Scott Wilson

South-East Asia Community Access Programme

LAO CONSULTING GROUP

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SEACAP 21/002: Feasibility Study for a National Programme to Manage Slope Stability

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Abbreviations

AADT	Annual Average Daily Traffic
ADB	Asian Development Bank
BAC	Basic Access Component (of the LSRSP-3)
CRM	Community Road Model
DFID	Department for International Development (UK)
DOR	Department of Roads
DOW	Department of Waterways
DPWT	Department of Public Works and Transport (formerly DCTPC)
EIU	Economist Intelligence Unit
ESD	Environment and Social Division (of MPWT)
GDP	Gross Domestic Product
IRI	International Roughness Index
JICA	Japanese International Co-operation Agency
LRD	Local Roads Division (of MPWT)
LSRSP-3	Lao-Swedish Road Sector Project 3
LTSP	Lao PDR Transport Sector Project (proposed)
MCTPC	Ministry of Communications, Transport, Post and Construction (now MPWT)
NPV	Net Present Value
NR	National Road
NUOL	National University of Lao PDR
PBMC	Performance-based Maintenance Contract
PMO	Prime Minister's Office
PRoMMS	Provincial Road Maintenance Management System
PTD	Planning and Technical Division (of MPWT)
PTI	Public Works and Transportation Institute (of MPWT) (formerly URI)
RAD	Roads Administration Division (of MPWT)
RMF	Road Maintenance Fund
RMS	Road Management System (covers national roads)
SEACAP	South-East Asia Community Access Programme
SIDA	Swedish International Development Cooperation Agency
URI	Urban Research Institute (now PTI)
VMC	Village Maintenance Committee
VOC	Vehicle Operating Costs
WB	World Bank

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PART A: REPORT ON THE FEASIBILITY STUDY

1. SUMMARY

This report is divided into two parts. The first (Part A) provides an account of a Feasibility Study conducted in April, May and July 2008 to assess the rationale and justification for a slope stabilisation programme in the road sector of Lao PDR. The second (Part B) describes the programme that is proposed. The material in this document is supported by a Background Paper, which provides the in-depth analysis of the various elements covered in the study. The study has been informed in part by the SEACAP 21 Project, Slope Stabilisation Trials on Roads 7 and 13 North.

The technical situation was assessed through a consideration of geology, terrain, rainfall and rivers, and how these combine to cause slope failures along roads. The majority of hillslope problems are found in the north of the country, where mountainous terrain and high rainfall are combined (although data are inadequate to provide a detailed picture). Slope failure problems caused by river bank erosion can occur in all parts of the country but only where roads are close to river banks so that the incidence of failure is small compared to hill slopes. Most slope failures affecting roads are relatively shallow slips in the weathered soil of cut slopes. However, there are also several other common types, some of which are deep-seated and can cause the loss of the entire road. Road construction practices also tend to trigger or accelerate slope instability, and it is clear that some improvements could be made to reduce the incidence of road-induced slope failures.

An attempt was also made to examine the economic aspects of roadside slope management. It has been difficult to draw definitive conclusions from this because of the scarcity of data on costs, and the lack of time for long-term measurement and monitoring. An important feature is that most roads, including National Roads, have relatively low traffic levels. Despite this, the costs of clearing debris and undertaking repairs under the emergency maintenance budget are high, and the economic impacts of disruption to road users can also be significant. Traffic users' costs also rise steeply with blockages longer than about three hours. Other costs, particularly in environmental damage and the effects on livelihoods, are also taken into account. The social appraisal suggests that the impacts of roadside slope instability on rural mountain societies are not significant at present.

However, although the low traffic volumes mean that for most roads it is not economically justifiable to invest in large-scale works, the analysis is sensitive to changes in the timeframe between construction and potential slope failure, and to changing traffic levels. This means that the economics are marginal, and under certain conditions investment are justifiable in proactive roadside slope engineering works. Ultimately the decision on investment in slope management has to be made on the more subjective basis of the expectation of road users, within certain technical and economic limits.

It is recommended that the MPWT move ahead with a slope stability management programme, drawing on donor support where necessary. This should include the approval of:
(a) service standards for different classes of road;
(b) an appropriate prioritisation process; and
(c) a policy for investment in reactive and proactive slope stabilisation according to the demands of road users.
It should also involve a substantial programme of skill development in slope management, which should be linked to the Ministry's evolving Organisational Capacity Development Plan.

2. INTRODUCTION

2.1 Background

Through the Transport Sector Project, the World Bank is assisting the Ministry of Public Works and Transport (MPWT) of the Lao PDR to move to a sector-wide approach to the planning and management of transport infrastructure. This is wide-ranging in scope and includes both technical and institutional development. The MPWT priority investment programme for the next few years will be formulated as part of this process.

A national slope stabilisation programme has been identified as an important need for the road sector. The intention would be to align donor resources to finance this as a component of the overall sector-wide project approach. Given SEACAP 21's technical work and experience on slope stabilisation, the MPWT and the World Bank requested SEACAP to support a feasibility study to help define the nature of such a programme.

SEACAP accordingly contracted Scott Wilson and its associated local partners (henceforth referred to as the Consultant) to undertake the feasibility study. The study had a timeframe of about four months including an extension to consider the significance of river bank erosion in slope failures. This report describes the finding of this study and is drawn from and supported by a Background Paper prepared by the Consultant that contains more detailed information, description and reference material.

2.2 Lao PDR Transport Sector Project

The proposed Laos Transport Sector Project (LTSP) is still under preparation, but it is likely that it will consist of the following main Components.

1. Investments in new or upgraded roads. This will commence with National Roads 1 and 6 in the first two years of the project, and detailed design for these roads has already started. It is expected that other roads will follow later.
2. Maintenance of the existing network. This will continue the work of the Road Maintenance Project, Phase 2, in making the RMS and PRoMMS systems the basis of management planning, and regularising the maintenance procedures.
3. Rural roads. A component to improve both the procedures used in the development and management of the rural roads network, and to build and upgrade a number of new roads.
4. Institutional strengthening. This will also follow on from the RMP-2 and will aim to help implement key parts of the Ministry's Organisational Capacity Development Plan, at both the strategic management and technical implementation levels.
5. Traffic safety. A component to develop this essential element of the sector, which is becoming increasingly important as traffic levels increase.

Within this framework there are several areas where an important technical issue like slope stability fits in. If any of the investments in Component 1 are in mountainous areas or close to rivers, then there is a key role in design and construction. More immediately, the boosting of maintenance procedures through Components 2 and 3 is a clear priority. To achieve this, some capacity development is certain to be needed, and this must be co-ordinated with Component 4. In this context, this report and the proposed slope stability management programme that it contains, corresponds with many of the sectoral activities that are expected to be included under the LTSP.

3. ASSESSMENT OF THE MAGNITUDE AND IMPACTS OF SLOPE INSTABILITY AFFECTING ROADS IN THE LAO PDR

The aim of this section is to assess the magnitude of the slope stability issue and its engineering, economic and social impact.

3.1 Technical appraisal

3.1.1 Landforms and geology

Lao PDR has an area of 236,800 sq km of which more than 75% can be described as mountainous, with elevations usually varying from 500 to 2000 metres above sea level. Most of the mountainous areas are located in the north of the country and in the Annamite chain, which forms much of the natural watershed between Laos and Vietnam. The country is roughly 1000 km long and has a width varying from 140 to 500 km. Figure 3.1 shows the topography of the country.

The following text describing the outline geology of the country has been copied from the Lao PDR Department of Geology and Mines website. "Metamorphic rocks believed to be Proterozoic outcrop in north-western and in eastern Lao PDR. Palaeozoic and Mesozoic cover rocks consisting of continental fluvial and shallow to deep marine sediments dominate throughout the country. These rocks have been intruded by numerous granitoid plutons comprising granodiorites, monzonites and quartz porphyries during the Devonian to Triassic. Permo-Triassic acid extrusive rocks comprising rhyolites and dacites are frequently seen especially in the southern part of Lao PDR. Extensive covers of redbeds of Mesozoic age are seen mainly in the southern part of the country. Intense folding took place during the Early Paleozoic, mid-to late Paleozoic and Triassic periods."

While the Consultant has been engaged primarily on Road 13N and Road 7 under SEACAP 21, other roads have been visited by the Consultant's geotechnical and river engineering staff, either as background to SEACAP 21, as part of this SEACAP 21/002 Feasibility Study and as part of ongoing work by Scott Wilson on the Nam Theun 2 Project. These visits have revealed the extensive outcrop of tectonically disturbed and closely jointed phyllitic and similar low-grade metamorphic rocks. These can be particularly susceptible to weathering, slope instability and erosion during the wet season (see section 3.1.2 below), although the majority of slope failures observed in these materials tend to be relatively shallow in depth Other low-grade metamorphic rocks commonly associated with slope instability include metasiltstones, slates and schistose rocks. Mudstones and mudstone-sandstone sedimentary sequences are also prone to landsliding when exposed in roadside cuttings, especially where bedding dips unfavourably to slope stability, and where cut slopes are cut steeper than bedding inclinations. Granitoid rocks often form the higher and steeper topography, and because they contain no bedding or foliation orientations, they are not commonly prone to landsliding. However, persistent joint sets can be the preferred planes of weakness along which sliding takes place if orientated unfavourably, and some deep-seated landslides have been observed in these areas.

3.1.2 Rainfall

Rainfall is a key factor in the triggering of slope failure. Water can be the single biggest activator of slope movements, since increased pore water pressures on existing or potential shear surfaces lead to a reduction in effective stress and a corresponding reduction in shear strength. This is the reason why the majority of slope failures occur in the wet season.

Erosion is a direct effect of running water, and can occur on any unconsolidated material when runoff occurs (i.e. when the rate of rainfall exceeds that of interception and infiltration).

Figure 3.1. Topographic Map of Lao PDR (map source: internet)

During the study an assessment was made of rainfall over Laos, and in particular in relation to the areas where landsliding is most common (see Background Paper, section 5). Rainfall distribution maps of the country vary and are very generalised, broadly based on the limited recorded data. The network of daily rain gauges has improved significantly in the last decade but there are still few continuous recording (autographic) rain gauges to provide reliable rainfall-duration-intensity curves for engineering design.

The weather in Laos is dominated by the Asian monsoon. The northeast monsoon coincides with the dry season from December to April, when there is hot and sunny weather with about 7 to 8 hours of sunshine a day. The south-west monsoon from the end of May until October brings the rainy season with cloudier skies and high humidity. In the lowlands, temperatures are high all year round.

During winter the northeast monsoon brings a relatively dry airflow, whilst summer brings the well-known rain-bearing south-westerly winds from warm maritime air in the Indian Ocean and Gulf of Thailand. Between the two monsoon seasons, there is a transition period when winds are light and variable.

Monsoon rainfall is characterised by thunderstorms often, but not exclusively in the afternoon or early evening. These storms begin with very high intensity rainfall which can last anything from a few minutes to one hour but which then reduces, sometimes quickly or maybe over several hours. Such storms can be very localised such that they can generate high runoff over a small area but individually are not significant over a large catchment. Rainfall in excess of 100 mm in 24 hours is not uncommon but this depends very much on the location, in high rainfall areas such rainfall may occur several times a year, in drier areas it can be expected on average every three or four years. The mountain areas exert strong physiographic influences and rainfall may be significantly greater than recorded in nearby towns.

