Conference Version

Climate Resilient Roads

Cambodia Rural Roads Improvement Project:
Results from Climate Change Adaptation

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This document was produced as part of the Nordic Development Fund's project C15: *Adaptation Approaches for the Transport Sector* under the ADB funded *Rural Roads Improvement Project* in Cambodia.

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Acronyms and Abbreviations

ADB	Asian Development Bank
CMDG	Cambodian Millennium Development Goals
CNMC	Cambodia National Mekong Committee
Danida	Danish International Development Agency
DDIS	Detailed Design and Implementation Supervision
DRR	Department of Rural Roads, MRD
EMRC	Emergency Management and Response Centre
FMMP	Flood Management and Mitigation Programme
FWUC	Farmer Water User Communities
GIS	Geography Information System
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Cooperation Agency
MIME	Ministry of Industry, Mines and Energy
MLMUPC	Ministry of Land Management, Urban Planning and Construction
MoE	Ministry of Environment
MoH	Ministry of Health
MOWRAM	Ministry of Water Resources and Meteorology
MPF	Multi-Purpose Farming
MPWT	Ministry of Public Works and Transport
MRD	Ministry of Rural Development
NAPA	National Adaptation Programme of Action to Climate Change
NCDM	National Committee for Disaster Management
NDF	Nordic Development Fund
NGOs	Non-governmental Organisations
NIS	National Institute of Statistics
QP	Quarterly Period
QPR	Quarterly Progress Report
RFMMC	Regional Flood Management and Mitigation Centre
RGC	Royal Government of Cambodia
RRAMP	Rural Roads Asset Management Project
RRIP	Rural Roads Improvement Project
RS	Right side
RST	Road Survey Technology
RUPP	Royal University of Phnom Penh
SEACAP	South East Asia Community Access Programme
SEILA	Decentralised Rural Development Programme (Cambodian Government/UNDP)
SIDA	Swedish International Development Agency
SNAP	Strategic National Action Plan for Disaster Risk Reduction
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Vehicle operating cost
WB	World Bank
WFP	World Food Programme

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1 Introduction

The annual mean temperature in Cambodia is increasing. In a tropical climate zone, that is projected to result in increased rainfall during rainy seasons and longer drought periods during the dry seasons. Subsequently, areas that are affected by flooding and drought today will be even more exposed to flooding and drought in the future and the geographical areas affected are likely to increase.

Several regions in rural Cambodia are heavily affected by negative climate impacts. Flooding, for example, severely decreases accessibility to health care, markets and other social services for several months every year.

As with many hazards, the best way to avoid damage caused by climate change are prevention and preparedness. Suitable methods for mitigation of various negative climate impacts on physical infrastructure are thoroughly described in this report together with supporting financial and cost & benefit analyses. Suitable methods for vulnerability mapping in general and vulnerability mapping of roads in particular are described, including a case study, at the end of this report.

Using climate-related projections and implementing procedures and methods as described in the following chapters, Cambodia will become more resilient to negative impacts from climate change.

2 Engineering Adaptation Options for Rural Roads

Rural roads are a big part of the Cambodian transport network. Rural roads are often the only link granting communities access to social and economic services and are therefore crucial for the survival of many Cambodian societies.

Climate-related risks and their impact on physical infrastructure are presented and evaluated in this report, along with suitable adaptation options.

A theoretical case study where various engineering adaptation options are implemented for road no. 2620/2KT2, including cost & benefit analyses, is presented. The case study road is located in Kampong Thom province and has repeatedly been severely affected by climate events like flooding. The length of road no. 2620 is 59.9 km and 2KT 2 is 6.1 km.

3 Climate-Related Hazards

Different climate change events and suitable mitigation measures are presented. Table 1 below presents events related to climate change and their possible effects on road infrastructure.

Table 2.1: Possible Climate Events and Risks to Roads

Climate Change Events	Risks to the Road Infrastructure
Extreme rainfall events	• Overtopping and wash away • Increase of seepage and infiltration pass • Increase of hydrodynamic pressure of roads • Decreased cohesion of soil compaction • Traffic hindrance and safety
Seasonal and annual average rainfall	• Impact on soil moisture levels, affecting the structural integrity of roads, bridges and tunnels • Adverse impact of standing water on the road base • Risk of floods from runoff, landslides, slope failures and damage to roads if changes occur in the precipitation pattern
Higher maximum temperature and higher number of consecutive hot days (heat waves)	• Concerns regarding pavement integrity, e.g. softening, traffic-related rutting, embrittlement (cracking), migration of liquid asphalt • Thermal expansion in bridge expansion joints and paved surfaces • Impact on landscaping • Temperature break soil cohesion and increase dust volume which caused health and traffic accidents
Drought (Consecutive dry days)	• Susceptibility to wildfires that threaten the transportation infrastructure directly • Susceptibility to mudslides in areas deforested by wildfires • Consolidation of the substructure with (unequal) settlement as a consequence • More smog • Unavailability of water for compaction work • Drought decreases mortality of plants along road alignments
Extreme wind speed	• Threat to stability of bridge decks • Damage to signs, lighting fixtures and supports • Increase of wind speed causes the dynamic force of water generated by waves on road embankments
Foggy days	• Traffic hindrance and safety • More smog

Source: RIMAROCC (Risk Management for Roads in a Changing Climate), ERA-NET ROAD (Coordination and Implementation of Road Research in Europe)

The main climate events in Cambodia are droughts, river floods, and flash floods due to heavy rains. All these events may have major impacts on road infrastructure.

The following table lists these events and what measures may be used to minimize the impacts.

Table 2.2: Possible Climate Change Events, Risks and General Mitigation Measures

Climate event	Risks to road infrastructure	Measures
Heavy rain for longer periods	• Water overtopping on road crest • Increased capacity of moistures and decreased cohesion of soil and increased seepage and infiltration across road body • Drainage system over capacity of and increase drainage erosion • Embankment instability or loss, road wash away	• Increase road level to at least 0.5 m over the maximum flood level • Erosion protection • Increase capacity of culverts Build up weirs and spillways • Increase capacity of compaction (lower moisture percentage) • Decrease hydrodynamic force of water through planting • Use resistant materials for building roads
Storm events (Typhoons, Cyclones) and extreme winds	• Destabilisation of bridges Trees blocking the roadway Damage to traffic signs	• Increase capacity of spillways and culverts • Embankment protection through tree plantings • Increase road inspections • Decrease road traffic during storms

4 Adaptation Options

With regards to climate change impacts, some methods are proposed to adapt to climate change events, especially flooding, which always cause damage to rural roads in Cambodia. Proposed Adaptation Options are shown in Table 4.1, discussed in detail in this chapter and with estimated cost in chapter 6.

Table 4.1: Proposed Climate Change Adaptation Options

No.	Description adaptation options
I	**Road specific**
I.1	Raising road level
I.2	Adjusting side slope

I.3	Paving road surface
II	**Drainage**
II.1	Improvement of cross drainage (culverts, bridges and spillways)
II.2	Ditches and drains
II.3	Permeable road
II.4	Install debris deflectors
II.5	Underdrain
II.6	Scour checks
II.7	Cut-off ditches
III	**Erosion**
III.1	Retaining walls
III.2	Gabions
III.3	Rip-Rap Protection
III.4	Grass sodding
III.5	Groynes (stream or longitudinal erosion conditions)
IV	**Hydrology**
IV.1	Ponds (retention/detention)
IV.2	Irrigation dams
V	Maintenance
V.1	Dust control
V.2	Inspection and repairs of road surface deformation
V.3	Clearing and cleaning culverts and drains
V.4	Inspection and Repair of erosion protection and scour checks
VI	**Planning**
VI.1	Realignment
VI.2	Revised road design standards
VI.3	Green planning
VI.4	Monitoring

4.1 Road Specific

Road specific is one of the major categorizes which is focus on road strengthen including raising the road level, adjust side slope and paving surface. This adaptation options can be applied in flood/drought prone areas.

4.1.1 Raising Road Level

Raising Road Level is one solution to adapt to climate change events, especially flooding. The road surface level will be raised to an elevation higher than expected flood level to reduce risk of road damage and to prevent an inaccessible road during flood event. According to MRD road standard, road design level should be 0.5 m higher than highest expected flood level.

Road design standard in many countries stipulate sub-grade elevation to be minimum 0.5 m above highest flood level, in order not to allow water to enter and submerge the substructure of the road.

The raised road can block water flowing from one side of the road to the other side, and therefore, it is important that proper cross-drainage of the road is well-considered.

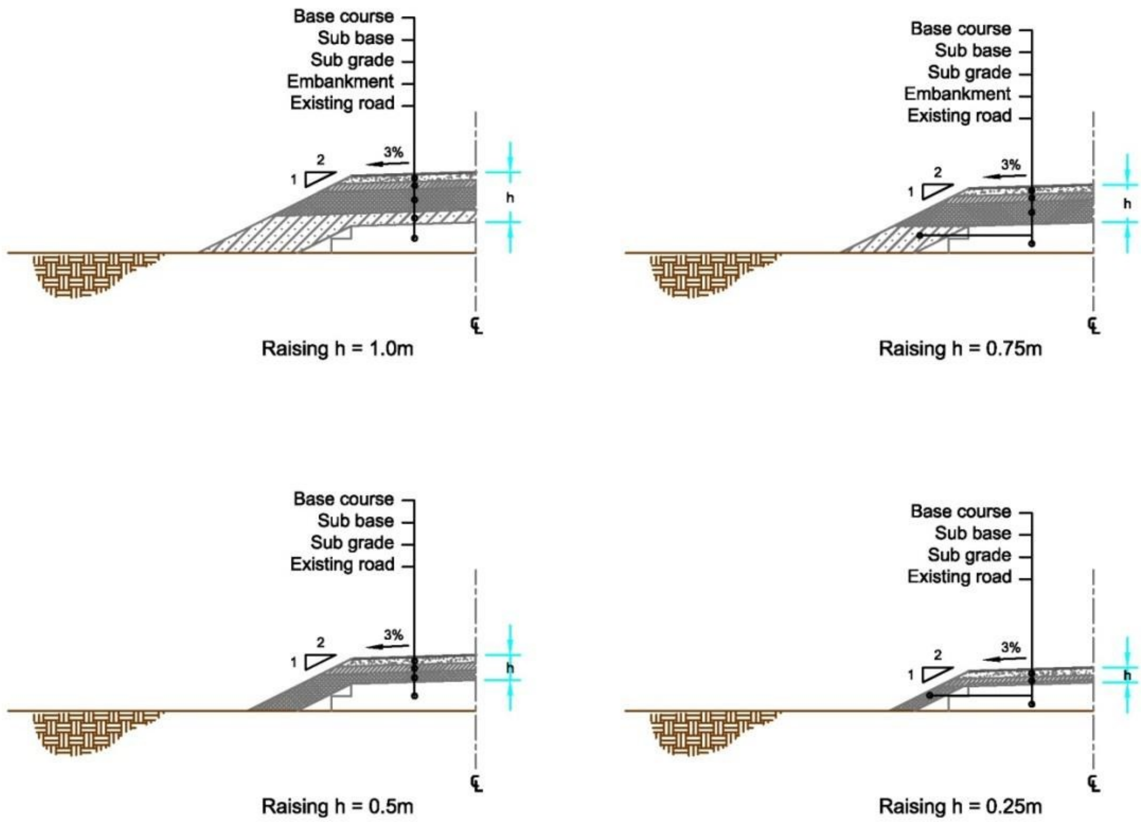
When raising the road elevation, it is important to use suitable materials and to compact the materials in a good manner.

