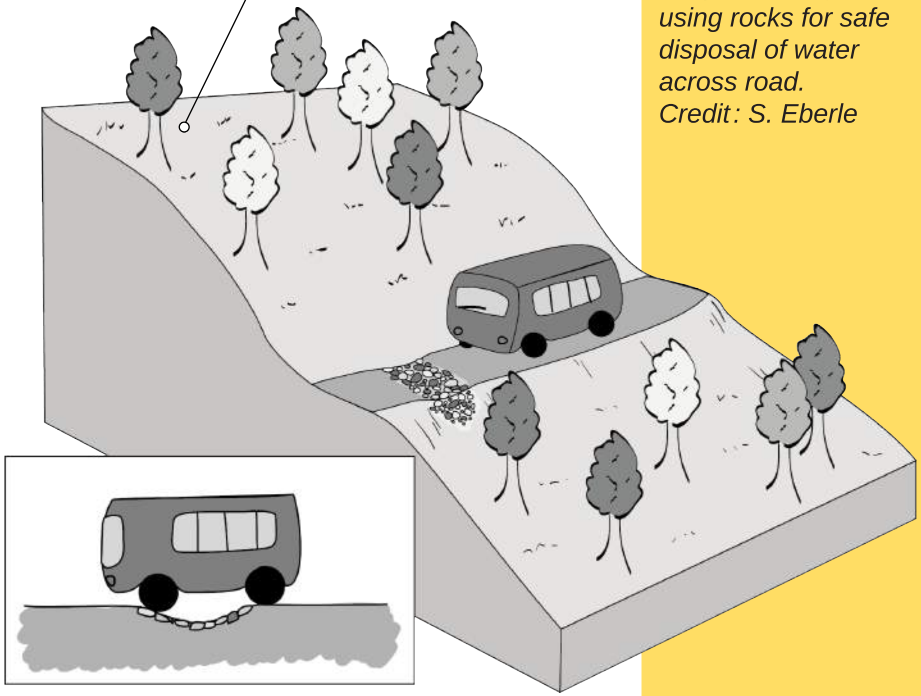


Figure 12A

Simple drainage using rocks for safe disposal of water across road.
Credit: S. Eberle

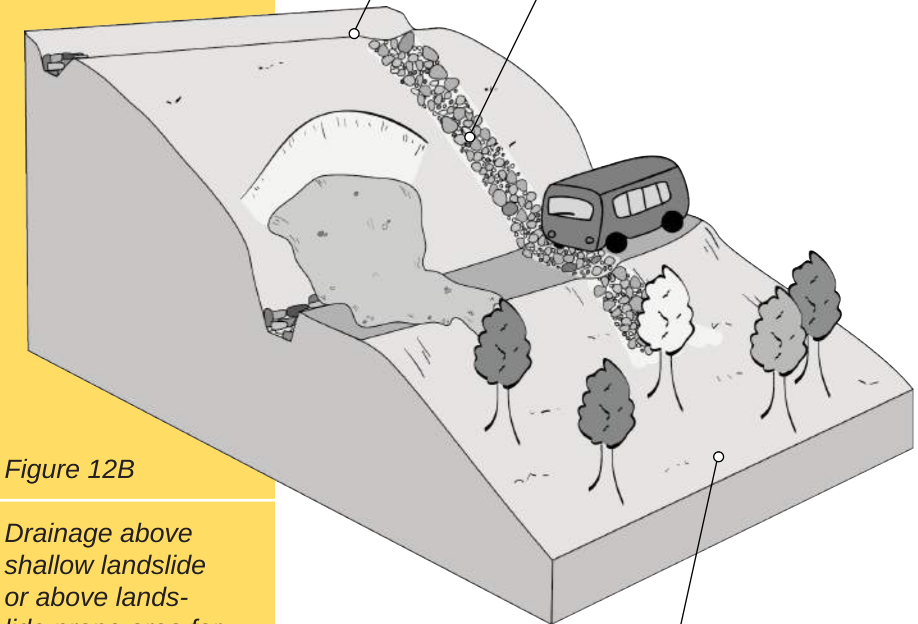


Figure 12B

Drainage above shallow landslide or above lands-lide prone area for shallow landslides and traversing road to divert water away from landslide area.
Credit: S. Eberle

5.2 Bio-engineering techniques to control water run-off (Source : Howell, 1999)

As vehicles compact road surfaces, they become impermeable, thereby accumulating the quantity and velocity of water. Accumulation of water on roads is the primary cause of gully erosion. The first and most important step of any landslide stabilisation project - especially when using bio-engineering along roads - is to see where water is coming from and where it can safely cross a road in order not to create more problems below and above the road. Most common measures include creating small drainage rills across the road while ensuring that there is a stabilised drainage below the road or creating drainage parallel to the roadside and channelizing water to a safer or natural stream downslope (Figure 13A and B). Drainage works can be constructed in a low cost manner using flatter stones or more expensively by cementing drainage areas or by using pipes crossing under roads. Usually it is no use undertaking other measures unless drainage problems have first been resolved. Once the drainage works have been constructed, maintaining the drainage (e.g. removal of debris and sediments) is essential. This includes regular checking of the drainage outlet to ensure that water exiting the drainage is not creating new problems below the outlet.

Figure 13A

Cemented drainage channel, with cemented stone walls to ensure longer lasting drainage. Photo credit : S. Devkota, 2014.

The next section gives " how-to " guidance of the most common problems caused by rural road construction of earthen roads and a number of low-cost bio-engineering solutions (Table 3).

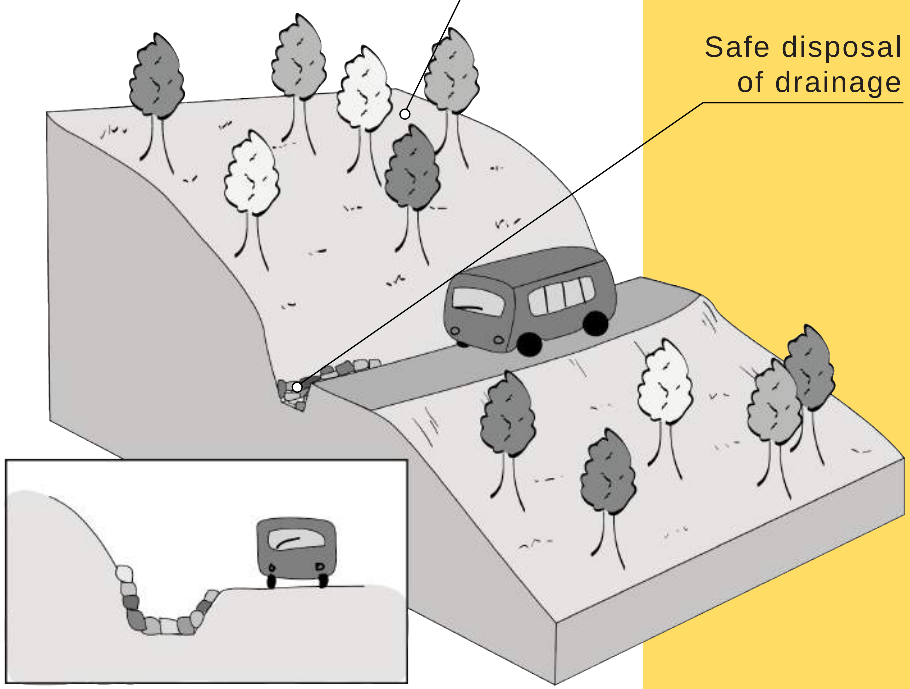


Figure 13B

Schematic illustrations of drainage works. Credit : S. Eberle

Table 3

Rural earthen road common problems and low cost bio-engineering methods described.

Problems	Solutions	
1. Surface erosion Control of run-off		Method 1.1. Turfing
		Method 1.2. Jute netting along with seedlings
		Method 1.3. Grass plantations
		Method 1.4. Facines
2. Gullies		Method 2.1. Live check dams
		Method 2.2. Vegetative stone pitching
3. Shallow landslides	DRAINAGE techniques +	Method 3.1. Palisades
		Method 3.2. Brush layering
		Method 3.3. Gabion walls combined with vegetation
		Method 3.4. Dry stone walls combined with vegetation
4. Secondary impacts on waterways from road construction		Method 4.1. Live check dams combined with vegetation and boulders
5. River bank protection		Method 5.1. Sandbags, bamboo vans & vegetation, if the problem is bigger gabion or stone / boulder retaining wall might be good

The following section gives an overview of most common bio-engineering techniques, the advantages and disadvantages of each, their requirements and suggested plant species. Figure 14 explains the decision-making process for selecting plant species for bio-engineering species. It is especially important to consider "what the people want" and it may be necessary to combine some species that are good for livelihoods (e.g. fodder species) with species that are especially good for bio-engineering and have deep roots. Fortunately in Nepal there are many species that can do both: especially broom grass (amriso / *Thysanolaena maxima*) and bamboo (baas / *Bambusa vulgaris*). See also Annex II.

