Sustainable Resource Development in the Himalaya

Engineering challenges for sustainable development in mountainous areas

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Wednesday, 25 June 2014

Contents of this Presentation

- Illustrate engineering challenges for infrastructure development in mountain regions
- Summarise terrain evaluation and geo-hazard assessment techniques for meeting these challenges
- Make recommendations for a sustainable engineering approach
- Conclusions & the way forward

Ethiopian Highlands, up to 4,500m

What is Meant by Engineering in the Context of Sustainable Mountain Development?

- Transport infrastructure, mostly roads, but also railways
  - Alignments
  - Excavations
  - Fill slopes
  - Retaining walls
  - Tunnels
  - River crossings
  - Drainage
- Buildings
- Hydropower schemes
- Power transmission
- Mining
- Water supply infrastructure
- Telecommunications

This presentation focuses on roads, but much of the discussion is equally important to other infrastructure


Near Gangtok, Sikkim

Main Challenges

- Difficult and extreme terrain
- Complex and variable ground conditions (geological/geotechnical)
- Extremes of climate: snow, ice, freeze-thaw cycles, intense and prolonged rainfall & climate change effects
- Severe geo-hazards, depending on topography, climate and geology:
  - glacial and landslide-dammed lake outbursts
  - snow avalanches
  - seismicity
  - landslides, rock falls and rock avalanches
  - meteorological floods
  - debris flows
  - erosion/scour and aggradation
  - aeolian hazards
- Complex land use interactions and land use change effects
- Environmental and social compatibility
- **Developing a *sustainable* outcome**

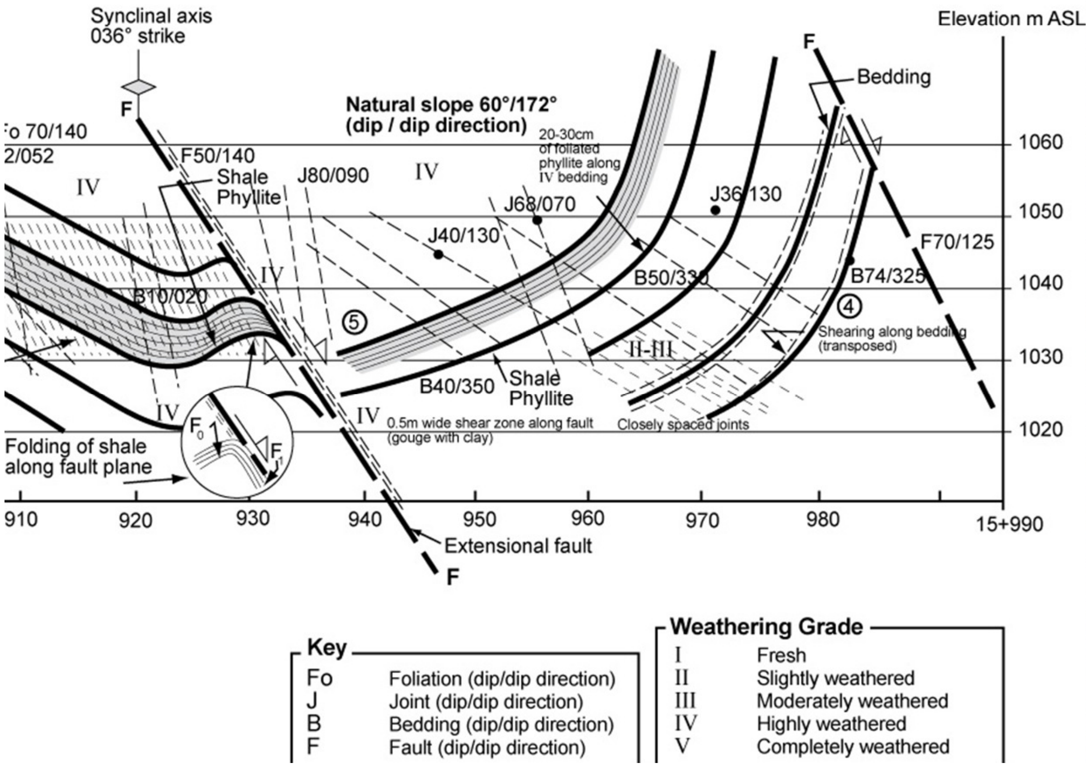
Difficult and Extreme Terrain

Arun Access Road, Nepal

Lake Sarez Access Road, Tajikistan

Complex and Variable Ground Conditions

Shagon-Zigar Road, Tajikistan



Extremes of Climate & Climate Change Effects

Severe Geo-Hazards: Seismicity

Wenchuan Earthquake, Sichuan Province, May 2008, Ms 8.0, Depth 14 km

Severe Geo-hazards: Landslides

Typhoon Ondoy, Halsema Highway, Philippines, 2009

Baipaza Landslide into Baipaza HEP reservoir, Tajikistan

Severe Geo-hazards: Floods

Meteororological Floods, Nepal & Tajikistan

Glacial and Landslide Lake Outbursts, Kyrgyz

Kutman Kul Landslide Dam, Kyrgyzstan
2840m asl
75 million m^3 of landslide
4 million m^3 of lake
Uranium mining, towns and transport infrastructure downstream

Severe Geo-hazards: Erosion and Aggradation

Halsema Highway, Philippines

Prithvi Highway, Nepal

Land Use and Climate Change Effects

- Yesterday, the students emphasised the role of deforestation.
- If deforestation gives way to well-managed land use then the effects can be minimised
- Where 'leaky' irrigation canals are constructed on marginally stable or erodible slopes then instability can be triggered or exacerbated
- However, deep-seated landslides often occur regardless of the occupying land use

CROWN AGENTS

AUTHOR: Hearn, G

Promoting Sustainable Rural Access and Developing a Risk Based Vulnerability Assessment for Rural Communities in the Changing Climate of Sub Saharan Africa

CROWN AGENTS REF NO.
AFCAP/GEN/127/D2

Final Report
Report No HGL 05

May 2014

Hearn Geoserve Ltd

BEIA 13 WINNER
British Expertise International Awards 2013: **Outstanding International Collaboration**

UKaid from the British people

'Flood envelopes based on historical floods tend to be conservative in their estimate, although large floods may be becoming more frequent due to land use and climate change, or their frequency may have been underestimated from short term records.' Hearn, GJ. 1997. *Principles of low cost road engineering in mountainous regions. Overseas Road Note 16, Transport Research Laboratory*, UK

Terrain and Geo-hazard Assessment for Sustainable Engineering

The performance of engineering infrastructure in mountains is usually determined mostly by:

- The stability of earthworks
- The impact of landslides
- Cross drainage erosion
- Sediment transport
- The impacts of floods

Seismicity may impact bridges, viaducts and retaining structures but it is often its effect on earthworks stability and the triggering or reactivation of landslides that is most significant

The focus of much of the remainder of this presentation will be on landslide, slope stability and flood-related hazards

What are the Fundamental Requirements?

- Make maximum use of all available data
- Make maximum use of analytical techniques
- Utilise the Observational Approach and always ensure that desk study interpretation is supported by field observations
- Consult with local expertise and communities
- Develop a geo-model for the project area
- Learn from past successes and failures

In many mountainous parts of the world the following conditions often combine to create worst-case scenarios for transport infrastructure:

Terrain/Geo-hazard Constraints

- Steep and complex terrain
- Tectonically disturbed rocks
- Adverse structures
- Deep weathering profiles
- Earthquakes and landslides
- High groundwater and soil saturation brought about by intense or prolonged rain
- Rivers prone to frequent flooding, channel scour and shifting channels

Resource Constraints

- Limited available information concerning ground conditions and geo-hazards
- Limited economic and technical resources to investigate ground conditions
- Limited capital resources with which to prevent or mitigate landslides

Terrain and Geo-hazard Assessment for Sustainable Engineering

- Remote sensing
  - Satellite interpretation
  - Aerial photograph interpretation
  - Airborne imagery, mainly LiDAR
- Hazard mapping
- Landscape modelling techniques
- Field reconnaissance mapping
- Engineering geological mapping
- Ground investigation, slope analysis, monitoring and design