Occasionally a typhoon from the South China Sea or Gulf of Thailand may cross over land and affect the country. When this happens these storms bring strong winds and torrential rain. The rainfall can be much more damaging than normal monsoon rainfall because the heavy rainfall is often sustained for more than 24 hours. Also the rainfall totals are much greater, e.g. the typhoon which struck central Vietnam on the 3rd August 2007 generating more than 600 mm rainfall near the coast still had enough force to drop almost 400 mm of rain in 30 hours two days latter as it tracked 500 km inland.

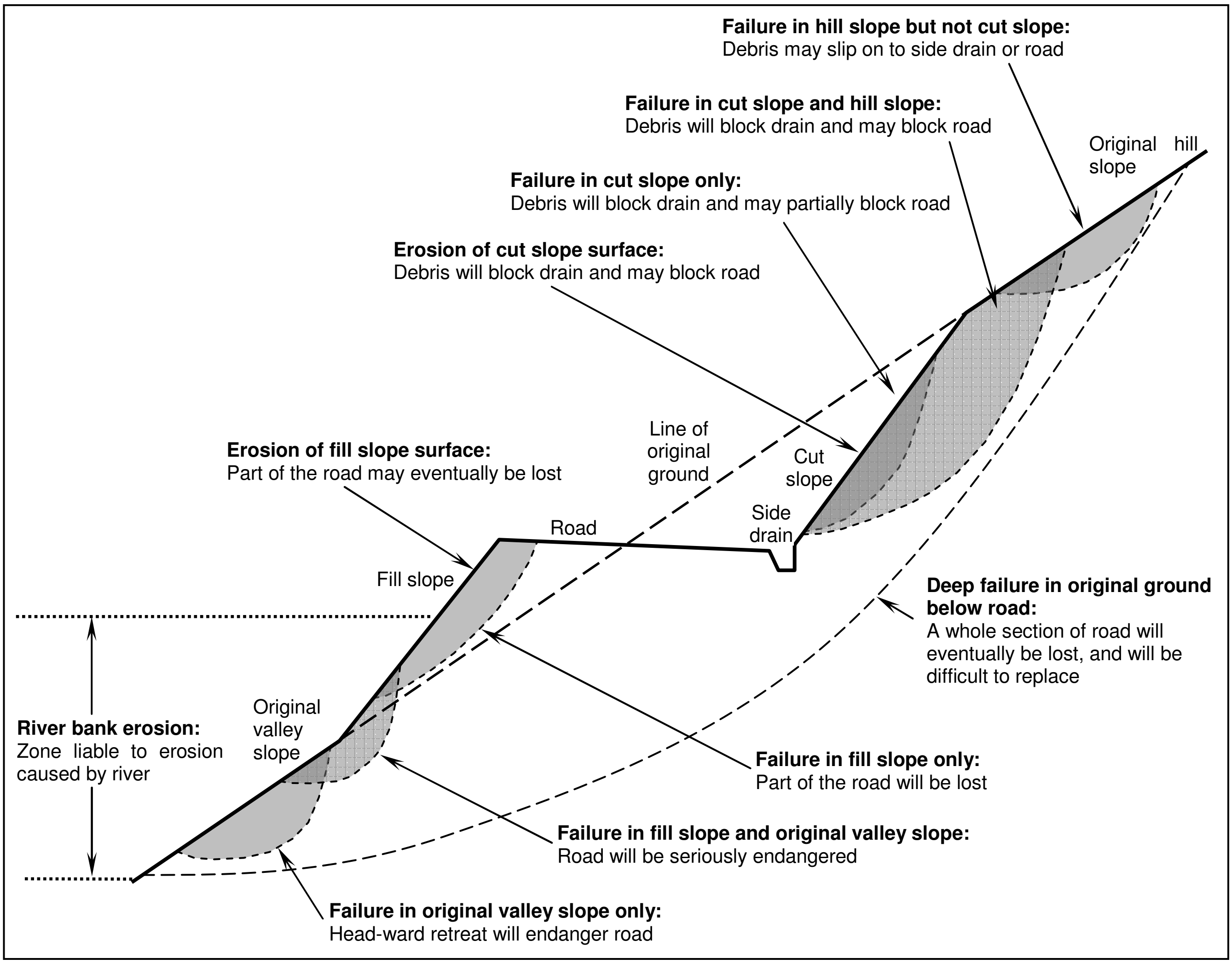
There clearly is a link between landslides and the amount and intensity of rainfall, but there are insufficient data currently available with which to determine this relationship in a predictive sense.

3.1.3 Slope stability in relation to roads

Mountain slopes are subject to the processes of weathering, erosion and slope instability. Changing patterns of storm rainfall, drainage and land use can accelerate erosion and slope instability. Road construction, through slope cutting, filling and alteration to drainage patterns, can also trigger significant slope instability and erosion. This can be on a wide range of scales, ranging from surface erosion to the triggering of slope failures several metres in depth. Consequently, while mountain roads often intersect pre-existing ‘natural’ landslides, much of the slope instability affecting roads is initiated by road construction itself, and often in association with the excavation of deep and over-steep cutting slopes. Slope instability is also common in fill slopes where they have been formed too steeply, have not been adequately compacted, or have not been benched into the original ground surface. On steep ground it can be difficult (or expensive) to design and build stable man-made slopes because the natural conditions are already close to the margin of stability. None of these problems are unique to Laos, but occur on most roads in mountainous areas that experience a pronounced wet season.

Where road alignments cross deep-seated landslides, the entire road bench can move, if the failure plane is beneath it. More often, however, it is the slopes above or below the road are affected. If the instability occurs above the road, then although the road may be blocked on occasions, the situation is not as serious as a failure of the slope below the road, where the formation of the road itself can be at risk. A detailed assessment of roadside slope instability is given in section 3 of the Background Paper. Figure 3.2 illustrates the common types of slope failure affecting mountain roads in general.

Figure 3.2 Common types of slope failure affecting mountain roads



3.1.4 River bank erosion

River bank erosion frequently occurs on slopes located below road lines. It can occur anywhere that a road runs along or close to the top of a river bank and may occur on mountain or lowland rivers. There are two situations which may occur:

- On a valley floor or on a flood plain where the land beyond the road and river is relatively flat and there is no hill slope in close proximity.

- Where the road is forced close to the river by a hill slope where the road may have been built on a river terrace, on embankment encroaching the river, or cut into the slope above normal river water level.

River bank erosion is additional to any of the failure mechanisms below the road illustrated by Figure 3.2 and will only be a factor where a river is present.

3.1.5 The magnitude of roadside slope instability in Laos

Data on the extent and volume of landsliding on Lao roads are difficult to obtain, as to date there has been no systematic research into the magnitude of the problem. Table 3.1 summarises the data provided by one Provincial DPWT. This shows that the incidence of landslides varies from year to year and place to place, as might be expected. Further information on this is presented in the Background Paper, section 6, but the data allow only a general rather than a detailed assessment of the magnitude of the slope instability affecting roads.

Table 3.1. Summary of landslides listed on two National Roads in Luang Prabang Province

Road	2003-04		2004-05		2006-07	
	Number	Vol. (m^3)	Number	Vol. (m^3)	Number	Vol. (m^3)
NR 4, 67 km	62	10,178	32	7,689	No data	No data
NR 13 North, 433 km	158	32,794	No data	No data	268	103,609

In an attempt to compensate for this, the Consultant has developed its own dataset of landslides recorded along selected roads in the National network. This dataset is presented in section 12 of the Background Paper, and discussed further in section 4.1 of this report. The dataset contains over 150 landslides from a surveyed length of approximately 1,100 kilometres of road. The highest densities occur along Road 3, Road 13N south of Luang Prabang and the eastern section of Road 8. These areas correspond to some of the steepest areas of terrain and areas of highest rainfall in Laos (see Background Paper for further details and discussion).

However, the pattern of roadside slope instability is not easily explained in terms of simple relationships with topography and annual rainfall distribution. Usually, the stability of roadside slopes can be expected generally to improve with age as cut slopes fail and ravel back to more stable angles, and vegetation re-establishes itself, thus encouraging stability. Newly constructed roads will be among the most prone to slope instability and erosion unless their earthworks slopes are rigorously designed to cater for the anticipated and actual ground conditions (including soil and rock types and rock jointing structures), and adequate provision is made for stabilisation and erosion protection works.

As mentioned in section 3.1.3, intense rainstorms can trigger extensive landsliding, often in localised areas. These landslides may occur on natural hillsides, though they tend to be most frequently developed in road cuttings, and can be either reactivations of existing landslides or the creation of new landslides on previously unfailed slopes. The location and frequency of intense rainstorms is unpredictable, and their distribution over time bears little correlation with the average annual rainfall pattern. Rainfall therefore further complicates the pattern of landslides that might be observable at any given time.

3.2 Economic appraisal

The economic implications of landslides on roads can be estimated by assessing the cost consequences of clearing landslide debris and repairing damage, the disruption to traffic through the closure of roads, the losses of lives and livelihoods, and damage to utilities and the wider environment. The appraisal carried out as part of this study is presented in section 7 of the Background Paper.

From the data available, it appears that the main expenses under current economic conditions are in the clearing and repair of road infrastructure following landslides, and in the impacts of traffic delays. The relatively low traffic levels mean that delay costs for road users only start to appear significant once there has been a blockage for about six hours. For example, even with an AADT of only 100 vehicles, a full day's blockage costs perhaps US $ 11,000 in traffic disruption. The cost is three times this for a busier road with an AADT of 300. The sparse rural population in the hills and the general avoidance of steep slopes for habitation mean that there has been no known loss of life as a direct result of landslides along mountain roads, while the effects on livelihoods are small. The effects on the wider environment can be significant when valuable forest resources are lost.

While it is difficult to be precise, it is clear from the available records that in some years the direct cost to the Nation from landslides has been at least US $ 5 million in repair costs through the emergency road maintenance budget. The indirect costs obviously increase this amount significantly, but the scarcity of data means that the estimates given here of the scale of economic impacts are somewhat speculative. A summary of the possible costs is given in Table 3.2.

Table 3.2. Speculative summary of possible overall "typical" landslide costs

Element	Cost (US $)	Assumptions and references
Landslide clearance and repair	37,000	Based on Table 7.1 in the Background Paper; assumes 1 landslide per 5 km at average cost of emergency maintenance in northern hilly provinces.
Value of time lost	4,500	Based on Table 7.3 in the Background Paper; assumes a full-day blockage on a road with an AADT of 300.
Vehicle operating costs	33,000	
Wider environmental damage	8,000	Based on Table 7.5 in the Background Paper;
Potential total per landslide	**82,500**	Broad estimate only.

3.3 Social appraisal

Apart from the road users, who are considered in the economic appraisal, the main primary stakeholders affected by landslides are people earning their livelihoods from the land affected. Because of the current land use practices in rural Laos, this mainly amounts to upland farmers, most of whom are still engaged in shifting cultivation. This practice means that there is a value to all areas of land in the mountains, whether it be currently cultivated, fallow (i.e. reverting through scrub to forest) or forest. Products from the forest are an essential part of Lao agriculture, to the extent that it is in fact meaningless to separate traditional agriculture and forestry.