The material shall be free from dirt, organic matter and shall be of such quality that it will form a firm stable course. Grading requirements shall conform to AASHTO, or similar requirements, for embankment, sub-base or base.

Compactions of layers of embankment, sub-base or base shall be in accordance to AASHTO, or similar requirements.

Embankment protection should be considered if there is a risk of erosion of the embankment.

In terms of the road safety problem, guardrails and traffic signs including guide posts should be considered carefully to reduce problems of high road embankment.



Raising the Road Level
Road Width 5m

4.1.2 Adjusting Side Slope

In terms of climate change, side slope should be adjusted from 1:2 to 1:3 or flatter to prevent flood damage and erosion from road surface runoff. Adjusting side slopes from 1:2 to 1:3 will also increase traffic safety of the road. Adjusting side slopes normally requires more land, and if the existing right of way is not sufficient, it might be difficult to acquire additional land.

If it is not possible to flatten the slope to 1:3 other measures could be considered, such as protection of slopes with rip-rap or gabion mattresses especially in areas with erosion problems.

Before starting any construction work, the ownership of land and the possibilities to get additional land need to be clarified.

Construction of a more gentle embankment slope is normally done through the method of benching, as shown below, in order to have a good and safe bond with the existing embankment.

4.1.3 Paving Road Surface

Most Rural Roads in Cambodia are unpaved laterite roads which are vulnerable to extreme weather conditions and climate change conditions.

Paving the surface of rural roads is therefore a good climate change adaptation option. For rural roads with generally low traffic volumes, surface dressings, normally double bituminous surface dressing (DBST), have been widely used in many parts of the world.

During the rainy season, a paved road will have better resistance to flooding, will drain the water from the surface more easily and will reduce the risk of potholes and water stagnation on the road surface. A paved surface will also reduce the risk of water penetrating and submerging the road construction layers and thereby reducing the bearing capacity of the road.

In the dry season, a paved surface will reduce the risk of dust on and around the road. It will increase traffic safety on the road and improve the environment for people living along the road.

4.1.4 Drainage

A good road drainage system, which is properly maintained, is vital for all type of roads.

A good drainage system conveys water from the surface of the road, as well from the different layers of the road structure, to a safe exit (stream or cross drainage structure). The drainage system also intercepts surface water flowing towards the road and conveys water across the road in a controlled fashion.

The destructive power of water increases exponentially as its velocity increases. Therefore, water must not be allowed to develop sufficient volume or velocity so as to cause excessive wear along ditches, at culverts or along exposed running surfaces, cuts or fills.

The presence of excess water within the roadway will adversely affect the properties of the materials with which it was constructed. Cut or fill failures, road surface erosion and weakened subgrades followed by a mass failure are all products of inadequate or poorly-designed drainage.

Different types of drainage structures are discussed below.

4.1.5 Cross Drainage

Climate change might increase rainfall intensity which will increase the risk for overflow and destruction of roads. The cross drainage of the roads, mainly culverts, bridges and spillways should be investigated and, if needed, modified.

When designing cross drainage, it is important to investigate the size and type of drainage to avoid water upstream of the roadreaching levels so high as to overtop the road. It is also important to investigate the areas downstream of the road to avoid erosion of the area due to increased size of cross drainage.

New culverts can be added or existing culverts can be increased in size. Culverts are normally pipe culverts or box culverts.

Pipe culverts are normally 0.5-1.5 m diameter culverts. Culverts with smaller diameters than 0.5m are difficult to clean and are not recommended. Long culverts should not have smaller diameter than one meter because of problems with cleaning when clogged. Pipe culverts can be constructed as single culvert or multiple culverts and they can be cast in place or precast as required.

Pipe culverts are normally constructed as reinforced concrete pipes but can also be made as corrugated metal pipes or plastic pipes.

Box culverts can be single cells or multiple cells. The size of the culverts very much depends of the flow of water and the height of embankment to be able to accommodate the culvert. Box culverts are normally constructed by reinforced concrete and cast in place.

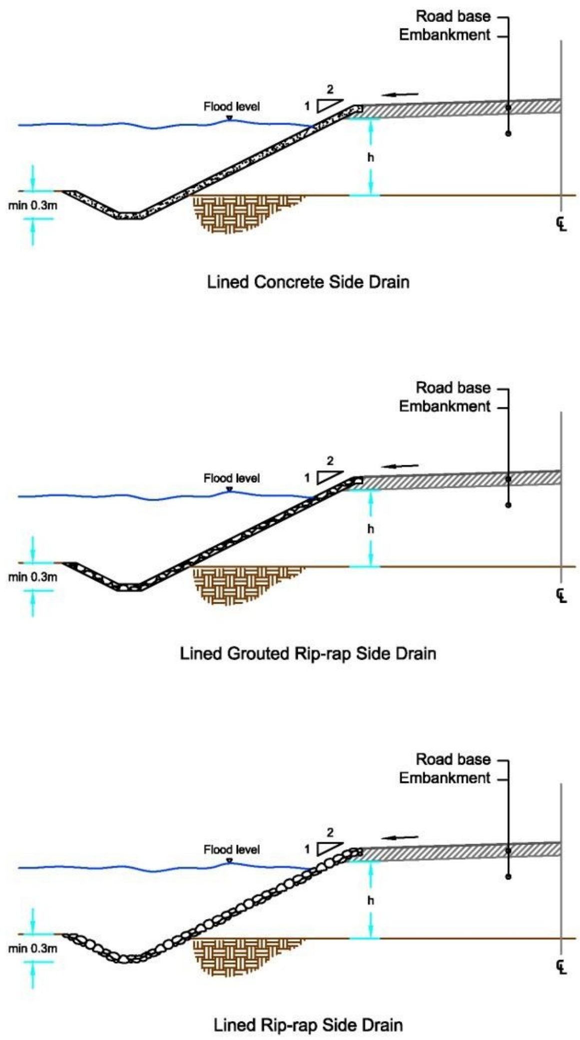
It is important to consider erosion problems around culverts where rapid flow is expected. Especially vulnerable is the outlet of culverts where embankment protection should be considered.

Spillways (Irish crossings) is an alternative solution to be used especially for low traffic roads where a limited amount of water can be accepted passing on top of the road. The spillway might be a good solution when there is a proper flow of water crossing the road and not as good when there is stagnate water on both sides of the road during long periods. The spillway should be designed with a length so that the maximum depth of water, passing the spillway, is not more than 0.25 m in order to have the road passable during floods. There should be proper warning signs before the spillway and guide posts on both sides of the spillways to warn the traffic of danger. The spillway must have a paved surface, preferably of concrete pavement and with protected embankment slopes.

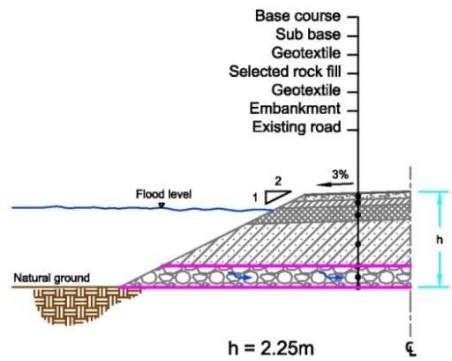
Bridges might be needed when there is a major stream of water. Bridges are generally expensive to extend or replace but additional culverts or spillways can be added to reduce the flow of water at the bridge site.

4.1.6 Ditches and Drains

Ditches or drains are normally constructed when the road passes through cut areas. The elevation of the bottom of the ditch shall be at least 0.2-0.3 m below the subgrade elevation in order for the ditch to drain the pavement structure of the road and collect water from surrounding areas. The size and shape of the ditch can vary depending on the amount of water expected. The ditch shall have a longitudinal slope towards an exit point, where the water can be safely discharged. Ditches can also be constructed at embankments to lead water from surrounding areas towards an exit point. Ditches might be protected by stone riprap or concrete and can also be combined with embankment protection depending on the amount of water expected. Ditches with steep longitudinal slopes are more vulnerable for scour and in need of protection. Normally ditches with slopes steeper than 5%, depending on soil conditions, need some sort of erosion protection measures.



Lined Side Drain



Permeable Road
Road Width 5m

4.1.7 Permeable Road

This option is known as Rock Sandwiches or French Mattresses, and are normally used in extremely wet areas or wet land. A layer consisting of clean rock wrapped in geotextile fabric is placed as the first embankment layer on the ground. The water is then supposed to pass through this layer from one side of the road the other. The rock layer will be a support foundation for the road during wet or muddy conditions.

It might be used in new roads but there is a relatively major risk that the rock passage might be blocked by silty materials which will reduce the flow of water through the embankment.

4.1.8 Debris Deflectors

Debris might be a problem, in some areas, during the rain period. Floating or submerged debris like tree logs, twigs, or leaves can obstruct the waterway entrance of culverts or bridges and block culverts or cause damage to drainage structures.

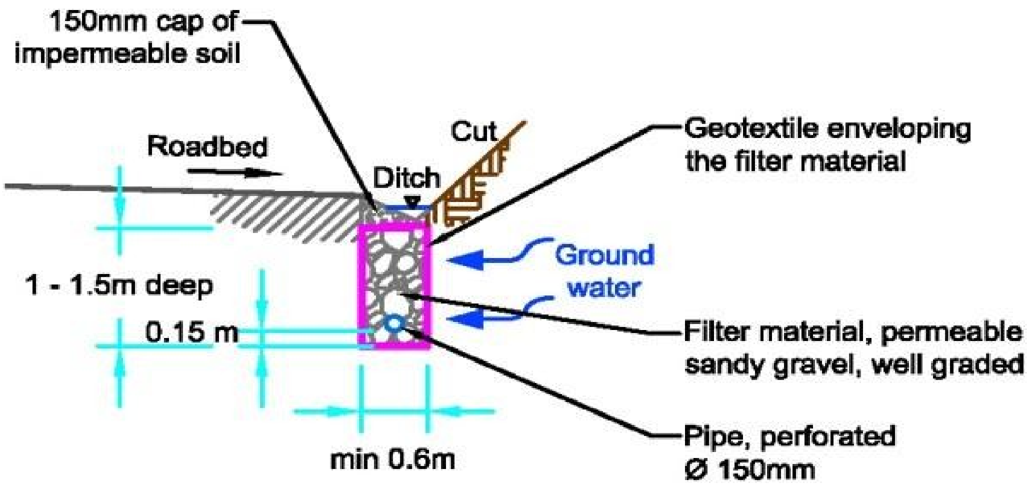
Debris deflectors can be used to protect culverts or bridges from getting clogged. There are many types of different debris deflectors built of steel, timber or concrete.