Satellite Imagery for Topographic Mapping

From James Mitchell

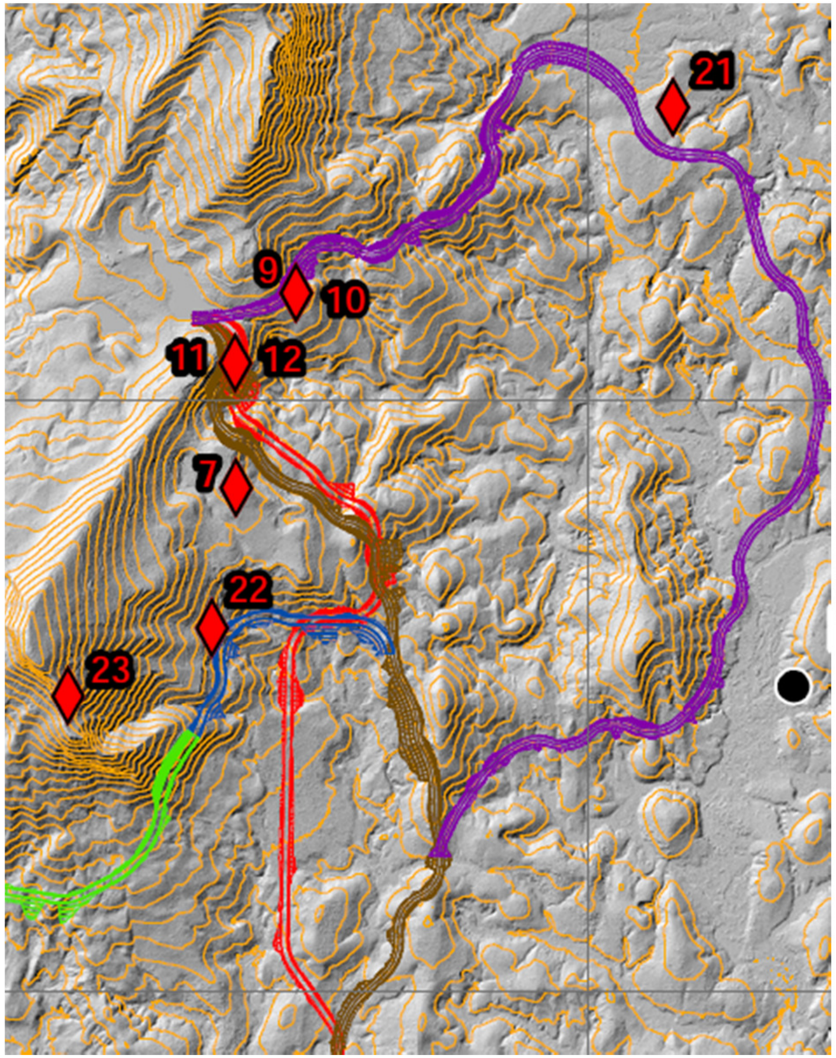
Sensor	Resolution	Horizontal Accuracy	Vertical Accuracy	Availability/ Archive length
SRTM	3 arc seconds (90 m)	30 m	5-15 m (terrain dependent)	Global Coverage
ASTER	30 m	30 m	15-30 m	Global Coverage
SPOT HRS DEM (SPOT5)	20-30 m	15 m	5-10m (terrain dependent)	Off the shelf product
Elevation10 (TerraSAR-X)	10 m	5-10 m	5-10 m	2007-
PRISM DEM	5m	5-10m	5-10m	2006-2011
Elevation4 (Pléiades)	4 m	3 m	2 m	2012-
Elevation1 (Pléiades)	1 m	1.5 m	1 m	2012-
Worldview 1 & 2	1 m	1-2m (with GCPs, terrain dependent)	1-2m (with GCPs, terrain dependent)	2008-
GeoEye-1	1 m	1-2m (with GCPs, terrain dependent)	1-2m (with GCPs, terrain dependent)	2009-

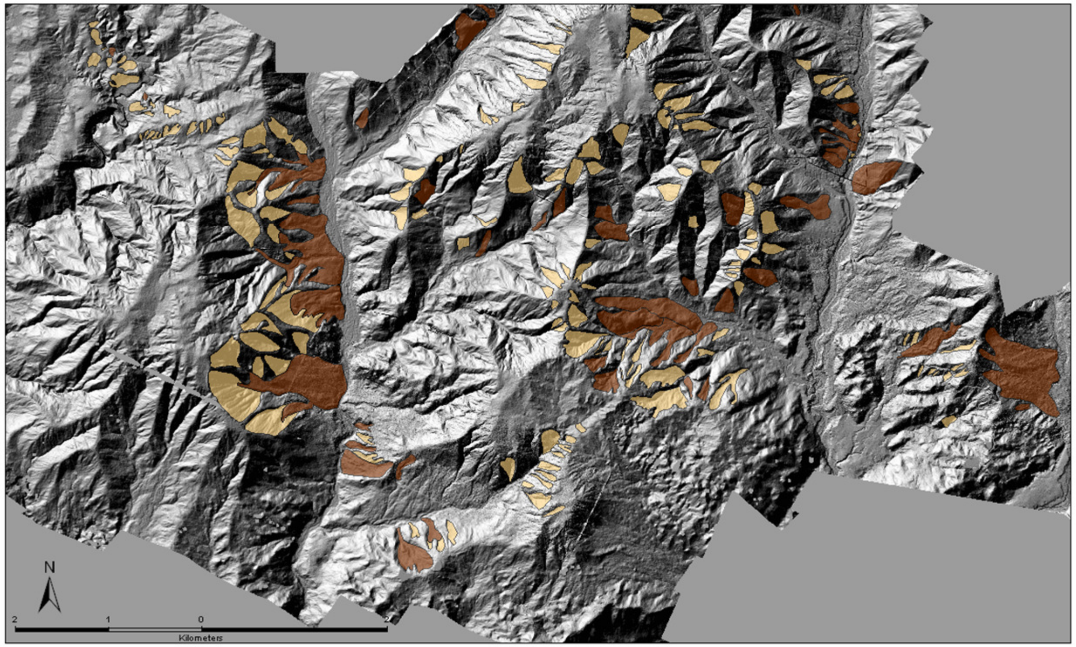
Satellite Imagery for Terrain and Environmental Interpretation

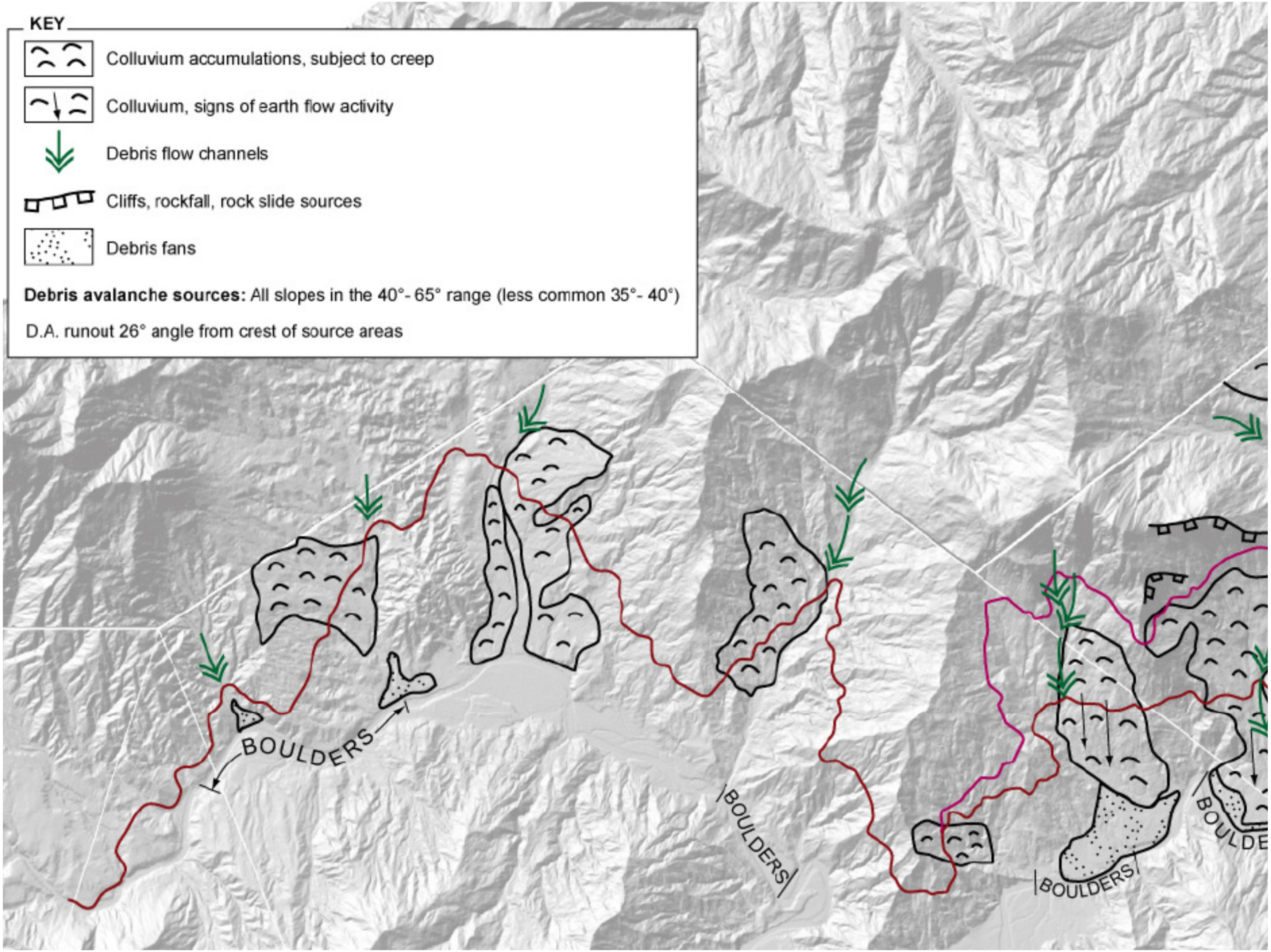
From James Mitchell

Sensor	Resolution B&W (m)	Resolution Colour (m)	Scene Size (km)	Launch Data
Worldview-1	0.5	-	16 x 16	2007
Worldview-2	0.5	2	16 x 16	2009
GeoEye-1	0.5	1.65	15 x 15	2008
Quickbird	0.6	2.4	17 x 17	2002
Pléiades-1A and 1B	0.68	2.7	20 x 20	2011, 2012
Ikonos	1	4	11 x 11	1999
Orbview-3	1	4	8 x 8	2003
SPOT-6	1.5	8	60 x 60	2012
Formosat-2	2	8	24 x 24	2006
SPOT-5	2.5	10	60 x 60	2002
ALOS PRISM & AVNIR-2	2.5	10	35 x 35	2006
RapidEye	-	6.5	77 x 77	2008
ASTER	-	15/30	60 x 60	2002
DMC	4	32	600 x 600	2002
Landsat-7 ETM+	15	30	185 x 185	1999