Detailed studies of the slopes around landslide trials under the SEACAP 21 project, presented in the social appraisal (section 9 of the Background Paper), show that all of the roadside landslides lead to some damage to productive land. However, while some of this is almost immediate – such as the loss of fruit trees – in other cases it may not really be felt because the land lost is under long term fallow, and will simply be replaced by extending future cultivation in another direction. Seen in terms of the national economy, the effects of roadside landslide damage to livelihoods is insignificant. Yet in the context of an individual household, it could potentially be highly significant if a large proportion of a season's crops were to be lost. This may increase in the future as roadside areas are increasingly settled and cultivated for cash crops.

Although there is certainly a social impact resulting from roadside landslides, it appears that it is not yet a matter of concern. There is very scattered population and adequate availability of land in the mountains, so few people are obliged to depend on marginal slopes. Hence the problems in Laos are very limited in comparison to more densely populated mountainous countries.

4. ASSESSMENT OF THE FEASIBILITY OF A SLOPE MANAGEMENT PROGRAMME

The aim of this section is to assess the technical and economic feasibility of a slope management programme.

4.1 Technical feasibility

4.1.1 Prevalence of different landslide types and the risk they pose to road stability and operation

Landslide types

Section 12 of the Background Paper contains an inventory of slope instability features recorded during reconnaissance drive-over surveys of selected mountain roads in Laos and a commentary on river bank erosion supported by representative site inspections. The purpose of these exercises was not to develop a comprehensive and thorough slope failure dataset for the entire road network, but to gain an overview of the nature of slope instability that affects roads most commonly.

Shallow failures in debris in roadside cuttings

By far the most common types of landslides affecting the road network are shallow debris slides in cut slopes. These are usually up to a metre or two in depth, and frequently originate in the upper, more weathered, portion of the cut slope. They also often occur along the rock head surface which, on side-long ground, usually dips out of the cutting and presents a preferred plane upon which sliding can occur. Rainwater and subsoil drainage usually percolates down to this relatively impermeable surface, and causes increased soil saturation and pore pressures at or close to the rock head surface, thus contributing to the initiation of slope failure. These failures occur rapidly in response to individual rainstorms or wet seasons, and frequently with little prior warning.

Rock falls in roadside cuttings

While few examples were recorded in the reconnaissance drive-over, rock falls can pose a significant hazard from steeper sections of cut, and usually during heavy rain.

Deep-seated failures in roadside cuttings

Deeper slope failures in cuttings are less frequent, but where they do occur they usually involve weathered rock, with failure often taking place along adversely orientated joint planes. Deeper slope failures also occur in pre-existing colluvial deposits: these are materials that have been deposited on slopes due to earlier landslides and general slope erosional processes. These failures may be several metres in depth, and can lead to either complete or partial blockage of the carriageway. They can either occur rapidly or, more frequently, as gradual displacements.

Shallow and deep-seated failures below the road

Below the road, the observed slope instability problems have been found to fall into two general categories. The first relates to the failure of road fill retaining edge walls, either as a result of ground movements and erosion on the slopes immediately below, or due to possible design or construction defects. The second relates to the effects of deep-seated landslide movements that may occur over large areas of slope and can result in failure of the entire road formation. These ground movements tend to be gradual and progressive.

In addition, there were several instances noted during the reconnaissance drive-over surveys, where the back scars of comparatively large and deep-seated landslides below the road have progressed upslope to the point where they are within a few metres of the outside edge of the road. In such instances the potential hazard posed by the encroaching landslide head may not be recognised until such time as damage occurs to the road shoulder or the adjacent pavement.

River bank erosion
River bank failures are scour failures, mass failures or commonly a combination of both which arise from changes in the size or location of a river channel. River bank erosion may cause partial or complete loss of the carriageway. The mechanism and causes are described in more detail at section 4 of the Background Paper.

The principal trigger is high flow velocity which washes away the material of the river bank; this may occur during a flood or it may be caused by a change in the flow currents at that place, either due to natural processes or human activities. River bank erosion is a normal process that can occur anywhere at any time on a natural stream. However in the context of this Feasibility Study it is only relevant to riparian roads (roads beside rivers). These roads can be in the mountains or the lowlands. Although the Feasibility Study only indentified a few locations where river bank erosion is affecting National Roads; the potential loss of carriageway where bank erosion does occur means that it cannot be neglected in any slope management programme.

Landslide Risk
The risk posed by a given landslide hazard to a community and its economic and social assets encompasses both economic and social losses. However, both are frequently difficult to judge, and the latter cannot be readily quantified. As far as a mountain road is concerned, the damage caused by a landslide or earthworks failure can range from blockage of side drains through carriageway blockage to loss of the entire formation and pavement. The economic loss is made up of both engineering and traffic losses or costs, including:

Engineering costs
- the cost of debris clearance
- the cost of repair and reinstatement

Traffic costs
- the disruption, delayed travel times and possible increased vehicle operating costs associated with traffic hold-ups.

Engineering Costs
The inventory presented in section 12 of the Background Paper provides a qualitative assessment of landslide or slope failure risk, based on its engineering consequence. The larger and more frequent the landslide movement, the greater the potential impact on the road, and hence the greater the potential to incur loss or increased risk. However, the actual value of loss or the degree of risk that occurs will also be dependent upon the value of the elements at risk and their vulnerability to the landslide movement or slope failure. Thus, for example, a side drain is less costly to replace than a retaining wall or a road pavement, while the road and its associated structures will be less vulnerable to damage or destruction from a cut slope failure than from a deep-seated landslide with a shear surface passing beneath the road formation.

Therefore, for the purposes of this exercise, risk can be expressed in the following way:

R (risk) = Magnitude (M) x Probability (P) x Value (Va) x Vulnerability (Vu)

Where:
Magnitude is the size of the landslide or slope failure
Probability is the likelihood of a ground movement or slope failure occurring within a given time, such as a road design life
Value is the value of elements judged to be at risk (e.g. a retaining wall or a side drain)
Vulnerability is the degree of damage considered likely to occur to a given element at potential risk should the ground movement or slope failure occur.

The inventory in section 12 of the Background Paper contains an assessment of risk, based on the above approach, for each slope instability feature recorded. For each feature, two assessments of *Risk* are made: the first is for the original or ongoing event itself, prior to any stabilisation works being carried out (i.e. prior to any mitigation[1]); while the second is for the later condition following the implementation of any stabilisation works that may have been undertaken (i.e. after any mitigation). Obviously, in many situations, where no apparent mitigation has been applied, the risk is judged to have remained the same. The effect of mitigation is included in the risk assessment by its perceived influence on *Probability*, in that a landslide that has been the subject of some form of stabilisation measures will usually have a lower probability of movement in a given period than it had in its original state. In each case, an assessment has been made of the effectiveness of the mitigation, and this has been taken into consideration in assigning the probability score, and hence the risk of future movement. It must be stressed that these assessments have been made with little or no background information other than what is most readily apparent from a rapid observation made from road level.

The inventory shows that the majority of landslides recorded relate to the damage to earthwork slopes, side drain blockage or partial blockage of adjacent sections of carriageway. Locations where road formation and carriageway loss can be attributed to landslide movements are relatively rare. From an engineering management perspective the latter case is the most serious, given that it is usually far more difficult to reinstate a stable road bench that has failed than it is to clear a section of road of slipped debris. The risk rating computation reflects this. However, another component of hazard, that has not been evaluated in the inventory, is the anticipated rate or speed of slope movement, as this cannot be undertaken on the basis of a rapid appraisal. Clearly a slow-moving, deep-seated landslide below the road which results in only a few millimetres of movement of the road bench per year is far easier to manage than a landslide that results in slope movements considerably in excess of this. Where acceptable in a traffic management context, it is likely to be more cost-effective simply to raise the surface of the road from time to time, rather than to attempt large-scale slope stabilisation (see section 4.1.2 below).

Traffic Costs

In addition to the consideration of engineering risk is the important aspect of traffic disruption during landslide events. Displacements of the carriageway caused by minor slope movements usually have minimal traffic disruption and associated economic effects, because it is usually quite easy to fill a depression or bulldoze a temporary diversion, if required. By contrast, a landslide from the slope above, that blocks the road for several days, can have a significant economic impact on road users, even if the road is eventually

[1] Mitigation refers to measures undertaken to reduce the effects of damaging events (in this case landslides). This can be either through stabilisation (for example earthworks and retaining walls), protection (such as containment walls to catch slip material before it enters the side drain and roadway) and monitoring (to provide forewarning of increasing slope movements, and thereby to allow timely engineering and traffic management measures to be undertaken).

restored to its pre-failure condition following slip clearance and slope mitigation. Thus, while the risk computation given in the landslide inventory is, in the study consultants' view, rightly based on engineering risk, it is possible that pressure on the MPWT from road users will be more driven by visible and immediate disruption (i.e. landslide scars and road blockage) than on a rational assessment of overall cost implications.

Consequently, while the risk computation contained within the landslide inventory is an assessment of engineering risk, incorporating both above road and below road risk outcomes, the hazard assessment and slope management prioritisation process taken forward in section 7.3, and Table 7.2 in particular, is based on the differentiation between above-road blockage potential and below-road gradual displacement potential. It also takes into account the preliminary observation that most below-road landslides referred to in the inventory, including those reviewed under SEACAP 21, appear to be slow-moving.

4.1.2 Appropriate engineering responses and mitigation

Engineering responses to these landslide hazards can be categorised into (a) proactive and (b) reactive measures.

Proactive measures
These are normally associated with measures undertaken during design although, from the perspective of a slope stability management programme, they can be implemented through road rehabilitation and improvement projects. The latter is, therefore, the focus of this discussion. Proactive measures mainly comprise measures to increase factors of safety by the excavation of reduced cut slope gradients, the cutting back of the upper portion of cut slopes where weaker weathered materials are often found, and the design of structures to increase the stability of slopes or protect against river bank erosion prior to potential failure. They can also be used to protect the road from a perceived rock fall, such as through the use of retaining walls and debris containment structures. The use of bio-engineering can also be an important proactive measure in increasing the general stability of slopes adjacent to the road in terms of shallow slides and erosion. However, there is a practical and economic limit to the extent to which proactive slope stability measures can be applied, due principally to (a) geotechnical or hydrological uncertainty as to where a slope failure is going to take place next (see section 4.2) and (b) the usual constraint of limited budgetary resources to finance anything other than reactionary slope management. Due to the combined effect of (a) and (b) there also comes a point where further investment in proactive measures becomes cost-ineffective. Furthermore, an intensive storm burst over a localised area, or a long return period flood in a river, may lead to surface soil saturation and slope runoff to the extent that slope instability and erosion are very likely to be triggered no matter what proactive measures are put in place.

