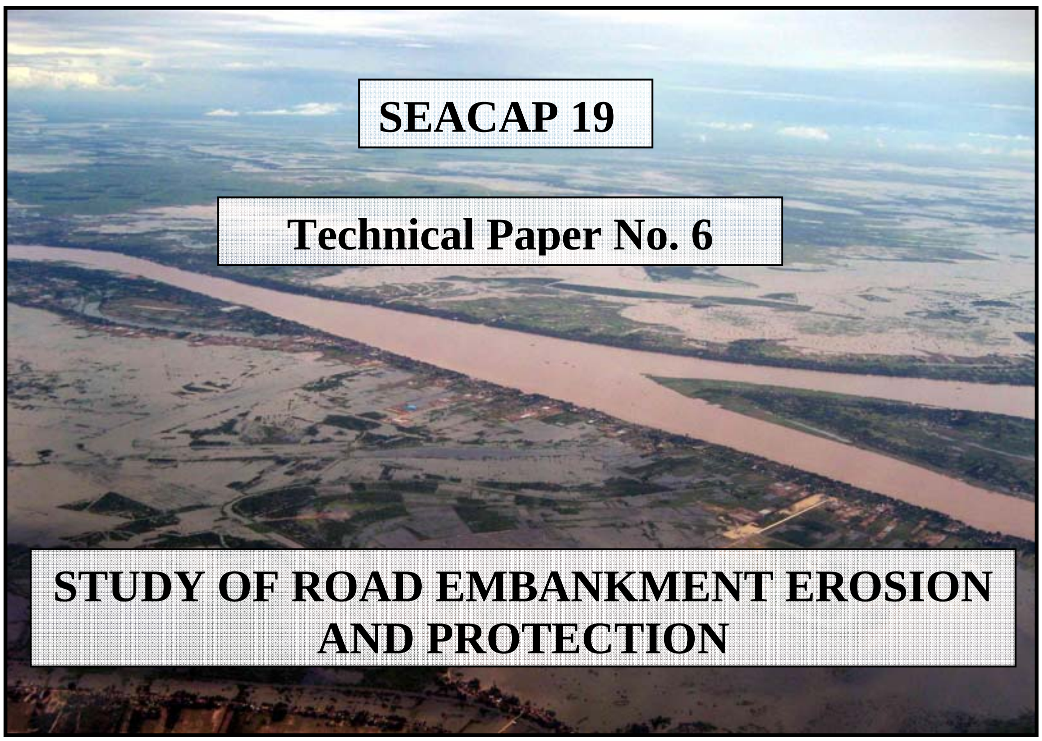
ROYAL GOVERNMENT OF CAMBODIA

SOUTH EAST ASIA COMMUNITY ACCESS PROGRAMME

DEVELOPMENT OF LOCAL RESOURCE BASED STANDARDS



May 2008

UNPUBLISHED PROJECT REPORT

UNPUBLISHED PROJECT REPORT

DEVELOPMENT OF LOCAL RESOURCE BASED STANDARDS

STUDY OF ROAD EMBANKMENT EROSION AND PROTECTION

By J Howell (Living Resources)

Prepared for: Project Record:	**SEACAP 019. Development of Local Resource Based Standards.**
Client:	**DfID; South East Asian Community Access Programme (SEACAP) for the Royal Government of Cambodia**

	Approvals
Task Manager	
Quality Reviewed, Project Manager	

CONTENTS

ABBREVIATIONS & ACRONYMS

IRRI	International Rice Research Institute
MPWT	Ministry of Public Works and Transport (Cambodia)
MRC	Mekong River Commission
MRD	Ministry of Rural Development (Cambodia)
MWRM	Ministry of Water Resources and Meteorology (Cambodia)
SEACAP	South East Asia Community Access Programme

DEVELOPMENT OF LOCAL RESOURCE BASED STANDARDS

STUDY OF ROAD EMBANKMENT EROSION AND PROTECTION

EXECUTIVE SUMMARY

This Technical Paper assesses the erosion of road embankments in the Mekong flood plains, and the possibility of using low cost approaches to mitigate the damage and includes the following key elements:.

- An in-depth review of the subject background. This provides an assessment of the rural road environment in the lower flood plains of Cambodia, and the key environmental and technical issues associated with the prevention of river bank erosion and road embankment slope deterioration by the erosive action of rainfall and flooding.

- A proposal covering the perceived need for research in this area, and an outline of how this might be done through suitable trials to develop technical solutions appropriate to the Cambodian environment. The techniques proposed are low cost and innovative, using bio-engineering as their basis.

- A summary of site investigations undertaken as part of the SEACAP 19 Task 6 programme.

In certain situations, the eroding banks of major river channels (particularly the Mekong and Bassac) are undercutting roads where they happen to run close to the main channels. More widespread, however, is the periodic damage caused to road embankments at a considerable distance from rivers, but crossing land subject to seasonal flooding. Standing water beside embankments allows waves to erode the earth side slopes, adding to the existing problem of erosion from rainwater runoff. These road embankments are so extensive in length that if they are to be protected at all, it must be done using low cost methods; and in effect, this means using vegetation.

The rainfall patterns and hydrology affecting the lower Mekong valley are complex, and although floods occur every year, they vary greatly in height and intensity. Some of the lower lying parts of the flood plains are inundated every year, while others receive floods only occasionally. The gradual movement of river channels and flooding of the lower plains are natural occurrences, and the silt and water brought in the floods are of critical importance to Cambodia's agricultural wealth. The difficulty is that so much infrastructure is needed in these vulnerable but densely populated areas.

Fortunately most of Cambodia's roads are routed well away from the main river channels, and at present there are relatively few locations where roads are actively threatened by river bank erosion. The main examples are sections of RN 21 beside the Bassac in Kandal, and RN 11 beside the Mekong in Prey Veng.

Flood damage to road embankments well away from rivers is a much more widespread problem. A very broad estimate of the lengths of roads potentially at risk from flooding can be made as follows: seven out of Cambodia's twenty-four provinces and cities are affected by major Mekong floods (not counting Phnom Penh); in these seven provinces there are 4,387 km of national and provincial roads

and 6,925 km of local roads, 42 percent and 29 percent of the national totals respectively. While not all of these roads are necessarily threatened and some roads in other provinces might be, the figures nevertheless give an indication of the general scale of the problem. The length of roads at risk is also increasing annually with new construction by a number of agencies.

The review shows how a number of options are available for low cost, vegetation-based approaches to embankment slope protection along significant lengths of roads. A carefully devised set of low cost trials is proposed to look not just at the exact species to use, but also the timing and methods of planting, and the layout of different types of plant and structures of vegetative materials. These should be designed to lead to an understanding of the site conditions that apply to each technique, and from that a set of guidelines, specifications and standards for all suitable options. There are many variables that need to be examined, and therefore the scale and design of trials must be adequate to address all of the questions.

It is proposed that the trials should be undertaken by a self-standing project administered by the MPWT, working in partnership with the Institut de Technologie du Cambodge. MRD should be invited to join with a suitable working agreement for collaboration, and possibly a similar arrangement made with MWRM. A consultancy group should provide the main technical services, following the successful SEACAP model. The research should be overseen by a steering committee that comprises officials from all of these four organisations, and this committee would be responsible for approving the detailed research strategy in each topical area, and ensuring ministerial collaboration to support the research.

DEVELOPMENT OF LOCAL RESOURCE BASED STANDARDS

STUDY OF ROAD EMBANKMENT EROSION AND PROTECTION

1 Introduction

This section introduces the Task and outlines the physical process that influence that influence the performance of road embankments in the Lower Mekong area.

1.1 Objectives of the Study

This study is one component of the project document preparation activities of the Project "Development of Local Resource Based Standards", administratively assigned as SEACAP 19 under the South-East Asia Community Access Programme of the UK Department for International Development. The task of the project is to assess the technical issues around five specific topics previously identified as being of importance in the development of appropriate Cambodian rural road standards, and if appropriate to prepare proposals indicating the way forward for further work.

The specific issues addressed by this study are the erosion of river banks close to roads, and of road embankments away from rivers but subject to damage from periodic high flooding, and possible low cost approaches to mitigate these types of flood damage. The work follows a similar pattern of key steps to the other tasks, namely:

- A review of existing documents and experience (national, regional and international);
- Field surveys and detailed technical assessments;
- Discussion and interaction with relevant stakeholders on the way forward; and
- Production of project documents for in-depth research.

This document therefore contains an assessment of the rural road environment in the lower flood plains of Cambodia, and a review of the key technical issues associated with the prevention of embankment slope deterioration by the erosive actions of rainfall, river flow and flooding. These investigations identified possible solutions appropriate to the Cambodian environment, which in turn allowed suitable trials to be specified that would carry this work forward.

Trial proposals are contained in a separate Concept Note which is attached as Appendix A. Notes on site visits made during this study are included as Appendix B

1.2 Processes of Erosion and Failure on Earth Banks

This section gives a summary of the physical processes that occur in earth masses, leading to their removal or failure through the action of water. It provides the technical background to the effects that occur in the river banks and embankments on the Mekong plains.

1.2.1 Damage caused by surface activity

Erosion is the removal of particles from a soil surface by a physical agent, usually flowing water. Although it is a surface feature, the surface will be progressively lowered if particles are continually washed away, giving rise to rill or gully erosion. Splash (or rain-splash) erosion is the spattering of small soil particles caused by the impact of rain drops on wet or weak soils; the loosened particles may or may not be subsequently removed by surface runoff. Sheet erosion is the removal of a fairly uniform layer of soil from the land surface by runoff water (or overland flow). Rill erosion is where numerous small channels of the order of tens of millimetres in depth are formed. Gully erosion is the process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area, often to considerable depths.

The exact conditions under which each of these occur varies greatly. Sheet erosion is uncommon under natural conditions, but can be found on extensive bare soils with compacted surfaces, such as unprotected embankment slopes. More visible is the development of rill or gully erosion through the channelisation of surface runoff (when it occurs) at the micro level. Once drainage lines start to form rills on weak materials, they can enlarge rapidly into gullies. Gullies begin as very shallow, narrow incisions in the slope (rills). If a gully is deeper than about one metre, its sides can suffer small mass failures in ways similar to river banks or hill slopes.

In a river, "*scour will occur when flow velocity and turbulence are sufficient to pick up bed and bank material, or when sediment swept along in the flow is large enough and travelling fast enough to abrade the channel boundary. The factors that control the pattern of scour are so difficult to quantify that there is no reliable physically-based method for assessing their combined effect*" (TRL, 1997). In practice, the erosion of natural river banks or man-made embankments by a flowing current or waves usually occurs through a combination of the two processes of erosion and small mass failure. The general model for this is shown diagrammatically in Figure 1.

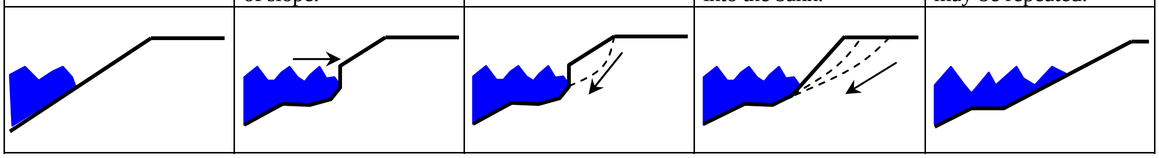
Shear failures or small rotational landslides are possible in slopes formed in the predominantly fine-grained soils that are found in the lower flood plains of Cambodia. Here, a rotational movement of material occurs, forming a spoon-shaped scar on the slope, which is roughly circular in plan. The debris would form a bulge near the toe, but in this situation is usually washed away by wave movement or the river current. Slumps are commonly aided by excess water pore pressures in the slope material. In a high river bank the slip circle can often be several metres deep.

Planar sliding or small translational landslides can occur in unconsolidated embankment slopes or river banks cutting into coarse, sandy sediments. In these failures, a 'slab' of material of more or less uniform thickness slides off the surface. Translational slides are typically rectangular in plan, with a straight head scar and straight sides running parallel down the slope. They are quite shallow, and on a weak bank on Cambodian flood plains may be only up to a few tens of centimetres deep or less.

In practice, many slides are compound in character, , in which a rotational component at the head degenerates into a translational or slump component below and identifying if there is a rotational or a translational mode of failure is can be difficult. . This is because non-plastic masses cannot sustain a circular slip plane except at the crown. In the Cambodian flood plain context, however, it is unlikely to be important in deciding treatment except for the largest scale of river bank failures.

Figure 1. Diagrammatic Representation of the Erosion-Mass Failure Combination Governing Bank Erosion

(1) Original river bank.	(2) Current or wave action erodes a section of slope.	(3) The steep part of the undercut bank fails.	(4) The failure works progressively up and into the bank.	(5) A new bank profile is left. the cycle may be repeated.



1.2.2 Failures due to internal water movements

Erosion by **piping** is a mechanism found in some earth slopes, where the removal of fine particles occurs along an underground channel. Percolating ground water in permeable soils of low plasticity can remove fines along a fissure to a point where an underground stream is formed. The roof of this stream cavern can enlarge upwards towards the surface and eventually collapse to create an open, elongated chasm or pit. In road engineering this occurs most commonly in poorly compacted fill behind retaining walls or underneath protective surfacings, but it can also happen on simple earth slopes. In the Cambodian flood plains it is most common in unconsolidated embankments formed from weak sandy soils. It might also occur behind gabion embankment protection or bridge abutments. It is usually avoided by placing a geotextile filter membrane behind the structure, to allow water to drain out without taking soil particles with it.

Pore Water Pressure, Hydraulic Gradient and Draw-down. When water infiltrates into the soil, it enters the voids and starts to fill them up. As a result, pore water pressure starts to rise. Pore water pressure is the pressure acting on soil grains by water held in the pores, and can be positive or negative. It is negative when the voids are only partially filled with water (this state is also known as soil suction). Pore water pressure becomes neutral just before the point at which the voids become completely filled with water. It becomes positive at the point when all the air has been expelled from the voids and the water phase in the soil-water mix becomes continuous. At that point, the water phase effectively becomes a column and hydrostatic pressure, equivalent to the height of the column and the unit weight of water, is exerted within the pores. The ability of soil to resist failure in soil mechanics terms can defined by its effective shear strength, which in turn is a function of the pore water pressure. In general terms, the pore water pressure within an embankment slope can, in times of flood, change rapidly from negative (aiding shear strength) to positive, or excess (decreasing shear strength). If upward water pressure is high enough the effective stresses in the soil disappear, no frictional strength can be mobilised and the soil behaves as a fluid.

Flow of pore water in soils is driven from locations of higher total head to locations of lower total head. The hydraulic gradient is the rate of change along the direction of this flow. In flood condition where a road embankment may be acting as retaining dam there can be conditions where there is a significant hydraulic gradient developed between an ‘upstream’ inundated face and a downstream face with lower water level. This can result in problems of face erosion through seepage from what is in effect a downstream 'spring line'

The problems of rapid draw-down are perhaps most commonly associated with embankment dams; however, similar conditions can occur in natural and man-made embankments along rivers and man-made drainage channels as a result of flooding. Road embankments may become saturated during a prolonged flood period; if, subsequently, the water level is rapidly reduced (drawn-down) at a rate faster than pore water can escape, then excess pore water pressure is developed and reduced stability can occur. The significance of this phenomenon is related to permeability of the soil as well as the rate and level of draw-down.

In a soil, its permeability or ability to transfer water is a function of the porosity. This is related to soil particle size and the degree of compaction. Table 1 shows the relationships between the predictable factors; the degree of compaction is more complex and depends on the history of activity of a site's materials. The general trend, however, is that the finer the material and the more massive its structure, the longer it will take for pore water to be released and the hydraulic gradient to be reduced. The presence of an impervious material (such as a masonry facing) on the outside of a saturated embankment will greatly reduce water drainage, and therefore increase the chance of high pore water pressure and a mass failure.

Table 1. Approximate Relationships Between Texture, Structure and Hydraulic Conductivity. Source: Landon (1991).

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

2 Appraisal of the Erosion Problem on Cambodia's Roads

This section summarises the nature and extent of road embankment deterioration problems associated with river flooding in the Lower Mekong flood plains of Cambodia. Two general problems are identified and discussed: river bank erosion adjacent to river channels and embankment stability under flood conditions remote from main river channels. General options for reducing the impact of these problems are outlined.

2.1 Roads on Flood Plains

It is not really possible to estimate accurately what lengths of Cambodia's roads run across flood plains and are vulnerable to damage by severe floods. This is because no two floods are the same, and the hydrological conditions experienced in the bad years of 2000 to 2002 were different in each year and will never be quite the same again: some areas will fare worse in the next high flood, and some better. On top of the variable hydro-dynamics, changing land uses mean that there are even more uncertainties as to what will happen in future high floods. What is certain, however, is that the population is most dense on the flood plains because of their great importance in agricultural production, and that a very significant and annually increasing part of the road network is also in these areas. A very broad estimate can be made as follows: seven out of Cambodia's twenty-four provinces and cities are affected by major Mekong floods (not counting Phnom Penh); in these seven provinces there are 4,387 km of national and provincial roads and 6,925 km of local roads, 42 percent and 29 percent of the national totals respectively. While not all of these roads are necessarily threatened, these figures nevertheless give an indication of the general scale of the problem.

So (2003) and Mao (2005) both mentioned very considerable damage resulting from the 2001 and 2002 floods, though not as great as that in 2000. In the severe 2000 flood, Yit (2004) estimated that there had been major damage to 1,800 km of national roads and 820 km of secondary and provincial roads, and to 60 percent of the rural and commune roads on the flood plains; the total cost of repairs to public infrastructure amounted to around US $ 47 million. He provided diagrams to demonstrate that the hydraulics around severely flooded roads had been investigated, resulting in a better understanding of a number of improvements to the design of roads on flood plains (also shown by SWK, 2002).

Goichot (2003) is one of the few international contributors to the debate on floods in the Mekong basin to consider the position of roads on flood plains. He points out that roads are regularly damaged by floods, their embankments often act as dams, increasing the level and duration of floods and thereby causing greater damage to local populations, and they affect the natural dynamics of floods and therefore have an impact on the movement of fish and other aquatic life. He suggested that road structures should be made more resistant to floods, and measures taken (mainly, it seems, through the provision of more cross-drainage) to reduce their negative impacts on the agricultural and fisheries productivity of flood plains, as well as on biodiversity and river morphology. Such an approach was considered as likely to have benefits to both financial investment in development and biodiversity conservation.

Looking at the problem from the perspective of disaster preparedness and relief, the IFRC (2003) pointed to the need for roads on embankment to withstand floods and help reduce the impacts of disasters in remote rural areas. In effect, this is calling for a pragmatic reconsideration of the whole design concept of roads on flood plains.

2.2 Stability of Natural River Banks

2.2.1 Assessment of the river bank problem

The lower plains of the Mekong valley represent the most agriculturally productive and densely inhabited parts of Cambodia. These occur from Kampong Cham downstream to the Vietnam border, and include the land around the Tonle Sap system. This represents the area of sedimentation of the Mekong and its tributaries, and from the geomorphological viewpoint is dominated by the characteristics and natural events of a lower river valley. Because of the vast scale of the Mekong, some of these features are very large in size.

The most significant factor is that the whole area is a flood plain, and therefore subject to inundation from time to time. The frequency, timing and depth of flooding varies, depending on the characteristics of each particular locality, with widespread flooding only occurring in exceptional years. Also of great importance is the fact that river channels migrate naturally. If left uncontrolled, bank erosion will occur on the outside of bends, and deposition on the inside of bends, with the result that river meanders (acute curves) tend to move downstream; sometimes they are cut off from the main channel, and are left as swampy lakes, forming the distinct "oxbow" shape. Within the channels, the main flow can vary and sand banks and islands appear or disappear as the flow changes seasonally. In short, the geomorphology of this part of a major river valley is extremely dynamic.

In a completely natural environment, this shifting of rivers is simply an ongoing pattern of evolution over a relatively long period of time. It only becomes a problem when it interferes with fixed man-made infrastructure. The tendency is for people to want to control the river, and this becomes a necessity when land ownership puts high values on property on every available land surface. No land laws are flexible enough to replace land lost on the outside of a bend with land gained on the inside, even if this were convenient.

This has an impact on the road network in areas where roads run close to the major rivers. In almost any year there is some erosion of the banks of the Mekong, Bassac and Tonle Sap rivers (and also accretion elsewhere on their banks). This means that parts of all roads running along the banks of these rivers are susceptible to damage every wet season, when river levels are high. Minor river channels appear only to shift significantly in years of exceptional flooding. This is when, in years like 2000, discharge water from the over-full Mekong flows over land not normally flooded, and drains off by means of channels that only rarely take such large volumes of water, and which thereby become unusually powerful for a short period. An example of this was the bank erosion of the Tonle Touch that damaged RN 11 in 2000, and it can also be seen, for example, along RN 8 to the east of the Mekong.

Section 1.2.1 above provides a description of the processes of erosion and mass failure. On the banks of the big Cambodian rivers these are at work on a large scale. Not very much happens for most of the year because the rivers are low and flow well within their channels. But when the flow level is high and the energy of the fast-moving water is considerable, erosion starts to occur by the physical scour of the current against the weak earth bank, usually on the outside of bends. In certain locations this may be increased by additional energy from waves, either generated by the wind or from the wash from passing boats. It can also be added to by water running down the bank in heavy rain, or by damage from the feet of people or animals, or through other man-induced physical damage. As the erosion cuts into and steepens the bank, and rainfall saturates the bank above the river level, the conditions become right for mass failures to occur, and whole sections of the bank can slump into the river.

An interesting study of bank erosion was undertaken by the Institut de Technologie du Cambodge (ITC, 2004). A length of 300 metres of bank was selected for detailed appraisal in the village of Chrouy Taek, Kandal Province. The bank had a dry season height of 8 to 10 metres, and each year about 20 to 30 metres width of land was reported to be lost, amounting to around 500 metres of lateral river shift over thirty years. In this period, the village had lost a pagoda temple, the houses of eleven families and a number of orchards. The shifting pattern of erosion and deposition in the area made river transport difficult during the dry season. For the same reason, the government had dredged the far side of the channel for the benefit of larger boats, further excluding the village economically and affecting the surrounding hydrology. Families whose houses were increasingly threatened were worried about their future, and during the research period one house was dismantled by the owners during the dry season, because they thought that it would soon fall into the river if they did not move it. The study was mainly restricted to a low-budget assessment of physical soil characteristics and water levels. Its conclusions were that the bank was composed of weak and cohesionless soil strata that were easily eroded under natural conditions. It appeared that the rate of erosion had been increased by the effects of waves from the wake of large boats during the wet season, and the alteration of the hydrology that resulted from the extraction of sand from the river bed during the dry season.

A study of slope instability in Vietnam by WSP (2003) included an assessment of the stability of road embankments running alongside channels, both natural and man-made, in the lower Mekong delta. The conclusions were that the high water level throughout the year, and the effects of the current and waves from boats, coupled with very weak materials and a lack of any form of stabilisation or protection, meant that the embankment slopes were extremely unstable. Both shallow slumps and deep-seated subsidence appeared to be common. There was evidence that bamboos and other plants growing along the channel banks, but especially bamboos, could slow down the retreat of the adjacent road embankment. Beyond this, there seems to be little comparison with the Mekong river banks in Cambodia because of the differences in the hydrology and sediment characteristics in the lower delta. Although WSP (2003) recommended that stabilisation trials be conducted, they were not undertaken.