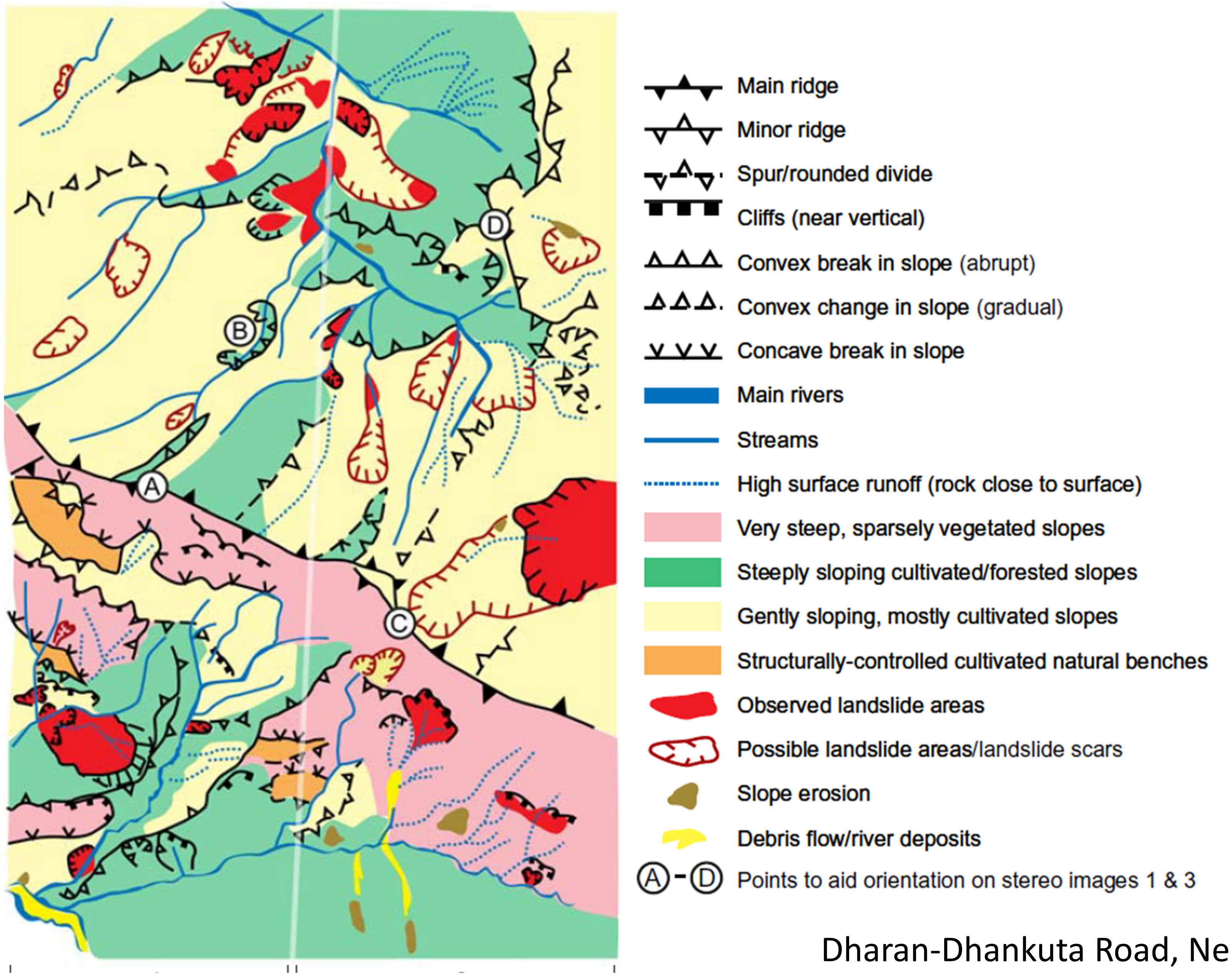
Use of Air-borne LiDAR imagery for DEM, Route Selection & Hazard Mapping





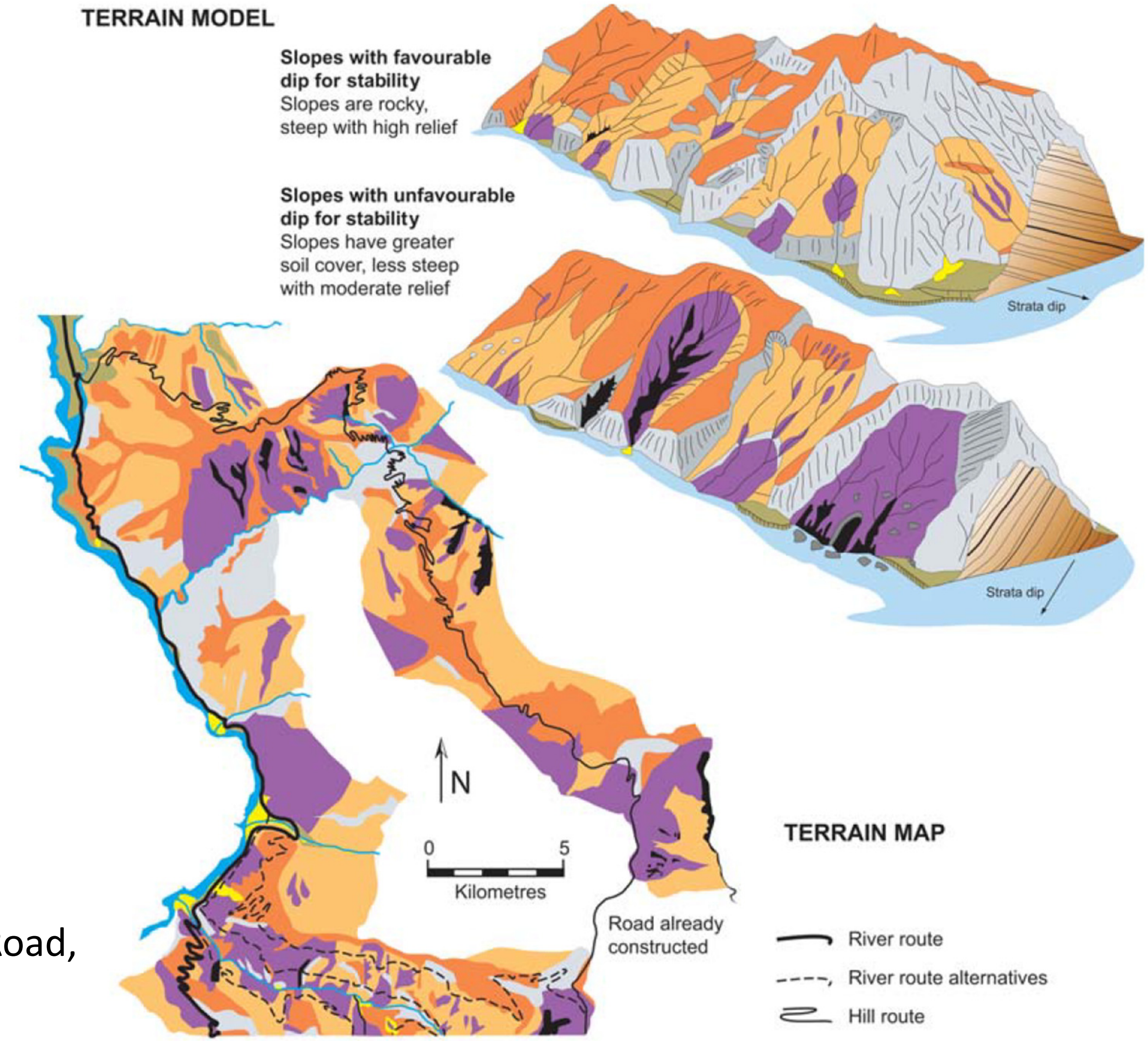

KEY
Colluvium accumulations, subject to creep
Colluvium, signs of earth flow activity
Debris flow channels
Cliffs, rockfall, rock slide sources
Debris fans
Debris avalanche sources: All slopes in the 40°- 65° range (less common 35°- 40°)
D.A. runout 26° angle from crest of source areas
BOULDERS
BOULDERS
BOULDERS