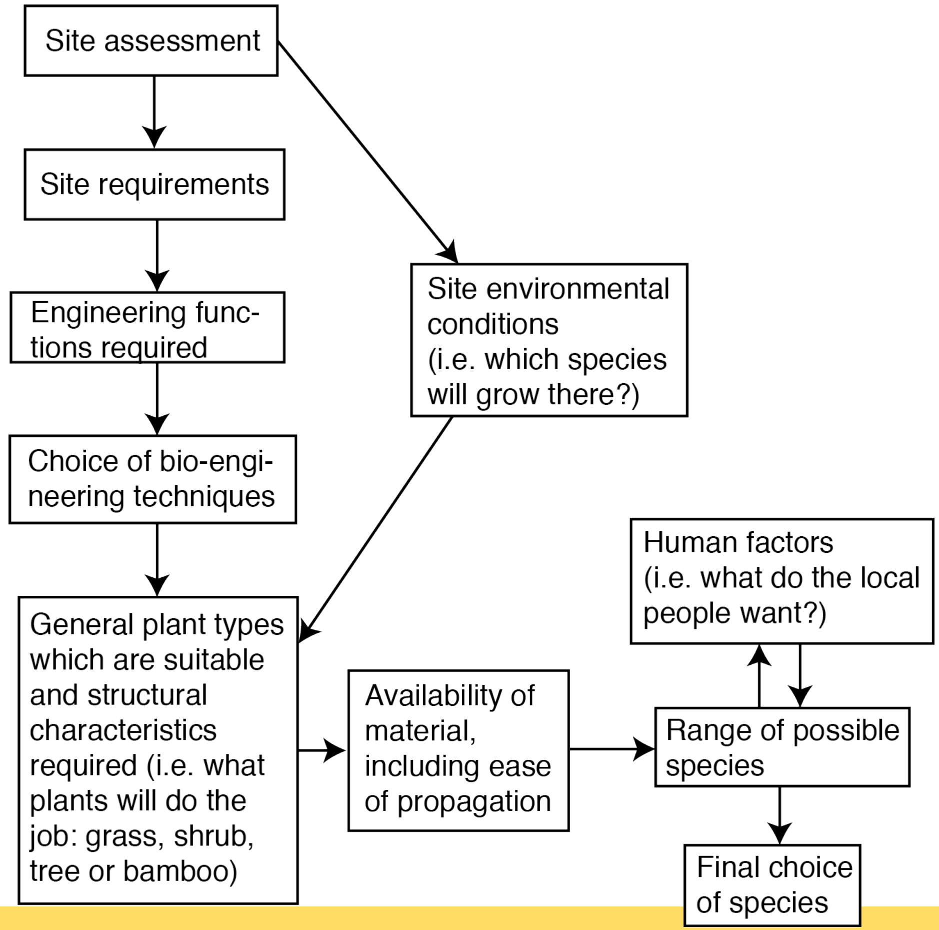


Figure 14

Diagram explaining the process of selecting species for bio-engineering. Source : Modified from Howell, 1999.

Surface erosion – control of run off
(Source : Howell, 1999)

Method 1.1. Turfing : Shallow rooting grass and the soil it is growing in, is placed on the slope. It is normally used on well-drained materials, where there is a minimal risk of slumping [1] (Figure 15).

How-to-steps
1. Check your drainage
2. Check the slope angle (see requirements)
3. Make sure the soil is well-drained
4. Identify a safe place for turf storage before plantation
5. Check available budget
6. Level the surface of the slope / embankment before placing the turf

Requirements
• If the slope or the embankment is gravel filled 50 mm layer of top soil should be laid and compacted [18]
• Slope should be < 30°, for slope > 25° require pegs to anchor the turf (hammer wooden pegs of 300 mm long & 30 mm diameter) in the middle of each turf
• Soil shall be well drained with minimal risk of slumping
• Protect from animals and grass cutting and remove unnecessary weeds
• As far as possible turf should be cut in the same day as it is to be placed ; if this is not possible, it should be kept very moist in a shady place [18]
• Turf shall be of 300 mm square is easy to handle
• Once the slope is covered, compact the turf with wooden hammer and water the turf thoroughly
• For larger area surface drainage (both horizontal and vertical) channel is required

Species : Bermuda Grass (Dubo) : *Cynodondactylon* (L.) Pers.

Advantage
• Useful for newly excavated slope or back fill slopes and embankments to protect from immediate flow of top soil in the presence of water

Function
• Armor, gives a complete instant surface cover

Disadvantages
• Relatively costly
• Creates equal bare areas at the source
• Discontinuity between turf and underlying materials which in extreme conditions can give rise to gradual creep or shallow planer failure
• Chances of animal tramping and grazing

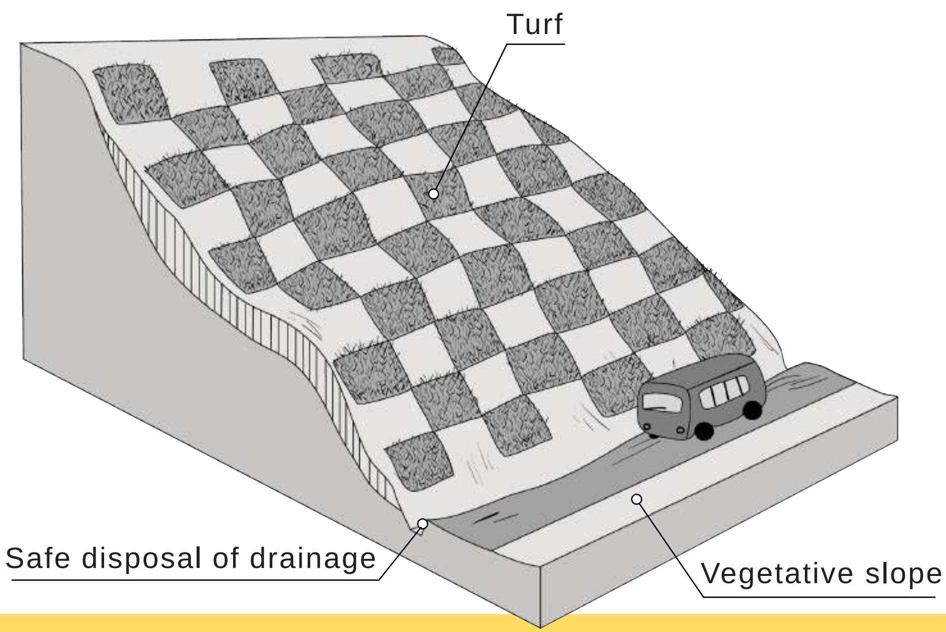


Figure 15

Schematic illustration ofturfing in patches for immediate protection of excavated surfaces.
Credit : S. Eberle

Surface erosion – control of run off
(Source : Howell, 1999)

Method 1.2. Jute netting along with seedlings : Locally made geo-textile of woven jute netting of standard mesh size 40 x 40 mm to protect slope surface and allowing seeds to hold and germinate (Figure 16).

How-to-steps
1. Check your drainage
2. Check the slope angle & length (see requirements)
3. Make sure the soil is well-drained
4. Identify a safe place for drainage disposal
5. Check available budget
6. Level the surface of the slope/embankment before applying the method

Requirements
- Slope should be of hard surface, should not be less than 45° and well-drained
- Better when slope is exposed to sun
- Slope must be trimmed to have even surface
- Hard wood pegs must be hammered to keep the net in proper position and to ensure that the net is not in tension and covers whole surface
- Plant seedlings shall be spread randomly over the netting surface just before the pre-monsoon
- Jute net does not require any maintenance however vegetation initially requires weeding and watering
- Drainage management – building horizontal & vertical channel to catch the surface flow

Species : grass species - Thatch Grass (Khar) - *Cymbopogon-microtheca*, Bigcord grass (Kush) - *Vetiverialawsoni*, Sabai Grass (Babiyo) - *Eula-liopsisbinata*, and hedge type species - Broom Grass (Amriso) - *Thysanolaena maxima*, Simali - *Vitexnegundo*, Bhujetro - *Butea minor*

Advantages
(mesh - 40 mm x 40 mm)
- Suitable for steep, hard slopes where existing conditions are too harsh for vegetation & slope angles of 45° to 60°
- Effective to establish permanent grass cover on steep cut slope

Disadvantages
- It does not protect the surface for more than 1 or 2 monsoon seasons [1] so should be used with bio-engineering techniques e.g. grass slips, and seedlings
- Jute could raise the moisture content in the soil which might be a problem where there is poor internal drainage

Functions
- Allows seeds to hold and germinate
- Protects surface, armor against erosion, catch small debris
- Improves microclimate on the surface
- Helps to establish a permanent grass cover on steep cut slopes
- Jute, being a biological product, decomposes into the soil & acts as a mulch

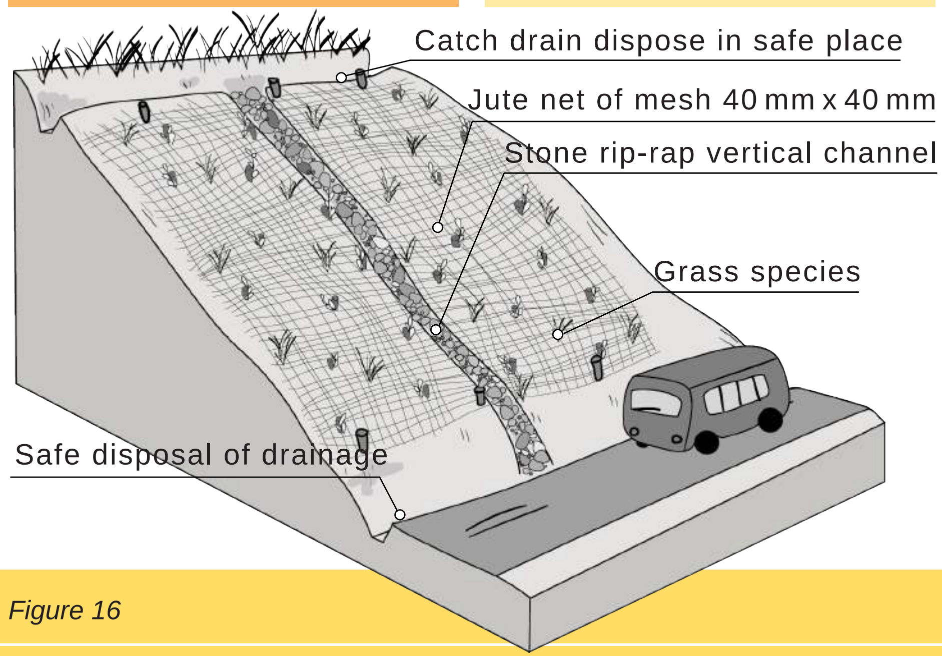


Figure 16

Schematic illustration of jute netting interspersed with deep-rooted vegetation. Credit : S. Eberle

Surface erosion – control of run off
(Source : Howell, 1999)

Method 1.3. Grass plantations: Rooted stem cuttings or clumps grown from seeds are planted over the slope in different ways (e.g. along contour lines, vertically, diagonally or randomly). They protect the slope with their roots and provide surface cover, reduce surface runoff and catch the debris (Figure 17).