2.2.2 General options for resolving river bank failures

Since river bank failures are caused by the effects of major flows of water, the general rule must be that there are unlikely to be any low cost options, and that relatively heavy civil engineering works are more likely to be successful than bio-engineering or other low cost surface protection works. There are several key features to address, however. Most important is to consider each site on the basis of a detailed geotechnical assessment, so that the actual mechanism of bank failure is clearly established before the course of action is finalised. If the problem is only erosion of the exposed bank, through the scouring effect of the river current, then flexible protection such as gabion mattressing may be adequate. But if there is a 'geotechnical' slope failure caused by undercutting and over-steepening of the bank, or a slump due to high pore water pressures, then a substantial retaining structure may be required. For both of these options, the designs used under the Emergency Flood Rehabilitation Project (SWK 2002 and 2003) are generally appropriate. Guidance on this is available in many general documents, including TRL (1997).

There is some evidence that large plants can retard the erosion of the banks of even the large Cambodian rivers. This suggests that a logical long term strategy might also be the establishment of plantations of appropriate trees between roads and rivers, or in belts on the river side of roads, wherever there is a danger that rivers may eventually cut their way closer to roads. This depends, of course, on there being adequate land available that is not used for rice cultivation. Another approach, that is logical in any case, is to standardise the planting of trees along the toe of all road embankment slopes. While fast growing trees like *Acacia auriculiformis* (smach téhs) are being planted by road upgrading projects, their performance in extreme flood conditions may not be as good as the well established but slower growing *Pithecellobium dulce* (âmpil tük) that grows on many river banks and older embankments.

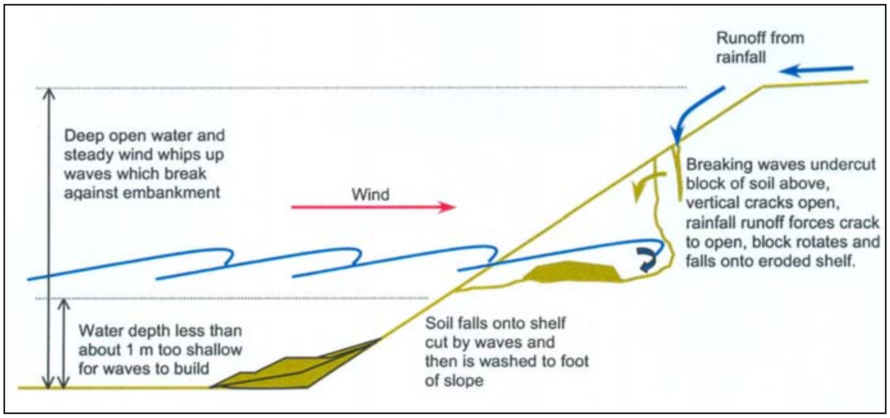
The MWRM considers minor shifts of the banks of the Mekong to be a problem, but not necessarily one that can be resolved (Veng, 2007). The ministry suggests that economic assessments of the relative costs of resolving bank erosion rarely show that action is worthwhile, mainly because of the very large scale of the river and the high cost of stabilising its banks in areas susceptible to migration.

2.3 Stability of Road Embankments away from Rivers

2.3.1 Assessment of the road embankment problem

The particular issue of wave erosion of road embankments is described clearly by SWK (2002), who had the benefit of observation immediately after the flood of 2000, and during the 2001 and 2002 floods. "*Erosion of road embankments by waves is a problem specific but not unique to Cambodia. During the flood season water can stand deeply beside a road without over-topping the road. Outside villages and where there are few trees or bushes beside the road the large, deep, open expanse of water provides significant 'fetch' for wind-generated waves. Fetch is the technical term to describe a length of open water exposed to the wind over which waves build up. In Cambodia there is usually a steady south-westerly wind during the flood season and embankments exposed to this are particularly prone to erosion damage by waves. The waves lap against the embankment and road shoulder, gradually eroding the soil and pavement. Figure 2 illustrates the mechanism… There are plenty of examples around the country that reveal wave damage is less where there is a combination of grass and woody vegetation on the slopes. It is usually only the slope about 1 metre above the base of the embankment that is affected; when the water is shallow the waves are small and cause little damage*." It is clear from this description as to exactly how the mechanisms described in section 1.2.1 above actually affect the road embankments under these conditions. The photograph in Figure 3 illustrates the problem on a typical national road embankment.

Figure 2. The Mechanism of Wave Damage.



Source: SWK (2002).

Figure 3. Illustration of Wave Erosion on a Section of RN 8 in Prey Veng.

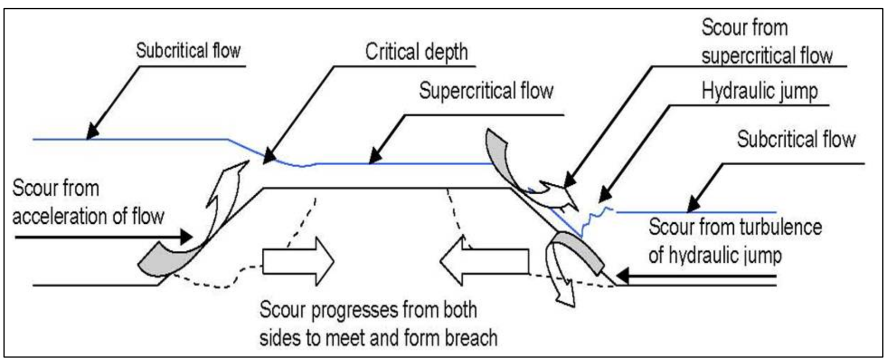
In most years, when the Mekong flood level is not exceptional, the road embankment problem is restricted to relatively few sections of road. However, in years with high flood levels, such as the three years of 2000 to 2002, a far greater length of roads can be affected. In effect, any road is at risk where inundation rises above the surrounding ground surface by about one metre. This may be quite a high proportion of the many thousands of kilometres of roads that are potentially at risk from flooding (see section 2.1).

As discussed in 1.2.1 it may also be that small slumps can occur on some embankment slopes as a result of high water levels against them, even if waves are not a factor. This can occur where embankment slopes are designed and constructed below the Factor of Safety required for geotechnical stability for the encountered excess porewater flood conditions. This would account for the formation of what are taken to be wave benches at lower levels on some embankment slopes, or on the lee side, where they are sheltered from the prevailing wind during the flooded period.

Yit (2004) presented a diagram (see Figure 4) showing the mechanisms of erosion in the worst cases of serious flooding, where road embankments are over-topped to a significant level. Meon (2005) presented examples of similar problems resulting from a disastrous flood on the Elbe in 2002. These features were also considered by SWK (2002) in terms of the design of roads in severely flood prone areas. It was clear after the three years of high floods from 2000 to 2002, that in many areas roads running at right angles to lines of natural drainage have nowhere near enough cross drainage at critical times; for example, on RN 11 in Prey Veng, around 25 percent of the total flood flow appeared to bypass bridges in 2000 and 2001, either by over-topping the road or by flowing through breaches. The national design standard for drainage (MPWT, 2003b) assumes a typical closed catchment in designing road cross drainage, and takes no account of the possibility of the encroachment into culverts or bridges of huge volumes of water from the Mekong during high floods.

Site investigations during the preparation of this assessment confirmed the findings of others. When freshly finished, virtually no road embankments are properly protected against erosion of any kind, even from rainfall running off the road pavement. This was observed as a problem in places on RN 1, RN 7 and RN 8 (see accompanying Annex). Even where standard procedures of turfing the shoulder and planting trees on the side slopes are used, they are not effective until the plants have established themselves and spread, and additional vegetation has colonised, and this takes several years. While this provides a basic protection against erosion, rarely are embankments properly protected against wave and current damage, except in a few places on RN 11. Where basic bio-engineering was used under the Emergency Flood Rehabilitation Project (an extremely useful lesson learning process), there were some important flaws: these are discussed in sections 4.2 and 4.3 below.

Figure 4. Mechanisms of Embankment Destruction by Over-topping Flows.



Source: Yit (2004).

2.3.2 General options for resolving the erosion of road embankments

In consideration of solutions, SWK (2002) had these comments. "*The situation is analogous to an embankment dam, which is usually protected against waves by rock riprap, concrete slabs or similar means. On cost grounds such protection is out of the question for roads in Cambodia. But it is clear that wave action will remain a problem unless vulnerable embankments can be protected. In particular it is the pavement edge and top upper part of the slope that requires protection. This is because the problem is only significant when the upstream water depth is deep… The challenge is to find an effective low cost method of slope protection for the embankment.*" There are many ways of protecting slopes, but the general principle is summarised by the Japanese Highway Public Corporation: "*Slope protection by structures is generally to be used only when protection by vegetation does not maintain surface stability*" (Ingles, 1985). Vegetation will always be the cheapest form of surface protection on earth slopes, but in areas subjected to severe stresses it may need to be designed as carefully as any other engineered structure.

There are places where, in high floods, a significant depth of flow might be expected over certain sections of roads. This issue is discussed by SWK (2002) in relation to RN 11 in Prey Veng, where, in 2000 and 2001, cross drainage could cope with only about three-quarters of the high flow and it was not practical to increase bridge capacity to accommodate the entire flow. The solution adopted under the Emergency Flood Rehabilitation Project, was to identify certain sections of road as floodways, and there to install appropriate physical protection that would withstand the forces illustrated in Figure 5. This seems to be a very appropriate response, especially as SWK (2002) provided a relatively low cost but sufficiently robust design.

For the remainder of the road network, however, appropriate bio-engineering works are likely to be the only realistic solution because of the cost factor. In cost estimates of the road sections requiring embankment protection in 2002, SWK (2002) calculated that hard engineering protection would cost around US $ 1 million, whereas bio-engineering should be able to fulfil the same function for around only $ 60,000 to 70,000. The uncertainties of flooding on the Mekong plains are so great that it is impossible to know which sections will need protection in any particular year. Yet all roads on the flood plains need embankment protection to ensure that they remain intact and serviceable in even the most extreme flood conditions (which is exactly the time when they will be most needed), so it is essential that they are all covered. This can be done with vegetation, but only through use of the right species, and methods and configurations of planting.

2.3.3 Experience from the irrigation sector

Officials working in the irrigation sector point out that their work on flood plains suffers similar problems to those encountered in the road sector. Soils tend to be very poor for dike construction, just as they are for road embankments, and the stability and protection of dams and dikes are just as difficult. Wave and current erosion lead to widespread difficulties in the network of water distribution channels on the plains.

A number of methods have been attempted to resolve these difficulties encountered that are based on the general experience that earth dikes are quick to build, but tend to fall apart very easily. Both surface erosion and piping occur commonly. Irrigation dikes have very different erosion regimes between the inside and outside of their channels, and obviously the hydraulics affecting the earth banks are quite different from roads. A summary of approaches to protection that have been tried is as follows (Veng, 2007).

- High compaction specifications. There are difficulties in assuring the quality of normal compaction, so the effectiveness of carefully controlled higher compaction specifications has been tested. They appear to make little difference.
- Concrete linings. These appear to work well, but increase total channel construction costs by two or three times.
- Rip-rap bedded into fine sand. This is quite successful, but the materials are difficult to find and hard to transport, and increase costs dramatically.
- Grass turfing. This works initially, but tends to die of drought in the dry season. When the rains come again, the top of the dike becomes soft and erodible before the grass

cover gets established again. Many dikes are built from soils with low fertility and water holding capacities.

- Geotextiles. These have been used in some areas as a lining under a rock surfacing. They are not always successful.
- Improved construction materials. A JICA project has undertaken trials to improve dike construction by mixing materials to increase earth performance. Local soils were mixed with introduced materials to give a better consistency through mechanical stabilisation. The results are not widely known, except that it is an expensive option.

An interesting comparison was made by irrigation sector personnel, between the relatively poor site conditions found on many dikes, which make vegetation establishment difficult, and the mixed materials and ecological niches found along natural river banks, which give rather superior site conditions where vegetation tends to colonise more readily.

3 Review of Environmental Factors of Relevance to River Bank and Road Embankment Dynamics

This section summarises the relevance of natural factors such as; climate; geomorphology; soil type and existing vegetation as well the nature of the floods themselves.

3.1 Background to the Mekong and its Flood Plains

Overall, the Mekong river is 4,800 km long and its basin has an area of 795,000 km^2. Of this, 20 percent falls into Cambodian territory, but other upstream countries are Yunnan Province of China (21% of total basin area), Lao PDR (25%), Myanmar (3%), Thailand (23%) and, both upstream and downstream, Vietnam (8%). A total of 58.7 million people live in the overall basin, of which 90% are rural. Mekong water consumption in Cambodia is approximately 4.09 km^3 per year (2000 data), about a quarter of that used in the lower basin (i.e. excluding the area in China and Myanmar). The great majority of this, 97%, is used for agriculture. The agricultural contribution (crops, livestock and fisheries) to Cambodia's GDP is around 40.4% (1999 data). Wet rice is the main crop and is grown on the flood plains of the Tonle Sap, Mekong and Bassac rivers.

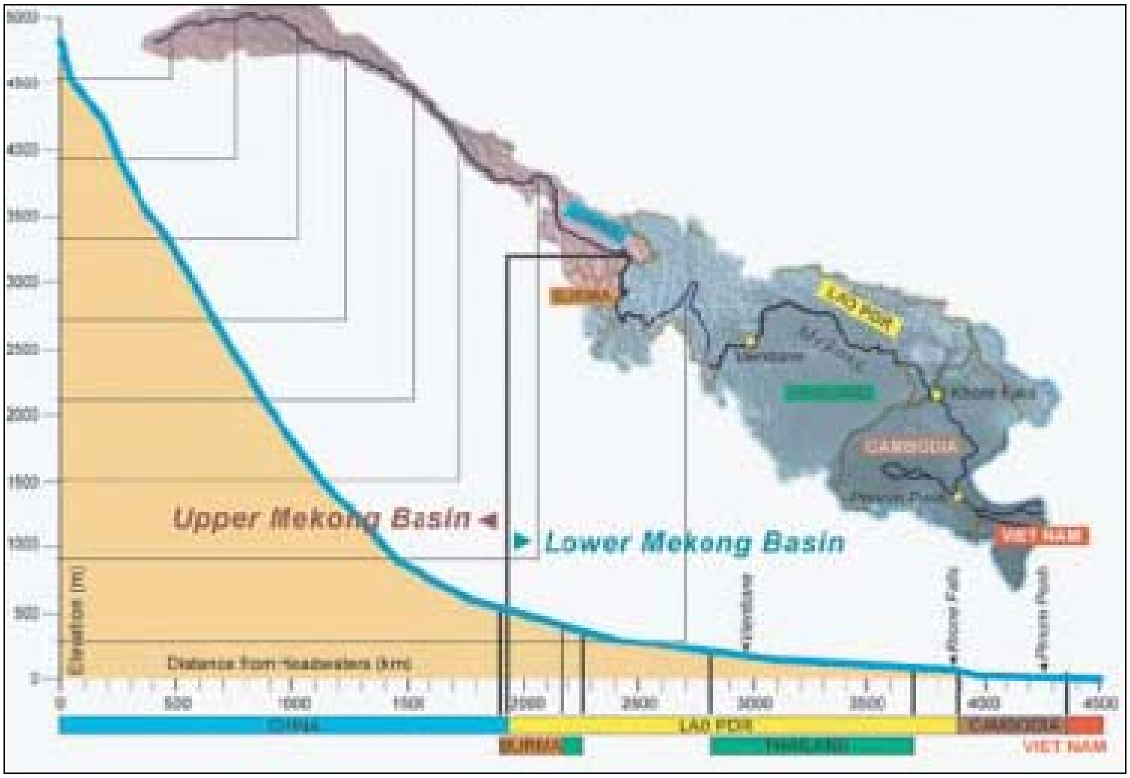
By the time the Mekong enters Cambodia, over 95% of the flows have already joined the river. From this point downstream the terrain is flat (see Figure 5) and water levels rather than flow volumes determine the movement of water across the landscape. The seasonal cycle of changing water levels at Phnom Penh results in the unique "flow reversal" of water into and out of the Great Lake via the Tonle Sap river. Phnom Penh also marks the beginning of the delta system of the Mekong river: here the mainstream begins to break up into an increasing number of branches. Agriculture is most developed in the delta and the population density is the highest in the entire river basin (MRC, 2005).

The Tonle Sap lake is the largest body of freshwater in south-east Asia and a key part of the Mekong hydrological system, as explained by MRC (2005). Its mean surface area changes from 3,500 km^2 during the dry months (January to April or May), to a maximum of up to 14,500 km^2 during the wet season. Maximum depths of 6 to 9 metres can be measured in late September to early October and minimum depths of around 0.5 metres in late April. The seasonal changes in the amount of water stored in the lake are from as low as 1 to 2 km^3 in the dry season, rising to 50 to 80 km^3 in the flood season. Differences between the water level in the lake and the water level in the mainstream Mekong cause the unique flow reversal in the Tonle Sap river. During the flood months, water flows up the Tonle Sap from the Mekong mainstream into the lake. As the water level in the mainstream falls in late September, water flows out of the lake down the Tonle Sap river and back into the Mekong mainstream. Nowhere else in the world is there a flow reversal this large. The lake retains about 80 per cent of the sediment and nutrients carried into it by the flow reversal. This annual natural fertilisation of the flood plains in Cambodia has been a key factor in thousands of years of successful wet rice cultivation and productive fisheries.

The seasonal storage of water in the Great Lake also acts as a huge natural regulator for water flows downstream of the Tonle Sap-Mekong confluence at Phnom Penh. This has advantages in terms of the seasonal distribution of flows in the Vietnamese delta: as stored water flows out of the lake back to the main river during the dry season, the low flows in the

Mekong are increased and are therefore higher downstream of Phnom Penh than they would be otherwise.

Figure 5. Longitudinal Profile of the Mekong from Headwaters to Mouth



.Source: MRC (2005).

3.2 Climatic Factors

In the upper part of the Mekong basin, rainfall is dominated by the south-west monsoon, peaking sharply with around 80% of rain falling between May and September. Lower down, such as at Phnom Penh, the heaviest rain comes during the final third of the year, as shown in Table 2. Annual totals here generally range between 1,000 and 1,500 mm, with a long-term average of 1,200 to 1,300 mm. During drought years the figures can be much less and have been as low as 650 mm. After the influence of the south-west monsoon from May to September, tropical storms and cyclones have a strong influence on the rainfall between September and November. This effect occurs over most of the lower Mekong basin during wet years, and largely accounts for the later peak in the annual rainfall. Major floods in the lower Mekong are generally the result of a combination of the effects of the south-west monsoon and severe tropical storms.

Table 2. Average Rainfall at Phnom Penh (mm). Source: MRC (2005).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
8	3	15	65	115	125	160	160	265	255	130	20	1,320

These average figures are misleading, however. Important variations are described by Nesbitt (1995), who summarised the Cambodian climate from the perspective of rice cultivation, and this may be important for all vegetation growth. *"Cambodia experiences a typical monsoonal climate with the major proportion of rain falling during the warmer months of May through to October. Little rain falls between December and March… However, variability is large both between years and between zones."* Most areas tend to experience an annual bimodal rainfall pattern with a first peak sometime between May and August, and a second peak in September or October. Nesbitt (1995 continues*: "Steady rain in the early months is healthy for the establishment of pre rice crops. However, this is (un) predictably followed by a mini drought of 2-6 weeks or longer. For this reason the cultivation of upland crops is not recommended in most of these areas except in the better drained soils possessing superior water holding capacities… Ambient temperatures remain reasonably constant throughout the year with the mean maximum in Phnom Penh being 33°C and the mean minimum, 23°C. The hottest months are March-May as the day lengths steadily increase and cloud cover is still minimal. It is during this period that evaporation peaks, placing considerable physiological pressure on crops.*" The varieties of rice used in the upland areas of Cambodia are drought tolerant, since there is a risk of lack of water in the likely but unpredictable period of reduced rain between the bimodal peaks of rainfall. It is important to note that because the earlier peak can occur over quite a wide time range (May to August), it is not visible in tables like Table 2 or graphs showing mean monthly rainfall over a considerable number of years.

The length of the dry season is recognised in the forest sector as having a significant effect on plant growth. The Cambodia Tree Seed Project (2003) lists this as being one of the key ecological factors that needs to be taken into consideration because of the dangers of water stress in plants. It gives two broad categories, with the southern Mekong plains being in the wetter of two categories, with less than four months of annual drought risk, and often as little as two months.

3.3 Characteristics of the Annual Floods

The mean annual discharge of the Mekong is approximately 475 km^3. Of this amount, about 18% comes from China and Myanmar, and only 5% from downstream of the Lao-Cambodia border. Most of the remainder comes from Laos and the major left bank tributaries, particularly those that enter downstream of Vientiane and Nongkhai. During the dry season, the proportion of water from China is much higher in the lower Mekong (40% at Kratie), than it is in the wet season (16% at Kratie). Hence the vast majority of water affecting the Cambodian plains during floods is derived from the tributaries entering the main river in Laos, and is the result of rainfall over the lower river basin.

Flood levels are difficult to define in an area as complex as the lower Mekong, because of the huge range of variables governing the hydrology. However, it is clear that there were exceptional levels of inundation in 1961, 1978 and 2000. In addition, after an 18-year spell of unexceptional floods from 1982 to 1999, there were exceptionally high floods three years running, in 2000, 2001 and 2002. The extreme nature of the 2000 flood was the result of unprecedented volume and the fact that the seasonal flood hydrograph began a month to six weeks early, causing natural wetlands to fill up long before they usually do. Floodwaters arriving later had nowhere to go except into areas that normally do not flood. These events were caused by unusually early and heavy rainfall in north-west Laos and south-west China in July, which added to rain from tropical storms from the South China Sea, affecting southern Laos and Cambodia. This led to a major discharge of the Mekong across the Laos-Cambodia border and the filling of the Tonle Sap six weeks earlier than usual. Then, heavy rainfall in southern Laos in August and September resulted in high Mekong discharge downstream and severe flooding around Phnom Penh at a time when the Tonle Sap was already full. Although the peak discharge level was not exceptional (it is typically exceeded about every five years), the significant factor was the total volume of flow over the whole season (MRC, 2005).

It is still unclear how much impact land use changes, particularly deforestation throughout the basin and irrigation in its lower parts, have had on the hydrological regime of the Mekong. The IUCN (1991) stated that "*The area of the Mekong delta that lies in southern Vietnam has been severely affected by deforestation in water catchments in Laos, Thailand, and southern China. As a result, there are dramatic fluctuations in the water level of the Mekong river – with frequent floods and low water levels during the dry season – that create increasing problems for local agriculture*." Koma (1997) wrote that "*Increased sedimentation is the consequence of intensive erosion. The recent floods in Cambodia, especially in 1991, 1994 and 1996, have been linked to deforestation associated with increased erosion, run-off and decreasing lake- and river-bed levels… Data on sedimentation reveal that the sediment load in the rivers is increasing. In 1996 the maximum sediment load in the Tonle Sap river, which flows from the Mekong river into the Tonle Sap lake during the monsoon season, was almost two times higher than in previous years… The irrigation network in Cambodia has also been adversely affected by the siltation problem… The capacity of many irrigation canals, coupled with poor maintenance, has been considerably lowered by embankment erosion and excessive siltation. In many canals the siltation situation has become so serious that farmers have started to grow rice along the canal beds.*" The World Bank (2003) reported that "Cutting of forests around and near the Tonle Sap has caused accelerated soil erosion and increased siltation… Increased siltation in the Tonle Sap is rapidly decreasing the lake's depth… There are various estimates of when the lake will be full of silt, but there is a lack of long-term data to draw any conclusions. However, it is known that siltation is occurring at a rapid rate…"

While the linking of presumed cause to observed effect remains largely anecdotal due to inadequate data, the removal of a large amount of forest cover over the entire Mekong basin, which is known to be occurring, can be reasonably expected to result in changes in the rainfall-runoff relationship. Less catchment storage of water would result in less water flowing into the river during the dry season from December to April; and lower catchment storage capacity would also tend to increase the rate of rainfall runoff during the wet season, resulting in an increase in flood volumes. There are a lot of hydrological data, at least for the main river, but linking rainfall to stream flow is difficult, even on an annual timescale. According to the MRC (2005), no one has yet found any conclusive evidence in the 90 years of historical data for any significant changes in rainfall-runoff relationships for the Mekong basin as a whole.