Air Photograph Interpretation



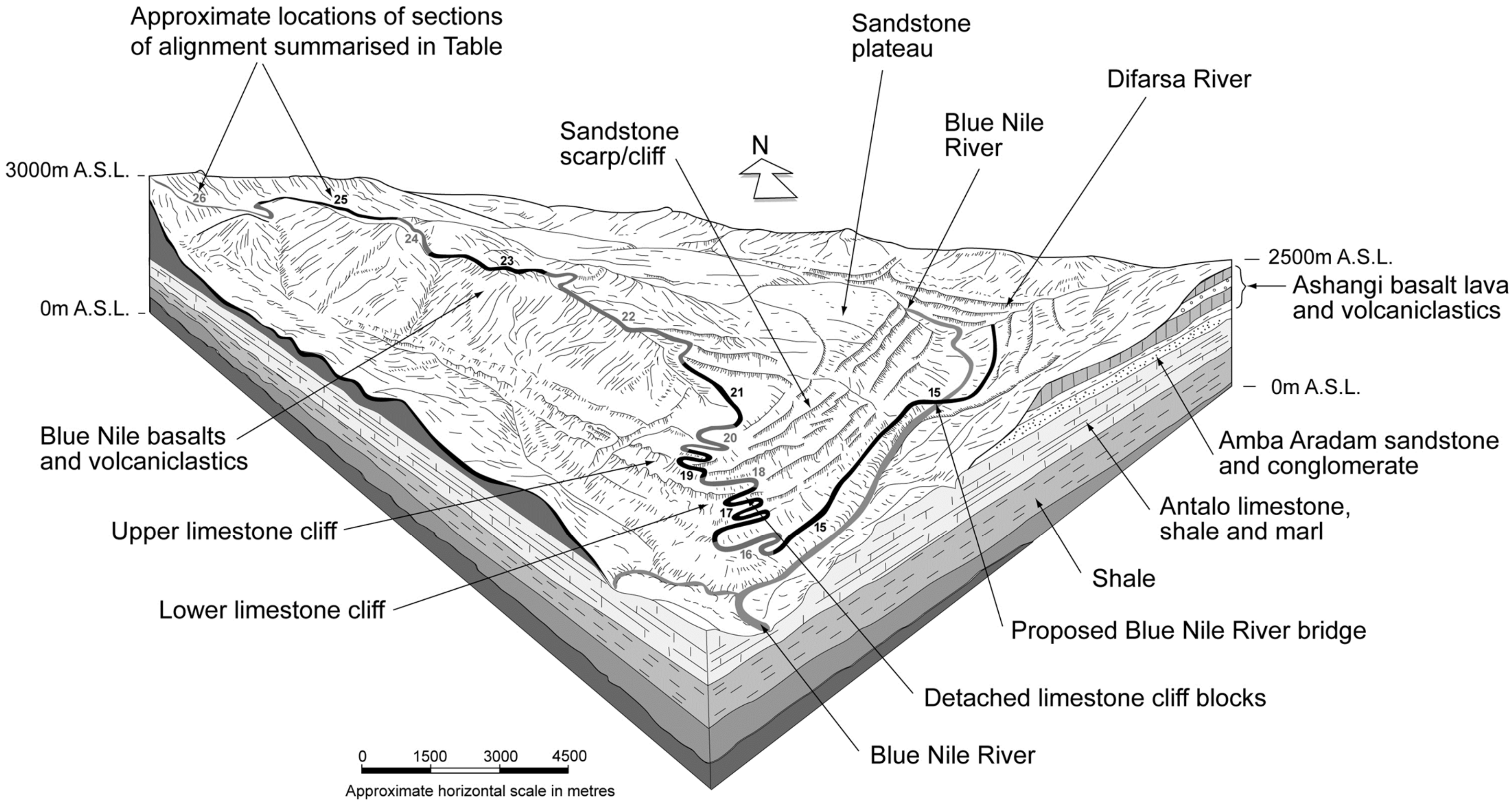
Dharan-Dhankuta Road, Nepal

Landscape Modelling



Arun Access Road, Nepal

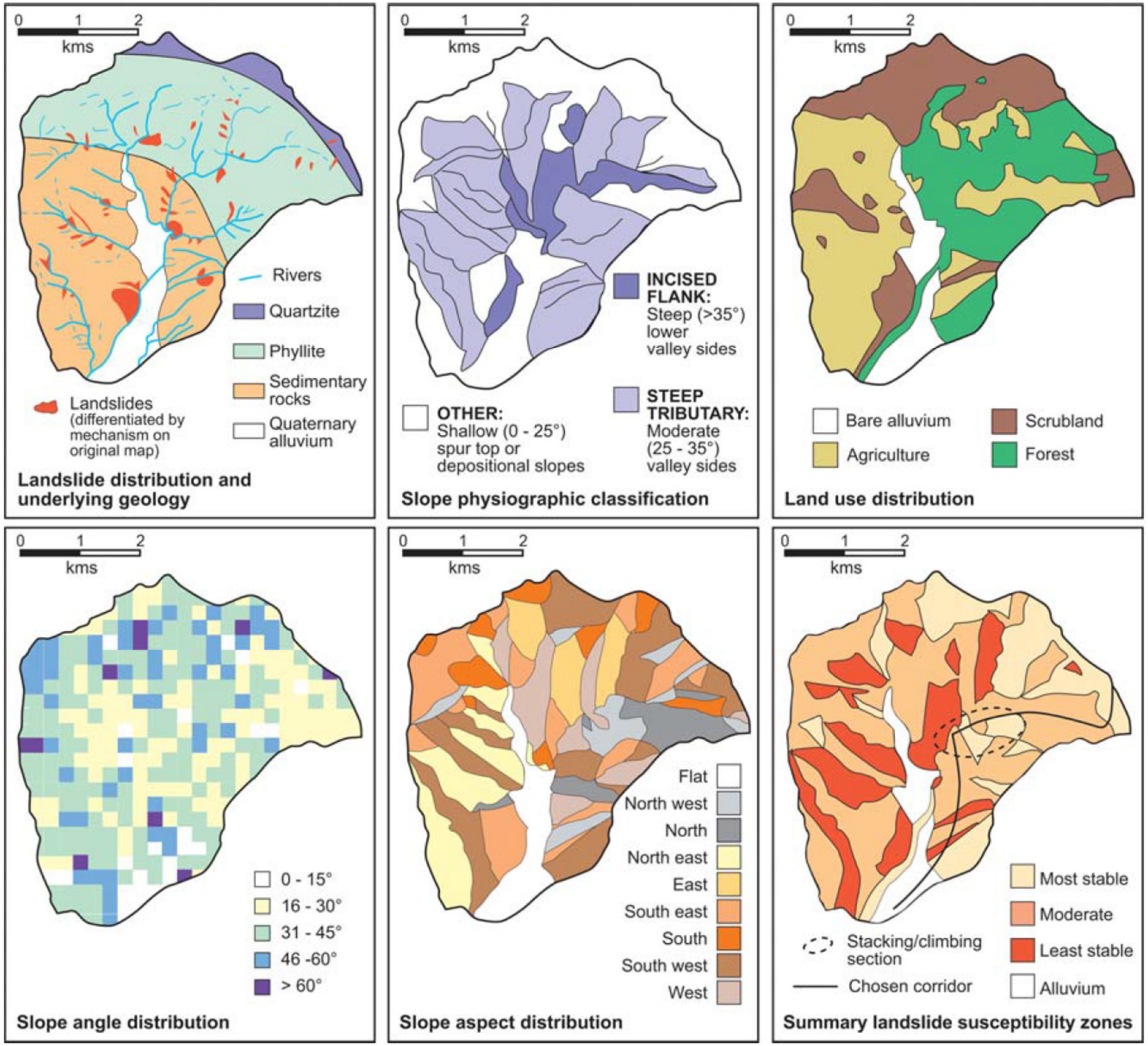
Landscape Modelling



Blue Nile River
Crossing, Ethiopia

Drawn by G Pettifer

Landslide Susceptibility Mapping

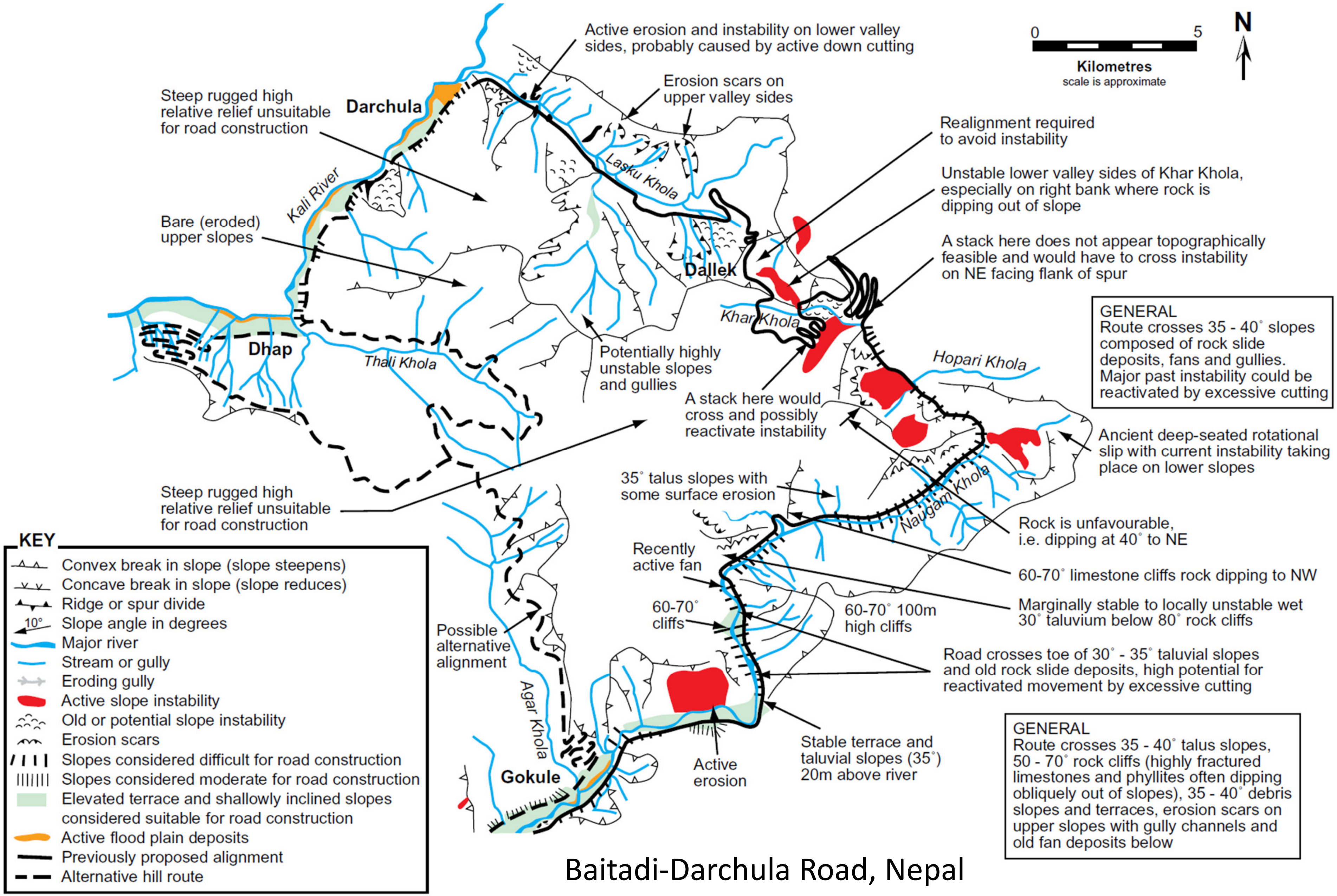


FACTOR	CATEGORY	O/E	SUSCEPTIBILITY RANK
ROCK TYPE	Sedimentaries	1.2	3
	Phyllite	0.8	2
	Quartzite	0.3	1
SLOPE ASPECT	North	0.7	1
	South	2.0	2.5
	East	2.2	3
	West	0.7	1
	North west	0.6	0
	North east	0.9	2
	South east	0.9	2
	South west	0.5	0
PHYSIO-GRAPHY	Incised flank	2.9	3
	Steep tributary	1.1	2
	Other	0.3	1
LAND USE	Scrub	1.0	NOT SIGNIFICANT
	Agriculture	1.1	
	Forest	0.9	
SLOPE ANGLE	0 - 15°	0.7	
	16 - 30°	1.0	
	31 - 45°	1.3	
	46 - 60°	0.8	
	> 60°	0.4	
CHANNEL PROXIMITY	Stream rank:		
	First order	0.9	
	Second order	1.1	
	Third order	1.5	
	Fourth order	0.9	
	Fifth order	1.0	

Build up of susceptibility rank for the illustrated catchment. Susceptibility ranks for each factor category are summed for every terrain unit and assigned to one of three susceptibility classes. 3 is the most unstable condition.