It is important, especially before the rainy season, to inspect and, if needed, repair the debris deflectors.

4.1.9 Underdrain

Underdrains are mainly used in built-up areas or in other areas with limited space for open ditches.

The purpose of underdrains is to remove water from the structure of the road and to hinder ground water from surrounding areas to reach the road structure. It is important to construct the drain with proper longitudinal slopes towards a safe outlet of the drain. The end of the drain can be a culvert or an embankment area where the elevation of the land is lower than the drain.



Underdrain

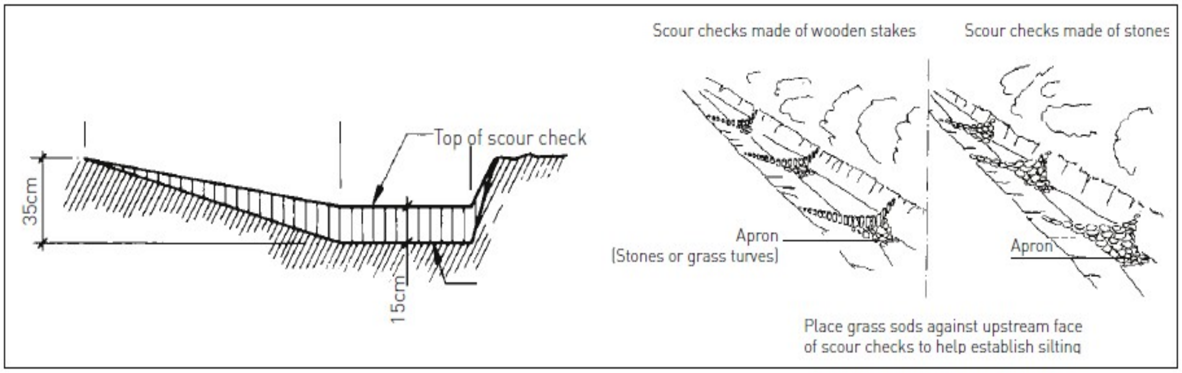
4.1.10 Scour Cecks

Scour checks are considered, in ditches, when the longitudinal slopes are more than about 5%. Scour checks will reduce the speed of the water in order to prevent erosion. It is normally constructed by concrete or stone masonry.

Table 4.2: Proposed Scour Check Spacing

Road gradient (%)	**Scour check spacing (m)**
4 or less	Not required
5	20
6	15
7	10
8	8
9	7
10	6

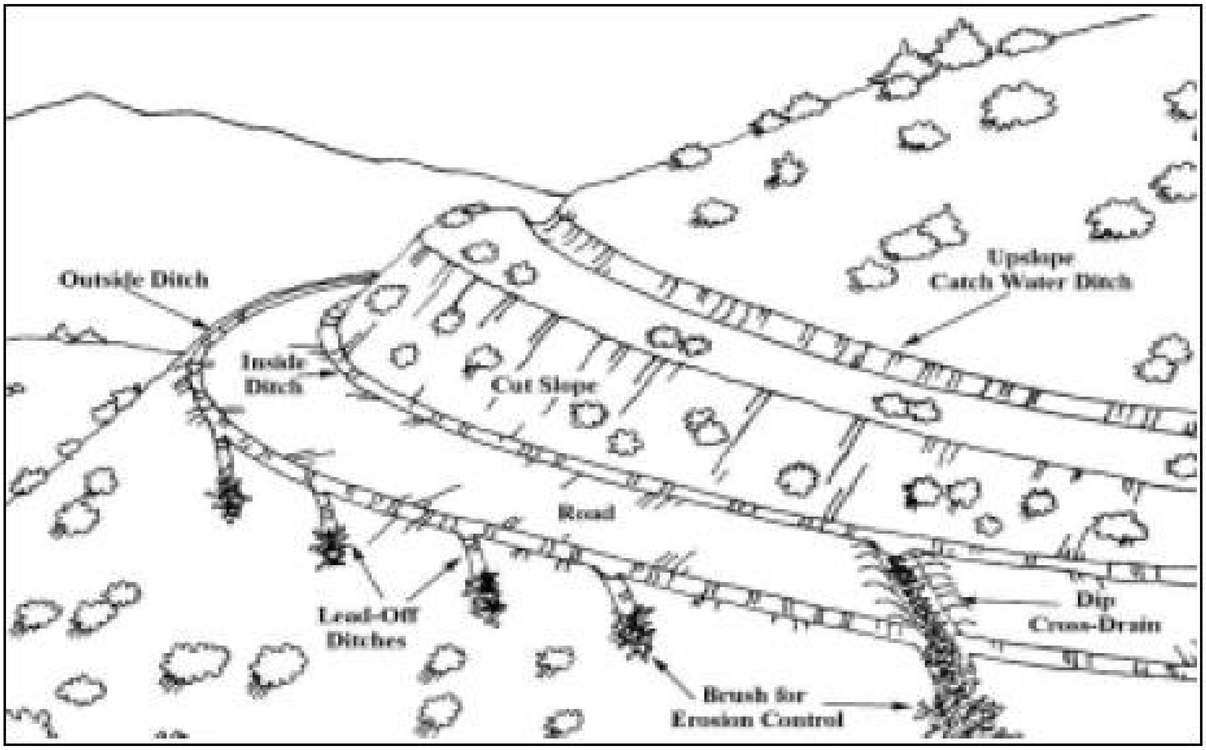
Source: ILO, Building Rural Roads, 2008



4.1.11 Cut-Off Ditches

Cut-off ditches or catch water ditches are normally constructed outside the limit of the road construction, in cut excavation areas, when elevations of surrounding areas are higher than the road. Cut-off ditches are constructed in order to prevent surface water from reaching the road construction.

Cut- off ditches are more or less parallel to the road and must end in a safe area away from the road construction.



4.1.12 Erosion

Erosion is expected to be a major problem, with possible increased rainfall, and to prevent increased erosion might be an important adaptation option to climate change.

The following are some of the methods to try to protect the road and its drainage system.

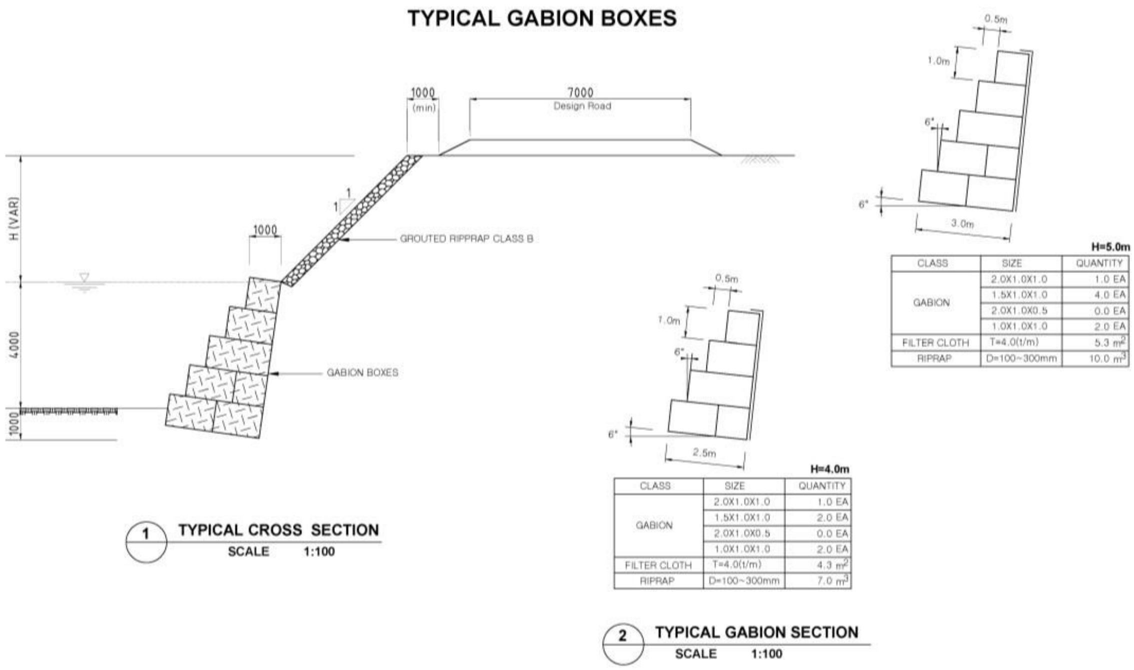
4.1.13 Retaining Walls

Retaining walls of concrete can be constructed along the road both as reinforced concrete wall and as unreinforced concrete wall. It is an expensive option and it will mainly be used when there is a major stream of water or a river flowing along the road and you do not want to reduce the water area with other protection measures.

4.1.14 Gabions

Gabion boxes are rectangular woven wire mesh baskets filled with rock to form flexible, permeable, monolithic structures. The boxes are normally one or two m3 each and can be constructed as shown to form a wall retaining structure.

Gabions can also be constructed as gabion mattresses, normally 30 cm thick, to be put on the embankment slope to protect from erosion.



H=5.0m

CLASS	SIZE	QUANTITY
GABION	2.0X1.0X1.0	1.0 EA
	1.5X1.0X1.0	4.0 EA
	2.0X1.0X0.5	0.0 EA
	1.0X1.0X1.0	2.0 EA
FILTER CLOTH	T=4.0(t/m)	5.3 m^2
RIPRAP	D=100~300mm	10.0 m^3

H=4.0m

CLASS	SIZE	QUANTITY
GABION	2.0X1.0X1.0	1.0 EA
	1.5X1.0X1.0	2.0 EA
	2.0X1.0X0.5	0.0 EA
	1.0X1.0X1.0	2.0 EA
FILTER CLOTH	T=4.0(t/m)	4.3 m^2
RIPRAP	D=100~300mm	7.0 m^3

4.1.15 Rip-rap

Rip-rap is normally used as protection of embankments and consists of layers of stone about 0.25-0.4 m thick.

The stones shall be hard, sound, durable angular field or quarry stones. The stones shall normally have a weight between 10 and 50 kg with shapes to allow for proper placing.