The activities of the Cambodia National Mekong Committee and the basin-wide Mekong River Commission are largely focussed on the policy of overall water management, flood monitoring and prediction, and safeguarding environmental issues while promoting appropriate development. There are regular conferences and fora on these matters, particularly the regional gatherings organised by the MRC (e.g. MRC, 2003 and MRC, 2006). Few of the contributions to these conferences give much consideration to practical issues such as infrastructure management.

In recent years, concern has grown as to the possible effects of the increasing number of dams and reservoirs on the Mekong tributaries, and those proposed to be constructed on the mainstream. In general they should have the effect of helping to even out the annual discharge. Whether this will have a significant impact on flood levels depends greatly on the management practices adopted, as well as on the flood characteristics. For really high floods such as that in 2000 (see above), when the natural wetlands were filled much earlier than usual, it would take very large reservoir volumes to reduce the flood volume significantly for the critical period. The potential hydrological changes over the river basin remain largely unknown and clearly require considerable additional research, particularly as the natural hydrology of the Mekong is already very complex and annually variable.

3.4 Geomorphology of the Mekong Flood Plains

Much of lower Cambodia is dominated by a series of alluvial plains. Some of these are now above flood level, even in exceptional years, and this study is concerned mostly with the active flood plains of the main Mekong valley (i.e. excluding the well developed lacustrine flood plain surrounding the Tonle Sap lake, which has much in common with the wider riverine flood plains). The two major types of active river plains distinguished in Cambodia are summarised by White et al. (1997) in the following paragraphs.

"***Meander flood plains***. *These occur along the middle stretch of the rivers and are comprised of river channel, natural levees, backslopes, and basin. Water is usually contained in the channel by the natural levees. When too much water is supplied, and the river overflows its levees, the basins are flooded. Sedimentation takes place at various rates depending on the water flow. The coarsest sediments (coarse sand and gravel) are deposited in the channel, fine sand and silt are deposited on the levees while clay is deposited in the basins. In Cambodia, the levees and backslopes are mainly used for housing, vegetable and cash crop farming or, very occasionally for rice production. Backslopes may be considered as the transition zone between the levee and the basin. Soils in the basins show distinct hydromorphic properties, and are used mainly for rice production as water in the basin recedes. Peat [organic soil] may accumulate in the basin areas that do not drain. Meandering rivers migrate laterally, changing the sedimentary pattern as they move. Levees break causing the channel to be cut off and later to be filled with sedimentary material. This creates a system of old and new levees and abandoned meanders. The Mekong-Bassac river system has formed many such patterns. The meander flood plains are observed along much of the Mekong river and parts of the Bassac river as well as along other rivers of the country. This landform meets the expansive flood plains in the southern half of Kandal, Takeo and Prey Veng and the lacustrine flood plains of the Tonle Sap.*

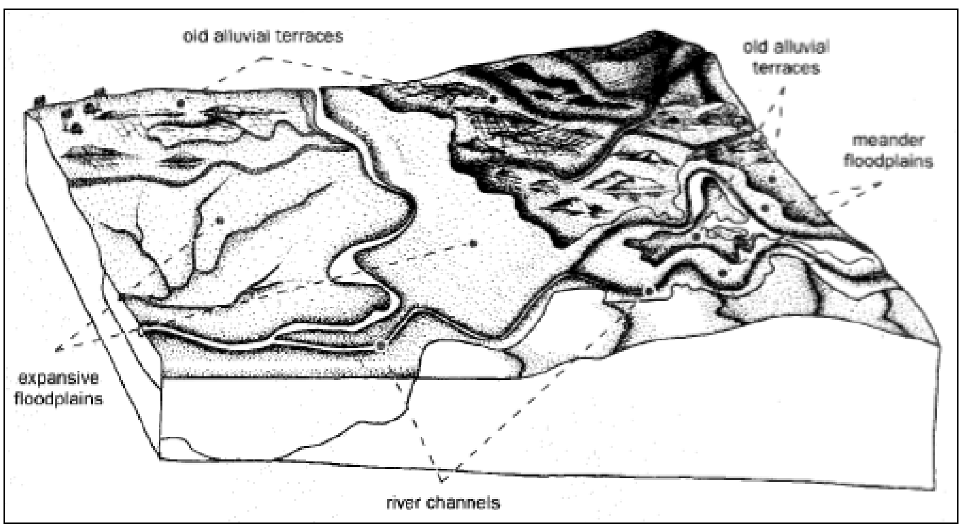
"***Expansive flood plains***. *These are important landforms in Cambodia that are related to, but need to be distinguished from, the meander flood plains. The expansive flood plains occur along the lower stretch of the river. These areas are characterized by a main river channel, a levee of medium or heavy-textured soil, behind which extends a wide, flat extensive basin with few features. The basin may extend up to several kilometers from the river channel in some areas of Takeo and Kandal. The basin is also traversed by shallow secondary channels without levees in which water flows during periods of low water levels. The basins, as well as much of the levees, are covered by more than two metres of water for extended periods each year. These areas predominate in the southern half of Takeo, Kandal, and Prey Veng, around the Mekong-Bassac river system*."

White et al. (1997) also refer to "old alluvial terraces". Their description is given in the paragraph below, and suggests that these terraces are subject to only very occasional river flooding. Working in the mid 1990s, when there was a long period between major floods, they were clearly under the impression that river flooding was very rare on this surface; had they seen the floods of 2000, 2001 and 2002, they might have worded this description differently. The relationship between the alluvial terraces and the active flood plain types, which can be difficult to distinguish in the field, is illustrated in Figure 6.

*"**Old alluvial terraces**. These landforms, which occur in all rice-growing provinces of Cambodia, are former river, lake, or marine flood plains that are now above the level of regular flooding. The soils are derived from alluvial material carried in the waters of the old rivers that once flooded these areas. Now the soils are flooded principally by rainwater only; soil nutrients are not replenished by annual alluvial deposits, and the soils undergo alternate reduction and oxidation with leaching that causes a net loss of nutrients and clay movement down the profile. Occasionally in years of exceptional flooding, some of these areas may be flooded with water from nearby rivers but for only short periods by relatively fast flowing water. Some of these soils may also be located on the fringes of lake or river flood plains. They may be flooded for intermittent periods each year depending on seasonal conditions. The water reaching them contains little silt load and the length of inundation never exceeds three months. Soils on the alluvial terraces vary widely depending on age and erosion level. Older, relatively higher terraces may be dissected, usually forming wide flat valleys, giving the terrace an undulating topography. Very young terraces that only recently ceased to be part of the active, present-day flood plains, are flat and may show transitional soil characteristics between the flood plain and the older terraces."*

Within these landforms, there are three main recognised hydrological sub-divisions: pluvial, where soil water is derived mainly from rainfall; phreatic, where plants are fed by both rainwater and, during the wet season, by temporarily shallow groundwater; and fluxial, where low-lying areas are consistently flooded by groundwater for a significant part of each year (White et al., 1997).

Figure 6. Relationship Between the Main Flood Plain Units.



Source: White et al. (1997).

3.5 *Flood Plain Soils*

Recorded soil classification in Cambodia started in the early twentieth century, but its development was somewhat sporadic until the mid 1990s, when there was a concerted effort by the International Rice Research Institute and the Australian aid programme to assess and describe, and delineate better, the soils of the main rice growing areas (Oberthür and White, 1995). Because of the prevalence of low-lying, seasonally wet land, the cultivation of rice in Cambodia is concentrated on the Mekong flood plain, and around the Tonle Sap lake.

While the majority is relatively productive, deep water rice growing areas were identified that were less productive, in the locations subject to deeper flooding; these are mainly in the swampy locations in the delta, particularly close to the Bassac river, and in a fringe around the Tonle Sap lake (Nesbitt, 1995).

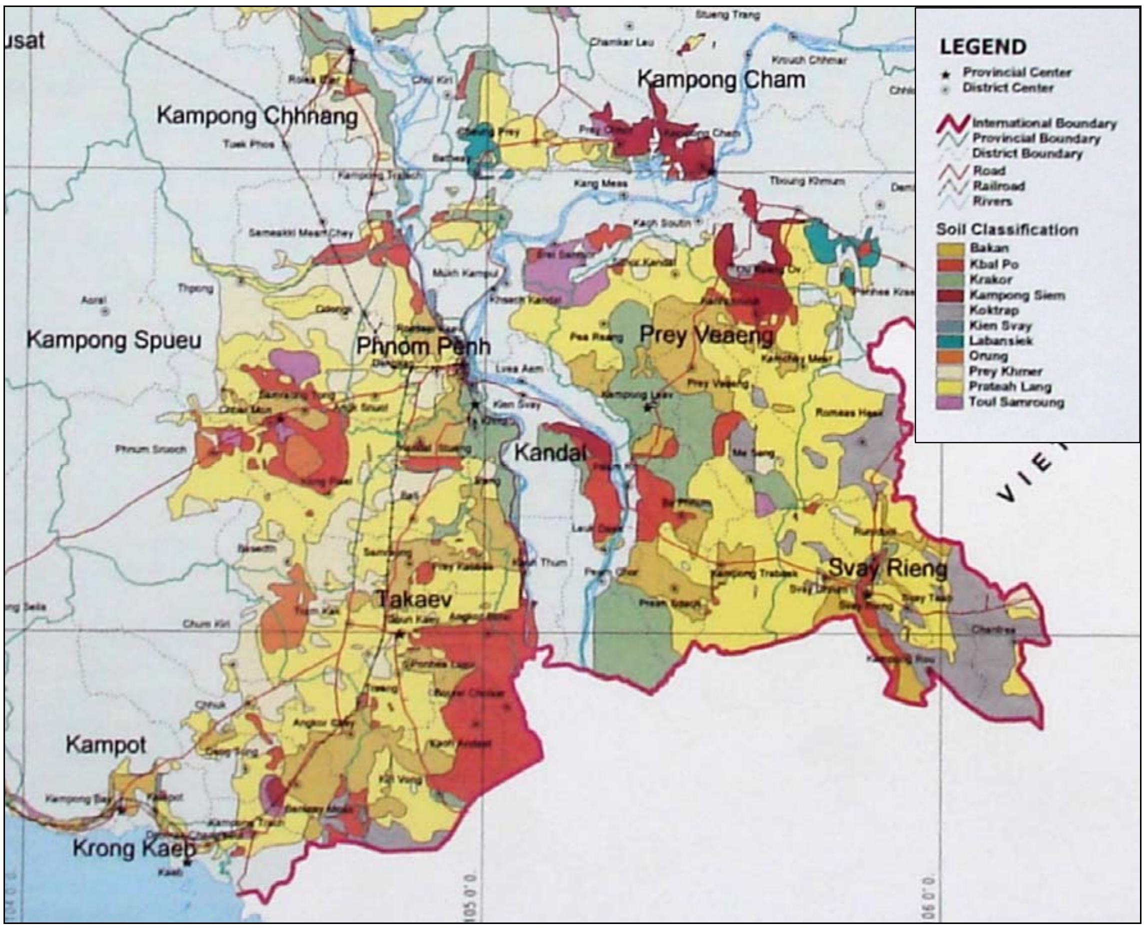
The systematic agronomic assessment of soils first reported by White et al. (1995) was developed into a national system of classifying rice soils (White et al., 1997), leading through the re-surveying of some areas and re-interpretation of soils in others, to a soil map of the main rice growing areas (Cambodia-IRRI-Australia Project, 2000): see Figure 7. Because this incorporates physical characteristics, particularly texture or soil particle size distribution, it also has value for civil engineering; and because it covers most of the lowland areas in the upper Mekong delta, it encompasses the soils that make up the river banks and road embankments that are the subject of this study. The main characteristics of the soils are summarised in Table 3.

Since it was established, the rice soil classification of White et al. (1997) has remained the definitive system for agronomic purposes. It was considered appropriate to use as the basis for a regional comparison by Bell and Seng (2004), and proved to equate well with the findings of surveys and classifications used elsewhere, both in south-east Asia and world-wide.

Bell and Seng (2004) assessed the regional agro-climatic situation as follows, making reference to the rice-growing ecosystems of IRRI. "*In the shallow, drought- and submergence-prone sub-ecosystem, drought and submergence may occur on a particular field within the same growing season or in different seasons. This sub-ecosystem is important in north-east Thailand and Laos but is the most widespread of the sub-ecosystems in Cambodia [see Table 4]… While the sub-ecosystem concept is useful in regional classifications of rice growing areas according to surface hydrology, in practice sub-ecosystems are not clearly separated and it is sometimes difficult to assign even a single farm to a particular sub-ecosystem... Location of on farm drains, and of road embankments and drains under roads can markedly affect where the run-off is directed. Lowland rice is uniquely dependent on surface hydrology and the duration of standing water in relation to crop-growth stages... The surface water depth in paddies changes continuously during crop growth... There is relatively little data with continuous recording of surface hydrology and even less has been systematically assembled to allow better classification of agro-ecosystems*." While this probably refers more to land with greater slopes than are found on the lower Cambodian flood plains, the rules remain true for the micro-environments found in the short but abrupt slopes of river banks and road embankments, and under the unpredictable rainfall and flooding regimes of the lower Mekong valley.

It is clear from site visits to the Cambodian flood plains that, while changes in land use increasingly obscure the subtle but important geomorphological features, and the hydrology is altered both naturally and through human activities, the liability for flooding is still readily detectable. In large part this can be determined by assessment of the soils, which betray the dominant characteristics of the original site that will in most cases still prevail when high flood conditions occur. The type of sediment and hydrological characteristics are clear from the soils, which have been comprehensively classified in the flood plains.

Figure 7. Extract of the Cambodian Soils Map Showing the Main Mekong Flood Plain Area



Source: Cambodia-IRRI-Australia Project (2000).

Table 3. Summary of the Main Flood Plain Soils.

Cambodian soil group	Group concept	Characteristics	Extent[1]
Active flood plain soils			
Group 4: Krakor	Grey to brown, but not dark grey, very dark brown or black, loamy or clayey topsoil over a sandy, loamy or clayey subsoil.	A firm soil, usually with a loamy topsoil and a slightly heavier subsoil. It cultivates well and has good yield potential. A cracking phase is quite common.	≈15%
Group 6: Kbal Po	Dark grey, very dark brown to black, clayey topsoil, which forms large deep cracks over a clayey subsoil.	Always occurs on fluxial lands (i.e. depressed locations dominated by groundwater). Distinctive through its dark topsoil, which can be very thick. Cracks when dry. One phase has a very low pH (similar to acid sulphate soils).	≈15%
Group 7: Kein Svay	Brown, loamy or clayey textured soil (topsoil and subsoil) with a weakly developed profile.	Restricted to the river levees and associated backslopes of the meander flood plains; in landscapes with many abandoned levees, it is often interspersed with Krakor and Kbal Po soils.	<2%
Old alluvial terrace soils[2]			
Group 0: Prey Khmer	Sandy textured profile extending deeper than 50 cm.	A soil dominated by its sandy nature, which often extends more than 2 metres in depth, and excessive drainage. They are usually formed from former beaches and point bars.	10-12%
Group 1: Prateah Lang	Sandy topsoil less than 40 cm thick over a subsoil that has a loamy or clayey texture.	A relatively light surface layer lies above a heavier subsoil, which often forms a firm plough pan. Weathering, leaching and cultivation have led to the transportation of clay down the profile since the alluvium was deposited.	25-30%
Group 3: Orung	Loamy to clayey topsoil less than 40 cm thick over a sandy subsoil that is thicker than 10 cm.	A sharp boundary between a relatively heavy topsoil and a relatively light subsoil, reflecting a change in particle size of the original alluvium.	1-2%
Group 5: Bakan	Loamy or clayey topsoil that does not crack or has only shallow surface cracks occurring over a mottled loamy or clayey subsoil.	A soil found mainly in depressions of the landscape where finer material has collected. The surface sets hard when dry and tillage is difficult since it must be done when the soil is at the right moisture content. However, infiltration is slow, and it is good for irrigation and rice growing.	10-15%
Group 8: Toul Samroung	Clayey or loamy topsoil which forms wide cracks that penetrate deeper than 5 cm into the soil over a clayey or loamy subsoil; the topsoil is grey or brown, but not dark grey or black.	Almost exclusively found on the higher alluvial-colluvial plains, except around a few minor rivers on the old alluvial terraces. Often similar in character to the Bakan Group, but with deeper cracking and a blocky structure.	7-10%
Group 9: Koktrap	Dark grey, very dark brown to black topsoil with a clayey or loamy texture over a light grey or light brown, loamy or clayey subsoil.	Essentially a cultivated rice field soil in lower phreatic but not fluxial positions (i.e. with limited groundwater influence), mainly in the very southern provinces. The dark colour is distinctive.	≈5%

[1] Approximate proportion of the entire rice-growing area.
[2] All of these soils are also found on the higher alluvial-colluvial plains, except the Koktrap Group.

Data source: White et al. (1997).

Table 4. Relative Occurrence (as percentage of total area) of the Main Rainfed Lowland Rice Sub-ecosystems in South and South-East Asia.

Country	Shallow soils (0 to 25 cm) and prone to:				Medium to deep soils (25 to 50 cm)	Total area ('000 ha)
	No water stress	Drought	Drought + submergence	Submergence		
Laos	33	33	33	0	0	277
Cambodia	10	29	57	0	5	747
Thailand	9	52	24	12	3	6,039
Total	20	36	15	16	13	35,907

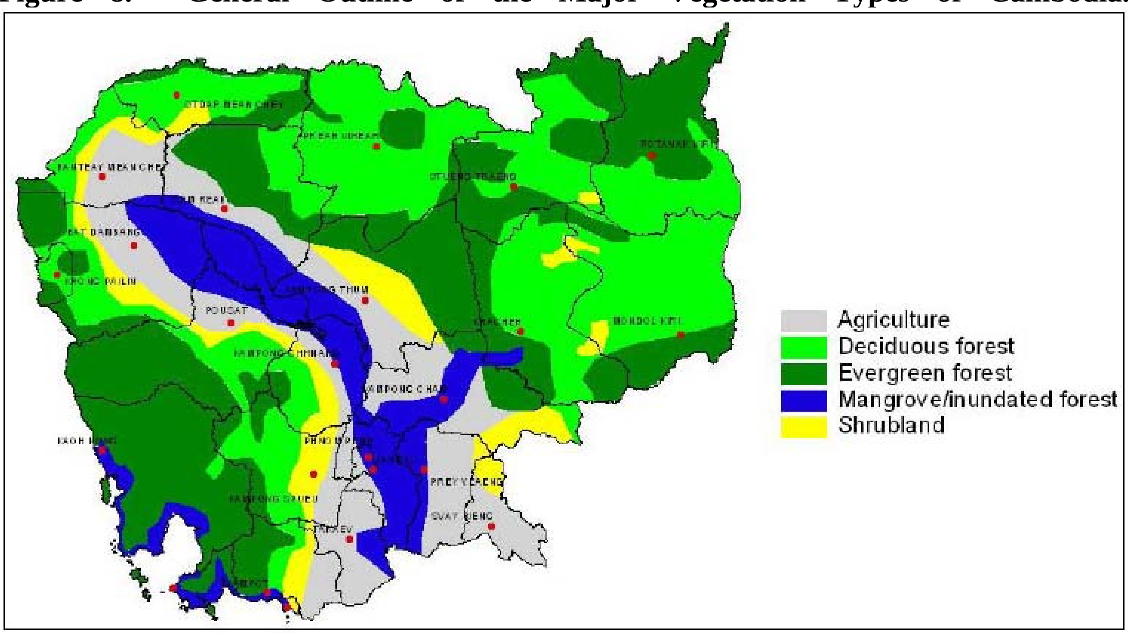
Source: Quoted in Bell and Seng (2004) from original source: Wade, L.J., Fukai, S., Samson, B.K., Ali, A. and Mazid, M.A. 1999. Rainfed lowland rice: physical environment and cultivar requirements. Field Crops Research, 64, 3–12.

3.6 Natural and Colonising Vegetation

There appear to be no published studies of the vegetation specifically found in the flooding zone of disturbed river banks or man-made embankments in lower Cambodia. The CTSP (2004) summarises the situation as follows: "*Generally speaking, botanical work in Cambodia has been very limited. Until recently, our understanding of the country's flora and vegetation reflected the ad hoc activities of a small number of botanists and foresters. Most of these authors have studied a limited number of vegetation types, sites, or ethnobotanical aspects of Khmer culture, and most of these works were produced before the political and economic implosion of Cambodia in the 1970s.*" None of the older studies focussed on the flood fringe areas, and so this review uses oblique references to these ecosystems in a number of papers. Estimates of the total number of species found in Cambodia range from 3,000 to over 8,000 according to the CTSP (2004), and even the magnificent work by Dy Phon (2000) lists only the part of the number with recognised uses in agriculture, building, fishing and medicine.

In an attempt to summarise the distribution of vegetation, the CTSP (2003) produced the map in Figure 8 as part of a broader characterisation of the ecology of the country. This is a useful starting point, as it demonstrates how the central part of the lower Mekong valley in Cambodia is dominated by inundated forest (the mangroves are only on the coast), and shows that rice land agriculture covers most of the rest of the flood plains. However, a more in-depth assessment is needed to understand the variations in vegetation in these flooding areas, and what they might offer in the protection of embankments.

Figure 8. General Outline of the Major Vegetation Types of Cambodia.



Source: Cambodia Tree Seed Project (2003).

The lower Mekong has a unique ecosystem that is usually described as flooded or inundated forest. Estimates as to its size vary depending on survey methods and classifications. The MRC/GTZ system suggested that there were almost 220,000 ha in 1996/97, or 1.2% of the land cover of Cambodia; the FAO/UNDP system estimated 370,000 ha of intact forest and almost 260,000 ha of secondary flood forest in 1992/93 (Forest Administration, 2004).

A number of papers give brief reference to the flood forests. Baltzer et al. (2001) state that the flora of Cambodia, as a whole, are very poorly enumerated, but that a rich diversity of habitat exists in all of the ecological systems. Van Liere and McNeely (2005) describe how the freshwater swamp forest is found only along the edges of the Great Lake and certain banks of the Mekong. "*Dominated by Homalium brevidans and Hydrocarpus anthelmintica, this forest type is considered vital to the continued productivity of the Great Lake. The recent clearing of much of this forest has led to increasing siltation, thus threatening the very existence of the lake (which is less than 1 metre deep during the dry season). During the rainy season, when the lake quadruples in size, the swamp forest serves as the spawning ground for many species of fish*." Ohta et al. (2004) describe the soils of an area of swamp forest in Kampong Thom dominated by *Melaleuca leucadendron*.