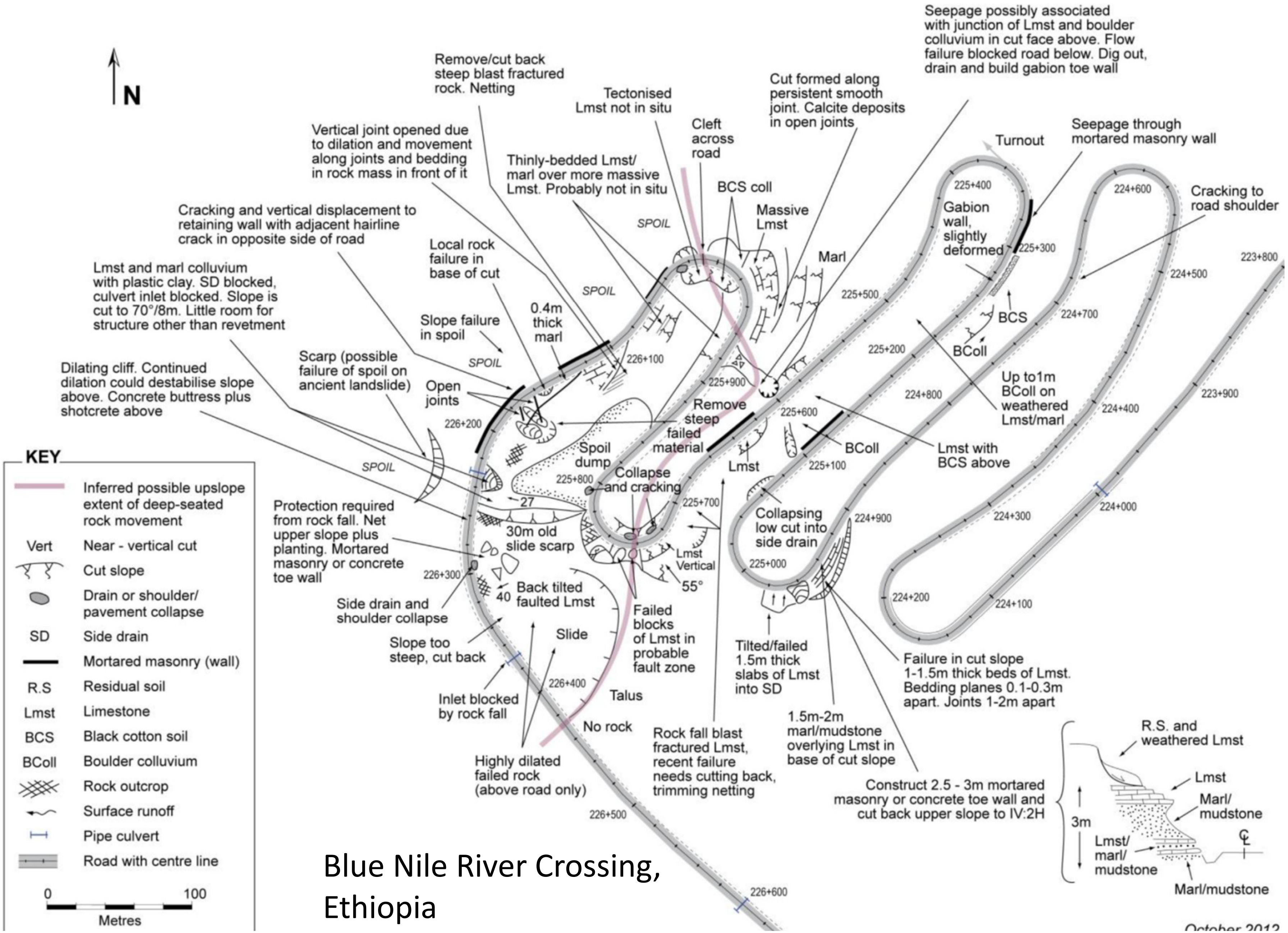
Dharan-Dhankuta Road, Nepal

Engineering Geological Reconnaissance Mapping



Baitadi-Darchula Road, Nepal

Engineering Geological Mapping for earthworks design



Blue Nile River Crossing, Ethiopia

Avoiding Sensitive Habitats

Liberia, courtesy ArcelorMittal

Black areas – Level 1 biodiversity value

Grey areas – Level 2 biodiversity value

Broken red line areas – approx mine boundaries

Light brown areas – approx proposed waste dumps

Blue areas – sedimentation ponds

Engineering Necessity or Engineering Futility?

Harmonizing the Engineering with Landscape Constraints and Service Level Requirements of the Infrastructure

Darjeeling-Teesta Bridge, India

Green Roads

Shagon-Zigar Road, Tajikistan

Arterial Roads

The Building Blocks of Sustainable and Responsible Engineering

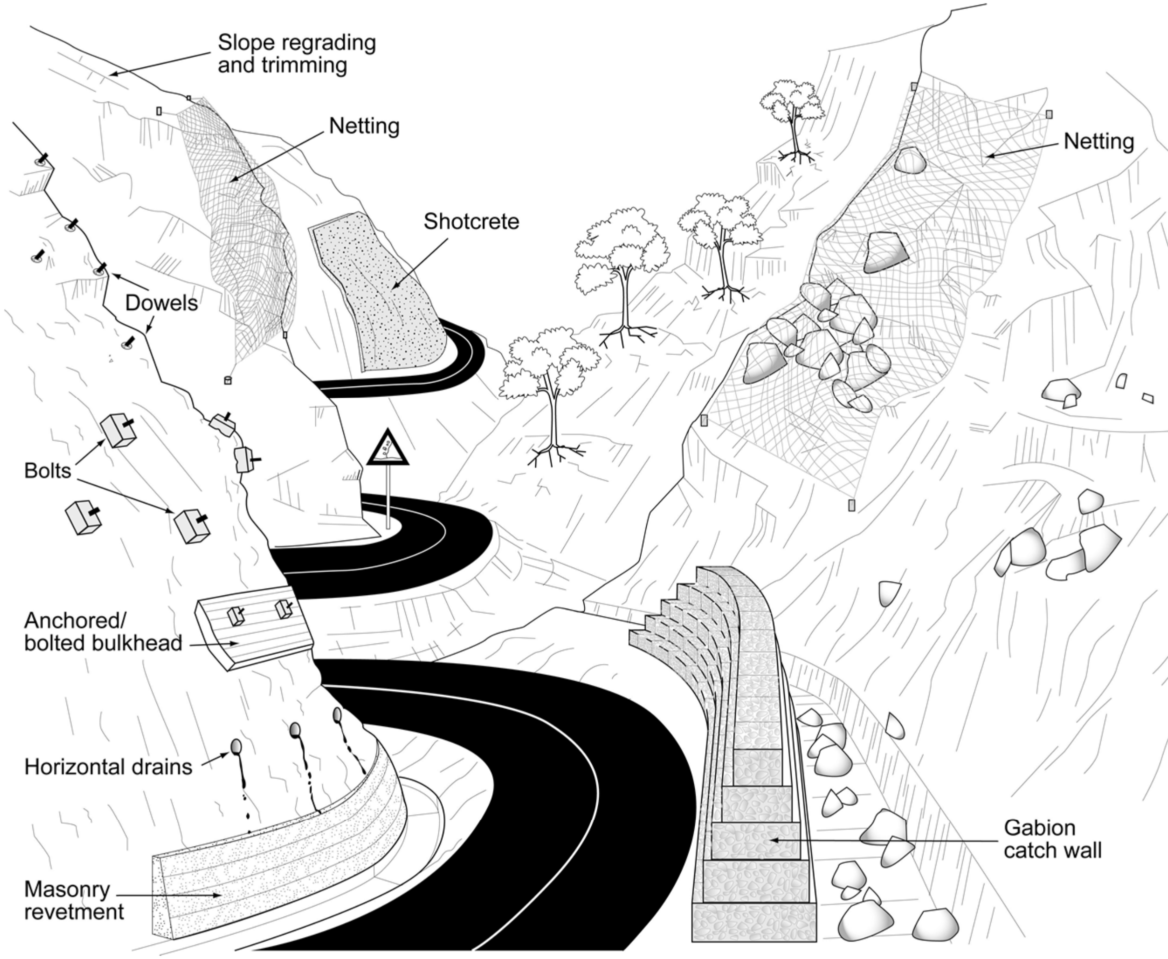
Engineering Imperatives

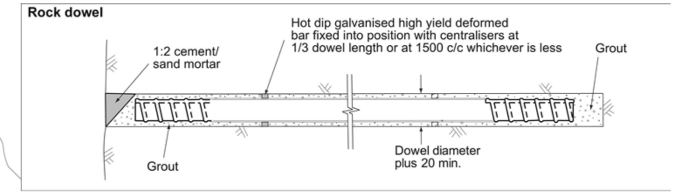
- Design the engineering to suite the need
- Avoid geo-hazards in route selection
- Avoid excessive earthworks in route selection
- Cut slopes according to the strength of materials exposed
- Try to balance cut and fill
- Maximise drainage crossings, i.e. minimise drainage concentration
- Do not construct anything that cannot be maintained