Rip-rap can be used as loose rip-rap where larger stones are placed on the slope and gaps are filled with smaller stones.

Rip-rap can also be constructed as grouted rip-rap when a grout (cement+sand+water) is placed between the stones. The surfaces of the stones shall be cleaned from adhering dirt and clay and shall be thoroughly moistened with water after placement. Grout shall be applied while the stone is moist and shall be worked into the interstices to fill the voids completely.

Grouted rip-rap is more durable but is also slightly more expensive to construct.

4.1.16 Grass Sodding

Grass sodding is a low cost option to protect the road ditches and embankments from erosion impact. Generally, grass may die in the dry season or eaten by domestic animals, requiring regular re-sodding.

The sod consists of live, dense and well-rooted growth of permanent grasses suitable for the soil in which it is to be placed. The sod shall be placed only when the soil is moist and favorable to growth. Deep thick root grass like Vetiver is a plant for soil erosion control which has been used extensively and very successfully in Thailand and Vietnam.

A major problem with grass sodding, in dry areas, is the possible negative effect of dry and hot periods.

4.1.17 Groynes

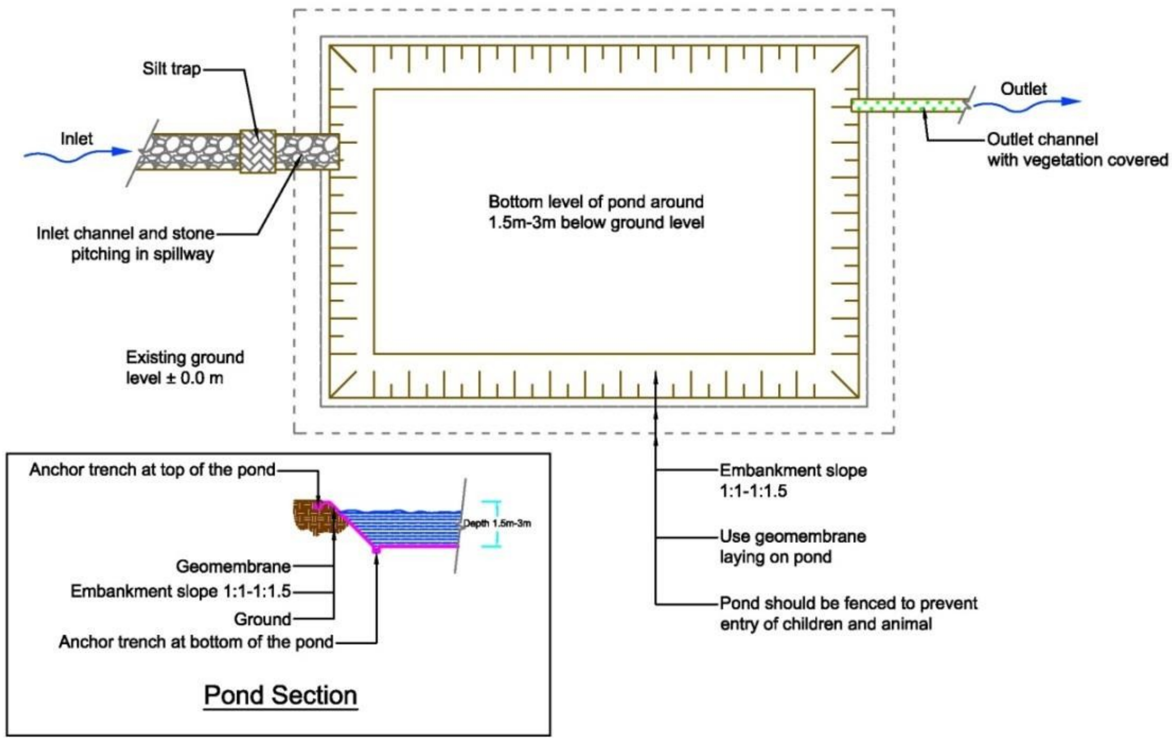
Groynes are structures constructed at an angle to the flow, and the road, in order to deflect the water from the road embankment. The dyke can be constructed from different materials including stone, bamboo, concrete or any material that is not easily detached by the river and is strong enough to withstand the flow and the impacts of debris. It might be suitable for protecting roads which are located along a stream or river.

4.1.18 Hydrology

Ponds and irrigation dams have a very limited effect in protecting roads but can be of use for villages to store water, to be used for irrigation during dry season.

4.1.19 Ponds

A pond is a small reservoir constructed for the purpose of collecting water and storing water from surface runoff. Storing water runoff can reduce the peak flow and erosion and it might be useful for agricultural purpose in areas impacted by drought. In areas with a high infiltration rate of soil, plastic fabric should be used to cover the pond otherwise water would be quickly absorbed. The volume of the pond should be designed depending on the water demand.



Pond

4.1.20 Irrigation Dams

In rural areas, dry season agriculture and the pre-rainy season establishment of food and cash crops cannot be undertaken without large quantities of water. To rely upon stream flow at a time when temperatures and evaporation are often at a peak can be unrealistic and risky. A small irrigation dam could be constructed to solve this problem but before any dam is constructed, an assessment of the hazard potential should be made.

4.2 Maintenance

Regular maintenance is an important part of climate change adaptation in trying to provide year-round use of roads. Many rural roads are in bad condition due to inadequate maintenance and will therefore deteriorate faster than necessary. Rural roads are more vulnerable due to reasons such as low standard construction, heavier traffic than planned for and more effected by weather than planned for.

Maintenance is carried out to prolong the life of the road and delay the day when complete rebuilding will be required. There are several kinds of road maintenance for rural roads such as routine, periodic, emergency and spot maintenance.

Some important areas of maintenance are shown below

4.2.1 Dust Control

Dust is a major problem for unpaved roads during the dry season. Dust will cause accidents on the road due to bad visibility and is a major problem for people living along the road.

Dust can in principle be avoided permanently through paving of the road surface, though this solution might not be economically feasible for all low traffic rural roads.

Dust on unpaved roads can be reduced by applying water, organic binder, petroleum or chemical additives.

Some possible such suppressors, which draw moisture from the air to improve fine aggregate cohesion, can be spread on the road, such as Calcium Chloride, Lignin Sulphonate, Sugar Beet Molassess or Bentonite. Unfortunately, none of these dust suppressors present a long-term solution and they all have to be repeated regularly.

Applying speed control might be another possible solution to reduce dust, especially in villages or populated areas. It is, however, difficult to control the speed and might therefore have a limited effect.

4.2.2 Inspection and Repair of Road Surface Deformation

It is very important to the service length of a road that the surface of the road is maintained in a good manner. Rutting, potholes, corrugation, depressions, shoulder failures and other defects of the surface have to be repaired, especially at the end of the rainy season.

Rutting, longitudinal depressions in the wheel paths, can be corrected adding suitable material to the surface. On gravel roads, suitable gravel shall be added, properly graded and compacted. Paved roads are treated by surface dressing and if the ruts are deep, they should be patched before surface dressing is applied.

Potholes are small depressions in the road surface often caused by poor drainage of the surface or week subgrade. Potholes may be corrected by patching with well-graded materials and compacting. For paved roads, the patching shall be covered by surface dressing.

If no regular maintenance is performed, the road will not serve as expected and the road will deteriorate at a very fast rate with great risk of an early road failure.

4.2.3 Clearing and Cleaning of Culverts and Drains

Culverts and drains must be maintained regularly in order that no debris will block the flow of water. This is especially important close to forest areas where branches and other debris from trees can be brought by the water.

In areas with slow water flow, the culverts can easily be blocked by sand deposits that can considerably reduce the flow area of the culvert. In order to facilitate cleaning of culverts, no cross drainage structures smaller than 1 m diameter should be used.

4.2.4 Repair of Erosion Protection and Scour Checks

Erosion protection and scour checks have to be inspected and repaired regularly and especially after the rainy season and heavy rainfall.

Maintenance of erosion protection is important in order for it to work as expected. If no maintenance and repair is made of the erosion protection, the road might be damaged and the cost of repair will later be much higher.

4.3 Planning

4.3.1 Realignment

Based on cost/benefit assessment, realignment could be a good solution for climate change adaptation. The cost of new road construction could be lower than the maintenance cost of the present road, especially for roads located close to rivers frequently flooded and causing road damage. It is important that the new proposed location is located away from the stream corridor and major risks of flooding. A new location must also serve local communities in a similar or approved manner.

When considering new alignment, it is also important to consider existing planning of the area so the new alignment follows master plans and land use plans of the area.

4.3.2 Revised Road Design Standards

Climate change factors should be added to road design standards, especially focusing on areas with major risks of flooding that might cause erosion and damage to the road.

The most important factors are the road levels, the cross drainage of the road and erosion protection of the road.

The expected flood level around the road has to be established and the new road elevation has to be designed at a safe level above the flood elevations. The road elevations should be at least 0.5 m above the flood levels

Many countries have set their standards for the subgrade level at 0.3-0.5 m above the expected flood level in order not to risk to have the pavement soaked by water. This level will result in road elevations approximately one meter above flood levels.

The cross drainage of the road has to be adequate. For a new road, the flow of water has to be investigated properly along the road and the type and size of cross drainage to be designed. Improvement of existing rural roads has to include local observations and discussions with local citizens about flood damages and the way to avoid similar problems.

Proper erosion protection has to be constructed, especially important is the outlet of cross drainage structures and expected major flow of water along the embankments.

4.3.3 Green Planning

Green planning is one climate change adaptation component in the TOR for this project. Green planning has been adopted for the project road 2620 as tree planting along the road. In addition to increasing the green area along the road, the project will benefit the local population through employment of local laborers in the area and later with crops from the planted trees, mainly mango trees.

4.3.4 Monitoring

All roads should be regularly monitored in order to control and propose improvement of the road as well as the area around the road. If an early warning system is established in the area, it should be maintained and monitored regularly.

5 Project Road 2620/2KT2

5.1 General

Road 2620/2KT2 is frequently affected by flooding events and was chosen as a project road, on which road several alternatives of reconstruction were to be investigated, discussed and presented with economic analyses.

Road 2620/2KT is mainly located in Prasat Sambo district and Sandan district in Kampong Thom province. The length of the road is 59.9 km and 2KT 2 is 6.1 km.

The total cost of the present reconstruction was USD 5.0 million equal to about USD 75 000 per km of road.

The road is designed by the consultant, Sambo Engineering Co., LTD in association with Korea Consultants International and is at present under construction. As ofJanuary 2014,the aggregate course level has been built, but no seal coat has yet been constructed. The construction has been delayed but the construction of the road is estimated to be finalised during 2014.

A field trip along the project road was conducted during January 2014 to study the condition of the existing road and possible damages of the road.

It was noted that the most vulnerable part of the road was between approximately Km 25 and Km 50. Some parts of the road were not repaired after the last flooding of the road.