The most comprehensive assessment of the "wet" forest types is given by Rundel (2001). "*Swamp forests typically occur in areas permanently inundated with shallow freshwater. Care must be given, however, in separating the seasonal swamp forests that characterise extensive areas of the Tonle Sap basin and low lying flood plains of major Cambodian rivers from the classic swamp forests of south-east Asia with permanent flooding. Conditions of permanent flooding compared to flooding for 6-8 months produce differential selective factors and thus a distinctive floristic assemblage for each of the two forms of swamp forest… The area of seasonal swamp forest and marshland in Cambodia was once quite large but has been significantly reduced in size by human activities*."

The paragraphs below summarise the account given by Rundel (2001). A consideration of the wet habitat forests is relevant in the context of this review since it demonstrates the local prevalence of a very wide range of species that might offer potential for river bank and road embankment protection in the exceptional conditions found on the lower Cambodian flood plains.

The Tonle Sap **wetlands** can be divided into two broad forest associations: a short-tree shrubland covering the majority of the area, and a stunted swamp forest around the lake itself. Similar swamp forests are also present along flood plains of major rivers, although an evergreen gallery forest with similarities to tropical rainforest is also locally present along limited river areas. The strong seasonal cycle of flooding around the flood plain of Tonle Sap has made the great majority of woody species deciduous, losing their leaves when the lake deepens and the plants are submerged. A group of small tree species is most common among the larger plants in these forests: *Barringtonia acutangula, Barringtonia micrantha, Elaeocarpus griffithii, Elaeocarpus madropetalus, Hydrocarpus anthelmintica* and *Mallotus anisopodum.* The main storey trees` are less common, but particularly include: *Crudia crysantha, Cryptocarya oblongifolia, Cynometra* cf. *dongnaiensis, Cynometra* cf. *inaequifolia, Diospyros* cf. *bejaudii, Diospyros sylvatica, Diospyros* sp., *Garcinia* cf. *loureiri, Homalium brevidens, Homalium griffithianum, Lophopetalum fimbriatum, Mitragyna* cf. *diversifolia, Terminalia cambodiana* and *Xanthophyllum* cf. *glaucum*. Much of the Tonle Sap flood plain forest is dominated by low shrubby growth, which appears to be the result of many decades of increasing disturbance, yet the actual composition appears to be related to soil and flooding conditions as much as to human disturbance.

The Tonle Sap **short tree-shrubland** association forms the dominant vegetation cover over approximately 80% of the flood plain in those areas with soil that is not saturated during the dry season. In general, the dominant woody species form a semi-continuous canopy of deciduous species reaching no more than 2 to 4 metres in height, though with individual plants growing higher where it is wettest, and some species with shrubby growth forms in this community are capable of reaching tree size in swamp forest habitats. Among the widespread and dominant woody species are: *Barringtonia acutangula, Bridelia cambodiana, Brownlowia paludosa, Capparis micrantha, Cissus hexangularis* (liana), *Croton mekongensis, Croton krabas, Dalbergia pinnata, Gardenia cambodiana, Gmelina asiatica, Phyllanthus taxodiifolius, Popowia diospyrifolia, Quisqualis indica, Stenocaulon kleinii* (perennial vine), *Terminalia cambodiana* and *Vitex holoadenon.*

The Tonle Sap **swamp forest** is 7 to 15 metres in height and originally dominated the dry-season shoreline of Tonle Sap, covering about 10% of the flood plain, and forms the second forest association. A similar community once occurred as a gallery forest along the seasonal flood plains of many major rivers in southern Cambodia, following channels or other waterways and occasionally occurring in isolated depressions which hold surface water through the dry season. This community around Tonle Sap is generally flooded by 4 to 6 metres of water for up to eight months each year, at which time the majority of species lose their leaves. Rather than forming a continuous forest, this community is broken into a mosaic of stands of large trees and open areas with floating aquatic herbs typical of the lake itself (see below). Two tree species, *Barringtonia acutangula* and *Diospyros cambodiana* are the primary dominates of this community, and generally occur with woody lianas. Other common tree species are: *Crataeva nurvala, Crataeva roxburghii* and *Coccoceras anispodum*. Common shrub species are: *Brownlowia paludosa, Cudrania cambodiana, Dalbergia entadoides, Gmelina asiatica, Hymenocardia wallichii, Ficus heterophylla* and *Vitex holoadenon*

At Tonle Sap, **aquatic flora** grow along the shallow shoreline, and dense mats of herbaceous vegetation 1 to 3 metres tall may emerge from shallow water but are more typically floating. Large clonal mats of these species float freely over the lake, thereby colonising large openings and gaps within the swamp forest. Notable among these are extensive rafts of the floating legume *Sesbania javanica* which can produce huge mats of thickened rhizome, bearing aerial stems that reach to 2 metres above the lake surface. Given the heavy human impact around Tonle Sap for centuries, it seems likely that the structure and diversity of the aquatic flora is now greatly altered from its original composition. The dominant floating herbs of these communities include: *Brachiaria mutica* (an introduced species from Africa), *Eichhornia crassipes* (water hyacinth, an introduced species and considered a highly invasive threat to the overall ecosystem) and *Polygonum barbatum.* There are also reports of distinctive communities occurring in isolated ponds in the upper reaches of the Tonle Sap flood plain; in some of these, grasses and sedges are important. Two grass species that have widely invaded the wetland margins of Tonle Sap are *Brachiaria mutica* and *Echinochloa stagnina*: these were introduced at some time in the past from Africa as high quality plants for grazing, and have become dominant species in many areas of the lake.

Hydromorphic savannas often occur in areas of poor drainage around the margin of many forest communities and along rivers, and are dominated by grasses. This community is called a *veal* in Khmer, and it has soils that are commonly saturated for at least six months of the year. Characteristic plants include species of the grass *Saccharum* and a diverse group of the Cyperaceae (sedge) family. An unusual habitat of freshwater marshland occurs around Prasat Tuyo (Bassac marshes) south-east of Phnom Penh between the Bassac and Mekong rivers. This marshland is inundated by up to 3 metres of water from July to November, but forms a wetland surrounding a narrow body of open water during the dry season. The vegetation of this area consists of scattered individuals of *Barringtonia acutangula* in a wetland swamp matrix. The community structure of floating herbs appears to be very similar to those found around Tonle Sap, with a zonation of species, and the presence of alien plants.

Riverine or evergreen gallery forests occur in a scattered distribution along the channel of the Mekong and other major rivers. These flooded forests, often forming open and discontinuous belts along river banks, are best known from scattered areas along the Mekong river in Stung Treng and Kratie Provinces. Riverine gallery forests may vary greatly in structure and diversity, and some are characterised by species tolerant of inundation with very strong river flow for part of the year, and drought conditions in unconsolidated sandy soils at other times.

McDonald et al. (1997) point out that although Tonle Sap is a freshwater lake, some elements of its flood plain flora show indications of relationships with **coastal mangrove habitats**. The endemic *Terminalia cambodiana*, for example, is restricted in distribution to Tonle Sap and the southern coastal zone of Cambodia and adjacent Thailand. Species relationships in the genera *Diospyros* and *Barringtonia* also show this pattern. They also reported the collection of what appeared to be a new species or variety of the mangrove *Lumnitzera racemosa* in the upper flood plain of Tonle Sap.

4 Review of Erosion Control and Bio-engineering Relevant to Earth Slopes in Cambodia

This section outlines the principles of bio-engineering in relation to countering the perceived erosion problems in the Lower Mekong. Previous uses of bio-engineering in Cambodia are briefly reviewed and the existing vegetation options for bio-engineering application are summarised.

4.1 Bio-engineering in General

Bio-engineering is commonly defined as the use of living vegetation, either alone or in conjunction with civil engineering structures and non-living plant material, to reduce shallow-seated instability and erosion on slopes. It can be used on either natural or man-made slopes (sometimes referred to as "ground bio-engineering"), and on stream banks (where it might be called "water bio-engineering"). The options for this use of vegetation in engineering are numerous and have been covered extensively in the literature. Techniques are well established, with particular practical experience coming from the Alpine countries, particularly Austria (Schiechtl, 1980), and the United States (Gray and Lieser, 1982), which have formed the basis of recent thinking and practice. The current most comprehensive examples of text books are Coppin and Richards (1990), Gray and Sotir (1996), Morgan and Rickson (1995), and Schiechtl and Stern (1996). Conferences regularly either focus on bio-engineering (e.g. International Erosion Control Association, 1999), or contain a significant number of articles on the subject (e.g. HMG Nepal and PIARC, 2003). Key parts of the prolific literature on vetiver grass are reviewed in a later section.

Country- and terrain-specific examples of the detailed adaptation of bio-engineering works for particular application in the road sector may be found in many instances, such as the Caribbean (Clark and Hellin, 1996), Nepal (Howell, 1999) and Hong Kong (Geotechnical Engineering Office, 2000), and more generally for roads in any geologically recent mountain belts (TRL, 1999).

What this mass of literature reveals is that a standard series of techniques is now fairly well standardised around the world. These are heavily oriented towards the stabilisation of steep mountain slopes, and the rehabilitation of landslides. In many climatically cool areas, they rely exclusively on vegetative structures employing hardwood cuttings, such as brush layers and fascines. In tropical climates there is greater use of grasses, though this has sometimes led to reviewers being apparently under the false impression that vetiver is the only available large grass species in the world. Terminology remains confused, and this situation is compounded both by minor differences between the English, German and French literature, and the ways in which the names of the methods are translated, and by a certain amount of variation in English terms between Europe, Asia and North America. While there is no world-wide institution that co-ordinates the approach, the International Erosion Control Association, essentially an American trade organisation, is the most dominant body.

The use of bio-engineering works in the protection and stabilisation of embankments is less clear than its use on steep mountain slopes, perhaps because it is less spectacular and there often appears to be little of note to record in text books and conference submissions. To a large extent this appears to be considered to be covered by the older or more traditional soil conservation manuals (e.g. Longland, 1983; Fifield, 1996), while text book authors and conference participants have focussed on the more complex problems of steeper terrain. This is valid in that much embankment protection is relatively straightforward, except in large flood plain and coastal situations.

4.2 Bio-engineering Experience in South-east Asia

Although research theses commonly refer to the evidence of bio-engineering used in ancient China, written references covering the topic in south-east Asia are available only for the last few decades. An example of how bio-engineering emerged in the region is provided from the Philippines by Agpaoa et al. (1976). This comprehensive manual was written for use in the forest sector, and since its compilation received significant German support. It benefited from the inclusion of traditional Alpine "biological engineering", which covers most of the techniques now used routinely in many countries as part of bio-engineering works on steep slopes. This approach has proved valuable in Asia, since it has helped to bridge the divide between vegetative slope protection provided by the agriculture and forest sectors, and the requirements of the infrastructure engineering sectors. This transfer of technology is also considered important by Barker (1999), who provided an outline of the various ways in which bio-engineering was introduced to many parts of Asia between the 1970s and late 1990s. While at one end of the spectrum there was a strong focus on labour-based methods in rural areas where labour was cheap (e.g. Howell, 1999, for Nepal), at the other end there has been reliance on higher-technological approaches for urban areas with steep slopes but high economic values on the protection of infrastructure (e.g. Geotechnical Engineering Office, 2000, for Hong Kong).

An extraordinarily wide range of bio-engineering applications was described by IECA (1999) in the substantial proceedings of a major regional conference on the subject. Many of the key papers were republished in edited form by Barker et al. (2004), and for Asia these remain the biggest documentary records of activity in this technical field. The general coverage is summarised in Table 5.

Table 5. Summary of the Main Bio-engineering Applications in Asia, as given in IECA (1999).

Main discipline field	Summary of sub-topics
Agriculture	• Hedgerows and other inter-crop vegetative erosion control measures. • Soil management practices, indigenous approaches and perennial vegetation in cropping systems.
Forestry	• Agro-forestry and non-timber forest products in improving fertility and reducing erosion. • Re-afforestation as a means of controlling erosion.
Watershed management	• Vegetative soil conservation in particular environments. • Bio-engineering measures for embankments, bunds and dams.
Mining	• Revegetation and stabilisation of mine tailings.
Waterways	• Methods of streambank stabilisation using bio-engineering and other measures.
Infrastructure, particularly in the transport sector	• Bio-engineering methods as applied in particular environments in a large number of countries. • "Appropriate" methods of landslide stabilisation, mainly focussed on bio-engineering. • Modelling and academic assessments of slope instability.

It is clear that there is a great deal of experience in the region, though care has to be taken in two main ways. One is the tendency for many writers, particularly in the Indian sub-continent, to write broad review papers that describe works undertaken in specific areas but described in general terms as if they are widespread and unequivocally successful, with very limited critical analysis of the benefits and shortcomings they provide. The other is the tendency of mainly young researchers to suggest that methods devised for very specific conditions of soil, landform and climate will be widely applicable elsewhere. Nevertheless, there is enough information available in publications of this nature to demonstrate that there is a large amount of active experimentation from which to draw significant lessons as to the validity of using bio-engineering measures for protective works in a number of "routine" and "extreme" environments.

4.3 Bio-engineering along Waterway Margins

While many of the standard text books refer in general to the use of bio-engineering measures for the control of erosion on streambanks, the only published book specially covering this topic is that by Schiechtl and Stern (1997 in English translation). This Austrian-based document describes the standard practices of bio-engineering as recognised internationally, but gives emphasis to the design modifications required to ensure that they are fully effective in stabilising river banks rather than simple slopes. It points out the need to consider the effects of vegetation on the flow of flood water, not only in reducing flow velocity close to the banks, but also in causing changes in the turbulence of flow. A method of calculating the effects of vegetation growth on channel discharge is given, and while this might be useful for vegetated irrigation canal banks in Cambodia, it does not apply to the scale of the big rivers of the Mekong system. This is essentially a book written for European and north American environments, and so assumes that rivers will be relatively small, have a limited variation between low and high water levels, and have a fairly steep bed gradient. It emphasises the important role played by the various species of willows (*Salix*) found in Europe, and most of the robust and more flood-resistant techniques seem to depend on these exceptional trees. Nevertheless, the principles are generally applicable in all waterway margins. Of particular importance is the implication that, for river edges subject to strong flow or deep flooding characteristics, bio-engineering systems based on the use of robust trees are the main option, strengthened where necessary with additional inert structures (such as timber cribwork or elements of gabions).

Schiechtl and Stern (1997) describe a range of waterway bio-engineering techniques, in three main categories as follows; the grouping is theirs and is somewhat idiosyncratic. They point out that the main advantage of the last group is that they are immediately effective, but with the drawback of being more expensive.

- Bank **protection** techniques based predominantly on vegetation: grass seeding, to create a vigorous cover of herbaceous vegetation; turfs of grass sward laid on a slope; direct seeding of shrubs and trees; vegetated surfaces incorporating erosion control netting of natural or synthetic materials; seed mats of fibrous materials impregnated with plant seeds; precast concrete cellular blocks filled with topsoil and planted; and live brush mats, where woody cuttings are laid over the surface as a cover.

- Bank **stabilisation** techniques based predominantly on vegetation: live cuttings, planted in the slope; wattle fences, made of horizontal stems woven between live vertical stakes; and layer constructions of woody cuttings (brush layers) or whole rooted plants (hedge layers) laid in trenches.

- **Combined techniques** using live and inert techniques: gully control with branches laid across the slope and anchored with stout poles; palisades of cuttings inserted in lines across the slope or forming live check dams in gullies; brush sills, where live cuttings are laid in trenches across gully beds; fascine sills, where bundles of cuttings are laid in the trench on top of the brush layer; wattle fence sills across gullies; vegetated gabion barriers; barriers made on a variation of the last few techniques, using a combination of brush work or fascines strengthened by geotextiles, wood or stonework; crib walls constructed with both live cuttings and strong timber sections; dikes or groynes using brush work, fascines or wattling, perhaps with inert elements included; surface repair grids made of brush work, poles, stones or other combinations; reed planting among stone pitching; reed rolls, of wire netting filled with stone, gravel and clumps of reeds; stone revetments reinforced with live cuttings; rip-rap similarly reinforced; fascines (tubular bundles), of either rock in a wire netting roll or live woody cuttings; and a number of other variations on these themes.

Not all of these techniques are suitable for use in other environments, and it is clear that a completely different range of species must be found to replace the plants from the lower Alpine slopes that form the basic repertoire of Schiechtl and Stern's work. Yet their widespread use of vegetation in combination with stone, gabions, geotextiles and timber demonstrates the versatile nature and numerous applications of true bio-engineering.

Among the more general text books, Morgan and Rickson (1995) include shoreline protection in their chapter on water erosion control. As with much European and north American literature, this assumes that the need is for protection against waves on the edges of permanent lakes and reservoirs. This assessment starts with a largely academic approach to wave energy and height, but also examines the different zones of vegetation at different levels of inundation along shorelines. This is of relevance to embankments on Cambodian flood plains, because it takes account of natural micro-site variations along the edge of flooded areas, and demonstrates the importance of designs adapted to local conditions. The general impression is that, in the most exposed areas, inert materials are often required to strengthen the vegetation work, in applications of bio-engineering works in the traditional Alpine style of Schiechtl and Stern. An example quoted from the sea coast of the Netherlands shows different approaches used where the fetch (uninterrupted wave generation distance) is greater or less than 2000 metres, though in other areas the effects of the underwater topography on waves is also reported as having a bearing on the choice of treatment.

Amid the proceedings of the numerous soil erosion control conferences over the last few decades, there are always papers describing approaches to the stabilisation of river banks and lake shorelines. In general these are summarised by the text books described above, particularly the more numerous north American contributions. Two papers worth mentioning here, however, refer to the use of geotextiles, particularly in Asia. Yee and Lee (1999) discuss the advantages of factory-produced synthetic geotextile fabrics in enhancing the revegetation of earth slopes on river banks and seashore dikes. While they do not provide long term protection in themselves, these materials certainly appear to be able to strengthen vegetated surfaces considerably in exposed locations. Loke (1999) examined the effectiveness and longevity of synthetic geotextile filters as a critical part of engineering design in the protection of river and coastal embankments. The importance of careful design was stressed, and evidence presented that demonstrated the long term serviceability of appropriate geotextiles.

4.4 Use of Bio-engineering and other Erosion Protection in Cambodia

There is a certain amount of use of vegetation in Cambodia that might be described as "indigenous bio-engineering". This includes traditions such as the use of bamboo piling and bags of earth or sand to reduce bank erosion, and the planting of trees or shrubs on river banks for the same purpose. There are also examples of the use of cut branches, banana leaves and other vegetative material to strengthen the foundations of tracks in swampy areas.

The use of bio-engineering has been limited in the Cambodian road sector, and no records of it were available from the MPWT and MRD. However, a record of the situation was made in 2003 by a consultant's report (SWK, 2002), which summarises the situation in the following three paragraphs.

"*The scope to use plants for roadside slope stabilisation was reviewed by a bio-engineering consultant in 1996 and a report was produced that gave recommendations for immediate and longer-term measures*[1]*. The focus of this report was to protect 500 km of the road network in one season and recommended Australian grown grass seed mixes as the only option. The use of seeding and mulching was recommended in conjunction with ongoing road improvement projects, while trials for local species were set up for future reference. Recommendations included research and training measures to develop knowledge and capability in the sector. The recommendations of the report were not followed, in part because of concerns over the widespread introduction of alien grasses in such a short period.*

"More recently a number of road projects in Cambodia have used seeding/mulching and turfing techniques for grassing road embankments, with varying success. Specifications for grassing of slopes appear in the Cambodian Road and Bridge Construction Standards of the MPWT. This Specification was prepared under Technical Assistance of AusAID and is strongly biased towards Australian practice. Little emphasis appears to have been given to the use of trees and shrubs in roadside vegetation.

"Grassing of slopes is done on a number of current road projects, both on national roads and on tertiary (rural) roads. Planting work being carried out under the Tertiary Roads Improvement Project in Kampong Cham and Kampong Chhnang Provinces were reviewed during the site visits in July 2002 for the World Bank FERP. British American Tobacco sponsored a successful programme of roadside tree planting on the RN 6 embankment north of the junction with RN61. The most successful method of grassing appears to be the use of small sods of grass collected from surrounding fields. It has been reported that the International Labour Office (ILO), working on rural roads primarily in the Northwest of the country, has used Vetiver grass in conjunction with road improvement work but recent enquiries have not been able to confirm this. Vetiver is native to Indochina and can perform very well for slope protection." (SWK, 2002).

The dismissive comments given above with respect to the Construction Specification for grassing (MPWT, 2003a) are entirely appropriate. The practices described are confused, contradictory and largely not very applicable to the Cambodian road environment. For example, it is specified that all grasses must be deep rooted, though emphasis is given of the use of "sodding" (turfing), which of course cannot be done with deep-rooted species. "Strip sodding" is described using turfs as narrow as 80 mm, which on an embankment slope is

[1] Wildin, J. 1996. Report on using Planted Vegetative Cover to Improve the Stability of Constructed Verges of National Roads in the Kingdom of Cambodia. SMEC, Australia. This document is no longer available in MPWT.

nowhere near wide enough to make any difference to the effects of runoff water. The MPWT's road design standard (MPWT, 2003b) makes no mention of surface protection. The newer interim standards for rural roads (MRD, 2006) specify that embankment slopes should be turfed to prevent erosion, but give no further details of the extent or characteristics this must follow.

The same report by SWK (2002), in assessing how to resolve various incidences of severe embankment erosion caused during the high floods of 2000, 2001 and 2002, in fact recommends the widespread use of both civil and bio-engineering techniques. While these recommendations are generally sound, some of the bio-engineering measures suggested have possible flaws. Table 6 summarises the suggestions made and the potential advantages and drawbacks.

Not mentioned by SWK (2002) is the use of mortared masonry by MPWT on a number of sites to protect embankment slopes from wave damage. The critical section of slope is covered in stones of 300 to 600 mm dimension, about one stone thick, and mortared together with a standard sand-cement concrete mix. A good example of this is to be found at km 19 on RN 1, and it is also used by the MWRM on critical sections of canal bank. It is said to be relatively low in cost, which is probably true. While it should provide good surface protection, it has two distinct disadvantages. The first is that there is no through-drainage to release water that accumulates in the earth embankment behind the facing, and pore water pressure can build up to a critical level and cause geotechnical failure of the slope and its masonry facing.. The second drawback is that it is inflexible and therefore relies on very good compaction of the earth embankment underneath; this is often not achieved, because of the problems of inappropriate materials, and achieving the right moisture content, rolling regime and quality assurance during construction.

Table 6. Commentary on a Summary of the SWK (2002) Recommendations.

Suggested technique	Description	Comments
Purely civil engineering for protection against stream flow		
Rip-rap	A layer of loose stone placed on a geotextile filter membrane, from well above the maximum flood level to a point below flood level; and if there is a danger of scour, beyond the toe of the embankment to a point further away than the expected depth of scour.	As designed, this is a sound technique. The SWK report describes shortcomings, particularly with its behaviour in the event of scour..,. It is a relatively expensive option, but useful in emergencies.
Special rip-rap with bio-engineering	Ungrouted rock laid over a geotextile filter from the base of the slope to about 0.5 m above highest flood level, with grass planting above. Special rip-rap is a double layer of 500 mm diameter rock to form a 1000 mm layer.	The SWK report presents this as an option, but states that gabion mattress with bio-engineering is better, and that this should only be used for water velocities of 5.5 m/s at bridge guide banks.
Gabion mattress	A thin layer of gabion (perhaps 250 to 300 mm thick) is placed as for rip-rap.	Stronger and more robust than rip-rap, and uses less stone, but also relatively expensive.
Gabion wall	A heavy structure of gabion (3 metres thick and 5 metres high in the SWK report's illustration) is built into the bank, with a gabion mattress to prevent scour underneath.	A very strong solution appropriate to substantial failures in the banks of the major rivers.
Bagwork	Bags filled with soil or a cement-sand mix, laid in overlapping layers to protect slopes and abutments.	Recommended in the SWK report only as an emergency repair: this is an appropriate recommendation.