How-to-steps
1. Check your drainage & place for safe disposal
2. Check the slope angle & length (see requirements)
3. Investigate the type of soil (e.g. well drained, poorly drained, etc.)
4. Identify the plant / grass species & required numbers
5. Check available budget
6. Level the surface of the slope / embankment before applying the method

Requirements
- Land development - remove debris, level the slope
- Backfill sites require some compaction
- Spacing of the line increases as slope increased (1 m for slope < 30°, 1 m - 1.5 m for slope > 30° & < 45°, 1.5 m - 2 m for slope > 45°). This also depends on root system of the plant to be used
- Spacing of plants is usually 10 cm for grass type species and may go to 20 - 30 cm for hedge type species (e.g. Amriso)
- Plantation shall start before monsoon such that the plant root system can develop & can hold the soil
- Trimming of long root and cut the shoots at about 10 - 15 cm above ground
- Compost of animal manure is required for stony soil
- Watering & protection from animals is necessary for early establishment

Species: grass species - Thatch Grass (Khar) - *Cymbopogon-microtheca*, Bigcord grass (Kush) - *Vetiverialawsoni*, Sabai Grass (Babiyo) - *Eulaliopsisbinata*, and hedge type species - Broom Grass (Amriso) - *Thysanolaena maxima*, Simali - *Vitexnegundo*, Bhujetro - *Butea minor*, Nigalo - *Drepanosachyumfalcatum*

Advantages
- Suitable for large slope angles (soil slope of less than 65°)
- Different plantation techniques for different soils (e.g. horizontal for dry soil, vertical for poorly drained soil and diagonal if there is doubt about soil properties)

Disadvantages
- Difficult on steep slopes
- Horizontal plantation - might increase infiltration on poorly drained soils
- With vertical plantations - increases runoff, rills can develop in weak soils
- With diagonal plantation - rills can develop in very weak soil
- Watering is necessary early establishment of the planted plant

Functions
- Reinforce the slope as root growth
- Cover surface and catch small debris
- Conserve moisture

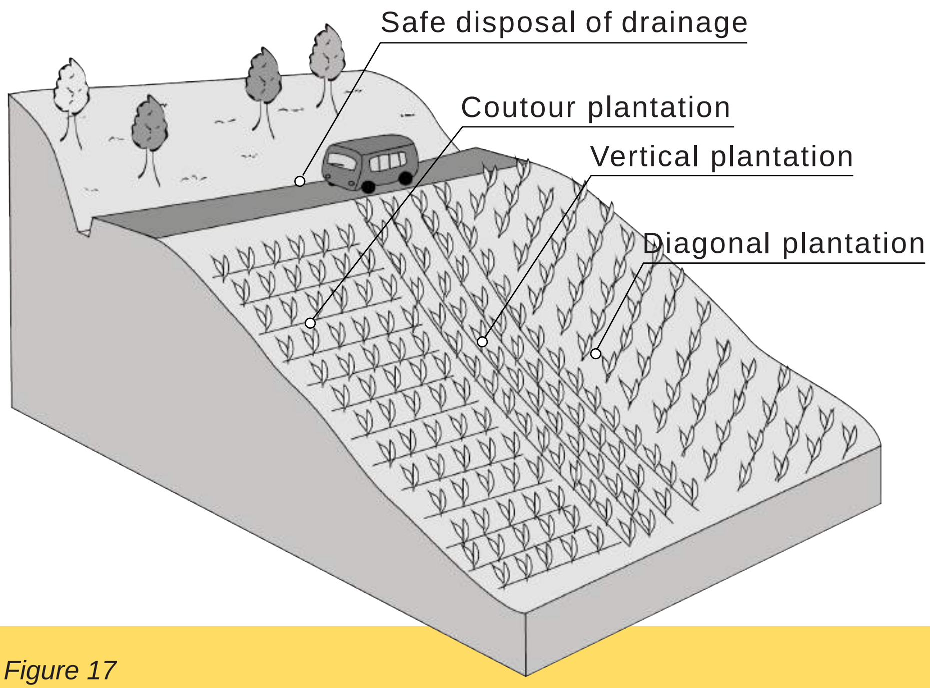


Figure 17

Schematic illustration of three different types of grass plantation (modified from Howell, 1999).
Credit: S. Eberle

Surface erosion – control of run off
(Source: Howell, 1999)

Method 1.4. Facines: Bundles of live branches are laid in shallow trenches later put out roots and shoots forming a strong line of vegetation. It is sometimes also called live contour wattling [1]. They can be established alongcontours or diagonally depending on the drainage requirement (Figure 18).

How-to-steps
1. Check your drainage & place for safe disposal
2. Check any springs & permanent or monsoon season spring on the slope
3. Check the slope angle (see requirements)
4. Investigate the type of soil (e.g. well drain, poorly drain, etc.) & soil depth
5. Identify suitable woody cuttings
6. Check available budget
7. Level the surface, remove the loose materials & mark for facine trench excavation

Requirements
- Place where immediate protection is not required
- Spacing of fascines increases as the slope increases (maximum spacing of 4 meter for slope < 30°)
- Woody cuttings of suitable species at least 1 meter long & 20 - 40 mm diameter (remember such cuttings must be kept moist before planting)
- Trenches of 15 cm deep & 20 cm wide where fascines are placed & backfill the trench as soon as possible
- Fascines ends must over laps such that they behave as a single cable
- In case of slope angle > 25° additional reinforcement by pegging the fascine at right angle to the fascine is helpful to keep it intact
- Maintenance of fascines through weeding which is necessary during post monsoon

Species: Assuro - *Adhatodavascia*, Dabdabe - *Gerugapinnata* Roxb. Simali - *Vitex negundo*, Bainsh - *Salixtetraspermo*, etc.

Advantages
- They form strong & low cost barrier against soil loss in variety of soil slopes
- Low cost & does not require much attention

Disadvantages / Limitations
- Slow growth of physical barrier
- Construction could cause disturbance in the slope
- Soil slope of 45° maximum is suitable

Function
- Armor & reinforced the slope, catch debris & if placed in angle provides efficient drainage

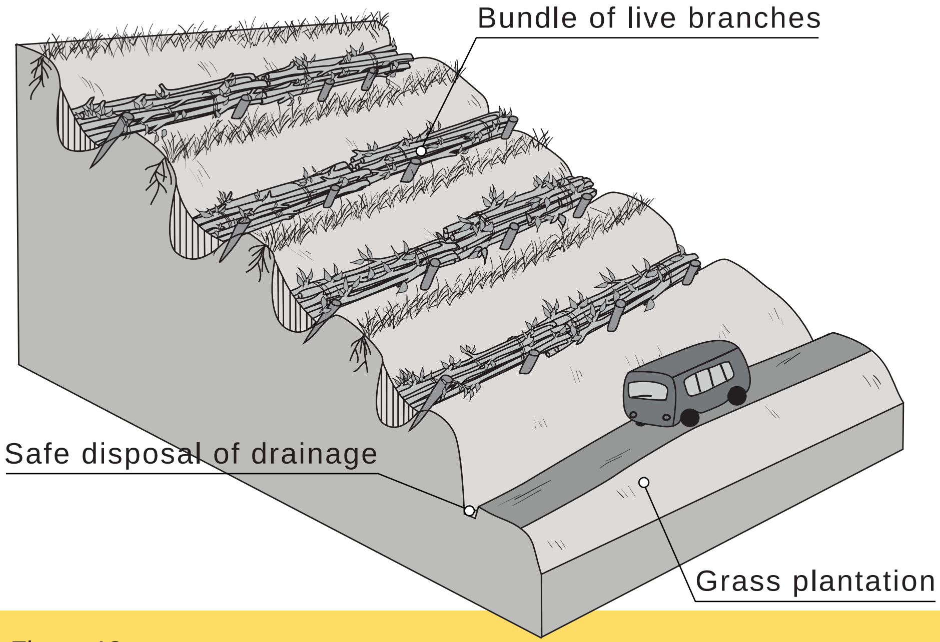


Figure 18

Schematic illustration of grass plantations and facines for shallow slope failures. Credit: S. Eberle

Gullies
(Source : Howell, 1999)

Method 2.1. Live Check Dams : Woody cuttings of shrubs or large tree species are planted across a gully, usually following the contours [1]. These form a strong barrier and trap sediments moving downwards. As time passes a small step-like terrace will develop in the floor of the gully (Figure 19).

How-to-steps

1. Check your drainage & type of gully (depth, width, etc.)
2. Check any springs & permanent or monsoon season spring on the slope
3. Check the slope angle (see requirements)
4. Investigate the type of soil (e.g. well drain, poorly drain, etc) & soil depth
5. Identify the suitable woody cuttings
6. Level the surface, remove the debris and mark for check dam locations

Requirements

• Maximum slope of the gully is 45°
• Drainage management along the road
• Gully requires modification of its side slope and floor before establishment of live check dams
• Spacing of live check dams is between 3 to 5 meters [18] depending on the slope profile & severity of the gully
• Careful positing of vertical hard wood cuttings (like pole) of largest size available & 2 meter long are to be used at 1 - 1.5 meters apart
• Place fascines or long hardwood cuttings on the uphill side of the vertical stakes and key the horizontal members into the wall of the gully
• Backfill is and compaction by foot is necessary around the check dam
• Some maintenance is required in case of monsoon damage during & after monsoon

Species : vertical cutting - Dabdabe - *Gerugapinnata-Roxb*, Coral Tree (Phaledo) - *ErythrinastrictaRoxb*. Horizontal cutting - Simali - *Vitexnegundo*, Assuro - *Adhatodavasica*, Bainsh - *Salix tetrasperma*, Nigalo - *Drepanosachyumfalcatum*, etc.