The road consultant, Sambo Engineering Co., LTD in association with Korea Consultants International, has proposed a new design for the damaged parts of the road, which were not yet executed.

SWEROAD has studied the area of the road as part of the Climate Modeling Component where Flood Levels have been estimated for the area, based on highest recorded flood levels since 1985. We have also compared the results of the GIS estimated flood levels with local reports about flood levels and with existing photos taken from the flooded areas.

Based on the above studies, we have investigated different alternative proposals for protecting the road and estimated the construction costs for different alternatives as well as economic NPV and EIRR.

Option 1: the present construction of Road 2620/2KT2, with road elevations raised about0.5 m above existing road levels.

Option 2: additional construction costs for road improvement, with Option 1 road elevations as the base, and with the road surface raised to minimum 0.5 m above estimated highest flood levels in the area.

Option 3: additional construction costs for road improvement, with Option 1 road elevations as the base, and with road surface raised to minimum 1 m above highest estimated flood levels.

Option 4: have the same proposed road elevations as Option 3, but construction costs are based on existing road instead of based on Option1, i.e. constructing option 4 from the start not after option 1 has been implemented.

5.2 Flooding of Road 2620/2KT2

The photos shown below were taken along the road during the flood that occurred in 2013 and shows major flooding affecting the road, especially the part of the road between Km 30 and Km 58.

The GIS observation map, shown below, also indicates that the most vulnerable part of the road is between km 35 and 50.

Km 31+200

Km 39+600

Km 43+800

Km 45+700

Km 47+000

Km 57+400

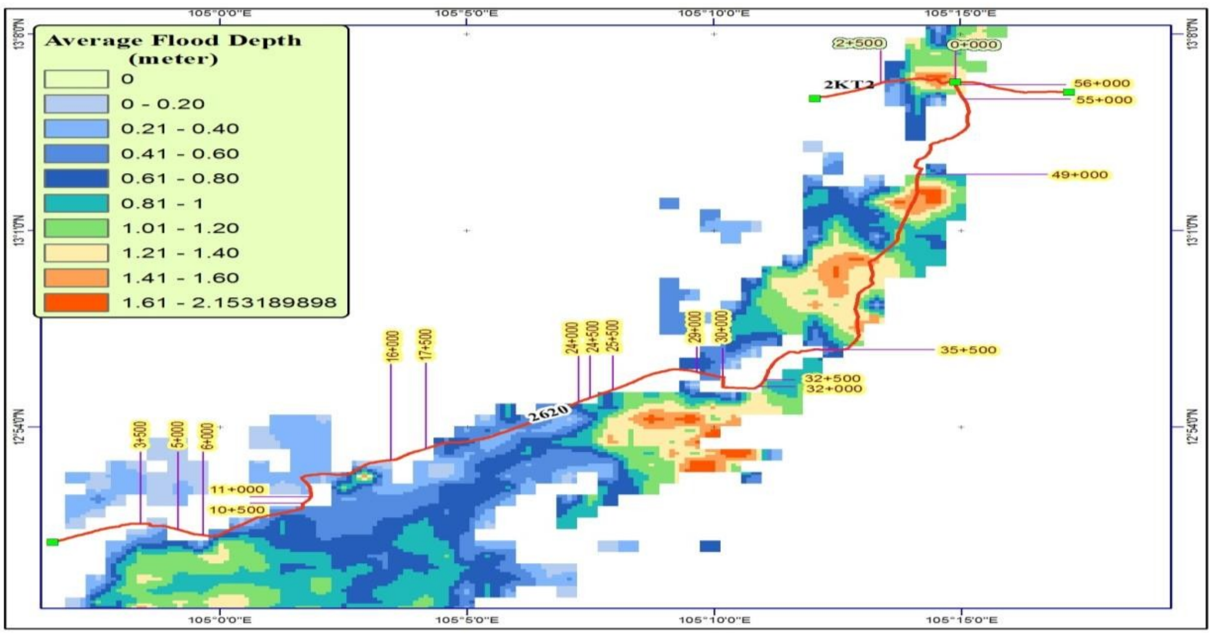


Figure 2: Flood depth around road 2620 from GIS observation

5.2.1 Option 1: Paving Surface

Option 1 is the actual cost of construction for the present upgrading of the road No. 2620 and road No. 2KT2. Option 1 also indicates the construction cost in general for upgrading, with DBST, an existing laterite rural road to a higher standard.

The total cost of construction for the present contract is about USD 5.0 Million as shown in the table below.

Table 5.1: Cost of Construction for Option 1

Description	**Cost in USD**
Earthworks	940 000
Sub base and Base Course	1 850 000
Bituminous Work	1 300 000
Structures	140 000
Drainage and Protection Works	30 000
Ancillary Works	190 000
General Provisions	550 000
Total	**5 000 000**

The road elevations of Option 1 are low in some areas of the road, compared with our calculation of flood levels and local observations, as earlier presented.

There is a major risk that future flooding will cause similar damage to the road, on a regular basis, if no further improvement to the road is made.

5.2.2 Option 2: Proposed New Road Elevations for Road 2620/2KT2, 0.5 m above Estimated Water Level

We have investigated flooding of the road based on latest information in order to arrive to a proposal, Option 2, where the road surface is at minimum 0.5 m above estimated maximum flood levels.

In order to estimate the highest flood levels for the area, we have studied photos taken from the flooded areas of the road, we have interviewed local citizens along the road and we have studied estimated flood levels in the area based on climate change modeling.

The studies show that the most vulnerable areas are from Km 29 to Km 56, we have then proposed to raise the road surface by an average of 0.5 m above the present road levels, under construction or already executed, on a total length of 13.7 km.

The new proposed road elevations are estimated to be at least 0.5 m above the highest recorded water levels which will reduce the risk of the road to be flooded by water.

In addition to the above reconstruction work we have also proposed the construction of 10 pipe culverts with diameter of 1 m in order to improve the cross drainage for the flooded area. We have also proposed some grouted rip-rap at the outlets of some of the culverts to reduce the risk of scour.

The cost of construction for this improvement is estimated to be around USD 1 300 000 as shown in Table 3 below

Table 5.2: Estimated Quantities and Cost of construction for Option 2

Item	Unit	Unit rate USD	Estimated Quantity	Value USD
Embankment	M3	4.3	15 000	64 500
Sub Grade	M3	5.4	44 000	237 600
Sub Base	M3	7.8	13 700	106 900
Aggregate Base Course	M3	18.9	12 400	234 400
Prime Coat	M2	0.85	82 200	69 870
Surface Course DBST	M2	4.75	75 400	358 150
10 New Pipe Culverts	No.	7 000	10	70 000
Grouted Rip Rap	M3	1 000	45	45 000
Contingencies				13 580
General Provisions				100 000
Total				**1 300 000**

5.2.3 Option 3: Road Elevations 1 m above Estimated Water Level

The main reason for the damages of road 2620 as well as most of the project roads, is the flood levels around the road is higher than the road surface, which will cause road damages by overtopping of water and scouring of the road pavements and embankments.

A high water level higher than 1 m below road surface can also submerge the road pavement and embankment and reduce the bearing capacity of the road. A road surface 1 m above highest water level and proper cross drainage structure will provide an all-season road that will considerably reduce risks for damage of any part of the road.

Option 3 shows the cost of construction for reconstruction of road 2620 and road 2KT2 based on the present elevations of the road (Option 1).

We have estimated a reconstruction of the road between Km 18 to Km 56.2. The road will be raised an average of 0.5 m except for 13.7 km where the road is proposed to be raised 1.0 m.

The number of culverts to be constructed will be increased to 20 and the proposed amount of rip-rap protection will also be increased.

The cost of construction for this improvement is estimated to be around USD 4 000 000 as shown in Table 4 below

Table 5.3: Estimated Quantities and Cost of Construction for Option 3

Item	**Unit**	**Unit rate USD**	**Estimated Quantity**	**Value USD**
Embankment	M3	4.3	125 000	537 500
Sub Grade	M3	5.4	150 000	810 000
Sub Base	M3	7.8	40 000	312 000
Aggregate Base Course	M3	18.9	32 500	614 250
Prime Coat	M2	0.85	226 000	192 100
Surface Course DBST	M2	4.75	207 000	844 700
10 new pipe culverts	No.	7 000	20	140 000
Grouted Rip Rap	M3	1 000	100	100 000
Contingencies				49 450
General Provisions				400 000
Total				**4 000 000**

5.2.4 Option 4

Option 4 shows the same end result, road elevations and cross drainage, as option 3 (in combination with option 1).

The total cost of reconstruction is calculated based on the laterite road which existed before the present reconstruction started (option 1).

Option 4 shows the total cost of construction for road 2620 and 2KT2, with the same road elevation as for option 3, if the flood levels observed and calculated above, had been considered already during the first design phase.

It shows the importance to include all factors in the design phase and especially rainfall data and high flood levels. The expected flood levels will be more important in the future and will probably be the most important factor in climate change adaptation.

The total construction cost for option 4 is slightly higher than for option 1 but much lower than if adjustments to road elevations are made later, as if option 3 is added later on.

Table 5.4: Estimated Quantities and Cost of Construction for Option 4

Description	**Cost in USD**
Earthworks	2 200 000
Sub base and Base Course	1 850 000
Bituminous Work	1 300 000
Structures	140 000
Drainage and Protection Works	30 000
Ancillary Works	190 000

10 new Pipe Culverts	140 000
Grouted Rip Rap	100 000
General Provisions	550 000
Total	**6 500 000**

5.3 Conclusion

Cost of Construction for the four alternatives:

Option 1 USD 5 000 000 Present design and construction of the road

Option 2 USD 1 300 000 Proposed minor adjustment to the present road to decrease the risk of damage due to flooding

Option 3 USD 4 000 000 Major adjustments of present road elevations to have an all-weather road

Option 4 USD 6 500 000. The same road elevations as option 3, but considering projected flood levels from the start of the project

The options above show the importance of considering all factors at the start of the design and especially the expected climate change factors.

If option 4 is designed and constructed at once the savings in the cost of construction is estimated at around 30 %.

Option 4 will also benefit the people in the area and the traffic on the road in a better way, with no interruptions of traffic flow because of flooding or repairs after flooding.

6 Cost Estimation

6.1 General

The cost of the construction works consists of (i) the direct costs of the works, and (ii) the indirect costs related to preparing and managing the works. Both direct and indirect costs are in principle expenses that will occur as a result of carrying out the work.

Cost calculations and unit cost might vary considerably depending on the size of the project and competition.

Cost calculations for adaptation options for road 2620 as well as presented unit cost are taken from bid prices received for Package A, where road 2620 is also a part. The unit costs are also compared to other similar projects in Cambodia.