Mainly bio-engineering for runoff and wave erosion prevention		
Topsoiling prior to planting	A layer of the best available, most organic and nutrient-rich soil is placed on the slope surface as a finishing to encourage plant growth.	In the construction of new embankments, it is generally best practice to strip topsoil (in the Mekong flood plain this equates to the plough layer) and use it as the final surface on the embankment. In other sites it is not necessary to place topsoil before planting, as the nutritional advantages are not enough to compensate for the physical disadvantages of an uncompacted surface layer. The choice of species for vegetation cover should also take this into account by using pioneer plants that do not need topsoil.
Grass planting	All bare slopes on embankments are planted with local grasses to prevent erosion from surface water runoff.	This is proposed as a means to prevent erosion. It is highly appropriate and should be standard practice on all roads. However, the SWK report appears to refer only to creeping sward grasses like *Cynodon dactylon* (smau chénhchiën or Bermuda grass), which is not very resilient. There are stronger, larger stature grasses abundantly available (with properties similar to vetiver).
Gabion mattress with bio-engineering	A thin layer of gabion (150 to 250 mm thick) laid over a geotextile filter from the base of the slope to about 0.5 m above highest flood level, with grass planting on the slope above.	This is a particularly thin gabion mattress, clearly designed to minimise the amount of stone used, while maximising the strength and robustness offered by the wire mesh.
Buried gabion mattress with bio-engineering above	As for the technique above, except that the entire mattress is buried under a layer (≈ 100 mm?) of topsoil and grass planted throughout; shrubs or trees may also be planted along the toe.	This is suggested mainly to prevent theft of gabion wire. Technically it is dubious: the gabion mattress would interrupt the capillary column in the soil, so that plants rooted in the topsoil would suffer severe moisture stress; also, the thin topsoil layer would be very susceptible to erosion.
Bio-engineering using local shrubs	Here the zone of physical protection in the techniques above is replaced by local shrub and small tree species planted as hardwood cuttings. In addition, a few lines on the ground in front of the slope are recommended.	This technique is sound, but world-wide bio-engineering experience has shown that the configuration of planting is very important. Sites where this recommendation was followed (particularly on RN 11) did not have dense enough planting: at least 5 times more planting material was needed, or alternatively different configurations with lines of shrubs interspersed with lines of large grasses.
Vetiver grass planting	Hedges of vetiver grass are planted in contours along the embankment slope, at 0.5 m vertical interval, with smaller grass in between; again, the same wave-prone zone is to be covered.	The SWK report suggests this to be the best bio-engineering solution and much cheaper than hard engineering works. The recommendation seems to have been based entirely on the Vetiver Network's promotional information, as there were no trials of this technique in Cambodia.
Geotextiles with bio-engineering	Surface reinforcement is provided in the same wave-prone zone by means of a three-dimensional synthetic geotextile (e.g. Enkamat) or an open weave organic alternative like reed matting, covered in soil and planted with grass.	This is mentioned as an option but not specifically recommended by the SWK report. There are many proprietary products that have been proved effective in lining channels and preventing erosion, mainly in north America.

Although it does not practice erosion control or bio-engineering, the Institut de Technologie du Cambodge has coverage of both these topics in the environmental component of its courses on rural engineering (ITC 2007a and 2007b). The course material provides a sound technical background to the mechanisms of erosion and the conditions under which it is to be found. It also examines in considerable detail the various options for the control of erosion, and distinguishes between physical and biological measures, as well as emphasising how well the two work together: this is bio-engineering. The methodology that is introduced is more specific to agricultural land in rolling and sloping terrain, and makes very little mention of flood plains or embankments. Many of the examples are drawn from francophone West Africa, but in general they apply to the upland areas of Cambodia. The most important consideration is that the graduates of ITC should all have a sound understanding of the processes of erosion, and means of their control.

4.5 Common Existing Roadside Vegetation

On river banks, the two most commonly observed smaller plant species are the large semi-aquatic grass *Phragmites vallatoria* (âmbaôhs or treng) and the floating weed *Eichhornia crassipes* (kâmphlaôk or water hyacinth). Both SWK (2002) and Dung et al. (2003) dismiss *Phragmites* as being apparently too weak and shallow-rooted to contribute significantly to erosion control, yet they do not account for its wide prevalence and high rates of survival in areas prone to deep flooding and fast flow rates. Water hyacinth can generally be discounted as "unfavourable" because of its prolific growth and tendency to block waterways, but again both SWK (2002) and Dung et al. (2003) also dismiss it without consideration of the benefits it might bring in protecting banks, though the first of these documents does mention its potential in reducing wave impacts. In addition to these, there is a range of tree species, some of which still need to be identified. On the bank of the Bassac beside RN 21, small but relatively old *Pithecellobium dulce* (âmpil tük) trees are common in locations subject to bank erosion: these are mainly about 7 or 8 metres in height, and often appear to have been pollarded. In addition, several other species of trees appeared to have been planted by householders seeking to protect their property from the river, and are surviving inundation well.

Plants colonising other road embankments (i.e. those prone to flooding only in very exceptional years) may offer potential for slope revegetation away from the rivers. These include: the prolific *Jatropha curcas* (lhông khwâng), a broad-leaved shrub that is common throughout south-east Asia, which is easy to propagate from woody cuttings and so distasteful to animals that it is often used for hedging; *Combretun quadrangulare* (sângkaè), a small tree also common on embankments; *Pithecellobium dulce* (âmpil tük), found here as well as on river banks, and which grows widely in Asia and has been used for revegetation works in the drier parts of India; and the thorny *Mimosa pigra* (prèah khlâ:b yiëk), though this is not favoured by local people because it is said to be damaging to fish stocks. Table 7 lists the main plants observed during field visits.

The assessment of flood damage by SWK (2002), made in the immediate aftermath of the high floods of 2000, 2001 and 2002, records a number of clear cases of embankment protection by woody shrubs, though not by the low creeping sward grasses and annual herbs: "*The most encouraging observation that can be made in terms of embankment erosion is the positive effect that isolated pockets of vegetation have had in preventing wave damage. [The photograph] shows how a slope covered with predominantly young [sângkaè] has protected the road shoulder… Given the success of native shrubs in controlling wave damage along sections of RN 11 where they are present it would seem clear that bio-engineering is the appropriate solution*." The report also refers to hedges made using large cuttings of lhông khwâng where the road adjoins private land, and also suggests that this species should work well with sângkaè.

There is a serious grazing problem in many areas, however. Large numbers of cattle are allowed to roam on the embankments, and according to SWK (2002), goats are also a particular nuisance in some areas. Despite this, the successful establishment of many shrub-based plantations along RN 11 by the Emergency Flood Rehabilitation Project demonstrates that resistant species are available, and can be used to good effect.

Table 7. Plants commonly found colonising disturbed roadside land.

Khmer name	Botanical name	Comments
Grasses		
Âmbaôhs, treng	*Phragmites vallatoria*	Large-leaved tall grass found very commonly on river edges.
Smau chénhchiën	*Cynodon dactylon*	Small, creeping sward grass, very common on grazed land; withstands heavy grazing and long inundation, but rooting is shallow.
Shrubs and small trees		
Âmpil tük	*Pithecellobium dulce*	Small tree, 6 to 10 m tall, small leaves and thorny branches, common on embankments; edible fruit.
Doëm pré:ng	*Eucalyptus* sp.	Two main species are most common: *E. tereticornis* and *E. camaldulensis*. Spindly tree with white bark, up to 15 metres tall.
Lhông khwâ:ng	*Jatropha curcas*	Shrub 2 to 5 metres high; grows easily from cuttings; widely used for hedging; shallow-rooted but easy to propagate.
Paboiy	Not identified	Woody shrub, 2 to 4 metres high, that colonises embankments.
Prèah khlâ:b yiëk	*Mimosa pigra*	Thin, thorny shrub that grows widely on the edges of wet areas and the lower fringes of embankments; not liked by farmers, who say that it damages young fish during floods and causes infections.
Rèak sâ	*Calotropis gigantea*	Bushy shrub, large pale green leaves and milky sap, that colonises embankments; deep tap roots; difficult to germinate from seeds in nurseries.
Rèang	*Barringtonia asiatica*	Tree that colonises embankments; very common.
Rumché:k srôk	*Pandanus humilis*	Shrub with long thorny, fleshy leaves, 2 to 3 metres high, producing many suckers; grows on river banks, used for hedges.
Sângkaè	*Combretun quadrangulare*	Small tree common on embankments; given as *C. laciferum* (sankae) in SWK (2002).
Smach téhs	*Acacia auriculiformis*	Fast-growing Australian tree often planted along roadsides.
Tros	Not identified	Woody shrub, 2 to 4 metres high, that colonises and grows strongly on embankments.
Non-grass herbs and other small plants		
Dânghët chhniëng	*Cassia tora*	Annual leguminous herb or sub-shrub with purple flowers and small seed pods.
Kâmphlaôk	*Eichhornia crassipes*	Water hyacinth, an aggressive, invasive weed in slow-moving waterways.
Poss. Pang' kacha:t	*Eupatorium adenophorum*	Weedy annual herb with weak, shallow roots.
Prèah khlâ:b	*Mimosa pudica*	Creeping herb with sensitive leaves; colonises many bare areas.

Main source for identification and Khmer spellings: Dy Phon (2000).

4.6 Erosion Protection Works Involving Vetiver Grass

In the Cambodian context, vetiver grass generally refers to a particular species, *Vetiveria zizanioides*, which grows naturally across many of the humid parts of lowland south-east and south Asia. It has been promoted as something of a "wonder" plant by the World Bank, and particularly by the Vetiver Network (see www.vetiver.org), a loose forum of donors, NGOs and academic institutions. Various arrangements of producing and using this plant are given the names of "Vetiver Grass Technology" and "The Vetiver System" in different contexts. The main uses to which it can be put are described by National Research Council (1993).

Dung et al. (2003) describe a series of trials using vetiver grass for the protection of embankments in the Vietnamese part of the Mekong delta. These were implemented under the supervision of Can Tho University, and while some trials were in Can Tho Province in the central delta, others were in An Giang Province, including Tan Chau District, very close to the border with Cambodia. The main objective of the trials was to stabilise the banks of irrigation canals, partly against erosion during floods, and partly because of damage from the wash of motor boats. The results seem to have been mixed, with some of the plots damaged by grazing and others requiring the seedlings to be watered for some months immediately after planting. However, once the difficulties had been overcome, a number of useful lessons appear to have been learnt. Once established, vetiver grass performed well in protecting against erosion, and it survived deep inundation. The difficult part appears to be the timing of plantation, as the canal sides fluctuate between drought and flood, with water level changes of from 2 to 6 metres. Planting at the end of the flood season, as the water level receded, seems to have been most successful in the central delta.

The success of the work described by Dung et al. (2003) in An Giang, Vietnam, is also reported briefly by Truong et al. (2007). *"Depending on the locations and flood depth, vetiver has been used successfully alone, and together with other vegetation to stabilize these areas. As a result, vetiver now lines rigorous sea and river dike systems as well as riverbanks and canals in the Mekong Delta. Nearly two million polybags of vetiver, a total of 61 lineal km, were installed to protect the dikes between 2002 and 2005. Between 2006 and 2010, the 11 districts of An Giang province are expected to plant 2,025 km of vetiver hedges on 3,100 ha of dike surface.*"

Truong et al. (2007) give the following recommendations for the configuration of vetiver planting on streambanks.

- Maximum bank slope should not exceed 1(v):1.5(h). The recommended bank slope is 1:2.5.
- Vetiver lines should be planted in two directions:
    - For bank stabilisation, the grass should be planted in rows parallel to the flow direction, on approximate contour lines 0.8 to 1.0 m apart, measured down the slope; and
    - To reduce flow velocity against the bank edge, vetiver should be planted in rows normal (i.e. at right angles) to the flow at a spacing between rows of 2.0m for erodible soil and 4.0m for stable soil (the soil types are not defined).
- The highest row should be planted at the crest of the bank and the lowest row at the low water mark of the bank, with the planting timed to coincide with the period of minimum river level.

In the specific context of streambank erosion protection, Truong et al. (2007) claim that, "*Vetiver planted in north Queensland (Australia) has withstood flow velocity higher than 3.5 m/sec in a river under flood conditions and, in southern Queensland, up to 5 m/sec in a flooded drainage channel*." Unfortunately this is typical of the rather unscientific claims made in literature promoted by the Vetiver Network, which give very limited information on other important environmental considerations, such as the size and density of the plants, the streambank material characteristics or the duration and depth of flooding.

There is more information on the performance of vetiver in flooded conditions, though somewhat anecdotal. Feng et al. (undated) report that in trials, vetiver could survive for three months in summer and five months in winter when fully flooded, and gradually resumed growing after the draining of flood water. However, flooding was found to inhibit the elongation of its roots. Xia et al. (undated) observed that, in a trial of eight grass species, vetiver and Bermuda grass (*Cynodon dactylon* or smau chénhchiën, a pan-tropical creeping or sward grass) could tolerate the longest time of submergence, at least up to 100 days and probably more than that; most of the other species survived for around a month. Xia (2002) reported the high survival rates of vetiver in a 50-day submergence trial. Focks (2006) has shown how vetiver makes a significant difference to bank stability in laboratory conditions.

Truong et al. (2007) point out that, "*Vetiver grows poorly in the shade, so planting it directly under a bridge or other shelter should be avoided*". This calls into question their suggestion of combining the use of vetiver on streambanks with the planting of bamboos: while both would grow well together for some time, there is a distinct danger that the bamboo will start to shade out the vetiver after a few years.

5 Conclusions

The purpose of this study was to assess the knowledge base for embankment stability and erosion control under flood and subsequent drawdown conditions. To do this, it examined a range of diverse issues, including relevant aspects of the geomorphology and soils, climatic and hydrological factors, and vegetation communities and patterns of plant colonisation, found in the upper Mekong delta (i.e. from Kampong Cham downstream to the Vietnam border, and the Tonle Sap system); and the potential use of low-cost and bio-engineering techniques in this environment.

From the assessment it is clear that the Mekong flood plains are part of a vast, complex hydrological system characterised by large but varying and unpredictable levels of annual flooding. These have brought about a diverse geomorphological landscape, with differences in terrain levels and characteristics that are difficult to detect on the ground but which have a significant bearing on the behaviour of materials and flood water. Soils are alluvial, and as a result they are variable, and loosely consolidated. Both natural river banks and man-made embankments are therefore weak and prone to erosion. The lateral movement of rivers can also give rise to mass failures in the steep banks.

In fact, few road sections are affected by direct river cutting, and as these are limited in length, and the methods for control are already understood, this is more an area where the implementation of existing knowledge is required than research to find new approaches. Straightforward flexible gabion retaining structures have already been designed, and need to be tried on critical sites.

It is embankment roads that may be far from rivers where the greatest uncertainties lie and further investigations are needed. A large proportion of the overall rural road network is on the flood plains. Because this land is fertile and forms the backbone of Cambodia's agricultural economy, it is relatively densely populated and has a large proportion of the roads, and these can be affected by flood damage. Problems exist where road embankments run through areas subject to prolonged flooding (more than a month) of at least one metre in depth, where wind-generated waves erode the weak earth slopes. Protection of these slopes against this widespread problem would also ensure that they are better able to withstand the more occasional, but also more serious, over-topping in very high floods. The uncertainties are both as to which areas might be affected by flooding and therefore liable to damage, and the best ways of preventing the erosion of embankments and safeguarding the roads.

The conclusion of the study is that roads built on simple earth embankments without special consideration of the Mekong flood plain environment are not a suitable engineering option, and low cost design improvements are necessary to safeguard the investment. Road embankments only fail when there is extensive deep flooding, but this is the very time when roads are most needed: apart from the cost of replacing infrastructure, roads are vital links in flood disaster mitigation.

The tools of low cost embankment protection are generally available, though there are also some unknowns.. Since there are thousands of kilometres of roads at risk from flood-related damage, the only means of protection that is affordable on such a scale is the use of appropriate vegetation systems – bio-engineering – to strengthen the earth surfaces of embankment slopes. There is considerable knowledge from neighbouring countries and the wider international community as to how this might be done, and a wide range of suitable plant species is available in Cambodia. There is also some experience of how to go about this, though the works examined in the field were found to have a number of flaws and to require refinements. Linkages with the irrigation sector may also be productive in finding solutions to the difficulties also faced in that discipline.

Emerging from this study is a recommendation for a series of applied trials of low cost methods for the protection of earth embankment slopes (see the accompanying document "*Proposal for Research on Road Embankment Protection*"). This would be based on the use of sound bio-engineering techniques, using experience from outside the country but designed to adapt the procedures to the Cambodian environment. The aim would be to develop better overall design standards, so that embankment roads in rural flood plain areas withstand the environment in which they are built.

6 Acknowledgements

This report was produced as part of the SEACAP 19 project contracted to TRL Ltd in principal association with KACE Ltd. The drafting of this report was undertaken by John Howell (Living Resources) and reviewed by Dr Jasper Cook (OtB Engineering Ltd). Comment and support from members of the SEACAP 19 Steering Committee under the Chairmanship of H E Suos Kong is gratefully acknowledged.

Valuable assistancert was supplied by other members of the SEACAP 19 Team including the Local Team Leader Heng Kackada (KACE Ltd).. David Salter, the SEACAP Programme Manager, provided key facilitation, guidance and programme support.

.

7 References

Agpaoa, A., Endangan, D., Festin, S., Gumayagay, J., Hoenninger, T., Seeber, G., Unkel, K. and Weidelt, H.J. 1976. *Manual of Reforestation and Erosion Control for the Philippines*. German Agency for Technical Cooperation, Eschborn.

Baltzer, M.C., Nguyen, T. D. and Shore, R.G. (Eds.). 2001. *Towards a vision for Biodiversity Conservation in the Forests of the Lower Mekong Ecoregion Complex.* WWF Indochina Programme, Hanoi.

Barker, D. H., Watson, A. J., Sombatpanit, S., Northcutt, B. and Maglinao, A. R. (Eds). 2004. *Ground and Water Bioengineering for Erosion Control and Slope Stabilization*. Science Publishers, Inc., Enfield.

Bell, R.W. and Seng, V. 2004. Rainfed lowland rice-growing soils of Cambodia, Laos and north-east Thailand. In: Seng, V., Craswell, E., Fukai, S. and Fischer, K. *Water in Agriculture*. ACIAR Proceedings No. 116e. ACIAR, Canberra.

Cambodia-IRRI-Australia Project. 2000. Soils of the Main Rice Growing Areas of Cambodia. Map at 1:900,000. Cambodia-IRRI-Australia Project, Phnom Penh.

CTSP (Cambodia Tree Seed Project). 2003. *Gene-Ecological Zonation of Cambodia*. Cambodia Tree Seed Project, Institutional Capacity Building of the Tree Seed Sector. Forestry Administration, Phnom Penh.

CTSP (Cambodia Tree Seed Project). 2004. *Cambodian Tree Species Monographs*. Cambodia Tree Seed Project, Institutional Capacity Building of the Tree Seed Sector. Forestry Administration, Phnom Penh.

Clark, J. E. and Hellin, J. 1996. *Bio-engineering for Effective Road Maintenance in the Caribbean*. Natural Resources Institute, Chatham.

Coppin, N. J. and Richards, I. G. (Eds). 1990, *Use of Vegetation in Civil Engineering*. CIRIA, London.

Dung, L.V., Phong, L.T., Danh, L.T. and Truong, P. 2003. Vetiver system for wave and current control in the Mekong delta, Vietnam. Proceedings of the Third International Conference on Vetiver and Exhibition, October 2003, Guangzhou.

Dy Phon, P. 2000. *Dictionary of Plants Used in Cambodia*. Imprimerie Olympic, Phnom Penh.

Feng, P., Chen, Z. and Jing, Y. (Undated). Research on adaptability of *Vetiveria zizanioides* to flooding. Uncited abstract, the Vetiver Network International, www.vetiver.org.

Fifield, J.S. 1996. *Field Manual for Effective Sediment and Erosion Control Methods*. HydroDynamics Incorporated, Parker (USA).

Focks, D.J.J. 2006. *Vetiver grass as bank protection against vessel-induced loads*. M.Sc. Thesis, Delft University of Technology.

Forest Administration. 2004. Forest Survey Data. Forestry Administration, Phnom Penh.

Geotechnical Engineering Office. 2000. *Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls*. GEO Publication No. 1/2000, Civil Engineering Department, Government of the Hong Kong Special Administrative Region.

Goichot, M. 2003. Flood Management and Flood plain Ecology. Second Annual Mekong Flood Forum, Phnom Penh, October 2003. Mekong River Commission.

Gray, D. H. and Lieser, A. T. 1982. *Biotechnical Slope Protection and Erosion Control*. Van Nostrand Reinhold Company, New York.

Gray, D. H. and Sotir, R. B. 1996. *Biotechnical and Soil Bioengineering Slope Stabilisation: a Practical Guide for Erosion Control*. John Wiley, New York.

HMG Nepal and PIARC: His Majesty's Government of Nepal and the Permanent International Association for Road Congress. 2003. *International Seminar 2003*. Department of Roads, Ministry of Physical Planning and Works, Kathmandu.

Howell, J. H. 1999. *Roadside Bio-engineering*. Department of Roads, Kathmandu.

IECA: International Erosion Control Association. 1999. *Proceedings of the first Asia-Pacific Conference on Ground and Water Bioengineering for Erosion Control and Slope Stabilization*. Manila, April 1999. International Erosion Control Association, Steamboat Springs (USA).

IFRC (International Federation of Red Cross and Red Crescent Societies). 2003. Red Cross / Red Crescent operating mechanisms at the regional level. Second Annual Flood Forum, October 2003. Mekong River Commission.

Ingles, O.G. 1985. Translation of Japanese Highway Design Manual. Part 1 : Earthworks. Research Report ARR 51, Australian Road Research Board, Victoria.

ITC (Institut de Technologie du Cambodge). 2004. Erosion des Berges du Mékong au Cambodge. Project PCSIU-2004, Département de Génie Rural, Institut de Technologie du Cambodge, Phnom Penh.

ITC (Institut de Technologie du Cambodge). 2007a. Lutter contre l'érosion et pour l'infiltration. Groupe de leçons 29 à 33 dans le cours d'environnement, Département de Génie Rural, Institut de Technologie du Cambodge, Phnom Penh.

ITC (Institut de Technologie du Cambodge). 2007b. Érosion et méthodes de lutte anti-érosive. Dossier inclus dans le cours d'environnement, Département de Génie Rural, Institut de Technologie du Cambodge, Phnom Penh.

IUCN (International Union for the Conservation of Nature). 1991. *The Conservation Atlas of Tropical Forests: Asia and the Pacific*. Macmillan, London.

Kaneko, A. and Adachi, H. 2000. Infrastructure Development. Part II of Comprehensive Report for the Japanese International Co-operation Agency, Tokyo.

Koma, Y.S. 1997. Cambodia Report. UN-ESCAP.

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

Loke, K.H. 1999. Geosynthetic filters for river and shoreline soil erosion control. In: International Erosion Control Association: *Proceedings of the first Asia-Pacific Conference on Ground and Water Bioengineering for Erosion Control and Slope Stabilization*. Manila, April 1999. International Erosion Control Association, Steamboat Springs (USA).