Nevertheless, drainage is also an important proactive measure that can lead to a reduction in slope instability problems. Adequate attention to detail in terms of the collection, control and safe discharge of slope and roadside drainage is often critical to the maintenance of stability in the road corridor. This not only relates to the design of adequate drainage capacity but also to the maintenance of drainage structures during operation. A number of cases have been identified where the pattern of side drains and road cross-falls has led to the discharge of road runoff, for example into concentrated areas of slope beneath the road, leading to erosion and undermining of structures. This outcome is perhaps less easily anticipated and thereby mitigated during design, and needs to be regularly evaluated during construction and operation. The blocking of roadside drains can have the same effect, and thus regular drain maintenance is important.

Reactive measures

Frequently, the small and shallow failures involving cut slope debris mentioned above can be dealt with by routine clearance operations. These failures commonly result in a steepened back scar that remains vulnerable to further failure and retrogression. Where practicable it may be cost-effective to batter back these upper, steeper sections of slope to a reduced gradient and protect the exposed surface with planting and bio-engineering combinations. In those instances where a sizeable volume of slide material remains within the cut slope (i.e. the slope failure has not ‘evacuated’ the slide scar), the remaining debris can be retained with a gabion wall, for example. This usually proves more effective than removing the remaining slide material, thus exposing a failure surface behind that then becomes vulnerable to further retrogressive movement.

Where deeper failures in cut slopes or natural hillsides occur above the road, then a combination of toe support by retaining wall and slope drainage is usually the most practicable. The larger landslides will require analysis before any stabilisation designs can be developed with the required level of confidence. A cut-off scale might be a plan area of 2500 m^2, since the investment in stabilisation works for landslides much larger than this is likely to warrant the need for ground investigation and slope analysis. Smaller landslides might be stabilised using prescriptive designs derived from experience with similar slopes, either along the same road or in similar ground conditions elsewhere.

In the case of landslides and slope failures below the road, the most critical parameter to ascertain is usually the depth below road level to the sliding surface. It is only when this is understood that possible remedial measures can be evaluated. Wherever the depth to stable foundations beneath sliding surfaces (and preferably rock head) can be reached within practicable excavation limits (usually up to a maximum of 10 metres on mountain roads, and ideally much less than this) then construction of road supporting retaining walls is usually the preferable option. These effectively cut the road off from the landslide movements taking place on the slope below. If the sliding surfaces are deeper, then it may be necessary either: (a) to lower the vertical alignment (if this is possible) in order to reduce the excavation depth; or (b) to attempt to stabilise the landslide through earthworks, drainage and possibly retaining structures. If the second course of action is followed it usually requires detailed ground investigation and analysis in order to yield a confident geotechnical design.

In the case of river bank erosion there will usually be a significant cost in securing or restoring the road, often there will also be external factors to consider such as damage to property or utilities. On lowland rivers where the land can be made available at acceptable financial and social cost the option to retreat and realign the road away from the river could avoid a long-term need to manage the erosion. Unfortunately in many locations and in particular in hill valleys the only option will be to restore the river bank with hard engineering works and wherever possible introduce river management measures to better control the river and reduce the risk of future problems.

4.1.3 Review of design standards

The MPWT has a suite of technical standards for the geometry of the different classes of roads. While in most instances these do not pose problems for highway engineering in flat or rolling terrain, in mountainous areas they can be challenging. This is particularly the case where roads are required to cross slopes that are either close to their margin of stability, or are already subject to gradual slope movements. A full review of design standards in relation to slope stability and landslide management considerations was beyond the scope of this feasibility study, but is a task worth undertaking by the MPWT. In particular, it is important to assess the sustainability of roads built to high geometric standards through steep and potentially unstable terrain, particularly with regard to the maintenance of large earthworks (cuts and fills) in slope materials that might become prone to instability and erosion.

A new classification and set of geometric standards has recently been prepared by the Department of Roads (2008) with the support of SEACAP 3 for low traffic volume rural roads. These include relaxation from certain standards to avoid excessive costs and environmental damage under certain circumstances. The MPWT might consider adopting a similar approach on other classes of roads.

It is recommended that a full review of road and slope design standards be incorporated in the proposed slope management programme given in Part B of this document.

4.1.4 Skill requirements

In order to ensure that a comprehensive capability exists in the sector for an effective slope stability management programme, it is essential that sufficient numbers of personnel are available with the skills required to undertake the following:

- Landslide recognition and engineering geology
- Risk assessment for prioritisation and selection of alternatives
- Site investigation and slope monitoring;
- Design of slope stabilisation and protection measures;
- Design of river works; and
- Construction of stabilisation and protection measures.

During the course of this feasibility study the consultant’s team consulted with many practitioners in the road sector. It was generally agreed there are few personnel available in Laos that possess these skills. The majority of personnel consulted were highway engineers, competent in their profession, but who have had limited or no exposure to engineering geology, geotechnical engineering, river engineering or bio-engineering methods of slope protection. The overwhelming conclusion was that, if a slope management programme is to be implemented, it must include a substantial element of skill development.

4.1.5 Computer programs

As mentioned in section 4.1.2 above, the design of slope stabilisation works for large landslides requires a level of confidence that can only be provided through geotechnical analysis. It is common practice to utilise standard proprietary software programs to assist in this process. These programs require the input of topographic, geological and geotechnical data in order to enable slope models to be developed that can then be used to assess the effects of stabilisation measures on the stability of a given landslide or slope. Programs are also available for the analysis of rock slope stability through using measured jointing patterns within, for example, a deep road cut.

It is recommended that the slope stability management programme described in Part B include provision for introducing these techniques to those personnel selected for training. The actual application of the programs to carry out stability analyses and design requires the skills and experience of an engineering geologist or geotechnical engineer, rather than a highway engineer, and it is recommended that provision be made within the MPWT for the development of a geotechnical group that is capable of carrying out this work, as part of the longer term slope stability management programme (see Part B below).

4.2 Economic feasibility

The economic modelling presented in the Background Paper (section 8) considers investments in proactive measures to reduce landslide hazards, both (a) during design and construction and (b) during operation. The economic modelling is inconclusive because of the scarcity of data on landslides and their associated costs. What it seems to show is that there may be positive net returns from investments in the proactive stabilisation and protection of slopes that are likely to fail or erode, but for this to happen the failure would need to occur quite soon, e.g. within a five year period. Since it is impossible to predict the location and timing of slope failures to this level of accuracy, it means that any decision on this would need to be based on policy rather than economics. The same is effectively true for the other main scenario considered, which is the increased use of proactive measures and improved engineering practices during road design and construction to reduce subsequent slope failures. A higher initial investment would almost certainly reduce recurring maintenance costs, and in the long term this would probably give a positive return.

The absence of a very clear economic justification for a substantially different approach to slope management means that the matter also has to be judged strategically, through “service standards” expected from the road, in terms of the frequency and duration of blockages that road users are prepared to accept. The time to clear road blockages is a function of the amount to be cleared and, probably more importantly, the measures that are in place for landslide clearance. Therefore it might be more economic to have a very good emergency response and allow the larger landslides to fail, than to invest in large sums of money in an attempt to stabilise them. However, there are also several other scenarios, more complex than the simple and most common situation of a road blocked by a failure from the slope above. One example is where a failure below the road takes out only part of the road, and does not impede traffic but is time-consuming and expensive to fix; another would be where a failure that takes out the whole road can be bypassed quickly, but the final fix is also time-consuming and expensive.

4.3 Strategic direction

The assessment of the technical and economic issues leads to the next stage of the study, which is an appraisal of what sort of slope management programme might be worthwhile. There are three main options.

- An alteration in the ways in which roads are designed and constructed in mountainous areas or beside rivers. This would involve a much greater analysis of potential slope instability during the road design phase, and incorporation of higher construction standards. The intention would be to develop roads that are less prone to slope instability.
- A *proactive* slope management programme, that seeks to prevent landslides from occurring. This might typically involve extensive use of slope drainage structures to minimise the risk of landslides being triggered in marginal areas, widespread use of low cost slope protection measures (such as bio-engineering) and judicious use of heavy slope retaining structures in sites where major instability can reasonably be anticipated (such as where roads cut deeply into colluvial slopes, or there is long term undercutting by a river).

- A *reactive* slope management programme, that responds to slope failures once they have occurred, along the lines that are being tested by the main SEACAP 21 research project. This seeks both to avoid further damage to the road and to restore it by treating failed slopes; and also, where feasible, aims to prevent existing failures from getting worse.

The formation of roadside slopes using better-adapted engineering standards to reduce potential instability on new roads is advantageous in environmental terms and would reduce long-term disruption and maintenance. As the analysis in section 6 of the Background Paper shows, it might well also be an economically advantageous solution. However, it would not help to resolve instability on existing roads.

The problem with a full proactive slope management programme is the large ongoing cost involved in monitoring slopes and installing engineering measures to overcome the inevitable "what if..." risks that emerge. This sort of monitoring would involve regular vegetation clearance for inspection, detailed topographic and geomorphological surveys of slopes, perennial monitoring surveys, exploratory drilling and slope modelling. It is valid for high-traffic roads in an advanced economy (e.g. Hong Kong), but not in rural areas of Laos. In effect, it would mean designing costly structures with an assured factor of safety to prevent failures occurring on any slope where there is doubt about stability; this could be a large number of sites in most mountainous areas.

The questions that arise from the foregoing are essentially these:

- At what cost do the Government of Laos and the Lao road user expect to have trouble-free roads? and,
- What level of risk is the road user prepared to accept for a disrupted service on different categories of road, i.e. what is the definition of 'trouble-free'?

These considerations lead to a risk-based strategy for service standards that underlies the functioning of a slope stability management programme. Guidance was requested from the Steering Committee and MPWT at the study's Inception Workshop (2 May 2008), as to whether this approach appeared valid. As it was considered so, it has been followed in the design of the proposed slope management programme. It forms the basis for the level of interventions and investment that are proposed. The risk-based strategy statement is given in section 7 of this report.

5. REVIEW OF THE MPWT'S CAPACITY TO MANAGE SLOPE INSTABILITY

The aim of this section is to review the capacity of the MPWT to provide quality engineering services for landslide prevention and management, the promotion of hill slope stabilisation, and control of river bank erosion, wherever these may impact upon National Roads.

The relatively brief account given here is supported by detailed assessments in the Background Paper:

- Section 10: Road Sector Organisation; and
- Section 11: Road Maintenance in Relation to Roadside Slopes

5.1 Outline of current road management procedures

Road management in Laos is divided between National Roads, under the Road Administration Division, and Provincial, District and Rural Roads, under the Local Road Division. Responsibility for implementation of management activities is decentralised to the Provincial DPWTs, with the central divisions retaining the remit for planning and monitoring. Budgetary control is kept at the centre, with approval from the MPWT required for the letting of contracts by the DPWTs. All works, including emergency maintenance, are implemented through contracts. Community involvement is only in the lowest category of Rural (or Village, Community or Basic Access) Roads. Routine maintenance activities are labour-based on all categories of roads.

Routine maintenance is carried out by the DPWTs, following well-established procedures based on a series of maintenance activity codes. The introduction of Performance-Based Maintenance Contracts (PBMCs) on to nearly a third of the National Roads network in the last year has altered the programming timeframe because they require a three-year plan. However, this is still administered through the DPWTs.