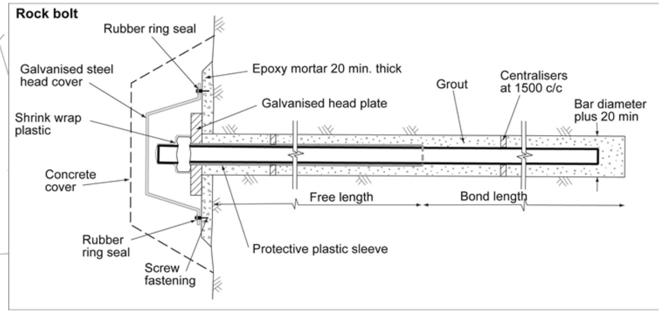
Environmental Imperatives

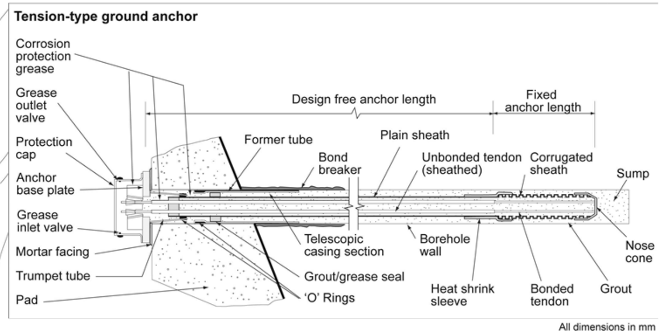
- Avoid areas of ecological or cultural significance
- Minimise spoil, i.e. maximise reuse of materials
- Dispose of spoil in safe areas
- Maximise roadside replanting schemes
- Minimise adverse effects on adjacent land uses and compensate accordingly

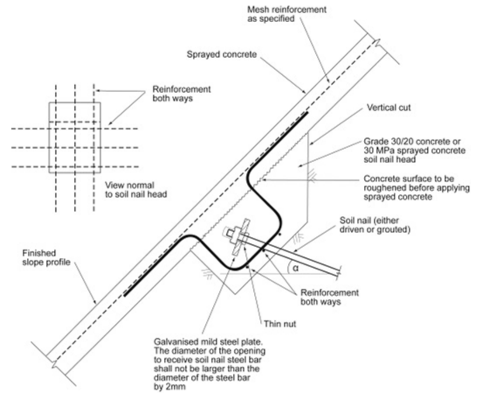
Rock Slope Stabilisation and Rock Fall Control



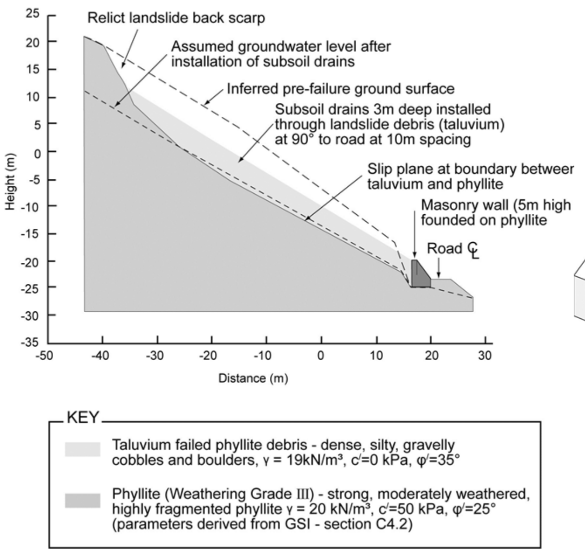


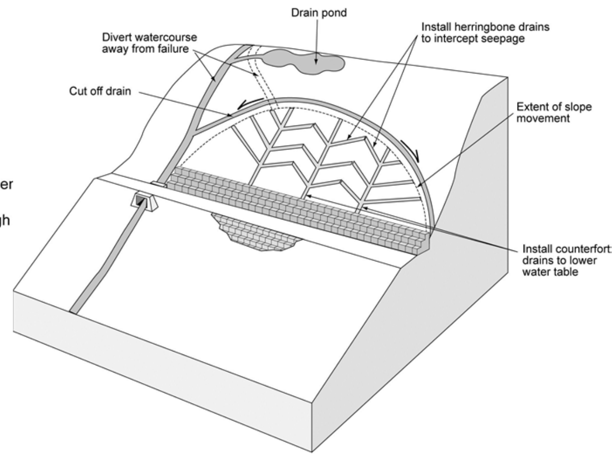


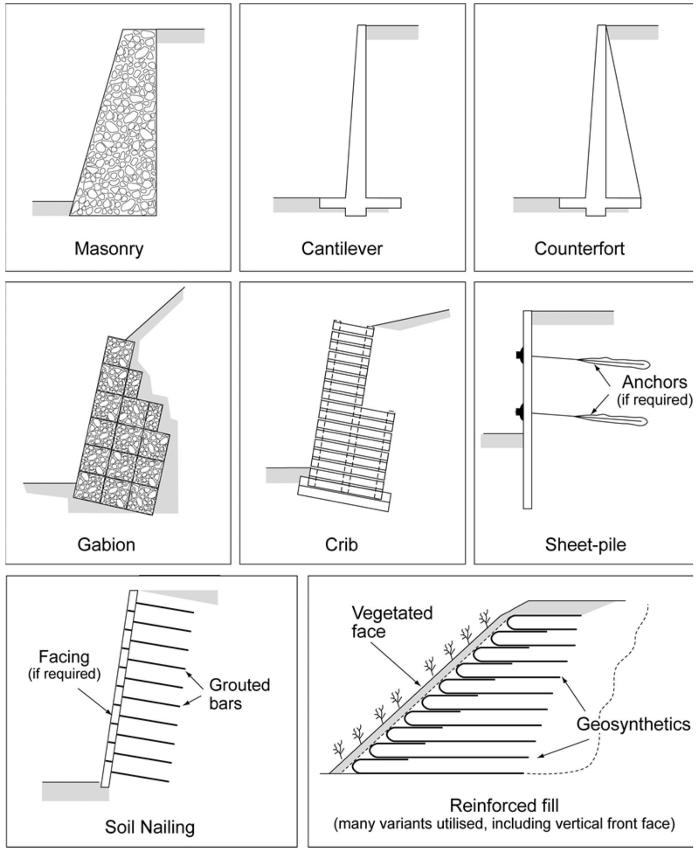


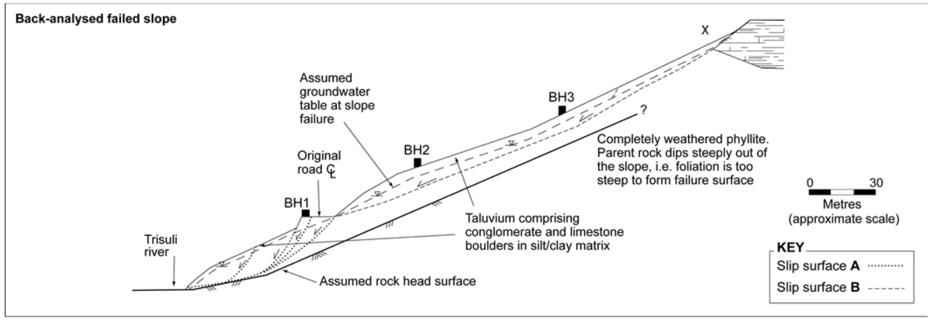


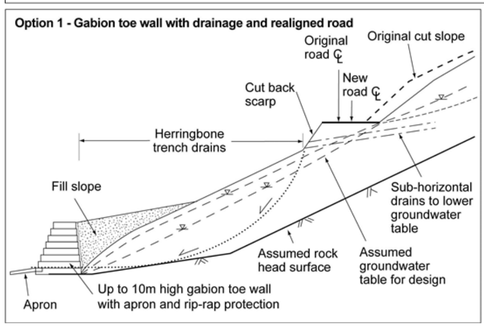
Earthworks Design and Soil Slope Stabilisation