Longland, F. 1983. *Field Engineering*. Intermediate Technology Publications, London.

Mao, H. 2005. Cambodia Country Paper. Third Annual Flood Forum, April 2005. Mekong River Commission.

McDonald, J.A., Pech, B., Phauk, V. and Leeu, B. 1997. Plant communities of the Tonle Sap flood plain. IUCN and Wetlands International, Phnom Penh.

MPWT (Ministry of Public Works and Transport). 2003a. *Construction Specification*. Ministry of Public Works and Transport and Australian Agency for International Development, Phnom Penh.

MPWT (Ministry of Public Works and Transport). 2003b. *Road Design Standard*. Ministry of Public Works and Transport and Australian Agency for International Development, Phnom Penh.

MRC (Mekong River Commission). 2003. Second Annual Flood Forum, October 2003. Mekong River Commission.

MRC (Mekong River Commission). 2005. *Overview of the Hydrology of the Mekong Basin*. Mekong River Commission, Vientiane.

MRC (Mekong River Commission). 2006. Fourth Annual Flood Forum, May 2006. Mekong River Commission.

MRD (Ministry of Rural Development). 2006. Interim Rural Road Standards for Tertiary and Sub-tertiary 1 Roads. Ministry of Rural Development, Phnom Penh.

Meon, G. 2005. Improving the flood management in Germany - lessons learned from the 2002 disaster in the Elbe region. Third Annual Flood Forum, April 2005. Mekong River Commission.

Morgan, R.P.C. and Rickson, R.J. (Eds). 1995. *Slope Stabilization and Erosion Control: a Bioengineering Approach*. E. & F. N. Spon, London.

National Research Council. 1993. *Vetiver Grass: a Thin Green Line against Erosion*. National Academy Press, Washington DC.

Nesbitt, H.J. 1995. Rice production systems in Cambodia. In White, P.F., Oberthür, T. and Domingo, L.V. (Eds). *Classifying Cambodian Soils from an Agronomic Perspective*. Proceedings of an in-country workshop on the classification of soils used for rice production in Cambodia, May 1995. Cambodia-IRRI-Australia Project, Phnom Penh.

Oberthür, T. and White, P.F. 1995. Soil classification in Cambodia – a summary. In White, P.F., Oberthür, T. and Domingo, L.V. (Eds). *Classifying Cambodian Soils from an Agronomic Perspective*. Proceedings of an in-country workshop on the classification of soils used for rice production in Cambodia, May 1995. Cambodia-IRRI-Australia Project, Phnom Penh.

Ohta, S., Toriyama, J., Kanzaki, M., Araki, M., Ito, E., Pol, S., Tith, B., Lim, S., Khorn, S., Pith, P. and Det, S. 2004. Forest soil and its properties in Kompong Thom, Cambodia. Proceedings of International Workshop on Forest Watershed, 2004, Phnom Penh.

Rundel, P.W. 2001. In Baltzer, M.C., Nguyen Thi Dao and Shore R.G. (Eds.) 2001. *Towards a vision for Biodiversity Conservation in the Forests of the Lower Mekong Ecoregion Complex*. WWF Indochina Programme, Hanoi.

Schiechtl, H. M, and Stern, R. 1996. *Ground Bioengineering Techniques*. Blackwell Science, Oxford.

Schiechtl, H. M, and Stern, R. 1997. *Water Bioengineering Techniques*. Blackwell Science, Oxford.

Schiechtl, H. M. 1980. *Bioengineering for Land Reclamation and Conservation*. The University of Alberta Press, Edmonton.

SWK (Scott Wilson Kirkpatrick). 2002. Expert Report on Embankment Erosion. Emergency Flood Rehabilitation Project, Ministry of Public Works and Transport, Phnom Penh.

SWK (Scott Wilson Kirkpatrick). 2003. Monthly Report for December 2003. Emergency Flood Rehabilitation Project, Ministry of Public Works and Transport, Phnom Penh.

So, S. 2003. Floods and droughts in 2002 in the Cambodian parts of the Mekong Basin - exposure, response and lessons learned. Second Annual Flood Forum, October 2003. Mekong River Commission.

TRL (Transport Research Laboratory). 1997. *Principles of Low Cost Road Engineering in Mountainous Regions*. Overseas Road Note No 16, Transport Research Laboratory, Crowthorne, UK.

Truong, P., Tan Van, T. and Pinners, E. 2007. *Vetiver System Applications: Technical Reference Manual*. The Vetiver Network International, www.vetiver.org.

Van Liere, W. and McNeely, J.A. 2005. *Agriculture in the lower Mekong basin: experience from the critical decade of 1966-1976*. IUCN, Gland.

Veng, S. 2007. Personal communication. Ministry of Water Resources and Meteorology, Phnom Penh.

White, P.F., Oberthür, T. and Domingo, L.V. (Eds). 1995. *Classifying Cambodian Soils from an Agronomic Perspective*. Proceedings of an in-country workshop on the classification of soils used for rice production in Cambodia, May 1995. Cambodia-IRRI-Australia Project, Phnom Penh.

White, P.F., Oberthür, T. and Sovuthy, P. (Eds). 1997. *The Soils Used for Rice Production in Cambodia: a Manual for their Identification and Management*. Cambodia-IRRI-Australia Project, Phnom Penh.

World Bank. 2003. Cambodia Environment Monitor 2003. The World Bank, Washington.

WSP (WSP International Management Consultants). 2003. Slope Protection Study. Second Rural Transport Project, Ministry of Transport, Hanoi.

Xia, H., Lu, X., Ao, H. and Liu, S. Undated. A preliminary report on tolerance of vetiver to submergence. Uncited abstract, the Vetiver Network International, www.vetiver.org.

Xia, H. 2002. Submergence testing vetiver grass. *Vetiver Newsletter*, No. 24, July 2002. the Vetiver Network, Arlington.

Yee, T.W. and Lee, S.T. 1999. Geosystems as hydraulic structures for channel and shoreline profile management to enhance habitats. In: International Erosion Control Association: *Proceedings of the first Asia-Pacific Conference on Ground and Water Bioengineering for Erosion Control and Slope Stabilization*. Manila, April 1999. International Erosion Control Association, Steamboat Springs (USA).

Yit, B. 2004. Risk Management and Mitigation for Flood and Sediment Disaster. Cambodian Country Paper for International Conference, Ministry of Public Works and Transport, Phnom Penh.

ROYAL GOVERNMENT OF CAMBODIA

SOUTH EAST ASIA COMMUNITY ACCESS PROGRAMME

DEVELOPMENT OF LOCAL RESOURCE BASED STANDARDS

STUDY OF ROAD EMBANKMENT EROSION AND PROTECTION

APPENDIX A

PROPOSAL FOR RESEARCH ON ROAD EMBANKMENT PROTECTION

CONTENTS

ABBREVIATIONS & ACRONYMS

ITC	Institut de Technologie du Cambodge
MPWT	Ministry of Public Works and Transport (Cambodia)
MRC	Mekong River Commission
MRD	Ministry of Rural Development (Cambodia)
MWRM	Ministry of Water Resources and Meteorology (Cambodia)
SEACAP	South East Asia Community Access Programme

DEVELOPMENT OF LOCAL RESOURCE BASED STANDARDS

PROPOSAL FOR RESEARCH ON ROAD EMBANKMENT PROTECTION

1 Introduction

1.1 Background to this Proposal

This proposal is an output of one component of the document preparation activities of the Project "Development of Local Resource Based Standards", administratively assigned as SEACAP 19 under the South-East Asia Community Access Programme of the UK Department for International Development. The task of the project is to assess the particular technical issues around five specific topics previously identified as being of importance in the development of Cambodian rural road standards, and if appropriate to prepare proposals indicating the way forward for further work.

The specific problem addressed by this topic is the erosion of road embankments, and possible low cost approaches to mitigate flood damage. This document therefore contains a summary of the perceived need for research in this area, and an outline of how this might be done through suitable trials to develop technical solutions appropriate to the Cambodian environment.

2 Summary of the Need for Research

2.1 Review of the Identified Problems

The main Technical Paper prepared as the background to this proposal and provides an in-depth assessment of the factors governing the erosion of road embankments on the flood plains of Cambodia. In certain situations, the eroding banks of major river channels (particularly the Mekong and Bassac) are undercutting roads where they happen to run close to the main channels. More widespread, however, is the periodic damage caused to road embankments at a considerable distance from rivers, but crossing land subject to seasonal flooding. These are so extensive in length that if they are to be protected at all, it must be done using low cost methods; and in effect, this means using vegetation.

The rainfall patterns and hydrology affecting the lower Mekong valley are complex, and although floods occur every year, they vary greatly in height and intensity. Some of the lower lying parts of the flood plains are inundated every year, while others receive floods only occasionally. Exceptional years cannot be predicted and sometimes occur close together: after eighteen low years, there were unusually high flood levels in the three successive years of 2000 to 2002, though 2000 was the highest. At these times a high proportion of flood plain roads can be affected. Damage is caused mainly by the impacts of waves, and the general prolonged saturation of unconsolidated earth masses during the months that flood water remains standing against the sides of the embankments. In exceptional cases roads are over-topped and the embankment slopes suffer severe scour.

A study of the natural environment of the Cambodian flood plains shows that, while changes in land use increasingly obscure the subtle but important geomorphological features, and the hydrology is altered both naturally and through human activities, the liability for flooding is still readily detectable.

In large part this can be determined by assessment of the soils, which betray the dominant characteristics of the original site that will in most cases still prevail when high flood conditions occur. The type of sediment and hydrological characteristics are clear in the soils, which have been comprehensively studied and classified in the flood plains. There is also a wide range of different vegetation types, some of which are quite unique in character because of their adaptation to the extraordinary conditions found in the riverine environments of the Mekong and Tonle Sap.

The gradual movement of river channels and flooding of the lower plains are natural occurrences, and the silt and water brought in the floods are of critical importance to Cambodia's agricultural wealth. The difficulty is that so much infrastructure is needed in these vulnerable but densely populated areas. Yet the thousands of kilometres of roads on the flood plains have been built to standard designs that have rarely included adequate provision for the dynamic environment in which they lie. There have been limited uses made of vegetation in the protection of earth slopes, or indeed of any protection. Most of what has been done is intended to prevent erosion from rainfall, and it has often not been comprehensive enough even for this.

On a ruthlessly technical appraisal, it is clear that a road on a flood plain that fails due to flooding is not properly designed for its environment, and is consequently a failure of civil engineering. Although the government has sets of standards for all types of roads, they tend to have been developed on the basis of designs for less severe environments, and do not include proper specifications for the protection of earth embankments. It is to find an affordable way of doing so, that has led to this proposal. There is much that needs to be done to protect these valuable assets, and the tools are locally available: it is largely a matter of using local natural resources carefully for better engineering benefits, through methodology adapted from elsewhere.

2.2 Significance of the River Bank Problem

Fortunately most of Cambodia's roads are routed well away from the main river channels, and at present there are relatively few locations where roads are actively threatened by river bank erosion. The main examples are sections of RN 21 beside the Bassac in Kandal, and RN 11 beside the Mekong in Prey Veng. In the future there will be other locations, as the rivers are certain to migrate gradually and other lengths of roads are within a few hundred metres of the big channels.

The current economic significance is not particularly high, though in a severe flooding year the complete removal of vulnerable sections of the roads named above could lead to a need for repairs in the range of US $ 0.25 to 0.5 million. Beyond the cost of rehabilitation, however, the loss of use of national highways would have more serious economic effects, particularly at a time of severe flooding when the urgent need for disaster relief means that good access is essential.

While this topic is included in this proposal, it is on a relatively limited scale. What appears to be most needed in this respect, is a standard approach to the assessment of damage from major river bank erosion, and guidelines on the design and execution of remedial measures. Longer term amelioration strategies might also be usefully investigated so that the retreat of banks, if not actually slowed, might not be accelerated through inappropriate land management.

2.3 Significance of the Road Embankment Problem

Flood damage to road embankments well away from rivers is a much more widespread problem than that of damage from the eroding banks of the major rivers. In a JICA assessment of Cambodian infrastructure, Kaneko and Adachi (2000) state: "Even trunk roads are vulnerable to flooding in Cambodia, especially during the rainy season, partly due to nature of their routing. They cannot be used all year round without appropriate maintenance work. However, Cambodia lacks the organizations, systems and funds necessary to carry out such maintenance work." While maintenance capacity has undoubtedly improved since then, vulnerability is still a concern.

A very broad estimate of the lengths of roads potentially at risk from flooding can be made as follows: seven out of Cambodia's twenty-four provinces and cities are affected by major Mekong floods (not counting Phnom Penh); in these seven provinces there are 4,387 km of national and provincial roads and 6,925 km of local roads, 42 percent and 29 percent of the national totals respectively (see Table 1). While not all of these roads are necessarily threatened and some roads in other provinces might be, the figures nevertheless give an indication of the general scale of the problem.

Table 1. Road Lengths in the "Flood Plain Provinces". MPWT and MRD Statistics.

Province	National and Provincial Roads (km)	Rural Roads (km)
Stung Treng	323	894
Kratie	507	213
Kampong Cham	1,446	1,609
Kandal	748	1,879
Prey Veng	300	486
Takeo	461	1,330
Svay Rieng	602	514
Total, "flood plain provinces"	**4,387**	**6,925**
Total, whole country	10,457	24,028
Proportion, flood plain provinces	42%	29%

Note: Phnom Penh is excluded on the basis that its roads are mainly within the encircling dikes.

The Local Roads Department of the Ministry of Rural Development has an annual budget for the construction of about 150 km of new roads each year. However, many more roads are being built by Provinces, Communes and even non-governmental organisations. A significant proportion of these are in the flood plains, since that is where Cambodia's population is most concentrated. The length of roads at risk is therefore increasing annually.

In the severe 2000 flood, Yit (2004) estimated that there had been major damage to 1,800 km of national roads and 820 km of secondary and provincial roads, and to 60 percent of the rural and commune roads on the flood plains; the total cost of repairs to public infrastructure amounted to around US $ 47 million. So (2003) and Mao (2005) both mentioned very considerable damage resulting from the 2001 and 2002 floods, though not as great as that in 2000, and although they did not provide estimates of the costs for the repair of damaged infrastructure, it clearly ran into the order of many millions of dollars.

The wider implications are more difficult to assess, particularly the consequences of losing road access at a time when it is most needed. In the 2000 flood, it is estimated that about 3.4 million people were affected, 84,710 families were evacuated, 347 people died, 7,000 houses were destroyed, and 1,000 schools and 158 health centres were seriously damaged in twelve provinces (Yit, 2004). While roads are essential for normal social and economic development, they become even more important at times of crisis. Yet in 2000 that was exactly when they failed. It is not possible to say how much more effective evacuation would have been, or how many lives would have been saved, if roads were better protected. It is evident that high floods will continue to be more disastrous than necessary if infrastructure cannot survive when it is most needed.

The great majority of roads that fail due to flooding are in rural areas. As a result, it is the rural population that suffers most from these events. The Strategic Plan for Rural Roads (MRD, 2006) makes it clear that most poverty is rural: 91 percent of Cambodia's poor live in rural areas, rural poverty is more severe than urban poverty and the rate of reduction of poverty in rural areas is less than that in urban areas. There is a clear and well established link between poverty and vulnerability when disasters occur. The link to the need for more reliable roads at critical times is therefore obvious. The need for improved roads and better mitigation measures was highlighted by the IFRC (2003) as an essential part of flood disaster preparedness.

The MRD's policy is to use labour-based assisted technology wherever possible (MRD, 2006). The proposed way forward (see below) gives emphasis to the investigation of the use of labour intensive bio-engineering methods. It is therefore in line with policy, and should contribute positively because labour-based systems provide a range of economic benefits, as well as contributing to the livelihoods of the individuals concerned.

2.4 The Irrigation Sector

Officials working in the irrigation sector point out that their work on flood plains suffers similar problems to the road sector. Soils tend to be very poor for dike construction, just as they are for road embankments, and the stability and protection of dams and dikes are just as difficult. Wave and current erosion lead to constant battles to maintain the network of water distribution channels on the plains. The MWRM has adopted a number of methods in its attempts to resolve the difficulties encountered, but no definitive or easily affordable solutions have been found. This ministry considers that it would be highly advantageous to link with any trials on embankment protection undertaken by the MPWT and MRD.

In the following sections, the suggestion is repeated of the involvement of the MWRM in the proposed trials. However, specific irrigation sector considerations have not been included in the detailed recommendations for research in section 4, and would need to be added if the research were to cover that sector comprehensively as well.

2.5 The Technical Research Requirement

Although this proposal is linked to the introduction of low cost technology that mainly uses locally available plants, there is still a need for practical research. This is because, while techniques of bio-engineering can be brought in from outside Cambodia, they need to be adapted to the particular environment of the flood plain embankments and the characteristics of the actual species that are available.

Technical aspects of bio-engineering that need to be covered by the research are numerous and are listed in some detail in the later sections of this proposal and in Annex AI. In summary, the main unknown quantities that create the need for research are as follows.

- The identification and testing of plants that will grow well on embankment slopes, when subject to between two and four months of both drought and inundation at different times of year. Species that can perform well in these conditions are not always easy to find.

- Bio-engineering techniques that will provide a strong and complete surface cover, to withstand both runoff and wave erosion. Low cost bio-engineering systems to achieve this will involve a range of options, not just a single technique.

- Communities of plants that can be managed easily, and which will provide strong protection for many years to come. Vegetation is highly dynamic, and as plants grow their composition and engineering performance can change; for the purposes of this work, long-performing robust systems are required.

- The possible advantages of combining bio-engineering works based on locally available resources, with high-technology materials such as synthetic geotextiles, need to be assessed. Simply relying on local materials may not be the most cost effective solution in the long term.

All aspects of engineering need to be tested to appraise the critical limits so that performance can be predicted and standards set for works implementation. This proposal covers a straightforward introduction of some new methods into the Cambodian Engineer's repertoire, and the type of testing that any professional would wish to see as the basis for widespread use.

3 Outline of the Proposed Way Forward

3.1 River Banks close to Roads

The proposed way forward to address the effects on roads resulting from the erosion and movement of major river banks is to establish a set of guidelines that can be adopted by the MPWT and MRD to address this problem when it arises. The emphasis needs to be on the development of appropriate approaches to the geotechnical assessment of the area, and the use of site investigation data to inform the design of a proposed solution. It is expected that this will concentrate on using heavy but flexible engineering measures, such as gabion structures.

In addition, longer term amelioration strategies against the retreat of banks need to be investigated and, if possible, appropriate guidelines produced for these as well. The aim would be that, if bank erosion cannot actually be slowed, it might at least not be accelerated through inappropriate land management and other activities. This must take a broad perspective of the factors affecting the river-land dynamics in specific areas, and might, for example, consider how boat traffic and sand extraction are affecting certain stretches of bank; and how appropriately managed forest cover might provide a bank-strengthening buffer zone in certain locations. In effect this involves developing a strategy with a more holistic view of river-land interactions.

An option is also suggested for a practical trial to test the procedures developed in this topic area. This would serve as a full-scale demonstration of the approach, and contribute greatly to the understanding of the problem.

3.2 Road Embankments away from Rivers

A wide range of new knowledge is required concerning the protection of embankments away from rivers but in areas prone to damage by flooding. Because of the very considerable lengths of roads involved, this must be low in cost, and therefore emphasis on the use of vegetation is essential. The main objectives proposed are to investigate, test and develop systems of surface protection that use local Cambodian plants in engineered configurations that ensure an adequately robust surfacing of earth slopes to withstand both runoff and wave erosion.

The keys to this approach are already identified, but need to be tested in field conditions to assess the optimum solutions for the Cambodian flood plain roads. Bio-engineering methodology used successfully in other countries can be adapted and applied. An initial list of plants with properties appropriate to use in bio-engineering works is already available from the background work in preparing this proposal (see Annex A2), while others can certainly be identified among the various natural communities.

A carefully devised set of low cost trials is proposed to look not just at the exact species to use, but also the timing and methods of planting, and the layout of different types of plant and structures of vegetative materials. These should be designed to lead to an understanding of the site conditions that apply to each technique, and from that a set of guidelines, specifications and standards for all suitable options. There are many variables that need to be examined, and therefore the scale and design of trials must be adequate to address all of the questions.

3.3 Possible Implementation Arrangements and Costs Involved

Organisation. It is proposed that the trials should be undertaken by a self-standing project administered by the MPWT, working in partnership with the Institut de Technologie du Cambodge (ITC), and with a working agreement with MRD, and possibly also with MWRM. It should be overseen by a steering committee that comprises officials from all of these four organisations, and this committee would be responsible for approving the detailed research strategy in each topical area, and ensuring ministerial collaboration to support the research.

Duration. For the research on road embankment protection, it is considered that an initial set of adequately financed trials over a period of a minimum of two years (three years would be better) could answer a number of the key questions raised. This would then point to ways forward for longer term research and monitoring. The smaller research questions on river bank stabilisation should also be effectively completed in a two to three-year period, but with less need of continued investigation.

Long term monitoring. One of the features of the key problem being addressed by the research on embankment protection is that it is part of a long term safeguarding policy. Many of the sites that are the target locations for the techniques that need developing, may not receive substantial flooding for a number of years. The bio-engineering methods that have to be used will take about three years to reach their critical strength, which would be outside the trial period. It is not possible to predict when a full testing of the sites would occur. It is partly for this reason that a research institute with permanent staff and a long time horizon should be involved in the research. The leadership of the ministry is essential because it is the main stakeholder, but inter-departmental staff movement is probably too frequent for such an organisation to be best placed for long term monitoring.

Research schedule. The simple bar chart in Figure 1 provides an indication of the timing that would be necessary for the research proposed. This assumes that a research period of only two years would be available in the first instance, and hence a number of activities are scheduled to run simultaneously, although it would be preferable to have them in sequence over a longer overall period. This bar chart takes no account of seasons, and in practice the research would need to be timed in detail, in accordance with seasonal constraints related to flooding and plant growth; this would normally be done when the detailed terms of reference are drawn up.

Cost estimate. Table 2 gives a very broad estimate of the main cost items required for the proposed research work.

Figure 1. Approximate Timeframes for Implementation of the Proposed Research

Research topic	Activity	Year 1				Year 2			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
River bank erosion									
Investigation and design of river bank stabilisation issues	Site investigation	■							
	Design of standard responses		■						
	Discussion, modification and adoption			■	■				
Implementation of river bank stabilisation trial	Site investigation	■							
	Design of site-specific stabilisation works		■						
	Contracting of works			■					
	Site works implementation				■				
	Monitoring and assessment of site works					■	■	■	
	Final assessment and modified designs								■
Review of broader and holistic management issues for shifting banks	Site investigations in different areas		■	■					
	Data assessment and reporting				■				
Protection of Road Embankments									
Detailed design of comprehensive trial programme on embankments	Field studies and investigations	■	■						
	Studies of available plant species	■	■						
	Site, soil and hydrological studies		■	■	■	■			
Implementation of comprehensive trial programme on embankments	Site investigations	■							
	Design of site-specific protection works	■							
	Arranging or contracting of works	■							
	Site works implementation (year 1)		■						
	Monitoring and assessment of site works			■	■				
	Redesign on basis of lessons learnt					■			
	Site works implementation (year 2)						■		
	Monitoring and assessment of site works							■	■
	Final assessment and recommendations								■
Data collection and interpretation of best practices for protection	Field observations and data collection	■	■	■	■				
	Assessment of site trials			■	■	■	■	■	■
	Documentation of findings					■	■	■	■
Development of Guideline Documentation									
Promotion of information on erosion protection on CNCTP website	Collection of information from sources		■						
	Scanning, uploading and organising			■					
Production of a comprehensive erosion protection manual for Cambodia	Initial drafting of manual	■							
	Consultation among stakeholders		■						
	Incorporation of feedback for 2nd version			■					
	Finalisation on basis of field trials								■

Table 2. Indicative Breakdown of the Costs of the Proposed Research.