Emergency maintenance is usually linked to routine maintenance, in that an annual budget estimate is also made and funds allocated from the Road Maintenance Fund in the same way. If the rains are particularly bad and emergency items cost too much, then a greater proportion is drawn from central government funds, through the Ministry of Finance. Where PBMCs are in place, they also cover emergency maintenance.

Periodic maintenance is planned annually through the Road Management System (RMS) for National Roads and the Provincial Road Maintenance Management System (PRoMMS) for Local Roads. These both follow a computer-based, menu-driven format, which channels decisions of maintenance interventions into a relatively narrow set of options. They are particularly restricted for off-road problems. While these systems are effective, they tend to dominate the decision-making process at road section level. Priorities are set through the computerised systems, but the level of expenditure is determined by a five-year rolling budget. Limited resources for maintenance overall mean that the centralised decisions on allocations between the Provinces are often not ideal.

In effect, all slope management comes under the emergency maintenance category, and this demonstrates the approach that is used. Proactive slope stabilisation works are rare, beyond a range of standard retaining walls and drainage systems for the higher standard roads. Most works are of a reactive nature, and the DPWT staff react as quickly as possible once a slope failure occurs; hence the advanced planning for an expected emergency budget and inclusion in the PBMCs. If a road is blocked, the first priority is to get it open and this is the stated purpose of the first emergency maintenance activity code (no. 311). There is considerable flexibility in the way that emergency funds can be used on both National and Provincial Roads, and the assistance of the Provincial Governor's Office, contractors and local people may be sought. In extreme cases, special additional central funds may be released through a process of declaring a big landslide as a National Disaster.

5.2 Current skill levels

The organisation and structure of the MPWT institution is a straightforward pyramid, with responsibilities delegated from central level down to the 17 Provincial DPWTs, and through them to around 150 District Offices of Public Works and Transport. The personnel under the Ministry include the staff in the provincial and district units, and number almost 1,800. Of these, only 26 staff members have just a school qualification, and less than 10 percent are aged over 50 years. Most dominant is the very high proportion of diploma and technician level staff. Although small by comparison, there are still 100 individuals qualified to master level and nearly 200 to bachelor level. However, as the bachelor of engineering degree qualification only became available in Laos from the late 1990s, for engineers qualifying before that time the diploma is considered to be equivalent.

The majority of graduates are civil engineers with a general degree in the subject. With experience they have become competent highway engineers. However, very few have received more than basic training in geotechnics or any other form of engineering related to slope stabilisation. A small number have attended study tours or overseas short courses on the subject, but in general have not had the confidence or support to implement new works after their return to Laos. The same pattern appears also to be the case for the private and academic sectors. For this reason the capability of road sector staff regarding slope management is taken to be basic and, in view of the high frequency and heavy expenditure on slope problems, in need of improvement.

5.3 Organisational development in the road sector

Over the last year, the MPWT has been going through a substantial re-organisation. The telecommunications elements of the old MCTPC were removed so that the reduced ministry is better focussed on transport infrastructure, and has a simpler organisation. The process is still continuing and so the details of the final arrangements are not yet clear. However, this process has brought about an awareness and acceptance of change, and has also demonstrated a capability of managing it effectively.

There seems to be no need for the organisation to be altered to encompass slope management issues, since it already has all of the elements required other than the particular skills. For this reason, almost all of the organisational change proposed in the slope management programme relates to skill development through appropriate training.

There have been several training needs assessments carried out as part of various donor-funded projects, and these have recently been consolidated into a single matrix, which is now incorporated into the draft Capacity Development Plan (MPWT, 2008b). This gives a strong emphasis to administrative and management training, and technical engineering is relegated to the end. There is no mention of slope stability or river engineering as specific topics. Under the Plan, the training needs matrix is due to be reviewed and revised, with a current target date of the end of November 2008.

PART B: PROPOSED SLOPE MANAGEMENT PROGRAMME

6. INTRODUCTION

6.1 Summary of the proposed programme

The sections below describe a programme for road sector slope management, and the expected outputs and implementation arrangements. This is based on the Feasibility Study described thus far in Part A of the report above, and the accompanying Background Paper.

In outline, the programme consists of the following elements.

1. A strategy for identifying landslides and potentially unstable sites and for carrying out risk assessment for prioritisation purposes.
2. A strategy for assessing the level of intervention required on each category of road.
3. A procedure that sets out to identify the priority for tackling hazardous slopes along the road network.
4. A suite of guidelines for due diligence and best practice preventative measures designed to avoid situations developing that might later give rise to the development of landslides and earthworks failures (particularly with regard to earthworks design and the design of drainage, river engineering and bio-engineering works) to be implemented as routine on slopes meeting specific criteria.
5. Procedures for site investigation and assessment using best practice to identify measures that might be taken to reduce hazards, and to respond to failures that have already occurred.
6. The training and other capacity development measures that are considered necessary in order to implement the proposed programme. This should include personnel from the Ministry, provincial departments, consultants and contractors.
7. Possible options for one-off rehabilitation projects. These are most logically based on single roads or Provinces, and the options are informed by the inventory of slope failures that has been prepared (see section 12 of the Background Paper and section 7 of this report).

6.2 Recommended actions

It is recommended that the following main actions be taken by the MPWT.

- Confirm the strategy of service standards (acceptable risk) for landslide disruption on different classes of roads, and adopt the recommended intervention levels.
- Adopt a system of prioritising landslide repair and proactive treatment that is based on sound engineering and economic assessment, and the Lao road users' priorities.
- Review and adopt the engineering procedures, response mechanisms and designs produced by SEACAP 21 and by this feasibility study, and disseminate them to all appropriate staff.
- Conduct a review of the geometric standards of all classes of roads with a view to reducing slope instability wherever possible.
- Add the proposed staff training to the consolidated training needs analysis under the Organisational Capacity Development Plan.
- Commission international specialists to prepare the training materials required.
- Undertake the proposed training within a period of three years.
- Conduct detailed assessments and undertake projects to rehabilitate the slope failures along seriously damaged roads, according to priorities determined using the processes described in this document.
- Seek donor support for appropriate parts of this programme, according to need.

7. STRATEGY

7.1 Standard of service

It is recognised that it will not be possible for all slopes to be stabilised throughout the road network. Therefore a compromise has to be reached between the cost-effectiveness of investments and the level of service provided to road users. The economic analyses conducted as part of this study suggest that only very limited interventions are appropriate for the lower categories of roads (i.e. District and Village roads), and that even for the higher classes (i.e. National and Provincial roads), full slope stabilisation is not economically justifiable at the current state of national economic development.

It is therefore recommended that the MPWT follows the strategy stated below for achieving service standards appropriate to the different categories of roads.

Strategy statement for MPWT's service standards for slope failure mitigation

The Government of the Lao PDR aspires to a national highway network that remains free of slope failures. However, in view of the terrain and climate of the country, economic considerations mean that it must be accepted that, in mountainous and riparian areas, and with high rainfall, the management of slopes may be limited so that the following standards apply.

Category	***In most years***	***In years of exceptional rain or flood***
National	*Occasional blockages may occur for up to 3 hours.*	*Blockages for up to 3 hours may be common, with possible occasional blockages for up to 12 hours.*
Provincial	*Occasional blockages may occur for up to 6 hours.*	*Blockages for up to 6 hours may be common, with possible occasional blockages for up to 1 day.*
District	*Blockages for up to 6 hours may be common, with occasional blockages for longer.*	*Blockages may be common, some exceeding 12 hours. The complete loss of small sections of the road is possible.*
Village	*Blockages may be common for up to a day.*	*Blockages may be common, some exceeding 1 day. The complete loss of small sections of the road is possible.*

Damage to roads in exceptional conditions beyond these limits will be deemed a national disaster. The MPWT will review these standards periodically and amend them as the national economic situation improves.

7.2 Recommended scope of the Programme

Based on the detailed assessments carried out under this feasibility study, the following programme scope is recommended.

- Improvement of engineering design standards where feasible.
- Wider use of slope stabilisation and protection measures of appropriate cost.
- Preventative treatment of obvious impending landslides and river bank erosion where feasible, on a sliding scale of investment cost for each category of road.
- Reactive treatment (clearance, damage assessment and repair) of all other failures, based on improved procedures and on a sliding scale of investment cost for each category of road.

Describing how to put this into practice across an entire road network is not easy, particularly as the traffic levels (and therefore the justifiable investment) vary considerably within each class of road. The guidelines given in Table 7.1 summarise the level of treatment that is suggested for each road category.

Table 7.1. Summary of recommended intervention levels (see text for conditions)

<table>
<tr><th>Road category</th><th>Improved design standards</th><th>Use of slope stabilisation and protection measures</th><th>Preventative treatment of impending landslides</th><th>Reactive treatment of failures that occur</th></tr>
<tr><td>National</td><td rowspan="4">Alignments chosen better to avoid areas of likely instability and river bank erosion.
Road and cutting width reduced to minimum allowable standard (may need review) for short sections (<100 m) in unavoidable unstable areas.
Cut slopes formed according to material characteristics as far as possible.
Fill slopes benched into original ground, compacted and graded correctly.
Adequate provision for slope drainage.
On District and Village roads, gradient increased to maximum allowable for short sections (<250 m) to avoid unstable areas/minimise cut.</td><td>Revetments, slope drains and bio-engineering measures used widely to stabilise cut slopes.
Judicious use of slope retaining structures when crossing active landslides. , and works to control river bank erosion</td><td>Take action when:
road surface subsides;
a below road failure is within 5 metres of the road edge;
the cut slope (or natural slope above the road) begins to show signs of distress
excessive erosion begins to occur</td><td>Clear road immediately.
Investigate site and design repair measures.
Implement slope repairs.</td></tr>
<tr><td>Provincial</td><td>Revetments, slope drains and bio-engineering measures used to stabilise cut slopes.
Some slope retaining structures on active landslides.
Some control measures for river bank erosion</td><td>Take action when whole road surface subsides.</td><td>Clear road as soon as possible.
Investigate site and design low cost repair measures.
Implement slope repairs.</td></tr>
<tr><td>District</td><td>Use low cost retaining walls and bio-engineering measures on appropriate key sites.</td><td>None.</td><td>Clear road.
Investigate site and design low cost repair measures.
Implement repairs to most critical sites.</td></tr>
<tr><td>Village</td><td>Use bio-engineering measures only on appropriate sites.</td><td>None.</td><td>Clear road only.</td></tr>
</table>

A complicating factor is that the unstable sites most in need of treatment may not be amenable to low cost or bio-engineering measures, because the only technical solution may be the use of civil works, including expensive retaining structures. This is why the conditional words “appropriate” and “some” appear in the table.

It is considered that most investment in slope stabilisation and protection over the foreseeable future will be on the higher categories of roads (i.e. National and Provincial). The proposed programme therefore implicitly focuses on practices that are most appropriate for these roads.

7.3 Prioritisation of interventions

The implementation and cost of the programme will be shaped by the number and type of interventions that are required, in order to achieve the standards suggested above. This will be determined by identifying the slope failures for which interventions are technically and economically feasible. Based on the list of possible interventions, a ranking should take place in terms of:

- The technical feasibility for treating slope failures;
- The expected Net Present Values (NPVs) (the higher the better to maximise socio-economic benefits); and
- The budget available to MPWT to carry out the proposed measures.