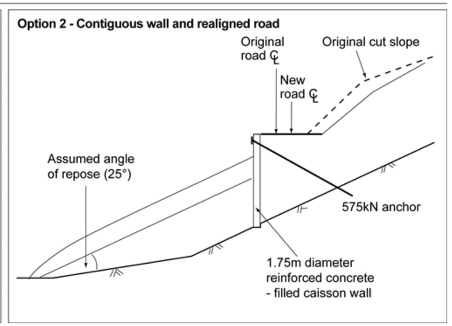


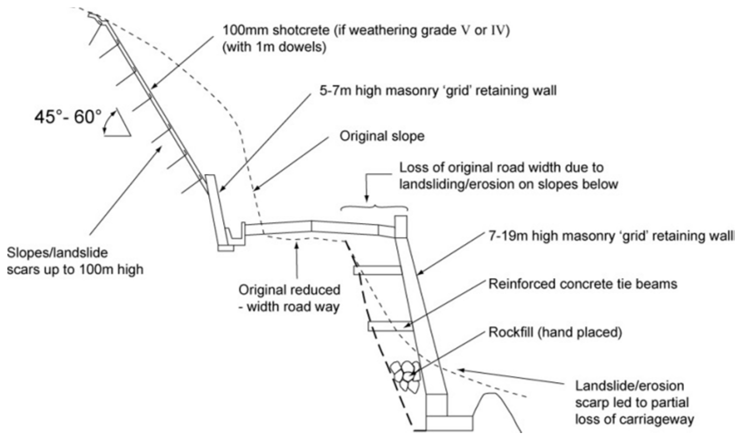




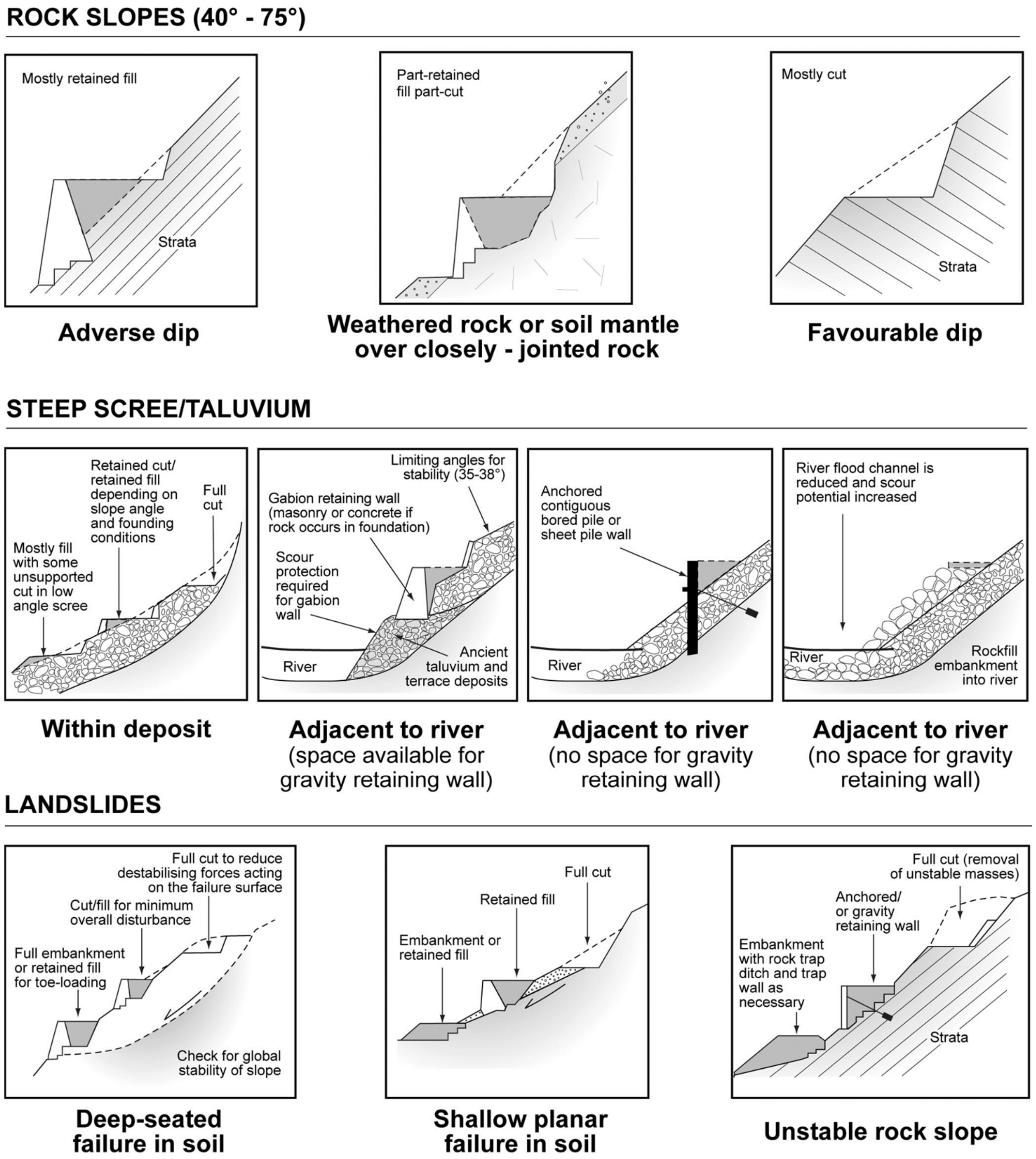




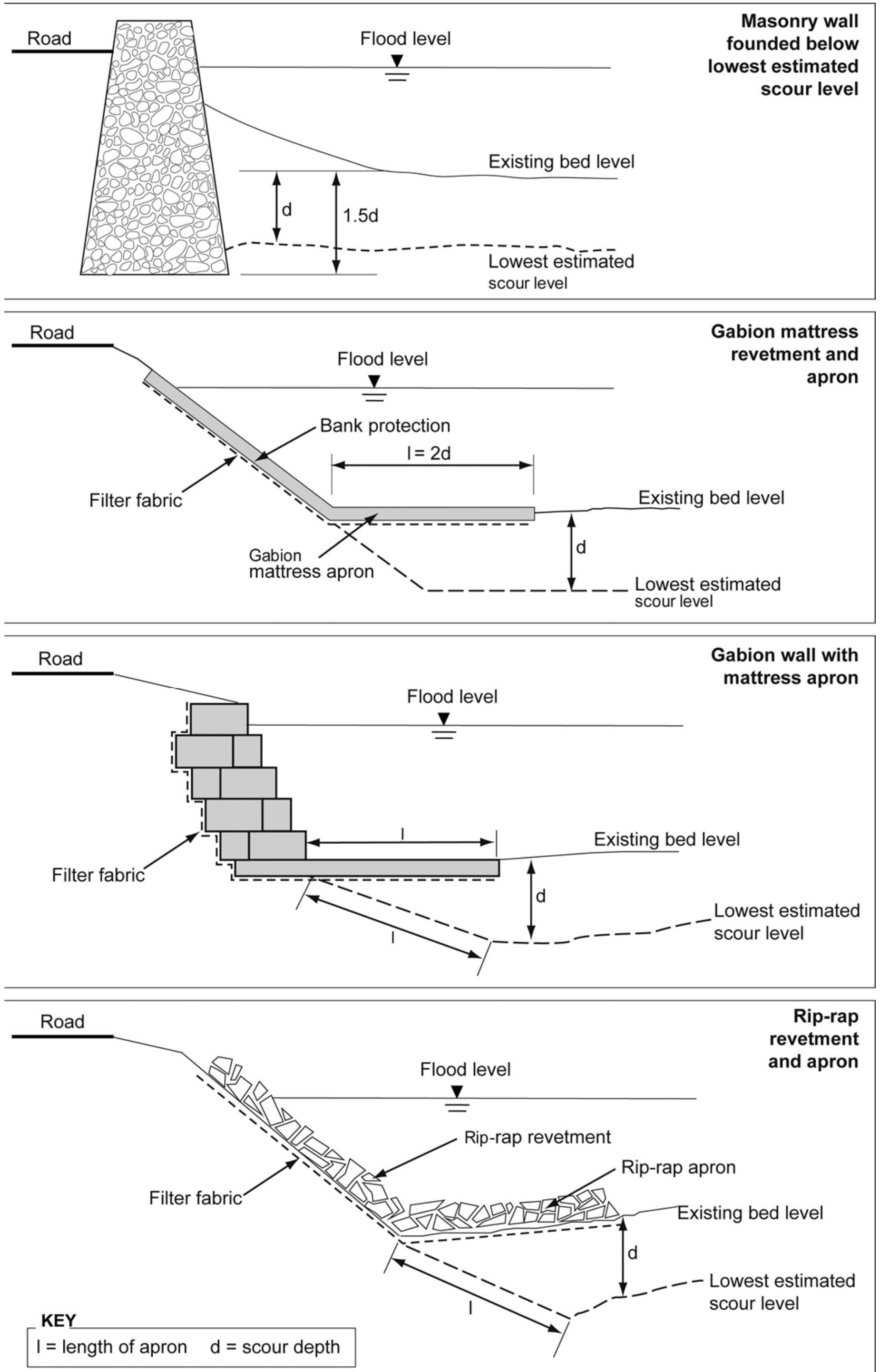




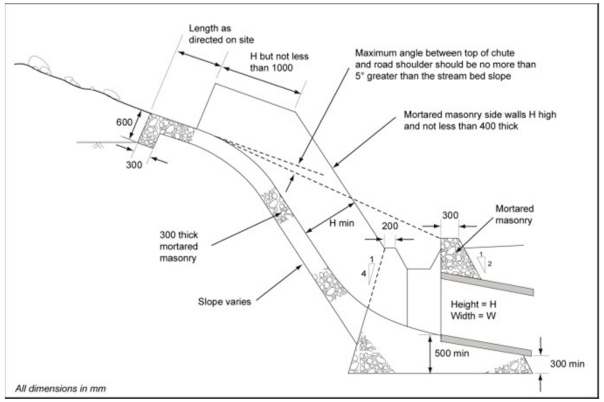
Its Knowing What to do Where which is of Greatest Importance