Research topic	Staff resources	Physical resources	Priority *
River bank erosion			
Investigation and design of river bank stabilisation issues	Cambodian: 6 p/m International: 1 p/m	Transport; access to sites; design office facilities.	2
Implementation of river bank stabilisation trial	Cambodian: 12 p/m International: 1 p/m	Transport; suitable trial sites; design office facilities; substantial contract funding.	3
Review of broader and holistic management issues for shifting banks	Cambodian: 6 p/m International: 1 p/m	Transport; access to sites.	2
Protection of Road Embankments			
Detailed design of comprehensive trial programme on embankments	Cambodian: 12 p/m International: 2 p/m	Transport; access to sites; design office facilities.	1
Implementation of comprehensive trial programme on embankments	Cambodian: 24 p/m International: 2 p/m	Transport; suitable trial sites; design office facilities; significant contract funding.	1
Data collection and interpretation of best practices for protection	Cambodian: 12 p/m International: 2 p/m	Transport; access to sites.	1
Development of Guideline Documentation			
Promotion of information on erosion protection on CNCTP website	Cambodian: 4 p/m International: 1 p/m	Relevant data resources; web-preparation office facilities.	1
Production of a comprehensive erosion protection manual for Cambodia	Cambodian: 3 p/m International: 3 p/m	Relevant data resources.	1

* 1 = highest priority, 3 = lowest priority. p/m = person months of consultant time.

4 Recommendations for Research

4.1 Stabilisation of Eroding Major River Banks

Aim

To establish effective procedures for the investigation and remediation of damage to roads resulting from the erosion and gradual migration of major river banks.

Main activities

- Identify the parts of the road network that are at risk from this problem and determine a suitable research site and strategy.

- Review the selected river bank failure during the lowest flow time. Map out the extent of failure in terms of micro-topography, soil physical properties and vegetation.

- Undertake a geotechnical assessment of the selected key research site, to determine geotechnical soil properties and assess whether the slumps found in the bank are shallow or deep-seated. This is expected to be based mainly on surface observations, with test pits and auger borings as necessary.

- Design appropriate site stabilisation or protection measures using flexible civil engineering structures and bio-engineering as relevant, such as would protect the length of road threatened in the most cost effective manner.

- Where they are lacking, devise suitable design standards and construction specifications for the stabilisation and protection measures considered appropriate to eroding bank sites of the type investigated.

- If funding is available for the implementation of a full trial, then draw up the contract documents, support the tendering process and act as the Engineer in supervising the construction of the measures designed in the above activities.

- In places there is evidence of well-established trees retarding bank retreat: an example can be seen near RN 21 in Kandal, where âmpil tük (*Pithecellobium dulce*) appear to strengthen spurs protruding from the general line of the retreating bank. In other areas, pockets of the original riverine vegetation associations survive reasonably intact. Investigate the role played by larger plants in strengthening river banks relative to areas that have been cleared and are now used for agriculture, dwellings or other uses. Consider the possible benefits that might be derived from plantation belts of appropriate trees on uncultivated land close to rivers, or the options of preserving or restoring indigenous flood forest vegetation along river banks, and how these areas might be managed for long term benefits.

- Research by ITC (ITC, 2004) suggested that the acceleration of retreat of major river banks was linked to the effects of wash from motorised river transport and the extraction of sand from the rivers. Consider these factors in relation to one or more of the sites investigated where the road network is at risk, and identify any key management implications that would be necessary to ameliorate the effects.

Key outputs

- A detailed research plan that identifies suitable study locations and describes the procedure, timing and cost of the work to be done.

- A report describing a best practice demonstration of the assessment, interpretation, design and implementation of the investigation and stabilisation of a site where bank erosion was causing damage to a road.

- A set of procedures for MPWT and MRD to adopt and follow in the future, including technical guidelines, specifications and standards, assessment, interpretation, design and implementation of the investigation and stabilisation of a site where bank erosion was causing damage to a road.

- Investigation and stabilisation of a site where major river bank erosion is taking place, following appropriate best practice approaches.

- A report describing an investigation of the areas along the major rivers where there is potential for improved long term management of either the river or the adjacent land to ameliorate the effects of river migration, and the processes required to put this into effect.

4.2 Protection of Road Embankments

Aim

To identify, design, test and record low cost options for the protection of road embankments on the Cambodian flood plains, from flood-related damage caused by runoff and wave erosion.

Main activities

- Identify the parts of the road network that are at risk from this problem and determine suitable representative research sites and research strategy.

- Undertake surveys of appropriate road embankments and other ecological sites, particularly areas of remaining riverine and flood forest, to verify and expand the tables of suitable (and unsuitable) species for bio-engineering works in the Cambodian flood plains, using the initial table in Annex A2 of this proposal as a starting point.

- Review the selected research sites during different seasons, to ascertain critical environmental factors through the year. Map out the extent of erosion of key areas, in terms of micro-topography, soil physical properties and vegetation.

- Carry out an assessment of the characteristics of the different soils found on the test sites. These should be diagnosed on the basis of the Cambodian classification given by White et al. (1997). In practice, soil characteristics might be limited to textural (particle size) class, though consideration should also be given to assessment of the fertility capability classification, as modified for Cambodia by White et al. (1997) from the generic system devised by Sanchez and Buol (1985). Since bio-engineering on the Cambodian floodplains will always be close to rice cultivation, it is important to establish whether there are methodological linkages through the soil characteristics.

- Design and implement a comprehensive series of site protection trials that use appropriate bio-engineering systems, such as would protect the length of road threatened in the most cost effective manner. This should use the detailed guidelines for trial designs given in Annex A of this proposal. A fundamental objective of these trials is to establish through rigorous field testing, a range of appropriate systems for embankment protection in Cambodia. It is envisaged that each of the techniques would be tried out on a section of embankment of at least 500 metres in length, in at least two different sites.

- Incorporate into the trials, the various cross-cutting studies detailed in Annex A as complementary to the main series of performance trials, to ensure that the broad range of variables and peripheral issues is covered by the research.

- Where they are lacking, devise suitable design standards and construction specifications for the measures considered appropriate to the protection of embankments from erosion in the ways investigated.

- Monitor and interpret the findings of the trials over a two or three-year period, to establish the success or failure of the methods tested, any modifications that might be needed, and the techniques that are appropriate for different environmental conditions in the Cambodian flood plains.

- Assess the conditions found on a representative sample of roadside slopes in the rolling and hilly areas of Cambodia. Use this information to scale out, as far as possible, the results of the embankment trials to make the results more broadly applicable across the country's road network.

Key outputs

- A detailed research plan that identifies suitable study locations and describes the procedure, timing and cost of the work to be done.

- A series of field trials of embankments in need of protection, investigated and protected following the suggested low cost, best practice approaches.

- An in-depth scientific assessment of the key environmental factors (including hydrology, soils and vegetation) and technical issues of erosion control through bio-engineering to back up the investigations and trials undertaken during the research project.

- A set of procedures for MPWT and MRD to adopt and follow, including technical guidelines, specifications and standards, assessment, interpretation, design and implementation of the investigation and protection of sites where erosion might cause damage to a road embankment.

- A final assessment of the research done and recommendations for a future strategy to cover longer term investigations and monitoring.

4.3 Development of Guideline Documentation

Aim

To provide Cambodian engineers and other decision-makers with the understanding and guidelines they need to design and implement a high standard of protection for earth embankments subjected to damage by floods.

Main activities

- Provide on-the-job training to counterpart private sector, government and ITC staff, on all aspects of the embankment protection research and trials.

- Give technical seminars annually on pertinent aspects of the embankment protection trials, to engineers and other decision makers in the participating ministries. These should give emphasis to the need for and benefits of widespread surface protection.

- Use the experience gained from this research, combined with the results of slope stabilisation trials in Laos under SEACAP 21, and other relevant national, regional and international information, to scale out the application of the new knowledge generated, to provide guidelines for erosion control measures in sloping areas of Cambodia, as far as it is possible to do so.

- Draw together all of the data, information and material of relevance into a practical set of guidelines on the best practices for Cambodia of embankment protection measures and vegetation in engineering.

Key outputs

- Accumulation on the website of the Cambodia National Community of Transport Practitioners (www.cnctp.info) of a mass of relevant documents from elsewhere, to cover all aspects of erosion protection and stabilisation of earth banks. This would include a re-scanning of the Nepal road sector manuals and other older from previous projects. Links would be provided to sites that already have relevant material.

- Development of a manual to guide road managers in the appropriate use of bio-engineering works in the specific context of Cambodian road embankments. If possible, the results from the trials proposed here and trials in Laos under SEACAP 21 will be scaled out to allow coverage of sloping terrain areas as well. This manual is envisaged as a fully comprehensive document, covering the regulatory as well as technical needs (i.e. including design standards and construction specifications).

4.4 Institutional Positioning

It is proposed that the roles and responsibilities of the main implementing agencies should be as given below. It is assumed that the project will be funded by an external donor, which will also support the provision of consultant-based technical assistance to support the research. In effect, the arrangements envisaged follow the successful SEACAP model.

Ministry of Public Works and Transport (MPWT)

- Take the lead role in co-ordinating and implementing the research project.

- Establish a Steering Committee for the project, chaired by a member of top management. Assign a senior lead researcher who will devote 50% of her/his time to work as the Project Co-ordinator, and who will act as the Secretary to the Steering Committee.

- Provide and establish a project office to accommodate MPWT staff and the technical assistance consultant throughout the duration of the project.

- Brief the project partners on the particular needs of the ministry regarding the protection of embankments on national roads. Work together to draw up detailed research plans that will fulfil the needs of MPWT regarding low cost embankment protection.

- Make a range of suitable sites available and participate fully in the implementation of a set of field trials. Support the Project Co-ordinator and his team in collecting and interpreting the field data from the trials, and work this into formats appropriate for use in the standards, specifications and manuals under the ministry.

- Provide technical and logistical support in the background investigations, and the design and implementation of the trials.

- Encourage other ministry staff to take an interest in the emerging lessons to inform their engineering activities.

- Participate in the writing up of the main project findings, with the knowledge generated shared appropriately as public goods with the ITC, government and consultant partners.

- Review the research outputs and adopt the documents produced as official procedures.

- Undertake, as far as is reasonable, to conduct long term monitoring of the field trials beyond the life of the project. This is considered important because of the uncertainty as to when the performance of the trials can be assessed following their severe testing in a high flood. The results of this monitoring will be shared openly with the partners.

Institut de Technologie du Cambodge (ITC)

- Participate in the Steering Committee at Professor level. Assign a Lecturer (professional level) to work with the project on a 50% of time basis.

- Provide academic support in the background investigations, and the design and implementation of the trials. Encourage staff members and a limited number of promising students to work closely with the project consultants in undertaking investigations of the key environmental variables (soils, hydrology, vegetation growth etc) and monitoring the trials.

- Encourage staff to interpret the emerging lessons to inform the teaching curriculum.

- Participate in the writing up of the main project findings, with the knowledge generated shared appropriately as public goods with the ministry partners and project consultants.

- Undertake, as far as is reasonable, to conduct long term monitoring of the field trials beyond the life of the project. This is considered important because of the uncertainty as to when the performance of the trials can be assessed following their severe testing in a high flood. The results of this monitoring will be shared openly with the partners, though it is expected that ITC will have full rights over it for the production of scientific papers.

Ministry of Rural Development (MRD)

- Participate in the Steering Committee at Under-secretary level. Assign a professional officer (qualified engineer) to work with the project on a 50% of time basis.

- Discuss with the Project Co-ordinator the particular needs of the ministry regarding the protection of embankments on rural roads. Work together to draw up detailed research plans that will fulfil the needs of MRD regarding low cost embankment protection.

- Make a range of suitable sites available and participate fully in the implementation of a set of field trials. Assist the Project Co-ordinator to collect and interpret the field data from the trials, and work this into formats appropriate for use in the standards, specifications and manuals under the ministry.

- Review the research outputs and adopt the documents produced as official procedures.

Ministry of Water Resources and Meteorology (MWRM)

- The shared interest is recognised of the MWRM with the ministries responsible for transport infrastructure, in protecting earth embankments made from the same local materials in similar locations under the MWRM's irrigation sector activities. The participation of the MWRM will therefore be welcomed to bring and share expertise, and benefit from joint results.
- Participate in the Steering Committee at Under-secretary level. Assign a professional officer (qualified engineer) to work with the project on a 50% of time basis.
- Discuss with the Project Co-ordinator the particular needs of the ministry regarding the protection of embankments on irrigation canals. Work together to draw up detailed research plans that will fulfil the needs of MWRM regarding low cost embankment protection.
- Make a range of suitable sites available and participate fully in the implementation of a set of field trials. Assist the Project Co-ordinator to collect and interpret the field data from the trials, and work this into formats appropriate for use in the standards, specifications and manuals under the ministry.
- Review the research outputs and adopt the documents produced as official procedures.

Technical assistance consultant

- Establish a team to work with the MPWT's Project Co-ordinator as the main executive staff in the implementation of the research project. The consultant's Team Leader will be an invitee to all Steering Committee meetings. The team will consist of an appropriate mix of local and international professionals and support staff, with their lengths of inputs determined according to the tasks assigned.
- Provide the logistical support for the day-to-day management of the project office.
- Facilitate and co-ordinate all interactions between the various project partners, to ensure that the project benefits from the combined resources of the organisations involved.
- Take the lead role in managing the technical aspects of the project. This will follow a standard research approach of detailed investigation and planning, the creation of detailed designs for trials, the selection of appropriate trial sites and the implementation of the trials, subsequent monitoring and data collection, and interpretation and dissemination of results.
- In undertaking the above, provide the specialist technical skills in all subject areas, particularly for techniques and knowledge from outside Cambodia. Liaise with the staff of the ministry partners and ITC to ensure that their staff skills are involved and tapped into as appropriate.
- Share all of the methodology and findings openly with the project partners, to encourage the adoption of appropriate new practices by the participating ministries and the inclusion of new knowledge in the ITC curricula.
- Act as Engineer in providing site supervision services during the establishment of trials, which shall be constructed using either a force account or a standard contractual arrangement. If the latter, then the consultant will also draw up the necessary documentation for approval by the project partners.
- Take a leading role in the writing up of the main project findings, with the knowledge generated shared appropriately as public goods with the ministry partners and ITC.

Implementation arrangements for field trials

As part of the early project planning, the partners are to give detailed consideration of the implementation mechanism for the field trials. This may be through the use of either contractors or force account workers, or a combination of both. There are advantages and drawbacks to both systems, but ultimately it is probably best to adopt the approach for the trials that is most likely to be the mode of implementation during subsequent use of the techniques developed.

The implementation of bio-engineering works by contractors has experienced difficulties elsewhere principally because the contractors engaged have been from the civil works sector and were completely inexperienced with the use of vegetation, and did not provide the care necessary to ensure successful planting. In addition, supervision by construction staff has often had shortcomings because of limited skills with unfamiliar materials not normally used in civil engineering. Trials in Laos under SEACAP 21 had no alternative to the use of civil engineering contractors, and so had to adopt the simplest methods and most robust species to overcome the poor quality of workmanship that was inevitable.

In other countries, notably some of the Indian states and Nepal, better results have been achieved through the use of force account workers. This is mainly because the implementing agency has much closer control over the timing and means by which the work is undertaken. Workers with the right skills can be assigned to tasks that require special care, and there is less risk of the work being rushed to meet contractual deadlines (which is a frequent cause of failure or poor performance in planting works). The use of force account works as an implementation mechanism should therefore be considered.

Annex A1: Main Design Criteria for Bio-engineering Trials

The following criteria should be incorporated into the detailed design of the embankment protection trials. An initial list of potentially suitable and unsuitable local species is given in Annex B.

No.	Trial topic	Suggested details
Standard performance trials		
1.	Use of grasses: what is the performance of large local grasses for embankment protection when planted in dense rows?	Use only grasses that form clumps and have stems and leaves at least 2 metres high: these have strong rooting systems unlike the short, creeping grasses. Select species that show a capacity to grow in both flooded locations and very dry locations so that they can survive both seasonal extremes. Grasses would normally be planted as stem-and-root slips or rhizome cuttings.
2.	Use of hardwood cutting-based methods: what is the performance of local shrub species in palisades, brush layers or other formations, for embankment protection?	Test a range of standard slope and waterway bio-engineering techniques that incorporate palisades, brush layers and fascines: a useful reference document for the design of these works is Schiechtl and Stern (1997). Consider the need for a horizontal barrier effect and the necessity of ensuring a good ground cover in between woody stems.
3.	Combinations of systems: what is the performance of a combination of bio-engineering techniques in maximising embankment protection?	A trial to see if the most robust solution might be a mixture of (for example) palisades or brush layers of shrubs interspersed with dense rows of grasses. Need to consider the shading issue for the grass rows.
4.	Combinations of systems: what is the performance of a barrier of shrubs or trees in front of the embankment and grasses on the embankment slope?	A trial to see if the most robust solution might be a barrier of woody plants in front of the embankment, and big grasses on the embankment slope. For example, several lines of âmpil tük at a dense spacing in front, then a thick line of sângkaè along the toe of the embankment, and then appropriate big grasses on the slope as in trial 1.
5.	Use of bamboos: what is the performance of local bamboos for embankment protection when planted along the slope toe?	A line of bamboos planted at the toe of embankments, probably with big grasses on the slope. Dy Phon (2000) lists nine bamboo species and other writers suggest similar numbers: from these, appropriate species need to be selected that can withstand inundation. This trial uses a similar barrier concept to the trial above.
6.	Use of vetiver grass in Cambodia: what is the performance of vetiver grass for embankment protection when planted in dense rows?	A trial to test the standard application of vetiver as promoted by the Vetiver Network, putting this into perspective against locally available grasses of the same size. Refer to Dung et al. (2003) and Truong et al. (2007) for details of trials in the Vietnamese part of the Mekong delta and elsewhere. Designs should be similar to trial 1.
7.	Use of imported hydro-seeding approaches: what is the performance of the most promising option(s) for hydro-seeding currently available on the market? This trial is dependent on suitable systems being available and affordable in Cambodia.	A trial to test out introduced systems of machine-based rapid application of vegetation cover to prepared slopes. It is only worth including if the species mixes offered include plants that will survive both drought and prolonged flooding, and display deep fibrous rooting characteristics and robust stems. The wider environmental and economic issues behind the largescale introduction of Australian grasses, for example, need to be assessed carefully before a trial of this nature.
8.	Use of geotextiles and other proprietary slope protection products: what is the performance of geotextiles, either organic or synthetic, in combination with appropriate vegetation? This depends on suitable products being readily available at an affordable cost.	A test of the robustness and longevity of surface reinforcement provided by means of an open weave organic covering, like coir netting or reed matting, or a three-dimensional synthetic geotextile alternative (e.g. Tensar or Enkamat geogrids). These would normally be lightly covered in soil and planted with appropriate big grasses or shrubs, using the species and techniques adopted in the trials above.

No.	Trial topic	Suggested details
Cross-cutting studies		
9.	Soil characteristics: what are the performances of the above standard trials on soils of different characteristics? What are the critical soil conditions that may determine the selection of particular species or techniques?	Throughout the trials above, it is necessary that the soil characteristics are assessed as a possible dominant factor in determining the most appropriate measures to adopt.
10.	Hydrological characteristics: what is the performance of the above standard trials in sites with different water regimes? What are the critical hydrological conditions that may determine the selection of particular species or techniques?	Throughout the trials above, it is necessary that the main hydrological regime is assessed as a possible dominant factor in determining the most appropriate measures to adopt.
11.	Timing of planting: what is the best timing for the establishment of different categories of plants, in sites of different characteristics?	A summary of the issues around the timing of implementation of bio-engineering works is given in a box later in this Annex. The standard trials above need to be designed so as to ascertain the optimum timing of planting. In particular, areas subject to prolonged flooding each year may best be planted in November as the water recedes.
12.	Use of specially adapted local species: what is the performance in the standard trials, of species identified from the special ecological habitats found in the lower Mekong and Tonle Sap basins? These include areas such as the hydromorphic savannahs (veals) and the riverine gallery forests found in Kratie and Stung Treng Provinces, which seasonally suffer considerable drought and severe inundation.	Use in the techniques for the standard trials above, of species derived from special ecological habitats. This might include grasses such as the *Saccharum* found in the veals, and common flooded forest trees such as rèang tük (*Barringtonia acutangula*). This work will require a detailed assessment of the various flood forest communities, perhaps through liaison with provincial Forestry Administration offices, the Tonle Sap Biosphere Reserve Secretariat or the WWF/IUCN offices.
13.	Resilience to drought and flood by individual species: what is the performance of the various species used in growing well and surviving different lengths of inundation and drought?	Detailed observations need to be made during the trials of the performance of the various species used, to ensure that as much information is derived as possible regarding performance in differing environmental conditions.
14.	Resilience to grazing: what is the performance of the various species used in surviving regular grazing?	Detailed observations are to be made as to the susceptibility of different species to grazing in different situations.
15.	Availability and ease of propagation: what are the logistics for the various species used in terms of obtaining planting materials and propagation?	If bio-engineering techniques are to be adopted as routine works, then it is important that the species used are as widely available and easily propagated as possible.
16.	Long term maintenance burden: what sort of maintenance tasks are likely to be required in order that each bio-engineering system will develop as required and fulfil its function indefinitely?	Both the road embankments and the plants on them are dynamic and need some level of maintenance. Plant performance must be monitored in order to determine how best to ensure they serve their engineering functions.
17.	Production of useful materials: what materials of use to mankind are produced by the plants, and how might these best be utilised?	As an additional benefit, a record needs to be made of what useful products can be derived from the plants used in the bio-engineering systems, how they need to be managed and who should use them.

Special note on the timing of bio-engineering works in Cambodia

On the basis of experience from elsewhere, it is tempting to assume that bio-engineering works would be most successful if planting were to be implemented as soon as the soil has been adequately wetted by rains in the south-west monsoon. The FA/CTSP (2005) guidelines for forestry planting simply state “The best time for planting is the start of the rainy season which varies a little among different ecological zones (early May-early June).” However, initial reviews suggested that there may be two differing reasons why this may not be most appropriate.

Nesbitt (1995) summarises the Cambodian climate from the perspective of rice cultivation. “Cambodia experiences a typical monsoonal climate with the major proportion of rain falling during the warmer months of May through to October. Little rain falls between December and March… However, variability is large both between years and between zones. Most areas tend to experience an annual bimodal rainfall pattern with peaks in either May, June, July or August and the second in September or October. Steady rain in the early months is healthy for the establishment of pre rice crops. However, this is (un) predictably followed by a mini drought of 2-6 weeks or longer. For this reason the cultivation of upland crops is not recommended in most of these areas except in the better drained soils possessing superior water holding capacities… Ambient temperatures remain reasonably constant throughout the year with the mean maximum in Phnom Penh being 33°C and the mean minimum, 23°C. The hottest months are March-May as the day lengths steadily increase and cloud cover is still minimal. It is during this period that evaporation peaks, placing considerable physiological pressure on crops.” The varieties of rice used in the upland areas of Cambodia are drought tolerant, since there is a risk of lack of water in the likely but unpredictable period of reduced rain between the bimodal peaks of rainfall. It is important to note that because the earlier peak can occur over quite a wide time range (May to August), it is not visible in tables or graphs showing mean monthly rainfall over a number of years.