The sections below describe how this process can be implemented.

7.3.1 Technical assessment

In order to assess the relative importance of investment in slope stabilisation, it is necessary to define unstable sites according to their failure mechanisms and the levels of risk they pose. This is described in sections 3 and 4 of this report. Table 7.2 below summarises the discussion of risk given in section 4.1.1 whereby road blockages are given an elevated risk level due to the traffic costs and levels of travel disruption that they induce.

Table 7.2. Hazard ranking for landslides

Actual (current condition) or expected consequences (without mitigation)	Hazard ranking				
	1	2	3	4	5
Road completely lost (including road subsidence greater than 1m)	✓				
Road partially lost		✓			
Road completely blocked		✓			
Road subsidence less that 1m		✓			
Road partially blocked			✓		
Productive agricultural or forest land lost or destroyed			✓		
Walls damaged or slope drainage blocked or damaged				✓	
Roadside drainage damaged or blocked					✓
Continued erosion without destroying vegetation cover					✓
Ranking 1. Top priority, emergency measures required immediately; buildings may need to be evacuated. 2. High priority; realignment may be necessary. 3. Moderate priority, but some temporary remedial measures are required immediately, such as slip debris clearance, emergency road signing etc. 4. Low priority, but some temporary remedial measures are required quickly, such as slip debris clearance. 5. Least priority, but should be tackled as soon as possible under routine maintenance.					

NB this table does not include reference to other risk elements, such as adjacent buildings, other infrastructure and services etc, as this is deemed to be beyond the scope of the roadside slope stability management review

7.3.2 Financial assessment for emergency responses

Failed slopes need to be assessed to judge the most appropriate technical response. At the same time, it will be possible to survey and measure the site to estimate the quantities of the works required to stabilise the slope. This will provide a list of costed works that need to be undertaken, ranked in terms of priority (see section 7.3.4). The total requirement can then be compared with the budget available to determine how many of the sites can be addressed, and how many have to be left until additional funds are available.

7.3.3 Financial assessment for preventative works

The possible interventions for each road should be incorporated into the economic framework model developed (see section 8 of the Background Paper). Although the required inputs are not complex or difficult to obtain, a major data-gathering exercise needs to be carried out by the DPWT for all vulnerable roads, namely:

- Likelihood of a slope failure taking place and its impact (costs);
- Possible preventative measures (initial and ongoing costs);
- Likelihood of the impact of a slope failure still occurring even with future stabilisation measures (costs); and
- Discount rates to be adopted.

Once the data required have been incorporated into the model, various forms of rankings can be carried out. For example, the higher the NPVs of an intervention, the higher is the benefit it is likely to generate. The main ranking options are as follows.

- If benefit maximisation is what is being sought, the MPWT can give high priority to the interventions with high NPV.
- If interventions are based on events likely to take place in the next year or two, then the MPWT could concentrate on implementing those slope failure stabilisation programmes likely to take place in the near future.
- If budgets are constrained and the aim of MPWT is to maximise the number of interventions, then ranking of those interventions with a positive NPV should be made based on cost.

7.3.4 Prioritisation of investment

The data accumulated from the technical and financial assessments described above allow a final priority list to be drawn for the identified sites. The way that this is done depends on whether the assessment is for a response to slope failures that have already happened, or for undertaking advance works to prevent landslides from occurring at sites where slope instability has been detected. For response to existing slope failures, this will be as shown in Table 7.3; for preventative works, it will be on the basis of completing Table 7.4. If the inventory of slope failures (section 12 of the Background Paper) or a long list like it is used, then a completed Table 7.3 or 7.4 would in effect be a shortlist of slope problems requiring treatment.

Table 7.3. Prioritisation matrix for response to existing failures

Site location	Failure category	Hazard ranking or risk computation	Estimated cost	Priority against MPWT strategy	Final list?

Table 7.4. Prioritisation matrix for preventative slope stabilisation works

Site location	Failure category	Hazard ranking or risk computation	Estimated cost	NPV at year 5	Priority against MPWT strategy	Final list?

In completing these tables, the ranking of hazard or risk can be drawn either from the hazard severity ranking given in Table 7.2, or using the “R” (risk) value calculated in the inventory of slope failures (section 12 of the Background Paper). However, as discussed in section 4.1.1, what appears to be the most rational engineering and economic approach to prioritising treatment has been adopted. Thus while, in engineering cost terms, the highest R values relate to the condition of road formation loss due to deep-seated landslides or river bank erosion, the effects of road blockages due to slope failures occurring above the road have been elevated in terms of risk level (Table 7.2) due to traffic costs and public or road user perception issues.

There is inevitably an element of subjectivity in completing these tables. This is partly because the availability of funds may not be adequate to cover all the sites that need treatment. More likely it will be because it is difficult to predict the likelihood of a given slope failure’s consequences in terms of road blockage time, in assessing the priority against the MPWT’s service standard strategy (see section 7.1). In many cases the final list will need to be adjusted against the total available budget, so that the greatest number of high priority sites can be addressed.

A worked example of Table 7.3 is given in Table 7.5, using a selection of sites drawn from the inventory in section 12 of the Background Paper. These sites include the highest risk ranking for above road landslide locations, where slope failure from above the road has given or could give rise in the future to road blockage. A selection of below-road failures has also been included. This selection is based on highest risk ranking, excluding those already reviewed under SEACAP21. This list will require further consideration and confirmation by the MPWT and its consultants as part of the slope stability maintenance programme, once it is implemented. The final column of the table indicates the consultant team’s recommendation, at this stage, as to which projects might ultimately be selected. These sites fall into two main regional zones (NR 12 in the south and NR 13 in the north), thus enabling the project to focus its resources more easily and avoiding the scatter of sites across the country.

Table 7.5. Worked example of the prioritisation matrix for response to existing failures

Site location	Failure category	Hazard ranking or risk computation*	Estimated Cost (US$)**	Priority against MPWT strategy***	Final list?
NR 3, 64+500	Above road	36	35,000	Moderate	
NR 18b, 91+700	Above road	27	30,000	Low	
NR 18b, 96+000	Above road	27	50,000	High	
NR 18b, 110+300	Above road	27	30,000	Low	
NR 13N, 262+900	Above road	24	60,000	High	✓
Oudomxay to Patmong 52+300	Above road	18	30,000	Moderate	
NR 18b, 81+800	Above road	18	30,000	Low	
NR 18b, 109+700	Above road	18	50,000	High	
NR 12, 136+900	Above road	18	50,000	High	✓
NR 12, 138+400	Above road	18	100,000	High	✓
NR 12, 141+500	Above road	18	100,000	High	✓
NR 3, 2+150	Below road	54	75,000	High	
NR 3, 9+850	Below road	54	75,000	Low	
NR 8, 119+300	Below road	54	100,000+	Moderate	
Oudomxay to Patmong 15+600 from Oudomxay	Below road	54	50,000	Moderate	
Patmong-Luang Prabang 68+100 from Patmong	Below road	54	100,000	Moderate	✓
NR 3, 10+300	Below road	36	50,000	Moderate	
NR 3, 19+500	Below road	36	100,000+	Low	
NR 13N, 239+400	Below road	36	75,000	Moderate	✓
NR 13N, 329+100	Below road	36	100,000	Moderate	✓
NR 13N, 335+900	Below road	36	100,000+	Low	

* Drawn either from the hazard severity ranking given in Table 7.2, or using the “R” (risk) value calculated in the inventory of slope failures (section 12 of the Background Paper).

** Estimates only provisional: will require confirmation during early stages of proposed Programme

*** According to the likelihood of a failure causing a total blockage or loss of the road for at least three hours (in the case of National Roads).

8. ENGINEERING PROCEDURES AND DESIGNS

8.1 Engineering procedures

Detailed engineering procedures are not required as part of this study, though the material available has been reviewed. A revised set of technical specifications was prepared for the SEACAP 21 slope stabilisation trials; these were amended after the first phase, and may need minor amendments as a result of lessons learnt in the second phase of works. The project will be completed within four months, and so the final version of the specifications will be produced in September 2008.

Another forthcoming output of the SEACAP 21 trials is a comprehensive Slope Management Manual for design guidance. This is also in preparation, and due for completion in September 2008.

A review of design standards is required, as discussed in section 4.1.3. This should assess the validity of the geometric and construction standards for each class of road in terms of the sustainability of the roadside slopes created in mountainous terrain, and the possibilities for relaxation over short sections to reduce the potential for creating further instability.

8.2 Engineering designs

A set of selected relevant standard details is provided as Appendix 1 to this report for the following key slope protection and stabilisation systems.

- Gabion retaining walls
- Masonry retaining walls
- Composite crib revetment walls
- Hand-applied chunam surface covering
- Slope drainage
- Roadside drainage
- Bio-engineering works.
- Gabions used for river bank protection
- Gabion river walls
- The Soda System

8.3 Engineering response mechanisms

The MPWT and the DPWTs have a series of procedures and response mechanisms for both recurring and emergency maintenance problems. There is no apparent reason why these need to be altered in terms of organisational arrangements. However, the conclusion of this study is that the skills of the engineers involved need to be enhanced to cover slope stabilisation works adequately. This will allow them to respond in a more appropriate technical way that ensures a better analysis of slope instability and the diagnosing of the correct treatment. Much of the reference material as to how to go about this will be provided in the SEACAP 21 Slope Management Manual when it is produced in September 2008. A summarised step-by-step procedure is given in section 14 of the Background Paper, to provide an outline of the recommended approach to slope stability management. This demonstrates clearly the importance of understanding ground conditions and slope processes before attempting to design or build any stabilisation or protection structures.

9. CAPACITY DEVELOPMENT

9.1 Organisational structure

The structure of the various organisations within the sector (i.e. the MPWT, the DOR, DOW, the RAD and the DPWTs) are assessed in some detail in the Background Paper (section 10). The conclusion is that there is no constraint arising from the organisational arrangements regarding the management of roadside slopes. In addition, the entire institution is in the process of re-organisation and is expected to become more efficient as a result. Under one component of the RMP-2, a substantial capacity development plan is being devised that will be implemented under the remainder of that project and the proposed LTSP. For these reasons, the capacity development proposed here is limited to awareness raising and technical skill development at different levels of staff, and in different parts of the sector.

The principal consideration to be made in relation to organisational arrangements is the necessity for the MPWT to have a core group of slope specialists to act as a resource to support any part of the sector when the need arises. As shown in the next section, it is recommended that these be four in number, and be trained to MSc level in engineering geology. There are four main possibilities for the siting of these individuals.

- In the Planning and Technical Division. The advantage of this is its central location and availability throughout the sector. The disadvantage is the small staffing assignment of the PTD.
- In both the RAD and the LRD. This would make the specialists central to the operational side of the DOR's work, and give them closer relationships with the DPWTs.
- Outside the MPWT. The specialists could be in the private sector or in an academic institution (such as the NUOL). This would reduce MPWT overheads, but could mean that they were not always available when required; this might be a disadvantage in emergencies.
- A combination of the above possibilities.

The deployment of central skills needs should be decided by the MPWT. The study's recommendation with regard to the above is to have two highly trained engineering geologists in each of the RAD and the LRD, and at least one outside the ministry, in the NUOL or the private sector.