Unit costs have been estimated for adaptation options proposed in chapter 4.

6.2 Unit Cost

6.2.1 Road Specific

6.2.1.1 Raising the road level

Raising the road levels always involve a new superstructure of the road and additional embankment material.

The road superstructure normally consists of pavement, base course and sub-base course and the thickness of each layer depend on the design criteria, amount of traffic and the quality of underlying layers.

As an example, the table below shows construction cost per meter of road for Road 2620, 7 m wide and raised 0.5 m.

Table 6.1: Example Cost of Raising Road Level Per m for Road 2620

Item	**Unit**	**Unit rate USD**	**Estimated Quantity**	**Value USD**
Embankment	M3	4.3	2.0	8.6
Sub Grade	M3	5.4	2.0	10.8
Sub Base	M3	7.8	1.1	9.4
Aggregate Base Course	M3	18.9	0.9	17.0
Prime Coat	M2	0.8	6.5	5.2
Surface Course DBST	M2	4.0	6.0	24.0
Total estimated cost per m road				75.0

6.2.1.2 Adjusting Embankment Slopes

The unit prices for the cost of construction very much depends on quantity, the location and the availability of materials in the area.

A very rough estimate for road 2620 with an average height of embankment of 1.5 m indicates a cost of 15-20 USD per m of road.

6.2.1.3 Paving Surface

A paving surface of single surface treatment SBST or double surface treatment is widely used for paving of rural roads with low traffic volumes. The cost of construction for paving surface depends very much on the existing pavement structure of the road. Normally, the existing gravel road has to be strengthened with a base course layer of, for example, an aggregate base course.

The cost of construction of a paving surface is expected to be between USD 30-50 per m of road, depending on the condition of the existing road.

6.2.2 Drainage

6.2.2.1 Cross Drainage

Insufficient cross drainage can be approved through additional new structures or widening existing structures. The approximate cost of culverts is indicated below.

The cost of construction for 1 m diameter pipe culverts including inlet and outlet structures is estimated to be about USD 3 500-4 000 per culvert.

The cost of construction for a 2x2 m box culvert is estimated to be about USD 15-20 000 and a double cell culvert with the same dimensions to be about USD 30 000.

6.2.3 Erosion

6.2.3.1 Retaining Walls

Concrete retaining walls can be constructed reinforced or without reinforcement. The cost of construction for retaining walls very much depends on the height of the wall and the foundation of the wall and it is therefore difficult to make useful estimate. Generally retaining walls are more expensive than other solutions but might be used for embankment protection, i.e. when space is limited.

6.2.3.2 Gabions

Gabions can be constructed as retaining walls or as gabion mattresses on embankments. Gabion walls are normally more economical than retaining walls but the cost of construction varies greatly depending mostly on availability of rock materials close to the construction site.

Gabion mattresses are an alternative to grouted rip-rap on embankment slope but are normally more expensive than grouted rip-rap.

7 Economic Analysis of Adaptation Options

7.2 Purpose of the Economic Analysis

The economic analysis of adaptation options for rural road aims to assess the economic feasibility of climate-proofing Cambodian rural roads through a number of structural (engineering) adaptation options. The use of Cost Benefit Analysis (CBA) allows decision-makers to appraise whether the adaptation investment is worth doing looking at both the benefits of having climate-proof roads and the adaptation costs of the priority adaptation measures. This economic analysis is also in line with Strategic Priority #1 of MRD proposed action to climate change for rural infrastructure, which is to create policies and study profile to increase the resilience of rural infrastructure development[1].

In order to use the CBA, fairly detailed data on potential engineering adaptation options, their effectiveness in addressing the vulnerability to climate change and their related costs and benefits might be required. For that reason, the economic analysis of adaptation options naturally takes place after information on the climate change vulnerability and the effectiveness of adaptation options are obtained, as shown in the following figure.

[1] Ministry of Rural Development, 2012, First Draft: Strategic Plan of Rural Development for Climate Change Adaptation in Cambodia.

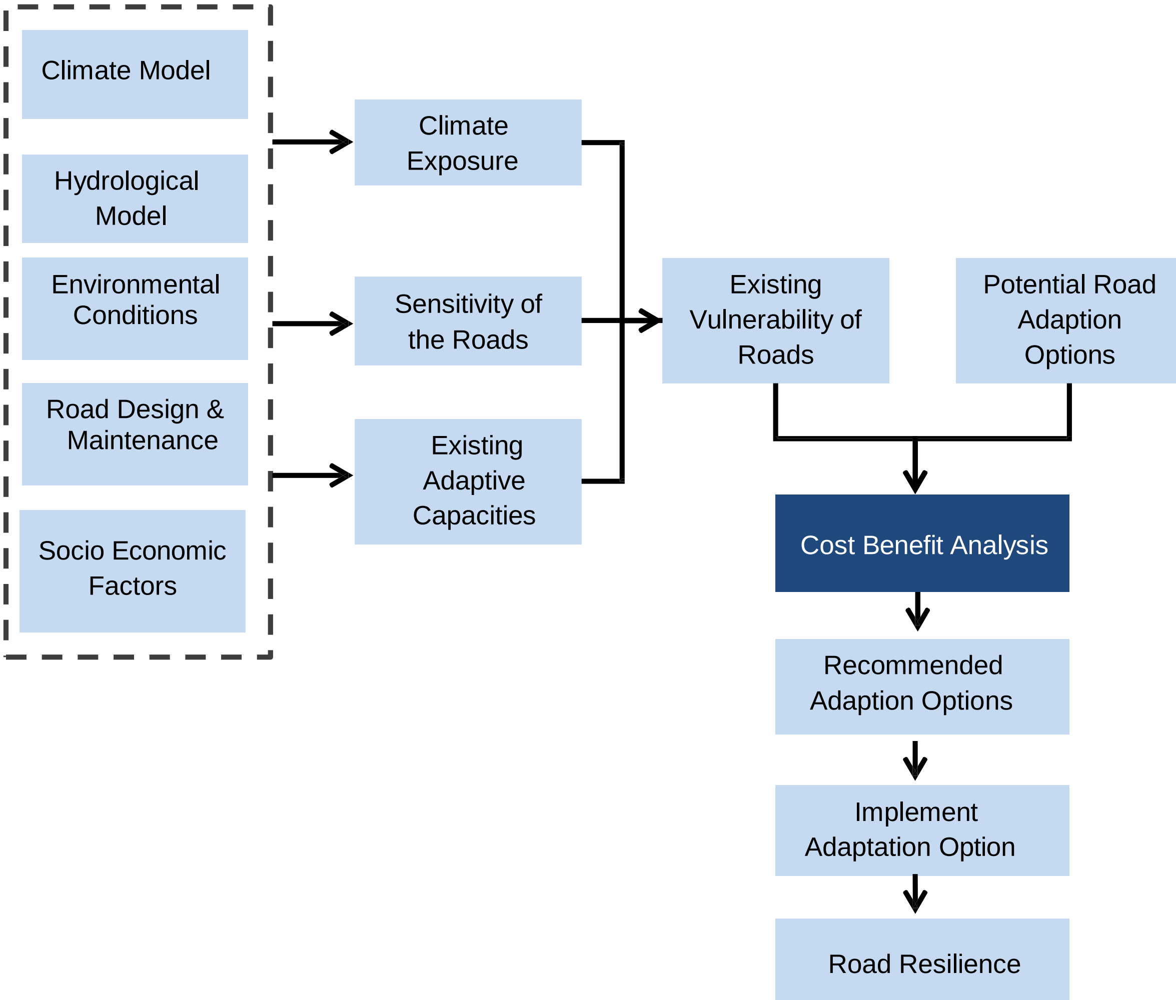


Figure 3. Determinants of Road Resilience

For this economic analysis, the CBA of adaptation options is conducted specifically for road 2620/2KT2. Nevertheless, the results and insights of the economic analysis are applicable to other rural roads in Cambodia and the estimates can provide a rough guide to the required adaptation costs for other rural roads.

7.3 Methodology

7.3.1 Overview of CBA framework

The methodology of the economic analysis follows the basic methodology of conducting a CBA. It is a powerful tool that enables a direct comparison of the efficiency of alternative projects. Nevertheless, this decision- making tool can also require a fairly high demand of data. The basic methodology of CBA of rural road adaptation is shown in Appendix.

This methodology consists of seven basic steps. The methodology can be refined or modified, especially with regard to the components of costs and benefits, to fit different contexts of rural roads and the associated environmental-socio-economic conditions around the roads, which will affect climate change vulnerability of and potential adaptation options for the roads.

CBA methodology is fairly similar to the whole life costing for rural roads using the Whole Life Transport Costs (WLTC) approach. This WLTC approach takes into account not only the benefits of improving roads for road users, but also socio-economic and environmental impacts of the roads to other users or community groups. MRD (2010) qualitatively assessed the environmental impacts of the rural road improvement projects, but the economic assessment was conducted using the Whole Life Asset Cost (WLAC) approach, which only accounts for the benefits accruing to road users and road maintenance savings.

The difference between WLTC and CBA is that CBA enables an extended analysis regarding the scope of impacts beyond road improvements. This information is highly relevant in the context of climate-proofing for road infrastructure, which can have a far greater reach of impacts beyond road users.

7.3.2 Specify Adaptation Options and Scenarios

To appraise the worthiness of projects under consideration, CBA compares these projects to a baseline, which is normally the “Do Nothing” option. The benefits and costs of each project are compared to the Do Nothing option to see if it is worth undertaking any of the alternative projects or if it is better to remain with the baseline.

Project evaluation for this economic analysis is conducted using incremental approach rather than absolute values, whereby the cost and benefit components of each project are directly measured against those of the Do Nothing option. Therefore, estimated benefits and costs of each project are additional to those from the baseline.

The evaluation period for CBA is 15 years after project construction is completed. This period is based on the design period for DBST road according to the Detailed Design and Implementation Supervision for Rural Road Improvement Project (MRD 2011).

It is assumed that the initial year (year 0) is 2014 and the construction will continue until the end of 2015. Therefore, the overall evaluation period is 2015-2030. The scope of analysis is concentrated on Prasat Sambour and Sandan district as the two main areas connected to the road.

7.3.2.1 The Baseline or Do Nothing Option

For this economic analysis, the Do Nothing option is a laterite road as the typical surface of rural roads in Cambodia. This baseline was chosen so that the estimations and insights from the CBA can have broader applicability for the context of Cambodian rural roads in general. Considering the focus of the project, CBA estimates are based on the physical road conditions as well as environmental, social and economic circumstances of the area around road 2620/2KT2.

The Do Nothing option implies that the current risks of climate change to rural roads in Cambodia remain unaddressed. Key characters of rural roads pertaining to these risks are:

(i) Rural roads are low classified roads that are highly prone to flood.
(ii) There exists little or no protection against erosion as shown by insufficient embankment slope (side slope of 1:2 or less).
(iii) During dry periods, road dusts can cause considerable respiration problems for surrounding communities.