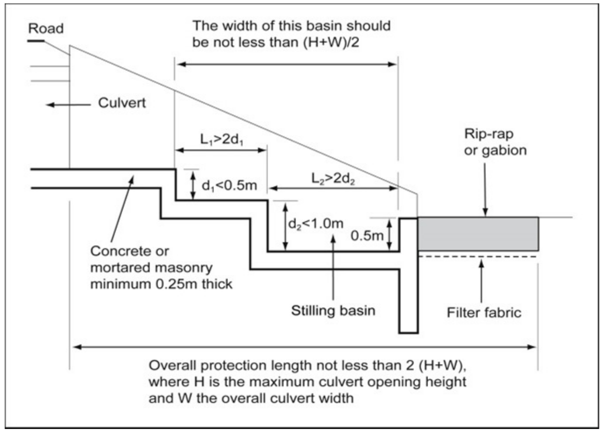


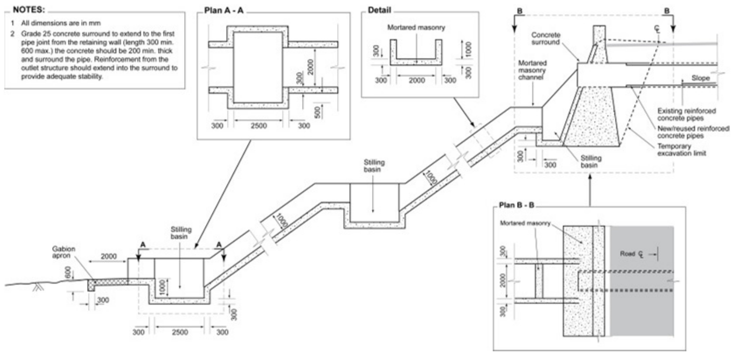
Flood Hazard Mitigation

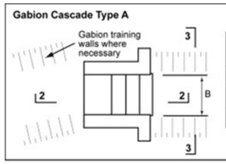


Engineering Erosion Control

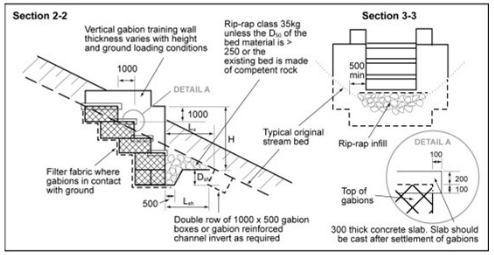


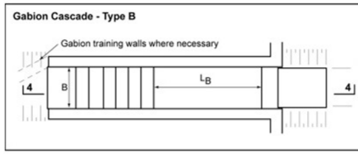




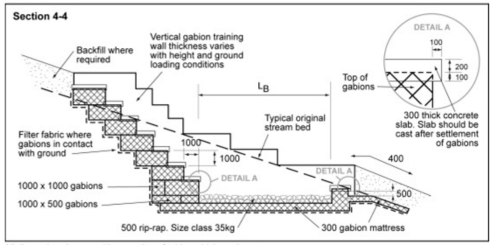


Culvert size	B	Drop H 3		4		5		6		7	
		D_{sh}	L_{sh}	D_{sh}	L_{sh}	D_{sh}	L_{sh}	D_{sh}	L_{sh}	D_{sh}	L_{sh}
0.6 dia	2.0	1.0	2.3	1.0	2.4	1.0	2.5	1.0	2.6	1.0	2.7
0.9 dia	3.0	1.0	2.9	1.0	3.1	1.0	3.3	1.5	3.4	1.5	3.6
1.2 dia	4.0	1.5	3.6	1.5	4.0	1.5	4.2	2.0	4.4	2.0	4.6

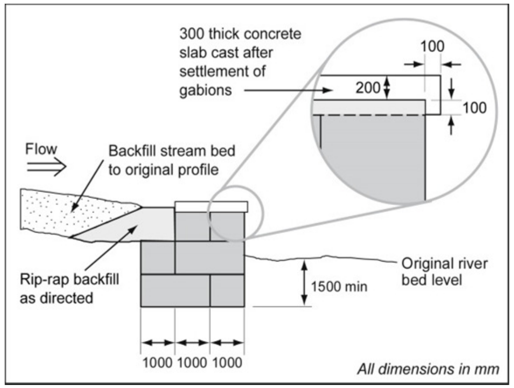


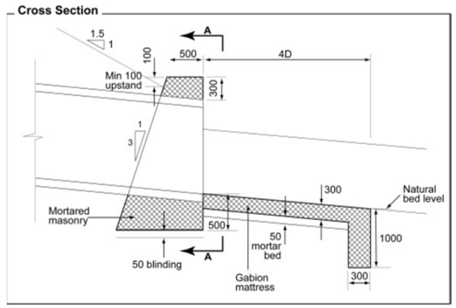


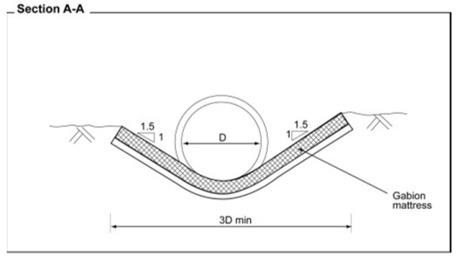
Culvert size	B	L_B
0.6 dia	2.0	4.5
0.9 dia	3.0	6.5
1.2 dia	4.0	8.5



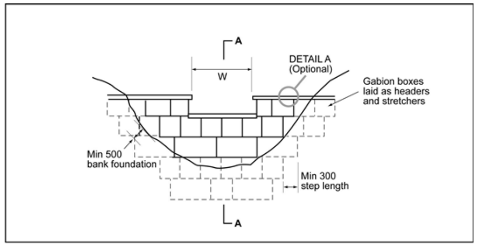
All dimensions in mm, with exception of tables which are in metres
Detail A optional depending upon sediment load and flow velocity

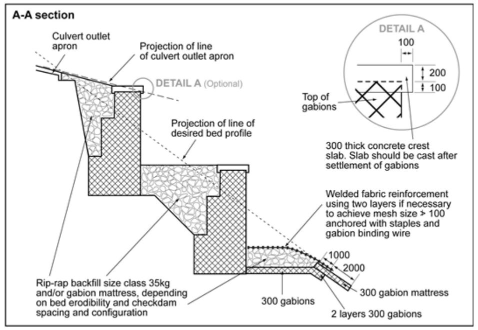






All dimensions in mm





All dimensions in mm

Community-Based/Participatory Erosion Control

Grass planted in horizontal rows

Grass planted in diagonal rows

Brush layering

Palisades

Truncheons

Wattle fences/live checkdams

Laos

Bhutan

Nepal

NB there has been an erosion control centre in Dehra Dun since 1974

Construction Materials and Methods

Local Vs Imported Materials

Calcrete Otta Seal, Mozambique

Labour-Based Vs Machine-Intensive

[DFID-Funded AFCAP and SEACAP Research](http://r4d.dfid.gov.uk/Output/)
http://r4d.dfid.gov.uk/Output/

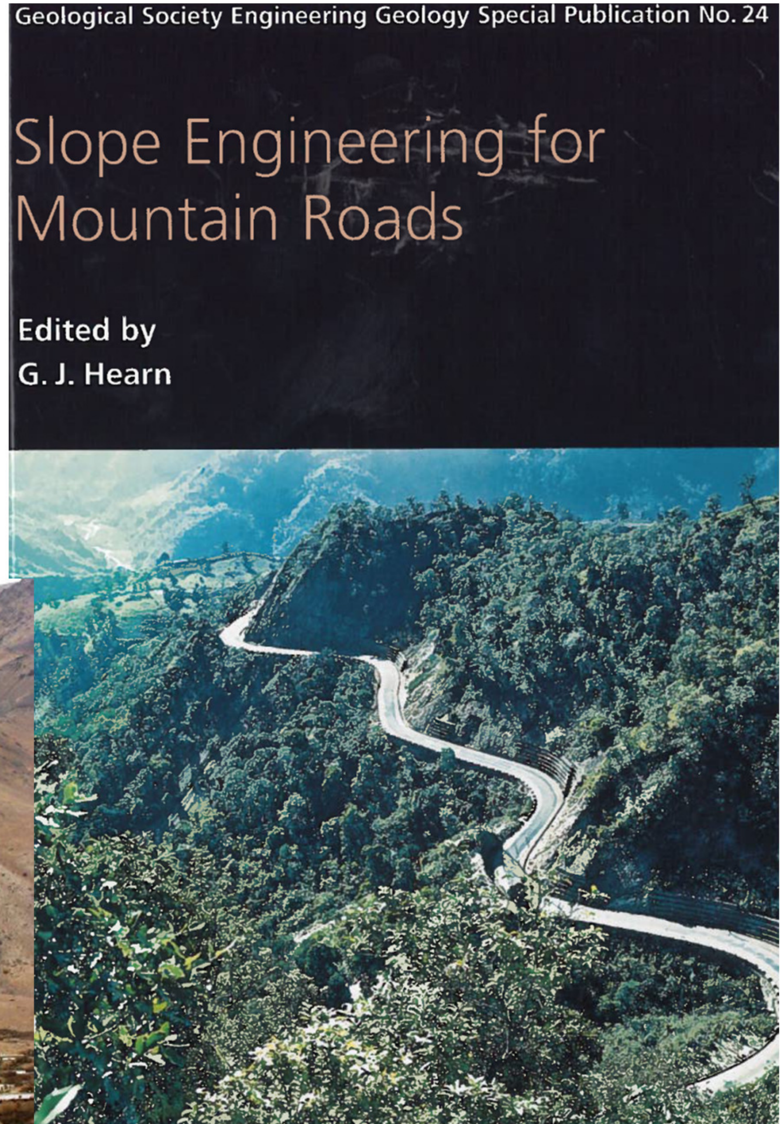
Choose the Right Solution for the Prevailing Topography and Ground Conditions

Sometimes it Can be Hard to Learn from our Mistakes

Change in Direction

Change in outlook

Further information on these techniques and designs for mountain roads can be found in:
Geological Society of London Special Publication No 24



Conclusions and Way Forward

1. Read the landscape – the landscape is made up of geology, geomorphology and land use, & geo-hazards past, present & potentially future – Prof Owen
2. Utilise all desk study data (including RS) for geological, geo-hazard, topographic and environmental data
3. Undertake field surveys & community liaison to collection site specific information and local knowledge – Mr Rinjin Jora Hon Minister UDLUB
4. Locate and design infrastructure according to 1-3 and according to service requirements, i.e. do not over-design or under-design
5. Do not reinvent the wheel: learn from the wider engineering & engineering geological community from past successes & failures & innovate accordingly
6. But, do not ignore the wheel!

8. Maximise the use of local materials, local knowledge & local skills, and maximise community participation – Prof Dominelli
9. Avoid environmentally sensitive areas and adopt environmental conservation practices – Dr Worah
10. Only construct what can be maintained, i.e. promote sustainable engineering


Thank You