Advantages

• Effectively protects the slope and stabilises gully at low cost
• Can be used in between masonry check dams
• Flexible in nature so it work even if there are some disturbances

Disadvantages / Limitations

• For large & active gullies require stronger measures which cannot be provided by vegetation alone

Functions

• A strong barrier is formed that traps materials moving downwards
• Catches debris, reinforce the gully and armor the slope
• Small step will develop in the gully floor in long run

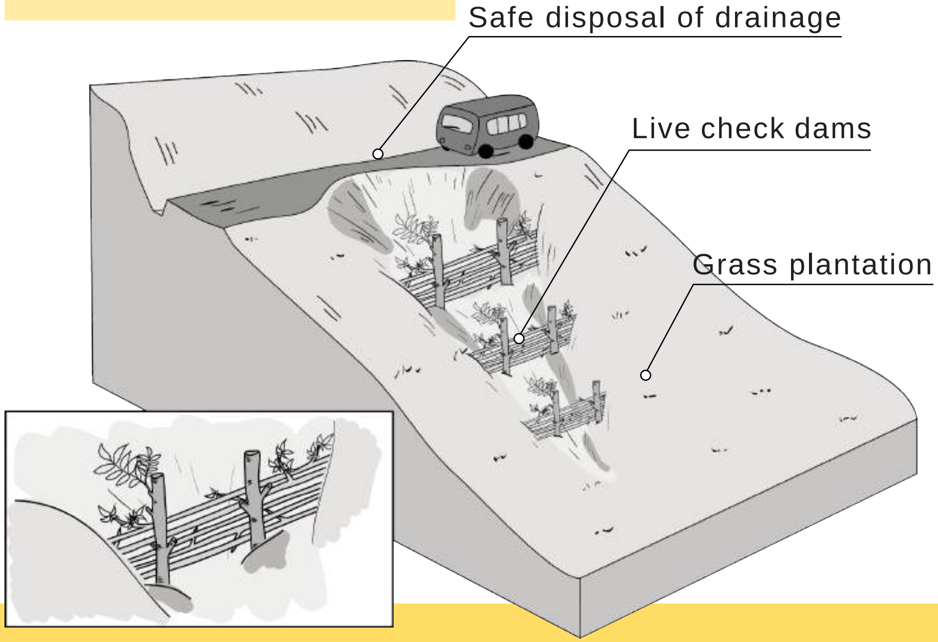


Figure 19

Schematic illustration of live check dams (modified from Howell, 1999). The illustration shows a damaged road which will need to be repaired to avoid further damage.
Credit : S. Eberle

Gullies
(Source : Howell, 1999)

Method 2.2. Vegetative stone pitching : Strengthening of slopes by combination of dry stone walling or cobbling and vegetation planted in the gaps between the stones. It is a stronger form of normal stone pitching (Figure 20).

How-to-steps
1. Check your drainage & type of gully (depth, width, etc.)
2. Check any springs & permanent or monsoon season spring on the slope
3. Check the slope angle (see requirements)
4. Investigate the type of soil (e.g. well drain, poorly drain, etc.) & soil depth
5. Identify the suitable plant species
6. Level the surface, remove the debris (if any) & placed the boulder vertically, keep space between the boulder (see requirement)

Requirements
• Gully floor with shallow depth of 45° maximum slope & shallow small slope failure where immediate protection is required
• Grass slips, or seeds of suitable shrubs are suitable but not the tree species
• Gully floor needs to be cleared until the firm base is exposed
• Stone pavement shall be made keeping the flat surface on top & maintaining uniform minimum gap (< 5 cm) which later fill out the gaps with soil
• The pavement shall be of U-shape in cross section
• Grass plantation is good for main channel and shrubs are for sides
• Maintenance might be required during monsoon if there is any damage (e.g. dislocation of the stone) due to the surface flow
• Roadside drainage management is important

Species : grass specie - Thatch Grass (Khar) - *Cymbopogonmicrotheca*, Bigcord Grass (Kush) - *Vetiverialawsoni*, Sabai Grass (Babiyo) - *Eulaliopsisbinata*, and hedge type species - Broom Grass (Amriso) - *Thysanolaena maxima*, Simali - *Vitexnegundo*, Bhujetro - *Butea minor*, Nigalo - *Drepanosachyumfalcatum*

Advantages
• Provides efficient protection of the drainage line from further eroding the bed at low cost
• Useful both for shallow and long gully & toe protection of cut slope or embankment

Disadvantages / Limitations
• It might be costly where there is not enough boulder / stone available (in case of larger area)
• The toe wall height is limited to 2 meters only beyond this height gabion or masonry wall is required

Functions
• Immediate protection of gully floor
• Vegetation further reinforced the slope as time passes

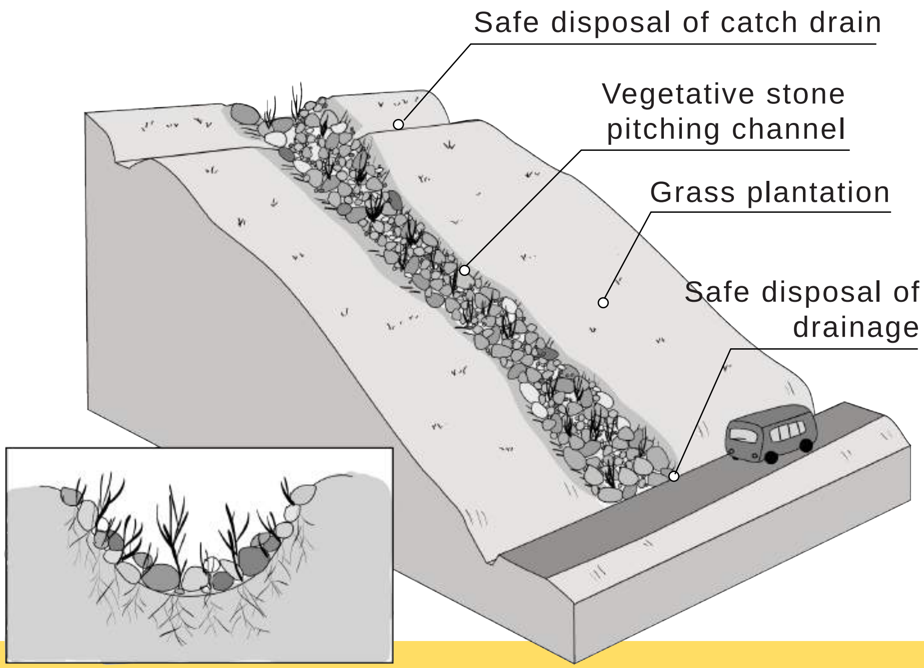


Figure 20

Schematic illustration of vegetative stone pitching.
Credit : S. Eberle

Shallow landslides
(Source : Howell, 1999)

Method 3.1. Palisades : Woody cuttings planted in lines across the slope following the contour. These cuttings form a strong barrier and trap earth materials moving down the slope. In the long run, a small terrace will develop and stabilise the slope. Palisades can also be installed atan angle if drainage is a problem (Figure 21).

How-to-steps
1. Check your drainage & type of slope failure (depth, width, length etc.)
2. Check any springs & permanent or seasonal springs on the slope
3. Check the slope angle (see requirements)
4. Investigate the type of soil (e.g. cohesive, sandy, gravelly, etc.) & soil depth
5. Identify the suitable woody cuttings
6. Level the surface, remove the debris and mark foundation trench for palisade

Requirements
• The slope needs to be cleared, removing irregularities & loose materials before implementation of the scheme
• Woody cuttings of 6 - 18 months old plant species should be used [1]
• The cuttings of 2 - 4 cm in diameter and 30 - 50 cm long are suitable planted densely in vertical fashion to form the barrier
• Spacing - 1 meter for the slope < 30° & 1.5 - 2 meter for slope > 30° to 60° shall be maintained
• Cuttings shall be prepared in the same day otherwise the cuttings must be kept in moist area till the plantation starts
• The cuttings shall be placed in bigger hole than the cuttings & deep enough to cover at least 2 / 3 of its length
• The ideal condition is only one node of the cutting or about 10 cm should protrude from the soil (however for this above ground protrude could be more in steeper slope as it helps to retain soil mass as well as raise new shoots & catch more debris)
• Maintenance is necessary during and after monsoon in the initial period
• Roadside drainage management

Species : Assuro - *Adhatodavascia*, Broom Grass (Amriso) - *Thysanoaenamaxima*, Simali - *Vitex-negundo*, Bhujetro - *Buteaminor*, Nigalo - *Drepanosachyumfalcatum*, Bainsh - *Salixtetrasperma*, etc.

Advantages
• A strong barrier is formed which in turn develops into a small terrace in the long run
• Low cost, efficient, less time consuming & can be used on a wide range of slopes of about 60° [1]

Functions
• The main engineering function is to catch (reinforce, armor) ; they can be angled to give a drainage function where necessary
• They cause minimum disturbance to the slope & particularly effective for steep landslides and debris slopes protection

Disadvantage / Limitation
• These are not strong as brush layering [1]

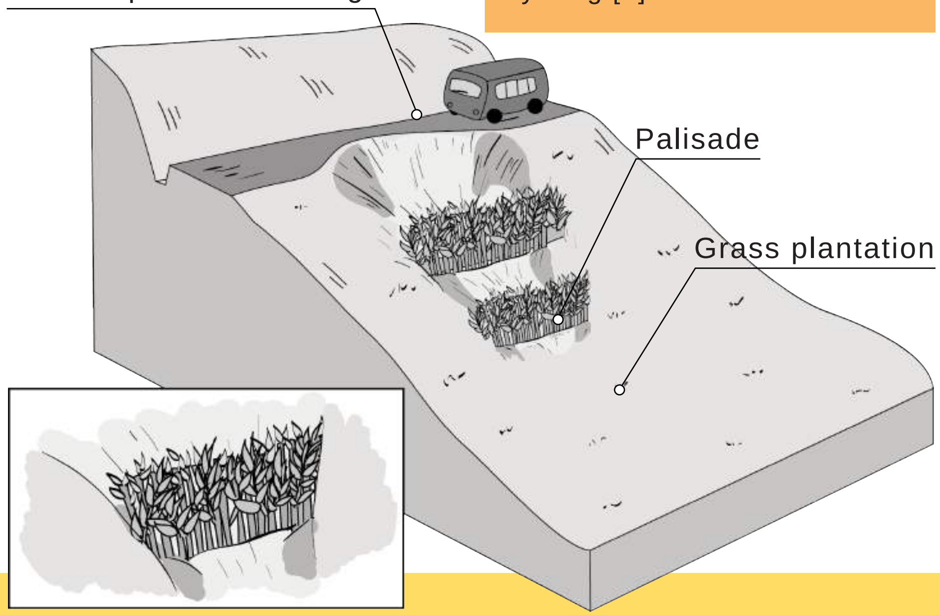


Figure 21

Illustrative scheme of palisades (modified from Howell, 1999).
The above illustration shows a damaged road which needs to be repaired to avoid further damage.
Credit : S. Eberle

Method 3.2. Brush Layering : Woody cuttings are laid in lines across the slope following the contour. It can be used for the slope of less than 45° and the slope shall be well-drained. The technique is effective for debris flows, to fill slopes and high embankments [18]. A strong barrier is formed preventing the slope from rill formations while trapping materials moving down the slope (Figure 22).