7.3.2.2 Four Adaptation Options

The assessed adaptation options for road 2620/2KT2 are presented in Chapter Five. Four adaptation options are to be compared to the baseline:

1) Option 1: paving surface, which is an on-going rural road improvement project. Option 1 was not actually designed to address higher flood risks from climate change and it is merely focused on surface improvement.
2) Option 2: proposed new road elevations for road 2620/2KT2 that is 0.5 m above the estimated water level. Option 2 is constructed in conjunction with Option 1.
3) Option 3: road elevations 1 m above the estimated water level. This option is constructed in conjunction with Option 1.
4) Option 4: The same specifications as Option 3 but it is designed and constructed from the beginning, with no connection to Option 1.

Two main scenarios are evaluated for each adaptation option:

1) Conservative scenario.
This scenario focuses only on the main direct benefits of the adaptation option to road users and total construction cost of the project. The estimated benefits are travel time savings, vehicle operating cost (VOCs) savings, maintenance cost savings, and reduced potential flood costs.

2) Extended analysis.
Under this scenario, the scope of estimated benefits is extended to include residual values of the road, induced traffic for tourism, reduced health costs from dust, and reduced socio-economic impacts from flood.

Elaboration of the estimated benefit and cost components are presented in more detail in a separate subsection.

7.3.3 Define the Lenses and Scope of Impacts

The lenses of analysis define whose perspective should be the basis of the analysis. This perspective will define how benefits and costs are identified. For example, in a construction project of a highway with or without tolls, the treatment of toll fees will be different depending on whose lenses are used. For a budgetary agency that receives toll revenues, toll fees are categorised as benefits. On the other hand, for a transport agency toll fees can be considered as costs to road users, who are the constituent of a transport agency. Thus, toll fees are categorised as costs.

The scope of impacts defines the boundary within which the impacts are accounted for. This scope mostly takes the form of spatial scale or governance scale, for example district level, provincial level or national level. The scope imposes significant implications on the number of groups or communities that are considered in the CBA. Naturally, a higher level of scope will imply a larger number of community groups. This can imply either higher costs or benefits depending on the impact.

For the purpose of this economic analysis, the perspective of MRD as a decision-maker represents government's perspectives and objectives in general. The aim of the decision maker is to maximize the social benefits for the whole community, with the focus of road users and communities around road 2620/2KT2. Therefore, any direct and indirect costs and benefits experienced by road users or other groups of the community from the use and construction of the projects, should be considered accordingly.

7.3.4 Assess the Costs and the Benefits

This step begins with the identification of all the components of relevant benefits and costs, or impacts, to be included in the CBA. These impacts take the form of: 1) direct benefits, 2) indirect benefits, 3) direct costs, and 4) indirect costs. The direct benefits and costs are easier to measure, while indirect benefits and indirect costs can be more challenging to estimate.

This step also includes the quantification of units of impacts by formulating the relationship between each adaptation option and the measurement variable. For example, time savings from improving a laterite road to a DBST road that is durable for 15 years should be different over the evaluation period to those from a DBST road that is durable for 10 years. When a variable that directly expresses the pertaining impact is not available, a proxy variable can be used.

Following the quantification of impacts, the measured units of impacts are valued in monetary terms using appropriate valuation methods. The selection of valuation methods is largely determined by data availability. When necessary, the benefit transfer method might be used, in which impact values from other similar contexts can be used with some adjustment to suit local factors.

Ideally, all the impacts, either benefits or costs, should be monetised at their economic values, rather than financial values. Thus the benefits should reflect producer and consumer surplus and the costs should be evaluated at the shadow price. When market prices are used due to data constraint, some adjustments need to be made to value the impacts at their true economic values, to the extent possible.

The economic analysis for road 2620/2KT2 takes into account the following main components of benefits and costs.

7.3.5 Direct Benefits

Direct benefits are defined as those beneficial impacts imposed by each adaptation option that arise from savings by road users, savings in road maintenance costs, increased residual value of the road at the end of its lifetime, reduced risks of accidents and reduced damage costs regarding road infrastructure when flood occurs. Savings by road users are calculated as travel time savings by individuals and freight as well as savings in Vehicle Operating Costs (VOCs).

Road user savings should also include those savings from generated traffic, which is additional traffic that operates as a result of better road conditions. In addition to generated traffic, road improvement can also bring about induced traffic. It can occur when road improvement leads to new or expanded economic activities that produce additional traffic being established in the area served by the road. Induced traffic can be related to the increase in agricultural production in the zone of influence of the road when reductions in transport costs are considerable significant. It can also be related to the opening up of new tourist facilities or industries.

Before the benefits to road users can be estimated, it is important to first project the traffic volume over the evaluation period, which includes information regarding vehicle types (motorised and non-motorised), number of passengers per vehicle type, and traffic counts for each vehicle type. This traffic volume is expressed in terms of Average Daily Traffic (ADT) as a base level. To take into account of seasonal variations in traffic volume, the Annual Average Daily Traffic (AADT) is calculated. AADT provides the basis in measuring all economic benefits which are tied to traffic volume.

This economic analysis uses the following unit values and key assumptions regarding traffic data:

1) Calculation of normal and generated traffic demand is separated from the induced traffic. The induced traffic mainly takes the form of tourism development and a separate traffic growth rate was also calculated for this induced traffic.

2) The baseline traffic for road 2620/2KT2 is calculated according to an AADT of 2357 vehicle per day. This is translated into 1312 passenger car unit/day.

3) Traffic growth rate is calculated based on the elasticity of traffic demand to economic growth. According to the World Bank, the elasticity of traffic growth rate to GDP growth rate in developing countries typically range from 1 to 2. The elasticity of demand is set at 1.5 for normal and generated traffic, which means that 1% economic growth will bring about 1.5% increased demand on traffic. Based on the most recent data on Cambodian economic growth (ADB 2014), the economic growth rate is projected at 7% for year 1- 5 and 5% for year 6-15. Generated traffic is assumed at 1%. The resulting traffic growth rates for normal and generated traffic are 11% for the first five years and 8% for the second five years.

4) Baseline traffic for tourism is 68 vehicles per day and it is estimated to grow by 25% over the first five years (ADB, 2011), after which the growth rate stabilises at 10%. Improved roads are expected to generate one hour in time savings.

7.3.5.1 Travel Time Savings

Road improvements should lead to an increase in vehicle speeds and results in reduced travel time for road users. For individual travelers, reduced travel time relates to more time for productive work or for leisure. Thus the estimation of the values of time savings needs to reflect the value of time pertaining to both activities. The value of time savings for non-work-related travel is normally harder to monetise than the work-related travel.

The following are approaches, key assumptions and unit values used for estimating travel time savings:

1) The World Bank's approach for estimating travel time savings is adopted for this economic analysis. The valuation of passenger time savings during working time is proportional to the labour value of the passenger. In accordance to the transport tool Highway Development and Management Model (HDM-4), savings from generated traffic are usually valued at half the level of those from normal traffic.

2) According to HMD-4, work trip is assumed to constitute 75% of the traffic. Working time travel savings is valued at 1.33 times of the wage rate to allow for non-wage costs to the employer. Non-working travel time savings should be valued in proportion to the household income. The non-working travel time savings should be valued at a factor of 0.3 of the household income for adults.

3) The value of time is based on a proxy of the hourly disposable income rate for rural area since data on wage rates are not available. Assuming that household work is on average 240 hours per month (as family members usually do some casual work), the projected value of travel time for work trips based on 2009 district and provincial statistics is $0.76/hour. This value is lower than that adopted for HDM-4 model ($1) and the economic analysis by Rural Asset Management (ADB, 2010) at $2/hour. This means that the unit values used for this exercise are in the lower end of the range of possible values.

4) Reduction in travel time associated with each adaptation option is estimated through expert judgement by the Consultant Team (CT). Option 1 is estimated to reduce travel time by 50%. Travel time savings is increased to 60% for Option 2 and 70% for Option 3 and Option 4.

7.3.5.2 VOC Savings

Vehicle operating costs (VOCs) vary by road conditions and improved rural roads result in reduced VOCs. Together with travel time savings, VOC savings are basic benefits that are evaluated in any road projects. These VOCs indicate resource consumption costs of each component of the vehicle per kilometer, such as fuel consumption and tyre wear. HDM-4 can model these VOCs against a wide range of factors, including surface conditions, geometry of road sections and vehicle characteristics.

The two main determinants of VOCs are surface roughness and speed. HMD-4 has estimated VOCs by vehicle type and type of surface roughness for Cambodia (Table 7-1). IRI 3 represents the expected level of a new DBST surface for rural roads improvement project by MRD, while IRI 6 represent surface conditions for the baseline laterite road. A higher IRI level shows a higher level of surface roughness, which implies higher VOCs. The VOC savings pertaining to each evaluated adaptation option are estimated using those estimates combined with the data on traffic volume for that particular road.

Table 7.1 Vehicle Operating Costs by Vehicle Type and Surface Roughness

Vehicle Type	VOCs ($/km)		
	IRI 3	IRI 6	IRI 12
Bicycle	0.03	0.04	0.05
Animal Cart	0.11	0.13	0.16
Motorcycle	0.03	0.03	0.04
3-wheeler	0.04	0.05	0.05
Car	0.22	0.26	0.31
Jeep/4WD	0.32	0.42	0.56
Pick-up	0.29	0.34	0.47
Minibus	0.15	0.2	0.32
Bus	0.32	0.46	0.57
Small Koyun	0.05	0.06	0.08
Large Koyun	0.21	0.36	0.45
Light Truck	0.22	0.29	0.36
Medium Truck	0.29	0.38	0.51
Heavy Truck	1.04	1.32	1.53

Source: RD (2010)

7.3.5.3 Road Maintenance Cost Savings

The savings in maintenance costs from sealed roads should be compared to the baseline condition in the Do Nothing option. In general, road maintenance consists of annual routine maintenance and periodic maintenance every few years. The differences in unit maintenance costs between laterite and sealed roads are presented in the following table. The actual maintenance frequency for the road might be higher than the presented numbers depending on the type of work and the rate of deterioration.

Table 6.1: Example Cost of Raising Road Level per m for Road 2620

Maintenance Type	Laterite Road	Sealed Road
Routine Maintenance		
Cost ($/km)	1000	900
Frequency	Annual	Annual
Periodic Maintenance		
Cost ($/km)	20000	15000
Frequency	Once every 4 years	Once every 8years

Source: Rural Road Asset Management Manual (2014)

The magnitude of maintenance costs above represents the required costs to ideally maintain the quality and functionality of the road. This can be very different and much higher than the actual maintenance costs budgeted for the maintenance of rural roads across provinces in Cambodia.