It is also necessary to have a core group of river engineering specialists. It is suggested that these are provided by the DOW which already has the core expertise. The DOW may need additional staff to cover the additional involvement for roads.

9.2 Skill requirements at different levels

As identified in the study report, if the road sector is to be able to manage slopes effectively, its staff need to be able to undertake these tasks to a high standard:

- Landslide recognition and risk assessment
- Site investigation and slope monitoring;
- Design of slope stabilisation and protection systems;
- Design of river engineering works; and
- Construction of slope stabilisation and protection structures.

Within each of these categories there are numerous technical matters that need to be addressed.

In order to achieve the strategy described in section 7, it is estimated that the slope management programme needs to assist the sector to reach the capacity summarised in Table 9.1. This assumes that around four individuals will be trained in slope management in each of two levels (i.e. engineer and technician) in each of the DPWTs. A significantly greater number would need to be added (perhaps 200 individuals) if training were to be extended to the District Offices of Public Works and Transport, but at this level training it is already being provided through the LSRSP-3 Basic Access Component.

Table 9.1. Estimated staff numbers requiring skill enhancement to achieve strategy

Organisation	Group	Level	Number
Department of Roads: RAD and LRD	Directors and Deputy Directors	Awareness and understanding	5
	Professional engineers in the central offices of RAD and LRD	Professional skills (design etc)	20
Provincial DPWTs	Directors and Deputy Directors	Awareness and understanding	33
	Professional engineers (site staff)	Awareness and understanding (construction etc)	52
	DPWT Technicians	Awareness and understanding (construction etc)	52
Consultancy companies	Consultants' design engineers	Professional skills (design etc)	20
	Consultants' site engineers	Professional skills (construction etc)	20
NUOL and other colleges	Academic specialists (lecturers and researchers)	Professional skills (design etc)	20
Contracting companies	Contractors' supervisory staff (qualified engineers)	Technical skills (construction and building)	20
	Contractors' construction technicians	Building skills	40

No single individual needs to be able to do all of the tasks listed above. Table 9.2 summarises who needs to be able to do what. However, in designing a skills development programme, many individuals consulted in the sector felt that it is important to ensure that the following main principles are covered.

- Specialist skills are developed in both the MPWT and outside organisations to ensure a spread of skills.
- Simply training engineers is not enough. Managers need to understand what their subordinates know, so that they can oversee, support and encourage them. Also, technicians need to understand the critical points of construction so that they can ensure a good quality of works.
- There must be a way that the training is perpetuated, not just conducted as a one-off exercise.

The proposed training programme for slope stability management is therefore intended to fulfil these principles, while resolving the shortage of appropriate skills.

The other key principle that underlies the proposed programme is the development of a small core group of specialists at central level in the MPWT, or among consultants and universities (see section 9.1). These would typically be highly trained individuals, educated to at least MSc level in engineering geology for slope stability and a suitable hydraulic degree for river engineering. Initially, in-country training should be given to a reasonable number of candidates (perhaps 40), who would in any case use this knowledge in their routine work. From this group, a small number should be selected for overseas training, in an appropriate course in slope engineering geology/geotechnical engineering. Depending on the individuals chosen, this would be either an MSc or a post-graduate diploma course.

The intention would be that they would form the sector's core specialists, and would then be available to apply their skills to the investigation and mitigation of high risk and complex landslides, contribute to risk management during landslide emergencies, and provide input to the management of roads located in areas of unstable terrain and subject to numerous slope failures.

Table 9.2. Summary of training needs

Group	What they need to know	Why they need to know it
Directors and Deputy Directors of RAD, LRD and the DPWTs.	A general understanding of slope stability and river engineering issues to be able to oversee specialists' work. Enough knowledge to be able to make informed decisions regarding the seriousness of slope instability.	To support and advise their staff in the day-to-day management of slopes, to ensure that the sector achieves cost-effectiveness and good service standards.
Site staff: professional engineers in the DPWTs; consultants' site engineers.	A practical understanding of how to investigate and monitor slopes. Knowledge of: slope dynamics and failure processes, and the means to resolve them; the principles and practices of slope stabilisation and construction; and the details important to ensure good quality works.	To assess slopes in the field and determine what processes are active, and what can be done about them. To design and cost works for repairing or preventing landslides. To oversee contractors' implementation of slope stabilisation and protection works.
Specialist staff: professional engineers in the central offices of the RAD and LRD; consultants' design engineers.	An in-depth understanding of the position and interaction of roads in mountain and riparian landscapes. Knowledge of: slope dynamics and failure processes; the means to resolve them; the application of good mountain and riparian road design principles; and the practices of slope stabilisation design and costing.	To design roads and construction projects in ways that ensure optimal alignments and designs in mountainous and riparian areas, so that slope instability problems and slope-related costs are minimised. To address particularly large or difficult slope problems. To advise in major emergencies.
Academic specialists (lecturers and researchers).	As for the specialist government and consultant staff above, plus the ability to teach others.	To provide slope and riparian management components to the engineering curricula at universities and colleges. To undertake research on critical slopes or particularly problematic landslides.
Contractors' supervisory staff (qualified engineers) and DPWT Technicians.	A thorough understanding of the principles and practices of slope stabilisation and construction; and the importance of construction details to ensure good quality works.	To construct slope stabilisation and protection structures, according to designs and specifications.
Contractors' construction technicians.	Practical knowledge of how to build slope stabilisation structures, and the importance of construction details to ensure good quality works.	To be able to build slope stabilisation and protection works to the accepted standard.

9.3 Recommended training courses and their implementation

Based on the details given in the sections above, it is recommended that a comprehensive, multi-level training programme be devised and undertaken on the basis of the details given in Table 9.3. The topics to be covered are given in Table 9.4. The scale of this should be verified through the consolidation of the MPWT's training needs analysis during 2008, under the Organisational Capacity Development Plan (MPWT, 2008b).

The implementation of the training depends in part on how it is organised and funded. The MPWT's standard approach involves the co-ordination of training by the Department of Personnel, and the contracting of specialists to provide the courses. This is entirely appropriate for this context. However, because of the lack of these technical skills in Laos, it is proposed that a tiered approach be used, similar to the development of the Rural Engineering Curriculum by the Basic Access Component of LSRSP-3 (MPWT, 2008a). This involves the use of international specialists to develop the training material and train/instruct selected Lao specialists in its content and delivery. These local specialists might be NUOL lecturers, or experienced MPWT and consultant engineers. The language for most of the training should be Lao.

Training events should be limited to a maximum of twenty individuals. With the exception of the senior staff (Directors and Deputy Directors), who would receive relatively formal lectures and seminars, the events should be participatory and semi-informal, following standard international practice for mature student training approaches. These include a considerable amount of discussion and experience sharing, as well as knowledge transfer.

It is on the basis of this outline that the cost estimates are provided for the training in section 11 of this proposed programme.

Table 9.3. Recommended training courses

Group	Type of course	Duration	Number to attend
Directors and Deputy Directors of RAD, LRD and the DPWTs.	Series of lectures and seminars	10 no. 1-hour-long lectures over the period of two weeks	30
Site staff: professional engineers in the DPWTs; consultants' site engineers.	Formal lecture room training with frequent site visits	4 weeks in two blocks; conduct regionally in 4 regional locations	60
Specialist staff: professional engineers in the central offices of the RAD and LRD; consultants' design engineers.	Formal lecture room training with frequent site visits	4 weeks in two blocks	40
	Specialist, in-depth overseas training (diploma or masters)	Typically a one-year course (1 year per person)	4
Academic specialists (lecturers and researchers).	Formal lecture room training with frequent site visits	5 weeks in two blocks	20
Contractors' supervisory staff (qualified engineers) and DPWT Technicians.	Split between classroom and site	1 week; conduct regionally in 4 locations; or run on-the-job	60
Contractors' construction technicians.	Practical site-based course.	1 week, on-the-job	40

Table 9.4. Summary of technical training components

Group	What they need to know
Directors and Deputy Directors of RAD, LRD and the DPWTs.	*Alignment selection* • General principles of alignment selection to ensure that slope problems are minimised. • Principles of landslide risk assessment and works prioritisation. • General principles of slope dynamics and landslide recognition. • General principles of river engineering • General principles of appropriate systems for stabilising and protecting slopes.
Site staff: professional engineers in the DPWTs; consultants' site engineers.	*Site investigation and slope monitoring* • Terrain evolution and slope dynamics; forms and processes of slope instability. • Practical approaches to site investigation and landslide mapping. • Diagnosing slope instability and determining solutions. *Design of slope stabilisation and protection systems* • Slope stabilisation and protection systems and how they work. • Design and construction of the various systems. • Quality control and monitoring. *River engineering* • Principal of river hydrology and hydraulics plus river processes • Design of river works
Specialist staff: professional engineers in the central offices of the RAD and LRD; consultants' design engineers.	*Alignment selection* • Roads in the mountain landscape • Roads in riparian landscapes • Terrain evolution and slope dynamics; forms and processes of slope instability • Recognition and mapping of landslides and potentially unstable slope conditions • Details of landslide risk assessment and works prioritisation • Practicalities of alignment selection to ensure that slope problems are minimised • Practical approaches to site investigation • Diagnosing slope instability and determining solutions • Slope stabilisation and protection systems and how they work. • Design of the various systems • Slope stabilisation, drainage and bio-engineering specifications • Principal of river hydrology and hydraulics plus river processes • Design of river works
Academic specialists (lecturers and researchers).	As for the specialist government and consultant staff above, plus: • Teaching the various elements. • Common pitfalls in the implementation of slope stabilisation programmes.
Contractors' supervisory staff (qualified engineers) and DPWT Technicians.	• The principles of foundation design, levels and laying-out. • The principles of good construction of gabion, dry stone and mortared masonry structures. • The importance of adherence to specification, quality control, and how to ensure it. • Costing and budgeting of slope stabilisation works. • Works in rivers
Contractors' construction technicians.	• Checking foundation suitability, levels and laying-out. • Adherence to specification, good construction practices of gabion, dry stone and mortared masonry structures. • Works in rivers • The importance of quality control.

10. POTENTIAL REHABILITATION PROJECTS

10.1 Introduction

The long-term aim of roadside slope management in Laos is the progressive reduction in slope stability hazards affecting the national and provincial road networks (see the Strategy Statement given in section 7.1 above. Within the existing road network, this will be facilitated by the continued implementation of emergency and other reactive measures as and when landslide events occur, plus the planned activities under the slope stability management programme. With respect to new road construction, section 3 of this report summarises some of the issues that relate to design and construction practices commonly encountered along mountain and riparian roads, and outlines procedures that could be adopted to reduce future landslide hazards.

This section outlines the slope rehabilitation projects proposed for consideration by the MPWT as part of the slope stability management programme. It also outlines proposals that could be taken forward by the MPWT for an enhanced ‘geo-engineering’ approach to future road design and construction projects as the road network becomes expanded and improved.