How-to-steps
1. Check your drainage & type of failure (depth, width & length)
2. Check any springs - permanent or monsoon season spring on the slope
3. Check the slope angle (see requirements)
4. Investigate the type of soil (e.g. well drain, poorly drain, etc) & soil depth
5. Identify the suitable woody cuttings
6. Level the surface, remove the debris & mark for brush layering

Requirements
• The method can be used on a wide range of sites up to 45° slope [1] and effective in debris sites, fill & high embankments
• The woody cuttings should be 6 - 18 months old having diameter of 2 - 4 cm & 40 - 60 cm long inserted mostly along contour line (it can be in angle if drainage is required)
• If possible cuttings should be prepared the same day otherwise keep the cuttings moist until planting
• Spacing of each layer shall be 1 meter in general & the spacing between the woody cuttings 5 cm
• Small terraces of about 40 - 50 cm wide with 20 % fall back into the slope
• Partially backfill (< 5 cm thick) the terrace with excavated materials
• Plantation shall start from the bottom of the slope & proceed upwards
• Toe protection is necessary if the slope ends up along the streams
• Maintenance during monsoon is necessary in the initial stage
• Protect from animals
• If it is by road side, proper drainage management is necessary

Species : Assuro - *Adhatoda-vascia*, Simali - *Vitexnegundo*, Bhujetro - *Buteaminor*, Nigalo - *Drepanosachyumfalcatum*, Bainsh - *Salixtetrasperma*, Coral Tree (Phaledo) - *Erythrinastricta Roxb.*etc.

Functions
• The main engineering function is to catch debris, reinforce the slope, and armors the surface
• If in angled it helps to drain the slope

Advantage
• Provides a very strong barrier especially on debris slopes at low cost [1]

Disadvantages / Limitations
• Construction activity may considerably disturb the slope
• Not effective on poorly drained slopes

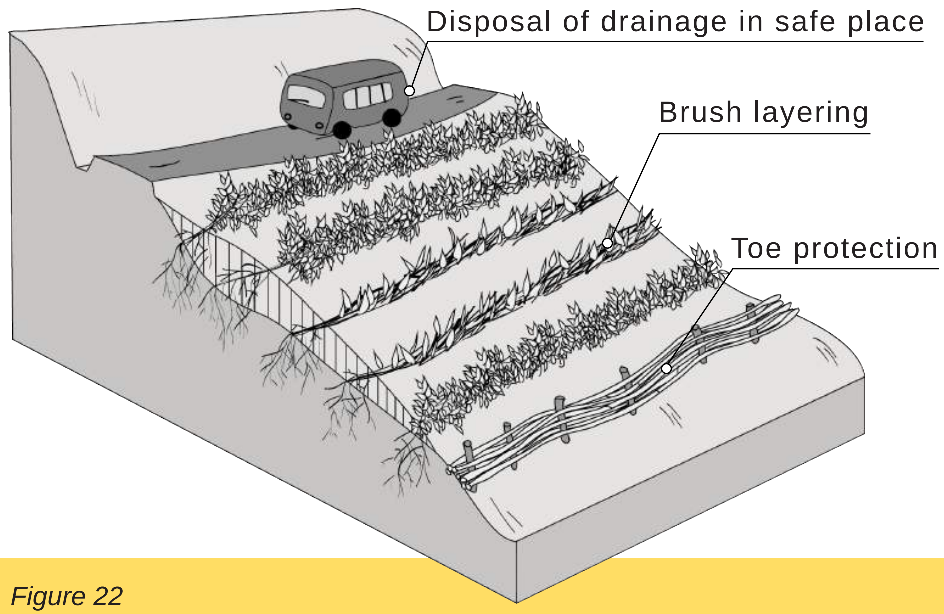


Figure 22

*Schematic illustration of brush layering.
Credit : S. Eberle*

Shallow landslides
(Source : Howell, 1999)

Method 3.3. Gabion wall combined with vegetation : Stone filled gabion walls have special properties of strength, flexibility and free drainage. It can be used up to 10 meters of height for retaining walls, cascade channels and check dams. Gabions can allow protection for vegetation and vegetation may provide additional stability once gabion walls begin to deteriorate (Figure 23).

How-to-steps
1. Check your drainage & type of failure (depth, width, etc.)
2. Check any water sources on the failed slope & surroundings
3. Check the slope angle & length (see requirements)
4. Investigate the type of soil (e.g. well-drained, poorly drained), the soil depth and depth of landslide. Note : some landslides may be too large for the techniques described here !
5. Prepare estimate for gabion boxes & boulders
6. Remove the debris & loose materials, prepare foundation
7. Well-drained gravelly materials shall be used as backfill

Requirements
• Proper understanding of the slope & underneath soil
• Type of failure-slope length, height, causes of failure springs & drainage line
• In general height of the slope should govern the height of the gabion wall (H_{gw} = 0.4 to 0.6 x height of slope)
• Depending on the slope type, cascade structures (gabion check dams) are also appropriate (e.g. long slope but narrow drainage system - debris flow line)
• Foundation for the gabion boxes shall be prepared 10 % back slope such that the wall outer face shall make angle of 10 % with the vertical plane
• Special attention should be made to binding the boxes together
• Back of the gabion should be filled with gravel materials or geo-textiles to keep the voids open & drain out the ground water
• In cascade type gabion check dams the distance between the two check dams should be protected in combination with boulder riprap & vegetation on either side of the slope
• Woody cuttings of shrubs & hedge type grass species are suitable for additional strength

Species : grass species - Thatch Grass (Khar) - *Cympopogon-microtheca*, Bigcord Grass (Kush) - *Vetiverialawsoni*, Sabai Grass (Babiyo) - *Eula-liopsisbinata*, and hedge type species - Broom Grass (Amriso) - *Thysanoaena maxima*, Simali - *Vitexnegundo*, Bhujetro - *Butea minor*, Nigalo - *Drepanosachyum falcatum*, Bainsh - *Salix tetrasperma*, Coral Tree (Phaledo) - *Erythrinas-trictaRoxb*.

Advantages
• Effective for significant shallow landslides where ground water is a problem
• More cost effective than concrete retaining walls

Functions
• Provide stability to the slope where passive support is lost
• Catch debris
• As vegetation grows, stability of the slope increases

Disadvantages / Limitations
• Costly where stone / boulders are not sufficient
• Requires skilled workmanship

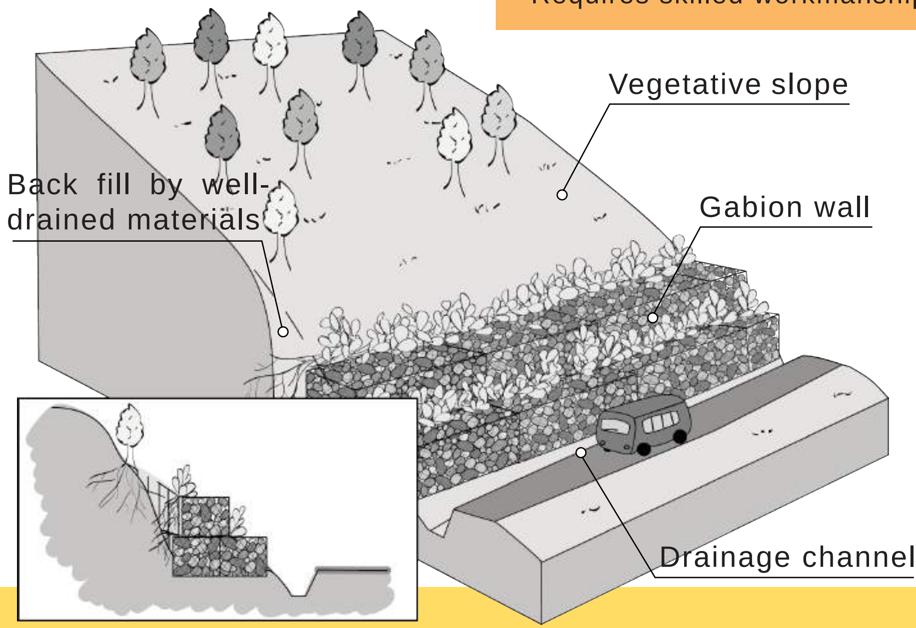


Figure 23

Schematic illustration of gabion wall interspersed with vegetation.
Credit : S. Eberle

Method 3.4. Dry stone walls combined with vegetation : Dry stone walls are low cost options for slope and road side slope protection. They can be used up to 2 meters high as retaining walls, cascade channels and check dams. Dry walls are for immediate protection of shallow slopes whereas vegetation provides additional stability as time passes (Figure 24).

How-to-steps

1. Check your drainage & type of failure (depth, width, length, etc.)
2. Check any springs & permanent or seasonal spring on the slope
3. Check the slope angle & length (see requirements)
4. Investigate the type of soil (e.g. well drain, poorly drain, etc.) & soil depth
5. Identify the suitable plant species & volume of boulders
6. Level the surface, remove the debris & prepare foundation for dry stone wall

Requirements

• Proper understanding of the slope & soil conditions - type of failure, slope length, height, causes of failure, springs & drainage lines, etc.
• In general height of the slope governs the height of the wall (H_w = 0.6 to 0.75 x height of slope)
• Removal of loose materials & debris is necessary to set up the foundation
• Depending on the slope type, cascade structure (check dams) also appropriate (e.g. long & shallow drainage system - debris flow line)
• Foundation for the wall shall be prepared with 10 % back slope such that the wall outer face shall make angle of 10 % with the vertical plane
• Back of the wall should be filled with gravel materials to keep the voids open to drain out the ground water
• In cascade type check dams the distance between the two dams should be protected by boulder riprap & vegetation on either side of walls
• Woody cuttings of shrubs & hedge type grass species are suitable for long term & additional strength

Species : grass species - Thatch Grass (Khar) - *Cymbopogon-microtheca*, Bigcord Grass (Kush) - *Vetiverialawsoni*, Sabai Grass (Babiyo) - *Eula-liopsisbinata*, and hedge type species - Broom Grass (Amriso) - *Thysanoaena maxima*, Simali - *Vitexnegundo*, Bhujetro - *Butea minor*, Nigalo - *Drepanosachyumfalcatum*, Bainsh - *Salix tetrasperma*, Coral Tree (Phaledo) - *Erythrinas-trictaRoxb*.