Dung et al. (2003) have identified the other difficulty of planting bio-engineering works in the parts of Cambodia subject to flooding, in the course of their trials of vetiver on canal banks in An Giang, immediately across the southern border in Vietnam. They found that, if grass was planted as soon as the rain started, it did not establish sufficiently well to survive inundation once the annual floods came; if it was planted in the dry season so that it did establish in time, it needed a significant amount of watering for at least two months after planting so that it not only survived the drought, but grew vigorously enough to survive the later inundation. The solution that they adopted was to plant immediately after the rainy season, to take advantage of the available soil moisture as the water level receded, which allowed the grasses to become established before the onset of the next dry season.

Annex A2: Initial Lists of Plant Species for Trials

Table A2.1. Plants Recommended for Bio-engineering trials.

Khmer name	Botanical name	Characteristics	Additional and cautionary notes
Grasses			
Âmbaôhs, treng	*Phragmites vallatoria*	Large-leaved tall grass found very commonly on river edges.	Probably grows only in sites with year-round moisture (i.e. not on embankment slopes).
Sböw	*Imperata cylindrica*	Tough, large stature grass, well known for its tendency to invade cleared forest areas across SE Asia; widely used for thatching.	May not stand flooding for long periods, but very drought tolerant; may be invasive of adjacent farm land, so try in small areas first.
Sböw rôniët	*Themeda gigantea*	Tough, large stature grass, common invader of disturbed forests; widely used for thatching.	As for *Imperata cylindrical*.
Skië, sbow rônndahs	*Vetiveria zizanioides*	Large stature grass, abundant in the plains.	Huge amounts of information available about this plant, but not in the Cambodian context.
Slëk kréi	*Cymbopogon nardus*	Citronella; medium-stature grass much cultivated in gardens.	Performance in floods not known; may be prone to grazing.
Slëk kréi sabu	*Cymbopogon citratus*	Lemon grass; large stature grass, introduced but widely cultivated.	As for *Cymbopogon nardus*.
Shrubs and small trees			
Âmpil tük	*Pithecellobium dulce*	Small tree, 6 to 10 m tall, small leaves and thorny branches, common on embankments; edible fruit.	Known to have exceptional drought tolerance, so try on the driest, most sandy embankments.
Lhông khwâ:ng	*Jatropha curcas*	Shrub 2 to 5 metres high; grows easily from cuttings; widely used for hedging; shallow-rooted but easy to propagate.	Rooting is weak, so it should be used in combination with other shrubs if it is to withstand wave or current erosion.
Paboiy	Not identified	Woody shrub, 2 to 4 metres high, that colonises embankments.	Consider trying both propagation from seed and use from woody cuttings.
Rèak sâ	*Calotropis gigantea*	Bushy shrub, large pale green leaves and milky sap, that colonises embankments; deep tap roots.	When used in Nepal, this was difficult to germinate from seeds in nurseries.
Rèang	*Barringtonia asiatica*	Tree that colonises embankments; very common.	Consider trying both propagation from seed and use from woody cuttings.
Rumché:k srôk	*Pandanus humilis*	Shrub with long thorny, fleshy leaves, 2 to 3 metres high, producing many suckers; used for hedges.	Grows on river banks and in swampy areas; as it is a semi-succulent, it may also have good drought tolerance.
Sângkaè	*Combretun quadrangulare*	Small tree common on embankments; given as *C. laciferum* in SWK (2002).	Consider trying both propagation from seed and use from woody cuttings.
Smach téhs	*Acacia auriculiformis*	Fast-growing Australian tree often planted along roadsides	Known to grow well in dry locations; performance in flooded sites is not known.
Tros	Not identified	Woody shrub, 2 to 4 metres high, that colonises and grows strongly on embankments.	Consider trying both propagation from seed and use from woody cuttings.
Non-grass herbs and other small plants			
None recommended		Unlikely to be strong enough to withstand wave impact.	

(Main source for identification and Khmer spellings: Dy Phon ,2000).

Table A2.2. Plants Not Recommended for Bio-engineering Trials. .

Khmer name	Botanical name	Notes	Reason for not using
Grasses			
Smau chénhchiën	*Cynodon dactylon*	Small, creeping sward grass, very common on grazed land; withstands heavy grazing and long inundation.	Weak rooting characteristics and the poor strength of the aerial parts makes it unlikely to withstand sustained wave damage.
Shrubs and small trees			
Prèah khlâ:b yiëk	*Mimosa pigra*	Thin, thorny shrub that grows widely on the edges of wet areas and the lower fringes of embankments.	Unpopular with farmers, who say that it damages young fish during floods and causes infections.
Non-grass herbs and other small plants			
Kâmphlaôk	*Eichhornia crassipes*	Water hyacinth, a prolific filler of wet areas.	This plant is too hazardous as an aggressive, invasive weed in slow-moving waterways.
Prèah khlâ:b	*Mimosa pudica*	Creeping herb with sensitive leaves; colonises many bare areas.	Weak rooting characteristics and the poor strength of the aerial parts makes it unlikely to withstand sustained wave damage.

(Main source for identification and Khmer spellings: Dy Phon ,2000)

Selecting plants for bio-engineering

Bio-engineering works require a large number of plants with very particular characteristics. The questions below provide a check-list of the attributes that must be satisfied in identifying appropriate plants. Choice of technique is an important first step because this determines the main category of plant types.

- Which bio-engineering techniques will address the specific problems on the site?
- What plant types (i.e. grasses, shrubs, trees or bamboos) are appropriate to use in those techniques?
- Which species fulfil these requirements and are suited to the environmental conditions of the site (see below)?
- Which of these species have the right characteristics (see below)?
- Which species can be made available at the right place, at the right time and in sufficient quantities?

For use on embankment slopes, **all plants** must be:

- Able to grow vigorously in very poor soils;
- Able to grow vigorously in full sunlight with no initial shade;
- Able to withstand 2 to 4 months of flooding;
- Able to withstand 2 to 4 months of water stress and drought;
- Perennial;
- Deep-rooting;
- Resistant to grazing;
- Acceptable to neighbouring farmers (i.e. not recognised as an invasive weed).

Grasses must be of the large variety (at least 2 metres tall) that forms dense clumps.

Shrubs must be capable of propagation by hardwood cuttings.

If there is still a choice of species after all the other criteria have been satisfied, then the plant that provides the most **useful products** (e.g. fruit, thatch or poles) should be selected.

References

Dung, L.V., Phong, L.T., Danh, L.T. and Truong, P. 2003. Vetiver system for wave and current control in the Mekong delta, Vietnam. Proceedings of the Third International Conference on Vetiver and Exhibition, October 2003, Guangzhou.

Dy Phon, P. 2000. *Dictionary of Plants Used in Cambodia*. Imprimerie Olympic, Phnom Penh.

FA/CTSP (Forestry Administration and Cambodia Tree Seed Project). 2005. Guidelines for Site Selection and Tree Planting in Cambodia. Forestry Administration and Cambodia Tree Seed Project (DANIDA), Phnom Penh.

IFRC (International Federation of Red Cross and Red Crescent Societies). 2003. Red Cross / Red Crescent operating mechanisms at the regional level. Second Annual Flood Forum, October 2003. Cambodia National Mekong Committee and Mekong River Commission.

ITC (Institut de Technologie du Cambodge). 2004. Erosion des Berges du Mékong au Cambodge. Project PCSIU-2004, Département de Génie Rural, Institut de Technologie du Cambodge, Phnom Penh.

Mao, H. 2005. Cambodia Country Paper. Third Annual Flood Forum, April 2005. Mekong River Commission.

MRD (Ministry of Rural Development). 2006. *Strategic Plan for Rural Roads*. Ministry of Rural Development, Phnom Penh.

Nesbitt, H.J. 1995. Rice production systems in Cambodia. In White, P.F., Oberthür, T. and Domingo, L.V. (Eds). *Classifying Cambodian Soils from an Agronomic Perspective*. Proceedings of an in-country workshop on the classification of soils used for rice production in Cambodia, May 1995. Cambodia-IRRI-Australia Project, Phnom Penh.

Sanchez, P.A. and Buol, S.W. 1985. Agronomic taxonomy for wetlands. In: *Wetland Soils: Characterization, Classification and Utilization*, pp 207-228. International Rice Research Institute, Manila.

Schiechtl, H. M, and Stern, R. 1997. *Water Bioengineering Techniques*. Blackwell Science, Oxford

So, S. 2003. Floods and droughts in 2002 in the Cambodian parts of the Mekong Basin - exposure, response and lessons learned. Second Annual Flood Forum, October 2003. Mekong River Commission.

Truong, P., Tan Van, T. and Pinners, E. 2007. *Vetiver System Applications: Technical Reference Manual*. The Vetiver Network International, www.vetiver.org.

White, P.F., Oberthür, T. and Sovuthy, P. (Eds). 1997. *The Soils Used for Rice Production in Cambodia: a Manual for their Identification and Management*. Cambodia-IRRI-Australia Project, Phnom Penh.

Yit, B. 2004. Risk Management and Mitigation for Flood and Sediment Disaster. Cambodian Country Paper for International Conference, Ministry of Public Works and Transport, Phnom Penh.

ROYAL GOVERNMENT OF CAMBODIA

SOUTH EAST ASIA COMMUNITY ACCESS PROGRAMME

DEVELOPMENT OF LOCAL RESOURCE BASED STANDARDS

STUDY OF ROAD EMBANKMENT EROSION AND PROTECTION

APPENDIX B
SUMMARY OF SITE INVESTIGATIONS

SEACAP 019

5 National Road No. 1

Date of visit: 7 September 2007.

Km 19

On the river side (NE) of the road there is recently built mortared masonry embankment protection. The embankment is about 4 metres high, and though the river bank is about 400 metres away, this section of road has clearly been subject to occasional severe flooding. The protection has been nicely finished with the flat faces of limestone rocks, and good (though often wide) brushed concrete pointing in between. The stone size is mainly in the 300 to 600 mm range, and has apparently been bedded directly on to the embankment so that it is only one stone, or about 300 mm, thick. There is a line of gabion at the toe. No provision has been made for water to drain out of the soil embankment.

Apparently the river used to overtop the road at this point, so the embankment has been raised to stop this happening. There is no erosion protection on the other side of the embankment.

This was said to be an example of the lowest cost type of hard engineering solution adopted by MPWT.

Km 39.5

An irrigation channel crossed by the road; the bank protection on the channel was examined . The water passes under the road by means of a large culvert, with reinforced concrete walls projecting beyond the road like a big flume. At the end of these, a gabion revetment has been damaged by the swirl of water when in full flow. Where the channel goes round a bend, its sides have been protected with mortared masonry. Otherwise the channel banks seem to have been left unprotected.

There was an interesting grass growing here, which was later found to be very common in riverine areas. It is medium-sized in stature, 2 to 3 metres high; the leaves are 10 to 20 mm wide, with a distinctive single pale streak running up the inner spine. It grows on gabions, and therefore is probably tolerant of drought (unless the roots are penetrating right through); and it also grows on mud banks and along the water's edge, where it is inundated for long periods. It is not listed in Dy Phon's dictionary.

Km 42.5

A plantation of *Acacia auriculiformis* (smach téhs) has recently been finished on the western slope of a newly formed embankment about 8 metres high, on the approach to a bridge, and continues for about 2 km. There is also a line of turfs of *Cynodon dactylon* (smau chénhchiën), the common creeping Bermuda grass, laid about 75 cm from the edge of the asphalt pavement on both sides. This is struggling to establish as the soil around it erodes due to runoff and spray from the road. There is no other protection on the steep slope of bare, unconsolidated soil. The trees were being watered.

Km 48

Acacia auriculiformis (smach téhs), planted a year ago on the approach to another bridge, appear to have established well and to be growing quickly. *Cynodon dactylon* (smau chénhchiën) is starting to spread between the trees.

Km 68

An example of bad piping of soil from the internal structure of a high section of relatively new embankment (constructed in 2003 during rehabilitation), but obviously with problems of compaction and drainage. The piping has occurred right at the end of a section of mortared masonry slope protection about 800 metres long, on the southern side of the road. The fate of the eroded material is not clear, partly because an earth access track has recently been made on the side of the embankment at this point. However, there is a void of at least several cubic metres in volume in the embankment, including the edge of the road formation.

6 National Road No. 7

Dates of visits: 5 and 7 September 2007.

Km 51 (approx.)

Along this section of road, north of the RN 6A-7 junction with RN 61, the embankment was re-made a few years ago. There are *Acacia auriculiformis* (smach téhs) and *Eucalyptus* sp. (doëm pré:ng) planted along the sides of the embankment, and these are growing well. However, nothing was planted in between, so the surface cover remains a weak mixture of creeping grasses and annual herbs.

Km 128 (approx.)

Acacia auriculiformis (smach téhs) planted on the slope of an embankment 5 to 6 metres high on the approach to a large new bridge. These seem to be growing well. There is an understorey of *Cynodon dactylon* (smau chénhchiën).

7 National Road No. 8

Date of visit: 5 September 2007.

This is a new road, mainly gravel-surfaced, recently upgraded from an MRD local road. At the point of inspection, a few kilometres east of the Mekong ferry near Preah Prasab, there was an unprotected embankment 2 to 2.5 metres high and eroding badly. The land to the south was flooded, and it was clear that in the past, when the flood level was higher, waves had cut a step near the toe of the embankment slope. This had a vertical or overhanging face about 50 to 60 cm high. Rills on the slope were 5 to 10 cm wide and about 50 cm deep. The material was very loose and unconsolidated, and in places pipe erosion was also taking place. The northern side was very similar, with just as large a wave step and as much active erosion. *Mimosa pigra* (prèah khlâ:b yiëk), the unpopular thorny shrub, was growing along the ground below the embankment, but nothing much was growing on the eroding slopes.

8 National Road No. 11

Date of visit: 7 September 2007.

Km 65

At this point the road runs very close to the main Mekong channel. There is a long section of gabion mattress to protect the western side of the embankment against river scour. This was presumably constructed in 2002 and 2003 under the Emergency Flood Rehabilitation Project. It seems to be performing well, except that there is worrying corrosion of the mesh wire on the lower levels. A wide range of plants are colonising the gabion, including the grass noted at km 39.1 on RN 1, and the common but unpopular *Mimosa pigra* (prèah khlâ:b yiëk).

Km 70 (approx.)

A long section of the embankment here has been planted with *Combretun quadrangulare* (sângkaè), again presumably in 2003 under the Emergency Flood Rehabilitation Project. These small trees appear to have been planted from hardwood cuttings (their form shows that they would certainly grow from such a method). They are growing well. Once established, they are obviously resistant to grazing by the numerous cattle roaming the area. However, there is no surface cover of the soil underneath the sângkaè, and since they are spaced around 1.5 to 2 metres apart, the result is that erosion is still taking place. The *Cynodon dactylon* (smau chénhchiën) grass that is dense at the bottom of the embankment is very sparse among the sângkaè itself. There are numerous annual herbs colonising the bare ground in places, but these are mainly shallow-rooted plants like *Eupatorium adenophorum* and the legume *Cassia tora* (dânghët chhniëng).

Km 72 (approx.)

A floodway with gabion mattressing on both sides of the embankment and depth markers along the roadsides. There is some piping out of fill in the embankment, affecting both the side slope and the edge of the road itself. There seems to be a geotextile membrane under the gabion work, so it is difficult to see what has happened to the eroded material. It is possible that it is related to settlement resulting from poorly compacted fill, or subsidence of the ground below the embankment.

Km 84

A mixture of planting, with *Combretun quadrangulare* (sângkaè) on the lower half of the embankment slopes and *Jatropha curcas* (lhông khwâ:ng) on the upper part. The embankment here is relatively low, being only about 2.5 metres in height. The shrubs are growing well and look good from a distance, but there is very little ground cover underneath, so that the soil surface remains bare and erodible under the canopy.

Km 130

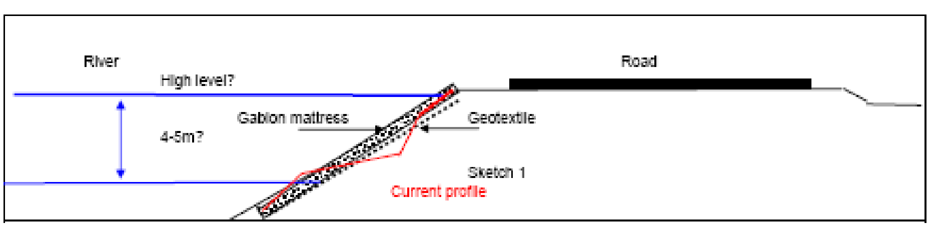
In this area there are several kilometres of embankment slopes planted mainly with *Acacia auriculiformis* (smach téhs), but also with a few *Combretun quadrangulare* (sângkaè) mixed in. The smach téhs is now 4 to 5 metres in height and is shaping into a fine avenue. However, these large plants are quite sparse, forming one main line of trees at an average spacing of about 1.5 metres. The result is better ground cover than in the denser roadside plantations seen in the previous sites, but only with a cover of creeping low grass and annual legumes; so it does not appear that the slopes here are any better protected against the impacts of waves than are those elsewhere.

9 National Road No. 21

Dates of visits: 13 June and 29 August 2007.

Km 26, Phreaek Koy (GPS 0500427 / 1256792)

At this point, the road is very close to the bank of the Bassac river, on the outside of a large bend. It is exactly the kind of location where bank erosion should be expected. In June, when it was mainly above water, this was diagnosed as a river bank failure below the road due to ineffective gabion mattress works, possibly in combination with blocked drainage paths (see Sketch 1 below). The embankment had slumped, exposing broken gabion and underlying geotextile.

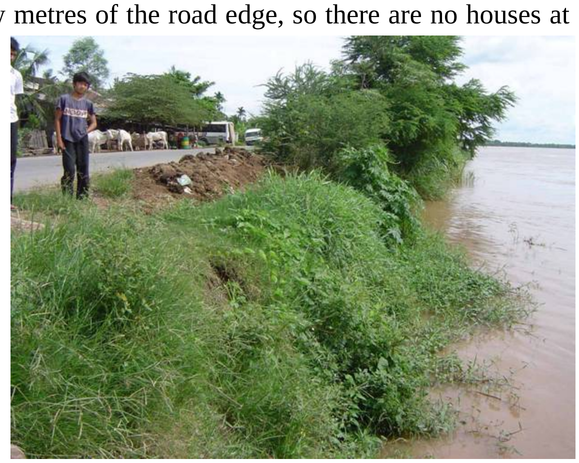


In fact the section of road threatened by bank erosion extends considerably beyond the section where gabion mattressing has been installed in the past. The slump has left a steep earth bank close to the road, along a stretch of at least 100 metres. Beyond this, the bank is further from the road (perhaps 10 to 15 metres), but its retreat is threatening the backs of a number of properties: it has a ragged plan, with some protrusions into the river and bays in between extending towards the road. There was evidence that the protrusions were associated with the presence of small trees like *Pithecellobium dulce* (âmpil tük). The local people claim that the bank is eroding at about 5 metres per year, and they are attempting to slow it by means of sand bag walls, and small piling of bamboos and tin sheets. It is difficult to determine how true this estimated rate of retreat is, but it is certainly gradual rather than sudden, and the vegetation seemed to be fairly thick along the river side of the bank. In August the river level was about 2 metres below the top of the embankment.

This site history appears to be rather complex. It is described in a consultant's report by Scott Wilson Kirkpatrick, dated November 2002: Expert Report on Embankment Erosion (Emergency Flood Rehabilitation Project, Ministry of Public Works and Transport). At that time a site assessment was carried out and the previous design for a major gabion wall on top of a rock fill foundation was changed in favour of the more flexible gabion mattress solution, on the grounds that there did not appear to be a deep-seated failure. This solution appears to have been implemented, as shown by a photograph dated 26 August 2003 in a later report by Scott Wilson Kirkpatrick: Monthly Report for December 2003 (Emergency Flood Rehabilitation Project, Ministry of Public Works and Transport). However, this later report also contains a photograph showing subsequent failure of the newly finished work following the lowering of water levels after the 2003 flood. The report appears to have brought out the original rock fill and gabion design again as a proposed final solution, though it also records that an expert was awaited from head office before implementing any further work. We have not been able to establish what actually happened after that.

Km 35 (approx.), Kaoh Khael (GPS 0503025 / 1244956)

Another area of erosion of the bank of the Bassac, on the outside of a gentle bend. Along most of the length of the failing bank, the river is within a few metres of the road edge, so there are no houses at this site. In June it was noted that erosion may have been exacerbated locally by human and animal access to the river, and while this is true, the major cause is the flow of the main current against the earth bank. The material is a stiff light brown, clayey silt, and it was sampled for testing during the June visit. At the time of the August visit, some small slumps were active in the edge of the road embankment where it was closest to the river, but otherwise the retreat of the river bank is gradual, and vegetation is present along most of the embankment side, even if this only consists of grasses and a few shrubs.



There are small trees in places, up to 7 or 8 metres high and mainly of *Pithecellobium dulce* (âmpil tük). Where these are found, the river bank is further back, but it is eating in between them. Some of these trees are quite old, and appear to have been coppiced. Even though the current has washed away the soil from some of the upper roots, they are still growing vigorously.

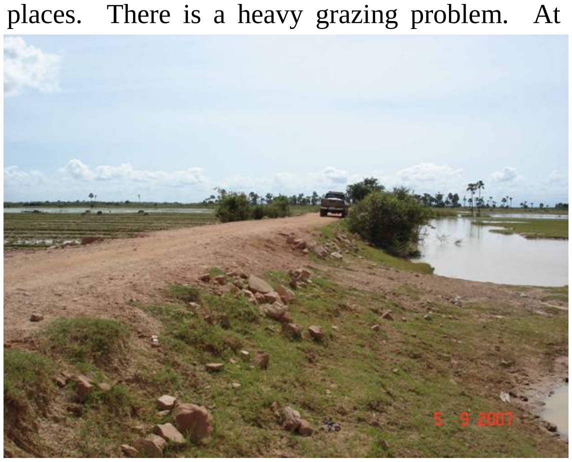
South of where the road is threatened by the river, some houses between the road and the river are also threatened by the erosion of the bank. Behind one of these, two species of trees have been deliberately planted to help slow the retreat of the bank. These were 2 to 3 years old and were growing well in several metres of flowing water. Unfortunately they could not be identified.

10 Local Roads

Date of visit: 5 September 2007.

Bati Commune - Omal Village Road (off RN 7)

This road is being upgraded progressively over a number of years. An earth track through the rice fields is being raised and improved to form an earth road on an embankment. There is no systematic effort to protect the embankment, but a number of both herbs, and annual and woody shrubs, have colonised the slopes in different places. There is a heavy grazing problem. At one site, there seemed to have been some grasses planted, but they had been eaten nearly out of existence. Some *Acacia auriculiformis* (smach téhs) seedlings had been planted recently, but they were rather close to the road (which was very narrow in any case).



New Local Road off RN 8

A steep embankment was being formed on this road, which was still under construction at the time of the visit. It was said that a number of shrubs had been planted on the slopes last year specifically to stop erosion, but they did not survive at all. No one was sure of the species used.