10.2 Proposed rehabilitation projects

It is recommended that a programme of road rehabilitation/slope improvement projects be established based on the risk ranking exercise described in Tables 7.2 to 7.4 above. Table 7.5 provides a list of possible sites, based on the Consultant’s landslide inventory, which the MPWT might wish to review. Table 7.5 also goes further, in recommending seven locations that could reasonably be chosen for rehabilitation during the first three years of the slope stability management programme, in conjunction with the capacity development activities recommended in section 9 above. This list will need to be reviewed by the MPWT and its consultants during the early stages of the slope stability management programme, but the locations identified are summarised below in Table 10.1.

Table 10.1. Proposed sites for rehabilitation within the first three years of the slope stability management programme

Site location*	Failure category	Risk ranking (from SW landslide inventory)	Estimated Cost (US$)**	Priority against MPWT strategy***	Final list?
NR 13N, 262+900	Above road	24	60,000	High	✓
NR 12, 136+900	Above road	18	50,000	High	✓
NR 12, 138+400	Above road	18	100,000	High	✓
NR 12, 141+500	Above road	18	100,000	High	✓
Patmong-Luang Prabang, 68+100 from Patmong	Below road	54	100,000	Moderate	✓
NR 13N, 239+400	Below road	36	75,000	Moderate	✓
NR 13N, 329+100	Below road	36	100,000	Moderate	✓

* The river bank erosion failure at Km 470+500 on 13N described at section 4 of the Background Report has been excluded from this list because it is assumed it will be reinstated as an emergency repair at the end of the 2008 wet season.

** Estimates only provisional: will require confirmation during early stages of proposed Programme

*** According to the likelihood of a failure causing a total blockage or loss of the road for at least three hours (in the case of National Roads).

These locations have been selected based on the anticipated preference to focus activities on a small number of regional zones (two) rather than on the basis of a scatter of locations across the country. Furthermore, some of the locations listed in the proposed shortlist (Table 7.5) are located along roads that have recently been improved or rehabilitated (namely NR3 and 8 specifically), and it is assumed that interventions at this stage along those roads would be inappropriate.

It is recommended that the MPWT, through the slope stability management programme, puts into place a risk assessment strategy, along the lines recommended in section 7, in order to confirm the list of sites for rehabilitation or improvement. When the investigation process is underway to establish the design for the rehabilitation works, it is recommended that an engineering geological approach is adopted whereby each area is first surveyed and then mapped by a trained engineering geologist. Ground investigation should then be planned, where necessary, in order to yield geotechnical information for analysis and design. These activities should be progressed in association with the capacity development described in section 9 above.

10.3 Enhanced geo-engineering for new road construction and improvement

Although not specifically part of the proposed slope stability management programme, it is proposed that the MPWT considers enhancing its geo-engineering approach to future road construction and improvement. In doing so it is anticipated that existing landslides might be avoided by judicious selection of alignments. Also, slope instability problems might be reduced by adopting enhanced engineering geological and geotechnical considerations into the development of designs and construction procedures. These are discussed in section 8 of the Background Paper, but the options for review are summarised below.

- Better alignment design. Increased study of the terrain in the design and fixing of the alignment of a mountain or riparian road can often lead to the selection of a more stable route for a road. This takes longer to achieve because of the additional topographical and geological analyses that are required, and greater time needed to verify the selected route on the ground. But it means that, through the selection of the route corridors with lowest relative relief away from rivers, it is often possible to avoid the most unstable areas of slope and minimise the need for major cuts and fills.
- Cut slope grades designed according to material characteristics. Road construction projects frequently use a single cut slope grade that is based on a perception of the most common material and the optimisation of earthworks costs (i.e. minimisation of cut). Since the weathered condition of the material varies considerably, both between cut slopes and within individual cut slopes, single standard grades often lead to sections of cut slope being formed that are too steep for weaker materials (see Figure 3.1 in the Background Paper). Designing to a variety of grades increases costs both because of additional site supervision and material sampling and testing, and because of higher earthworks volumes.
- Fill slopes properly formed. Many fill slopes are formed by side tipping of excavated material over the road edge and allowing it to compact itself over time, with only the final layer at road formation level mechanically compacted. This can produce a fundamentally unstable slope, or at least a slope that is subject to settlement once loaded by traffic. Adequate compaction of all fill embankment layers (to specification) will be more expensive because of the need to bench the original slope surface and compact the fill in layers as it is formed. Also, if a fill slope is to be built according to specification, then there needs to be some control of material grading and water content during filling and compaction, and this is not usually achieved by cut to fill through spoil tipping.

- Increased slope drainage. Many road design and construction projects underestimate the extent and volume of slope drainage required to collect and control discharge of surface water in peak rainfall events, and to ensure that high risk areas of slope do not become saturated to a critical extent by surface water and groundwater during the wet season. This requires careful consideration during design, with provision for sufficient quantities during construction. Its success also depends on the availability of resources during operation and maintenance, to ensure a fully functioning drainage system.
- Pro-active slope stability measures (mostly retaining structures), designed to achieve an acceptable slope factor of safety where this cannot be achieved through earthworks design alone.
- Pro-active slope protection measures (mostly bio-engineering and related works) designed to achieve an acceptable level of slope protection where this cannot be relied upon to establish naturally, or where there is an anticipated immediate need for slope protection to prevent slope instability from developing.
- Pro-active river engineering works designed to correct the channel migration which will sooner or later trigger bank erosion. Typically this will include the use of groynes or stub groynes to deflect flow away flow the bank and encourage deposition at the toe of the bank; also to clear deposition on the opposite bank. Also use of toe walls and mattresses that will protect against undercutting by scour.
- The reduction of geometric standards over limited sections of roads. In some locations it may be apparent that there is potential for slope instability that will be made worse by a full width of road or significant cutting or filling to achieve full curvature standards. If the road is made narrower over short critical lengths, or a bend is made sharper (with suitable traffic warnings), then long-term instability could be reduced or avoided. This would contribute to a reduction in the need for extensive slope stabilisation and protection costs during design and construction, as well as recurring maintenance costs during operation.

These suggested modifications to the geo-engineering approach are proposed for discussion purposes. Clearly, there are procedural, resourcing and engineering management considerations to be taken into account in each case, but it is recommended that these options be reviewed by the MPWT in parallel with the slope stability management programme as it goes forward. The economic analysis given in section 8 of the Background Paper suggests that it might well lead to long term cost reductions.

11. COST OUTLINE FOR THE PROPOSED PROGRAMME

The costs suggested below are outline estimates for guidance only. They need to be refined once the strategy adopted by the MPWT and its partners has been agreed.

11.1 Capacity development: training programme

The estimated costs of the training programme proposed in section 9 are as given in Table 11.1, on the basis of the assumptions given there.

Table 11.1. Estimated costs for training courses

Task / Group	Type of course	Number of participants	Estimated cost (US$)
Creation of training materials by a joint team of international and Lao specialists, plus monitoring delivery	Preparation of material for all in-country courses; advice on overseas courses	n.a.	250,000
Directors and Deputy Directors of RAD, LRD and the DPWTs.	Series of lectures	25	2,000
Site staff: professional engineers in the DPWTs; consultants' site engineers.	Formal lecture room training with frequent site visits	60	30,000
Specialist staff: professional engineers in the central offices of the RAD and LRD; consultants' design engineers.	Formal lecture room training with frequent site visits	40	20,000
	Specialist, in-depth overseas training (diploma or MSc)	4	200,000
Academic specialists (lecturers and researchers).	As above	20	10,000
Contractors' supervisory staff (qualified engineers) and DPWT Technicians.	Split between classroom and site	60	30,000
Contractors' construction technicians.	Practical site-based course.	40	15,000
TOTAL			557,000

11.2 Rehabilitation projects

These costs will comprise three main elements:

- Survey and ground investigation
- Design, contract documentation and supervision
- Capital works (construction costs)
- Ongoing performance monitoring

Survey and ground investigation

Using the costs for survey and ground investigation (drilling, trial pitting and laboratory testing) employed on the SEACAP 21 slope stabilisation trials as a basis, it is recommended that an estimate of US$ 5,000 is assumed for each location. For seven sites this would amount to approximately US$ 35,000.

Design, contract documentation and supervision

The cost of consultancy services required to undertake these tasks would amount to approximately US$ 200,000 over the three year period.

Capital works (construction costs)

From Table 10.1, the outline estimate of construction costs at the seven sites selected for illustration purposes amounts to US$ 585,000. These estimates are based on the bills of quantities and the final construction costs associated with the SEACAP 21 slope stabilisation trials. Details are contained in section 8 of the Background Paper.

Ongoing performance monitoring

The cost of ongoing slope monitoring and performance evaluation for all seven of the sites selected might amount to approximately US$ 10,000 per year, and thus US$ 30,000 for a three-year period.

11.3 Total cost estimate for three-year slope stability maintenance programme

The total estimated cost of the slope stability maintenance programme over a three-year period, on the basis of the assumptions and illustrated road/slope rehabilitation locations described above is shown in Table 11.2. This amounts to US$ 1615,050, including a 15% contingency.

Table 11.2. Estimated cost summary for slope stability management programme

Cost Item	Estimated Cost (US$)
Training Programme	557,000
Survey and Ground Investigation	35,000
Design, Contract Documentation and Supervision	200,000
Capital Works (construction costs)	585,000
Monitoring and Performance Evaluation	30,000
TOTAL	1,407,000
Contingency @ 15%	211,000
GRAND TOTAL	1,618,050

11.4 Enhanced geo-engineering for new road construction and improvement

The economic model in presented in section 8 of the Background Paper suggests that the introduction of the enhanced geo-engineering design and construction methods outlined in section 10.3 above would be marginally beneficial, leading to a 2% lower overall cost in net present value terms over a 50 year time period. But this takes into account only the engineering costs. If the consequences of delay times, vehicle operating costs and reduced environmental damage were to be introduced, there could be very significant differences in the long-term advantages of the enhanced geo-engineering approach. Table 7.3 demonstrates that, under the first scenario used above (current practices and two 6-hour blockages per year), there would be costs of US $ 18,700 incurred by road users, whereas under the second scenario (improved practices and one 3-hour blockage per year), there would be costs of US $ 2,300. Clearly this is hypothetical, but the differences are striking. If this happened, there would be an annual reduction of nearly US $ 16,400 per year in the costs to road users, or more than $ 0.82 million over a 50-year operating period. Meanwhile it is likely that traffic levels and economic values would increase with national development, giving much greater returns than those at the initial low baseline. Obviously this would be reflected back into the national economy.

APPENDIX: TYPICAL DETAILS FOR SLOPE STABILISATION, DRAINAGE AND BIO-ENGINEERING WORKS

No.	**Drawing**
100	Masonry retaining wall (below road)
200	Gabion retaining wall (above road)
300	Slope protection
400	Grass slips and grass planting lines
401	Shrub and tree planting
402	Hardwood cuttings
403	Brush layering, fascines and palisades
404	Large bamboo planting
405	Live check dam and vegetated stone pitching
406	Gabion wire bolsters
500	Slope and roadside drainage
600	Gabion check dams
700	Pipe culverts (1)
701	Pipe culverts (2)
801	Gabion components used for river bank protection
802	Type 1 gabion river wall on soil foundation
803	Type 2 gabion river wall on rock foundation
804	Type 3 gabion river wall with soil foundation and terramesh (high wall)
805	Elements of soda mattress
806	Example of soda system