Functions

• Provide stability to the slope where passive support is lost
• Catch debris and drainage
• As vegetation grows, stability of the slope increases

Disadvantages / Limitations

• Costly where stone / boulders are not sufficient
• Not suitable for deeper and wider gullies

Advantage

• Low cost (as compared to gabion wall) and effective for shallow slope failure and gully protection

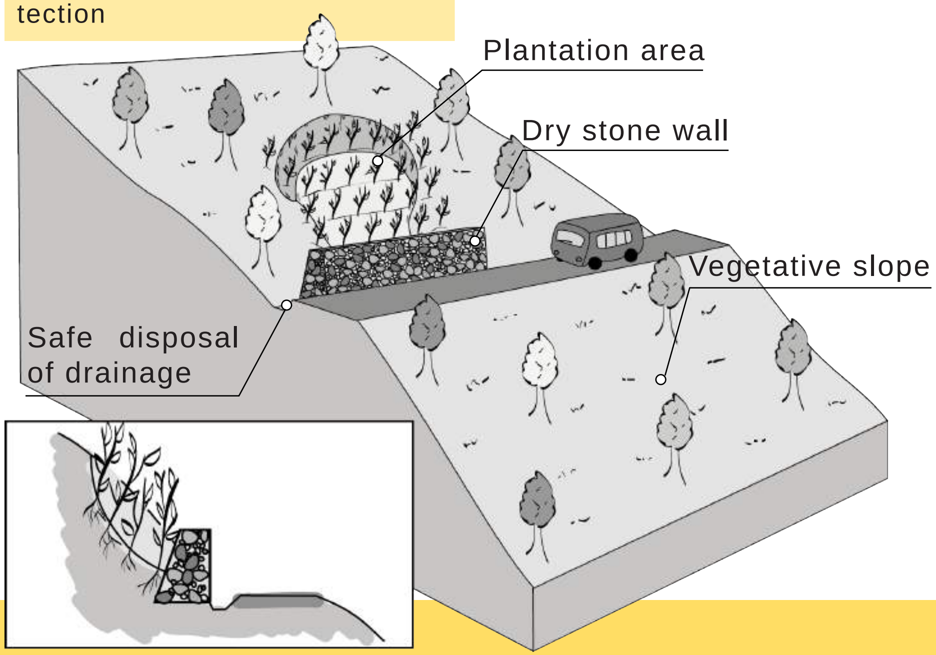


Figure 24

Schematic view of dry stone wall with vegetation. Credit : S. Eberle

Secondary impacts on waterways from road construction (Source : Howell, 1999)

Method 4.1. Live check dams combined with vegetation and boulders : As described in the introduction, degraded watersheds due to soil erosion, landslides, poorly constructed roads and accumulation of roadside water, lead to transportation of sediments downstream - and often - reduced water quality and quantity. The situation can be improved by applying bioengineering and simple civil engineering structures. It is extension of " live check dams " discussed in method 5 above. Live check dams are further reinforced by vegetation on either side of the failure or gully slope. Sometimes if the gully or the slope is shallow and the slope is less steep, dry stone check dams with vegetation alone is also effective (e.g. check dams) (Figure 25).

How-to-steps

1. Check your drainage, sources of water & type of gully (depth, width, etc.)
2. Check any springs & permanent or monsoon season spring on the slope
3. Check the slope angle (see requirements)
4. Investigate the type of soil (e.g. well drain, poorly drain, etc.) & soil depth
5. Identify safe disposal of drainage
6. Level the surface, remove the debris and mark for check dams

Requirements

• Soil slope should not be more than 30° & the failure is less than 2 meters in width
• Spacing of the check dams should be maintained between 3 - 4 meters
• Large woody cuttings of 3 - 5 cms in diameter are to be placed vertically at an interval of about 0.5 meter interval
• Dig out a groove of about 10 cm deep along the contour between the pegs & placed smaller cuttings keeping the lower end into the groove
• Longer cutting of 1.5 - 2 meter in length is to be placed horizontally to further reinforce the fence
• Keep the height of the fence around 50 cm and anchor the horizontal cuttings into the side wall of the slope
• If stone sufficiently available the live fence can be replaced by building dry stone check dams
• Additional plantation should be made along the edge of the gully or slope
• Regular monitoring & maintenance is require during & after monsoon

Species : grass species - Thatch Grass (Khar) - *Cymbopogon-microtheca*, Bigcord Grass (Kush) - *Vetiverialawsoni*, Sabai Grass (Babiyo) - *Eula-liopsisbinata*, and hedge type species - Broom Grass (Amriso) - *Thysanoaena maxima*, Simali - *Vitexnegundo*, Bhujetro - *Butea minor*, Nigalo - *Drepanosachyumfalcatum*, Bainsh (*Salix tetrasperma*)

Advantages

• Low cost, less time consuming & provides immediate protection
• Does not require high skill, local plant species is useful

Function

• Catch the debris, provides sufficient drainage for surface runoff, anchor the slope

Disadvantages / Limitations

• Not suitable for wider & deeper gullies as it become more flexible
• Not effective where ground water or springs is presents

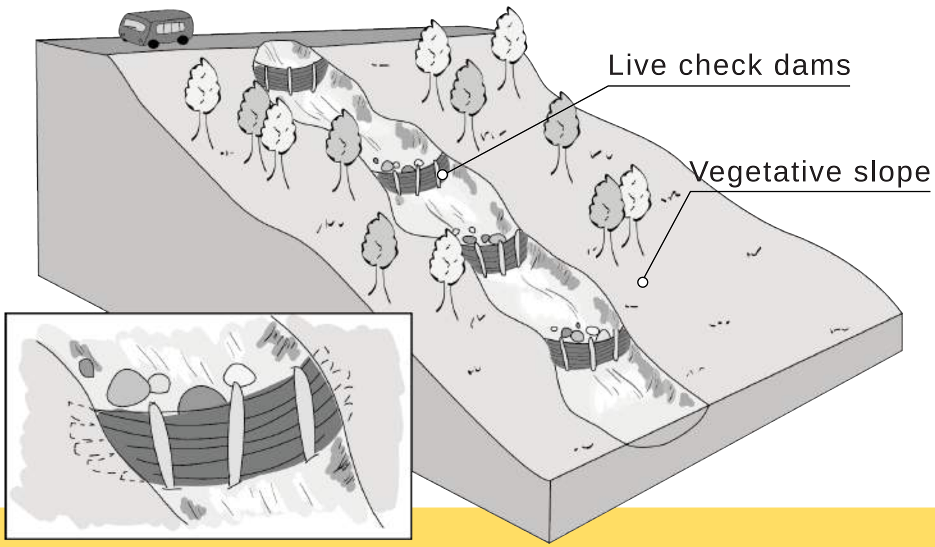


Figure 25

Schematic illustration of live check dam (can also be dry stone or gabion). Credit : S. Eberle

River bank protection
(Source : Howell, 1999)

Method 5.1. Sandbags, Bamboo Vans & Vegetation : This is most the simple and low cost method for bank protection in the plain area, mostly for meandering rivers in the Nepal Terai (Figure 26). It can also be used in the inner river valley basin where flash floods are common and where stone / boulders are not easily available.

How-to-steps

1. Check your river system - is it meandering ?
2. Examine high flood level & volume of flood water
3. Check the depth of bank and slope angle
4. Investigate the type of soil on slope & river bed (e.g. gravelly, sandy, silty, etc.)
5. Check availability of construction materials (e.g. bamboos)
6. Level the bank slope (should be less than 75°), & start pegging bamboo vans. Tie the vans across
7. Place the sand bags in-between the bamboo van

Requirements

• In general rivers having meandering characteristic can be treated applying this method

• Excavation is needed for vertical river bank to have some slope (< 75°), to make ease in plantation

• At least three tiers of vertical bamboo vans along the river bank (1 - 2 meter apart) & one in water, one in the slope should be hammered by wooden hammer and tied with the GI wire

• The toe of the bank where excessive under cutting is going need staggered sand bags up to the normal flood level (this can be done by stone if available) are to be placed

• The length of the sand bag wall & the bamboo vans is govern by the type & nature of the river course (where active under cutting is in progress)

• Plantation of grass species having long root system & grow fast is always good over the sand bags and in upper slope of the bank

• Plantation are should be protected from animals & regular monitoring & maintenance is require during & after monsoon

Plant Species : grass species - Thatch Grass (Khar) - *Cymbopogonmicrotheca*, Bigcord Grass (Kush) - *Vetiverialawsoni*, Wild Sugarcane (Kans) - *Saccharumspontaneum*, Vetiver - *Chrysopogonzizanioideand* hedge type species - Broom Grass (Amriso) - *Thysanoaena maxima*, Simali - *Vitexnegundo*, Bhujetro - *Butea minor*, Nigalo - *Drepanosachyumfalcatum*, Bainsh - *Salix tetrasperma*

Function

• Protect the river bank from under cutting, & enhance sedimentation

Advantages

• Low cost & provide immediate protection

• Use of local construction materials and local knowledge

Disadvantages / Limitations

• Require understanding of river morphology & flood water

• Not suitable for stream / rivers with high gradient

• Proper selection of plant is necessary, those plant having long root system & grows fast are suitable

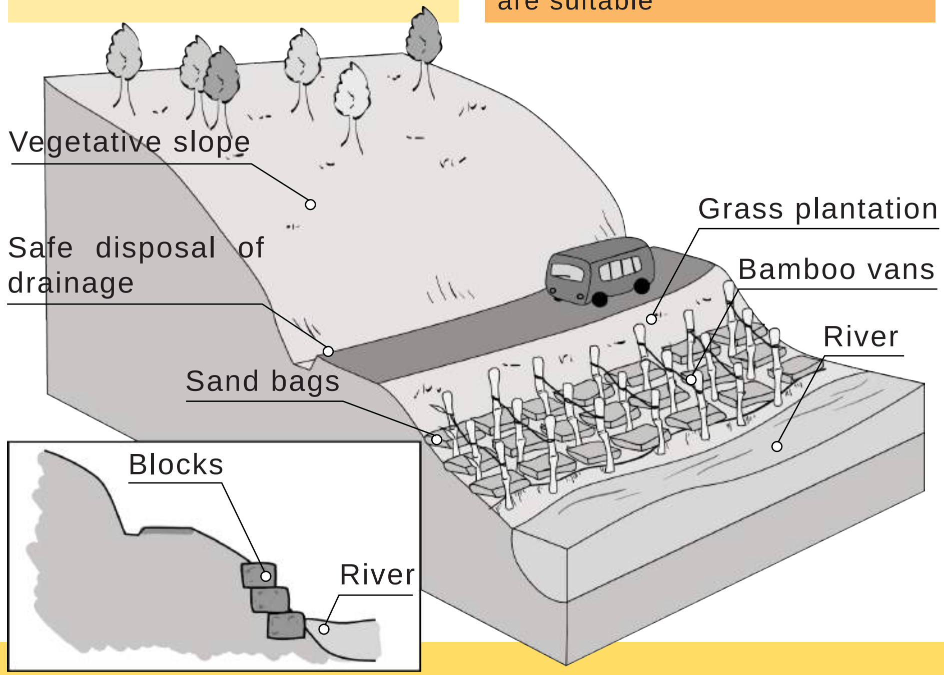


Figure 26

Schematic view of bamboo vans and sandbags for river bank protection. The zoomed image illustrates overlapping blocks or sandbags as an alternative technique for reinforcing river banks.
Credit : S. Eberle

6. Conclusions

With greater climatic uncertainty and increasing numbers of extreme events, local capacity to prepare for and recover from the impacts of climate change is diminishing. Large and small landslide events are a main cause of mortality in Nepal (after epidemics) for mountain populations and present a major impediment to rural development [19]. In parallel, rural road construction by local stakeholders and communities is considered a necessary coping strategy for improving rural livelihoods, yet many rural roads are creating unnecessary environmental damage to fields, waterways, water quality and hydropower dams. Bio-engineering measures, which are cost-effective and locally adapted, could significantly reduce severe erosion and landslides along roads but are rarely incorporated as part of road construction activities. Currently rural roads are constructed in a quick, "cut and dump" and unsustainable manner and require costly maintenance work after every monsoon season. What is needed is a change in mindsets toward more sustainable road constructions "cut, fill, ensure drainage, then plant", or "eco-safe roads", which take a bit longer to construct and have slightly higher initial costs but will be more cost effective over several years and safer for communities. We hope that this manual has contributed in a practical way toward this change in mindsets and practices.

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Annex I

Diagnostic tool for roadside slope failures

Choice of bio-engineering technique according to site (*Source: Howell, 1999*)
First carry out a site assessment (see pages 32-25).

Slope angle	Slope length	Material drainage	Site moisture	Technique(s)
> 45º	> 15 metres	Good	Damp	**Diagonal grass lines**
			Dry	**Contour grass lines**
		Poor	Damp	**1. Downslope grass lines and vegetated stone pitched rills** or 2. Chevron grass lines and vegetated stone pitchedrills
			Dry	**Diagonal grass lines**
	< 15 metres	Good	Any	**1. Diagonal grass lines** or 2. Jute netting and randomly planted grass
		Poor	Damp	**1. Downslope grass lines** or 2. Diagonal grass lines
			Dry	**1. Jute netting and randomly planted grass** or 2. Contour grass lines or 3. Diagonal grass lines

30º - 45º	> 15 metres	Good	Any	**1. Horizontal bolster cylinders and shrub / tree planting** or 2. Downslope grass lines and vegetated stone pitchedrills or 3. Site grass seeding, mulch and wide mesh jute netting
		Poor	Any	**1. Herringbone bolster cylinders & shrub / tree planting** or 2. Another drainage system and shrub / tree planting
	< 15 metres	Good	Any	**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	**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

Annex I

Diagnostic tool for roadside slope failures

Slope angle	Slope length	Material drainage	Site moisture	Technique(s)
< 30°	Any	Good	Any	**1. Site seeding of grass and shrub / tree planting** or 2. Shrub and tree planting
		Poor	Any	**1. Diagonal lines of grass and shrubs / trees** or 2. Shrub and tree planting
	< 15 metres	Any		**Turfing and shrub / tree planting**
	Base of any slope			**1. Large bamboo planting** or 2. Large tree planting
Special materials (in place of the measures described in the rows above)				
> 30°	Any	**Any rocky material**		**Site seeding of shrubs / small trees**
Any loose sand	Good	Any		**Jute netting and randomly planted grass**
Any ratomato	Poor	Any		**Diagonal lines of grass and shrubs / trees**

Gullies ≤ 45°	Any gully	**1. Large bamboo planting** or 2. Live check dams or 3. Vegetated stone pitching

Notes for " Choice of bio-engineering technique " table.
' 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 ratomato ' 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).
Source : Howell, 1999

Annex II

Recommended Bio-engineering Techniques and Timing of Implementation
(Source : Howell, 1999)

Site type	Materials and drainage	Aspect (orientation)	Recommended technique *	Timing of site works
Cut slopes in undisturbed ground (Usually > 35°)	Poorly drained materials liable to saturated slumping	North and east	Grass lines (diagonal)	Winter above 1800 m Monsoon below 1800 m
		South and west	Grass lines (diagonal)	Monsoon
	Other materials	North and east	Grass lines (diagonal)	Winter above 1800 m Monsoon below 1800 m
		South and west	Grass lines (contour)	Monsoon
Cut slopes in loose colluvial debris (Usually < 35°)	All materials	North and east	Brush layering	Winter above 1800 m Monsoon below 1800 m
		South and west	Grass lines (contour)	Monsoon
Fill slopes in mixed debris • Unconsolidated landslide debris • Tipped debris masses (Always < 35°)	Fine-textured matrix with impeded drainage	All	Fascine or vegetated stone-pitched slope drain with diagonal brush layering, plus grass lines (diagonal) within 5 m of road	Winter above 1800 m Monsoon below 1800 m
	Coarse angular debris	All	Brush layering (contour), plus grass lines (diagonal) within 5 m of road	Monsoon
	Very rocky debris with no fines	All	Palisades	Monsoon
Backfill above and around foundations of structures (Always < 35°)	Fine-textured matrix with impeded drainage	North and east	Grass lines (diagonal)	Winter above 1800 m Monsoon below 1800 m
		South and west	Grass lines (contour)	Monsoon
	Coarse angular debris	North and east	Grass lines (contour)	Winter above 1800 m Monsoon below 1800 m
		South and west	Grass lines (contour)	Monsoon

*Requires verification through individual site assessment.

ANNEX II

RECOMMENDED BIO-ENGINEERING TECHNIQUES AND TIMING OF IMPLEMENTATION
(SOURCE : HOWELL, 1999)

Site type	Materials and drainage	Aspect (orientation)	Recommended technique *	Timing of site works
Landslide head scars (Usually > 45°)	Slopes less than 50° in materials that can be excavated by hand	All	Grass lines (contour)	Monsoon
	All other sites	All	Shrub seeding	Any time
Gully beds (Usually 15 - 35°)	Damp, shady sites	All	Live check dams Bamboo planting	Winter above 1800 m Monsoon below 1800 m
	All other sites	All	Live check dams Bamboo planting	Monsoon
Lower side engineered road shoulders	Any	All	Grass lines (contour)	Monsoon
Bare, unvegetated slopes above cuts and below fill slopes	Any	All	Tree and shrub planting	Monsoon [Winter, for north - and east -facing sites above 1800 m]

*Requires verification through individual site assessment.

Special Situations	Supplementary Technique
Long slopes in angular, well-drained and unconsolidated debris where the slope angle does not exceed 35° and there is seepage or monsoon flow, but no concentrated torrent of water. Choose technique to suit the availability of local, cheap materials.	Bamboo crib walling Vegetated dry stone walling
Narrow channels in landslides and gullies where there is periodic concentrated water flow.	Live check dams
Channels and drains below springs and in gullies where significant water flow is common.	Vegetated stone pitching
Steep (> 45°) cut slopes in fine-textured, consolidated materials such as residual soils, but not on north-facing slopes or near seepage lines.	Jute or coir netting with random grass planting

Annex III

Popular bioengineering methods in Nepal and their effectiveness in different environment (modified from DSCWM, 2013)

S.N.	Systems	Location	Main functions	Other functions
1	Grass plantation (vertical)	Loose soil, embankment and fill slopes	Drain, Armour	Armour
2	Grass plantation (diagonal)	Loose soil, embankment and fill slopes	Catch	Armour
3	Grass plantation (horizontal)	Loose soil, embankment and fill slopes	Armour	Catch, Drain
4	Random plantation	Very steep (30 - 40 degree)	Armour, anchoring	Catch, Drain
5	Grass seed sowing	New Loose soil, steep and relatively dry	Armour, reinforcement	Catch
6	Turfing	New deposited soil, embankment	Armour	-
7	Brush layering	Loose soil, shallow slope protection	Carch, armour, reinforement	-
8	Palisade	Loose soil, slope protection, gully protection	Carch, armour, reinforcement	-
9	Fascine	Gully protection, shallow slope protection	Support	Catch, reinforce
10	Tree, shrub plantation	-	Reinforcement	Anchoring, support
11	Tree and Shrub seed plantation	Very steep, rock, instable slope	Reinforcement	Anchoring
12	Bamboo plantation	River bank and slope protection	Catch, reinforcement	-
13	Live Checkdam	Gully and shallow slope protection	Catch, armour, reinforcement	-

ANNEX IV

COMPARISON OF DIFFERENT VEGETATION AND ENGINEERING FUNCTIONS (SOURCE : MODIFIED FROM HOWELL, 1999)

Engineering Function	Woody vegetations		
	Trees	Shrubs	Bamboos
Catch	*	* * *	* * *
Armour	*	*	*
Reinforce	* *	* * *	*
Anchor	* * *	* *	⊙
Support	* * *	* *	* * *
Drain	⊙	⊙	⊙

Engineering Function	Non Woody vegetations		
	Clumping Grasses	Matting Grasses	Other Herbs
Catch	* *	*	⊙
Armour	* * *	* * *	*
Reinforce	* *	*	⊙
Anchor	⊙	⊙	⊙
Support	⊙	⊙	⊙
Drain	* * *	*	⊙

Symbols :

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

Annex V

List of plants for Bio-Engineering, Altitude and Propagation
(Source : Howell, 1999)

Local Name	स्थानिय नाम	Botanical name	Altitude	Sites	Best Propogation	Seed collection
List of Bamboo Species for Bio-Engineering in the Road Sector						
Choya / Tama bans	चोयारतामा बाँस	*Dendrocalamus hamitoni*	300-2000 m	Thin culm, heavy branching	Moist	Culm cuttings
Dhanu bans	धनु बास	*Bambusa balcooa*	Tarai 1600 m	Thick culm, heavy bhanching	Varied	Culm cuttings
Kalo bans	कालो बाँस	*Dendrocamus hookeri*	1200-2500 m	Heavy branching, brown hairs	Varied	Culm cuttings
Mal bans	माल बाँस	*Bambusa nutans*	Tarai 1500 m	Strong, straight culms	Dry / varied	Traditional method
Nobha / Ghopi / Lyas bans	निभा बास	*Ampelocamus patellaris*	1200-2000 m	Smaller, bluish culms	Varied	Traditional method
Tharu nabs	थारु बाँस	*Bambusa nutans*	Tarai 1500 m	Strong, straight culms	Varied	Traditional method
List of Shrubs Species for Bio-Engineering in the Road Sector						
Aak	आँक	*Calatropha giganteum*	Terai-1000 m	Hot and Dry ; Harsh	Seeds / polypots	Feb-Mar
Ainselu	ऐसेलु	*Rubus ellipticus*	1000-2500 m	Varied	Seeds / root cutting	Nov-Dec
Alainchi	अलैची	*Elettaria cordomomum*	1000-2000 m	Moist	Seeds / polypots	-
Amala	अमला	*Phyllanthus emblica*	Terai-1500 m	Hot and Dry ; Harsh	Seeds / polypots	Sep-Jan
Amba/ ambak	अम्बा	*Psidium guajava*	Terai-2000 m	Varied / and dry	Seeds / polypots	Aug-Oct
Aparajita	अपराजिता	*Clitoria ternated*	Terai-1500 m	Varied / and dry	Seeds / polypots	-
Assuro	असुरो	*Adhatoda vasica*	Terai-1000 m	Varied	Hardwood Cuttings	Use cutting
Bainsh	वैस	*Salix tetrasperma*	Terai-2700 m	Moist	Hardwood Cuttings	Use cutting

ANNEX V

LIST OF PLANTS FOR BIO-ENGINEERING, ALTITUDE AND PROPAGATION
(SOURCE : HOWELL, 1999)

Local Name	स्थानिय नाम	Botanical name	Altitude	Sites	Best Propogation	Seed collection
Baganbeli	बगानबेली	*Bougainvillea spectabilis*	Terai-1500 m	Varied / and dry	Stem Cutting	Use cutting
Ban chutro	बन चुत्रो	*Berberis aristata*	1500-3000 m	Varied / and dry	Seeds / polypots	-
Ban silam	बन सिलाम	*Elsholtzia blanda*	Terai-1500 m	Varied	-	-
Bayer	बयर	*Zizyphus mauritiana*	Terai-1200 m	Hot and Dry ; Harsh	Seeds / polypots	Dec-Mar
Bhimsenpati	भिमसेनपाती	*Buddleja asiatica*	600-1800 m	Hot and Dry ; Harsh	Seeds / hardwood cutting	Use cutting
Bhui katahar	भुइ कइहर	*Ananas comosus*	Terai-1600 m	Hot and Dry ; Harsh	Stem Cutting	Use cutting
Bhujetro	भुजेत्रो	*Butea minor*	500-1500 m	Hot and Dry ; Harsh	Direct seeding	Nov-Jan
Chiya	चिया	*Camellia sinensis (and other species)*	Terai-2000 m	Varied and moist	Hardwood Cuttings	Use cutting
Chutro	चुत्रो	*Berberis asiatica*	1000-2500 m	Varied / and dry	Seeds / polypots	Mar-Apr
Coffee	कफि	*Coffea arabica*	Terai-2000 m	Varied	Seeds / polypots	Aug
Dhanyero	धएरो	*Woodfordia fruticosa*	Terai-1500 m	Hot and Dry ; Harsh	Seeds / polypots	Mar-Apr
Ghangaru	ङंगरु	*Pyacantha crenulata*	1500-2500 m	Varied	Hardwood Cuttings	Use cutting
Ghurmiso	ङुमिसो	*Leucosceptrum canun*	1000-2500 m	Varied	Hardwood Cuttings / seeds	Use cutting
Kanda phul	काँडा फुल	*Lantana camara*	Terai-1750 m	Hot and dry	Hardwood Cuttings	Use cutting
Kettuke	केतुके	*Agave americana*	Terai-2400 m	Hot and Dry	Root Suckers	Use cutting
Kimbu	किम्बु	*Morus alba*	Terai-2000 m	Varied / and dry	Hardwood Cuttings / seeds	Use cutting

Annex V

List of plants for Bio-Engineering, Altitude and Propagation
(Source : Howell, 1999)

Local Name	स्थानिय नाम	Botanical name	Altitude	Sites	Best Propogation	Seed collection
Lalupate	लालुपाते	*Poinsettia pulcherrima*	Terai-1500 m	Varied	Hardwood Cuttings / seeds	Use cutting
Nil kanda	निलकन्७	*Duranta repens*	Terai-1500 m	-	-	-
Pate Siuli	पाद्दे सिउली	*Opuntia ficus indica*	Terai 1800 m	-	-	-
Rahar	रहर	*Cajanus cajan*	Terai-1500 m	Varied / and dry	Seeds	-
Sajiwan (Kadam in the Terai)	सजिवनरकदम	*Jatropha curcas*	Terai-1000 m	Hardwood cutting	Used cutting	-
Simali	सिमली	*Vitex negundo*	Terai-1750 m	Hot and Dry ; varied	Used cutting	-
Siuli / Sihundi	सिउलीरसिहुन्दी	*Euphorbia royleana*	900 - 1800 m	Varied	-	-

List of Grass Species for Bio-Engineering in the Road Sector						
Amliso	अमलीसो	*Thysanolaena maxima*	Terai-2000 m	Varied	Slip cuttings	Mar-Apr
Babiyo	बाबियो	*Eulaliopsis binata*	Tarai 1500 m	Hot and dry	Slip cuttings/ seeds	Jan-Feb
Dangre khar	दंग्री खर	*Cymbopogon pendulus*	Tarai 1200 m	Varied	Seeds	Dec-Jan
Dubo	दुबो	*Cynodon dactylon*	Tarai 1800 m	Varied	Stem Cuttings	Use cuttings
Kagati Ghans	कागती ३ाँस	*Cymbopogon citrates*	Tarai 1500 m	Varied	Slip cuttings/ seeds	Nov-Dec
Kans	कांस	*Saccharum spontaneum*	Tarai 2000 m	Hot and dry to moist	Slip cuttings	Nov-Dec
Katara khar	कद्दरा खर	*Themeda species*	Tarai 2000 m	Varied	Slip cuttings/ seed	Oct-Nov
Khar	खर	*Cymbopogon microtheca*	500-2000 m	Hot and dry ; varied	Slip cuttings/ seeds	Dec-Jan
Khus	खस	*Vetiveria lawsoni*	Tarai 1500 m	Varied	Slip cuttings	Sep-Nov
Kikiyu Thulo dubo	किकियु ७ुलो दुबो	*Pennisetum clandestinum*	Tarai 1800 m	Varied	Stem /slip Cuttings	Use cuttings

ANNEX V

LIST OF PLANTS FOR BIO-ENGINEERING, ALTITUDE AND PROPAGATION
(SOURCE : HOWELL, 1999)

Local Name	स्थानिय नाम	Botanical name	Altitude	Sites	Best Propogation	Seed collection
Napier	नेपियर	*Pennisetum purpureum*	Tarai 1750 m	Varied ; needs fertile soil	Steam cuttings	Use cuttings
Narkat	नरकट	*Arundo clon*	Tarai 1500 m	Hot and dry ; varied	Stem /slip Cuttings	Nov-Dec
Phurke	फुर्के झाँस	*Arunduella nepalesis*	700 - 2000 m	Varied ; stony	Slip cuttings/ seeds	Dec-Jan
Rato kans	रातो काँस	*Frianthus rufipilus*	900 - 2200 m	Varied	Slip cuttings/ seeds	Dec-Jan
Salimo Khar	सालिमो खर	*Chrysopogon gryllus*	800 - 2000 m	Varied	Slip cuttings/ seeds	Dec-Jan
Stylo	स्टायलो	*Stylosanthes guianensis*	500 - 1500 m	Varied	Steam /slip cuttings	Use cuttings
Thulo Kharuki	ठुलो खरुकी	*Capipedium assimile*	600 - 2000 m	Varied	Slip cuttings/ seeds	Dec-Jan

Annex VI
Landslide Inventory Report

Form - Landslide Report				
1. Inventory number				
2. Photo Numbers				
3. Name of visitor			Date of Visit :	
4. Date of landslides occurrence		Triggering Factors :		
5. Name of road (villages connecting)				
6. Landslide location (VDC, Ward No & Village)				
7. When was the road constructed		Start Date :	End Date :	
8. Landslide Reporter's name & address (in case reported by ……..)		Name & Address :	Landslide location :	
9. Phone & affiliated Institution (if any)			Email :	
10. Geographical Location & description of landslide				
11. GPS point name	Latitude (dms) :	Longitude (dms) :	Elevation (m a.s.l.) :	

Nature of Failure	Shallow	Debris flow	Deep	Others
	Length (m) :	Width (m) :	Depth (m) :	
12. Evidence of activity				
Headscarp well developed and preserved ?		Yes	No	
Cracks in the Slope ?		Yes	No	
Cracks in the road ?		Yes	No	
Road drainage affected ?		Yes	No	
13. Degree of Damage				
	Property : 1. House Damaged (Nos.) : 2. House Partially damaged (Nos) : 3. Cropland Damaged (Area) : 4. Forest (Area) : 5. Other :	Road : 1. Road damaged (Length) : 2. Road blocked : 3. Road partial damaged : 4. Drainage Damaged : 5. Other :		

Annex VI
Landslide Inventory Report

Form - Landslide Report	
14. What is most suitable method for addressing the problem?	
15. Please make a sketch of the landslides with your observations. Please, include also a list of species of trees and vegetation you recognize in the surrounding area.	