7.3.5.4 Increase in Residual Values

Residual value is the value of road infrastructure at the end of the evaluation period. The residual value of roads for Cambodia context is estimated to be 25% of construction costs, based on the assumption that much of the cost lies in the base course rather than the surfacing and the base course materials could easily be recovered (MRD, 2010). This general assumption on the residual value can be estimated more accurately when specific detailed design of the road and its traffic load are known.

7.3.5.5 Reduced Potential Flood Costs

Improved resilience of rural roads to climate change should result in savings of repair and rehabilitation costs (damage cost) of road infrastructure when floods occur. Improved resilience of road infrastructure from an adaptation option should also imply reduced damage costs when flood occurs. The value can be estimated by multiplying flood risk incidence by the savings in damage costs over the evaluated period.

Historically, Typhoon Ketsana that took place in 2009 affected 1.4% of Cambodia’s population across 14 provinces, 73 district and 336 communes (Royal Government of Cambodia, 2010). An estimation of the impacts of Typhoon Ketsana was conducted by looking at the direct impact (damages), indirect impact (losses) and the longer-term impact to the economy. Damage is defined as direct impact on assets, stocks and property. Loss is defined as indirect impact from affected flows, such as production decline, reduced incomes and increased expenditures, over the time period until the economy and assets have recovered.

In terms of the impacts to transport infrastructure, Typhoon Ketsana caused a total cost of $

25.47 million comprising of $14.39 million of damage and $11.08 million of losses. These values were estimated considering the needs of recovery for short term (0-6 months), medium term (1-2 years) and long term (1-5 years). The short term recovery provides emergency responses to render the road functional to some degree. The medium term efforts aim to recover existing roads to its pre-typhoon conditions. The long term efforts should address the long term rehabilitation of the roads. Direct impact to road infrastructure from Typhoon Ketsana took different forms, from major to minor damage. Examples of major damage are completely or partially destroyed sections of the roads, destruction of bridges, culverts, and drainage systems. Minor damage is caused primarily by flooding, fallen trees, inadequate construction materials (soil) and poor standards of road design.

Damaged roads impose higher vehicle operating costs (VOCs) and longer travel times associated with worsened road conditions. For the estimation of losses from Typhoon Ketsana, it was assumed that it would take six to eight months to restore the infrastructure to its prior condition.

This CBA estimation takes into account two flood impacts on road users:

1) Damages in terms of road rehabilitation once a flood occurs.
   The road rehabilitation unit cost for laterite road is $20,000/km (Rural Road Asset Management Manual, 2014).
2) Losses in terms of travel time and vehicle operating costs during a 6-month rehabilitation period.

The effectiveness of each adaptation option influences the extent of reduction in impacts and their associated costs. The road engineer expert within CT estimated that Option 3 and Option 4 have the highest effectiveness of 90% in reducing flood impacts to the road. Option 2 might reduce flood impacts to 50%, while Option 1 will have the lowest effectiveness level at 10%. Flood risk probability is assumed at 0.2.

7.3.6 Indirect Benefits

Indirect benefits are defined as those benefits that arise from increased productivity or income, or reduced household expenses, or reduced social or environmental costs imposed by the existence of road infrastructure. In essence, these benefits are not directly linked to road use and maintenance. On the other hand, these indirect benefits can also come from a reduction in indirect negative impacts, such as reduced loss of productivity compared to the Do Nothing option. For example, if laterite roads caused an increased health risk in terms of respiratory problems, then the indirect benefit of an adaptation option that reduces dust is a reduced risk of respiratory problem. The identification of these indirect benefits will be highly associated to the type of economic activities, characteristics of households, which benefit indirectly from better road infrastructure.

The CBA estimation for road 2620/2KT2 only accounts for indirect benefits in terms of increased tourism activities, reduced impacts of damaged road to agricultural activities, and reduced health costs from dust. Each of these indirect benefits is discussed in the following sections.

7.3.6.1 Increased Tourism Activities

The area adjacent to Sambo Prey Kuk temple has been planned to be developed for increased tourism activities and related market development for craft and local products. ADB (2011) estimated that the project to improve tourism activities and market access for the poor will result in baseline revenue of tourist expenditures on the local product market of $500,000 and parking revenue of $18,750 annually, generating a total revenue of $518,750. These benefits are incremental benefits compared to the baseline.

The economic analysis makes the assumption that 50% of the increase in tourism activities is contributed to improved road conditions and the induced traffic for tourism will occur a year after the road is constructed. Based on the ADB study, the growth rate for tourism in the area is expected to be around 25% in the first few years after road improvement and then decline to 10% in the remaining evaluation period.

7.3.6.2 Reduced Flood Impacts to Agricultural Activities

Damaged road infrastructure from flooding can disturb trade and distribution of agricultural products from the farm to retailers and consumers. For the CBA estimation, we assume a flood risk probability of 0.2 and that flood events can impact at least 20% of the farms during the wet season. The level of the impacted area is based on the effect of the 2011 flood in Kampong Thom(ADB, 2012). It is further assumed that only 50% of the losses from a potential flood is caused by damaged roads.

Based on the district and provincial data in 2009, the projected agricultural output of the area for the base year is 40,889 tonne/ha of rice and the inflation adjusted average farm gate price of $186.29/tonne of rice. The potential loss of output at the baseline year is valued at $273,687. Output growth is assumed to follow GDP growth for agricultural products at 0.5% (ADB, 2014).

Ultimately, the magnitude of reduced flood impacts to agricultural activities from each adaptation option is determined by the effectiveness of each option with regard to flood resilience. This represents the incremental benefits of adaptation option compared to the baseline.

7.3.6.3 Reduced Health Costs from Road Dust

Road dust contributes to the prevalence of Acute Respiratory Infection (ARI), which is one of the leading causes of childhood mortality and morbidity. The prevalence of ARI is significantly higher for rural children (NIS, Cambodia Demographic and Health Survey, 2010). To estimate the impact of road dust from laterite roads, we focus on the health impacts of the dust.

The benefit transfer method was used to estimate the value of reduced health risks. Transferred value was derived from the Willingness to Pay (WTP) study conducted in Laos (Kyophilavong and Bennet, 2011) The respondents were asked to reveal their WTP for cleaning up road dust in urban areas of Vientiane in order to reduce 60-70% of health problems from dust over a five-year period. The study finds that each respondent was willing to pay up to 4.71% of the resident's monthly income.

For this CBA estimation, it is assumed that 30% of the households are highly affected by road dust. The number of households in both districts is projected to grow at 5% per year according to the data. As all adaptation options have paved surface, it is assumed that they have the same level of effectiveness in removing road dust. Thus, the reduced health costs also increased proportionately starting at $57,491 in the first year.

7.3.7 Direct Costs

The direct costs for each adaptation option in this economic analysis includes material costs, labour costs, preparation costs and construction costs. Planning and design costs are not included in the analysis.

7.3.8 Indirect Costs

The economic analysis assumes that the project minimises any potential social and environmental impacts. Thus, these indirect costs are not specifically estimated.

7.3.9 Qualitative Analysis of Non-Monetised Impacts

It is very likely that not all of the impacts can be quantified and monetised due to lack of data or knowledge about the dose-response functions. When this occurs, qualitative analysis of the impacts can be conducted as an attachment to the Cost Benefit Analysis (CBA). This analysis can indicate how the non-monetised impacts might affect the direction of the CBA results and the weight or importance of the non-monetised impacts. Notes on the effects of non-monetised impacts should be part of the whole CBA framework and be part of the decision-making process. Cost Effectiveness Analysis (CEA) might be an alternative to assess non-monetised impacts.

In this economic analysis, all the major direct and indirect impacts have been accounted for. An important direct impact from road improvement might be an increased risk for traffic accidents due to higher vehicle speed and a reckless driving attitude. Nevertheless, it is very hard to estimate the increase in accident risk from improving road surface. There might also be other social and environmental impacts. However, there is insufficient knowledge and data to conduct qualitative analysis of how this might significantly impact CBA estimations.

7.3.10 Calculate the Net Present Value of Each Adaptation Option

The monetary values of impacts need to be converted to the Present Value in order to make them comparable. Net Present Value (NPV) is then calculated as the difference between the sum of all benefits and costs. The decision rule of CBA is to choose an option that has the largest NPV value.

The choice of the appropriate social discount rate is one of the most challenging problems of using CBA. For developing countries, these rates vary between 8 and 15% and ADB suggests the use of a social discount rate of 10-12% (ADB, 1997).

In this economic analysis, adaptation options are evaluated based on their NPV values and Economic Internal Rate of Return (EIRR). Social discount rate of 12% is used for the estimation.

7.3.11 Perform Sensitivity Analysis

In conducting a CBA, there is always some degree of uncertainty regarding the magnitude of impacts or the value assigned to each impact. Sensitivity analysis is conducted to acknowledge this uncertainty and to inform decision-makers of how and in what direction this uncertainty might affect the results.

Sensitivity analysis for this economic analysis looks at five main key variables that might affect CBA results: traffic growth rate, the effectiveness, baseline traffic or travel time, adaptation costs, and flood risk probability. Analysis on the results of CBA estimation and sensitivity analysis is discussed in the following section.

7.4 Estimation results and analysis

7.4.1 CBA Estimation Results

The CBA estimates both the financial and economic Net Present Value (NPV) for each adaptation option. The economic NPV is estimated at 80% of the NPV, in line with the current employment rate of Cambodia at 84% (ADB, 2014). Estimation results for the conservative scenario are presented in the following table.

Table 7.3 Cost Benefit Analysis Estimation Results for Conservative Scenario

Measure	Option 1	Option 2	Option 3	Option 4
Economic IRR	31.0%	29.1%	23.8%	32.4%
Financial NPV ($)	21 962 550	25 279 842	27 422 546	29 922 546
Economic NPV ($)	17 570 040	20 223 874	21 938 037	23 938 037
Benefit Cost Ratio	5.4	5.0	4.0	5.6
Costs ($/km)	75 529	95 166	135 952	98 187
Benefit ($/km)	407 289	477 037	550 190	550 190

Source: CT

As previously mentioned, the conservative scenario includes the benefits from travel time savings, vehicle operating cost (VOCs) savings, maintenance cost savings, and reduced costs for road repair/rehabilitation from potential floods. Since only the main direct benefits to road users are taken into account, the estimation results from the conservative scenario represent the lower band estimates of the net benefit of undertaking each adaptation project.

The results demonstrate that all the options are attractive investments with EIRR much higher than the social discount rate. Adaptation Option 4 proves to be the best adaptation measure because it exceeds other options in nearly all performance measures, i.e. EIRR, NPV, and benefit cost ratio. Option 1 has the lowest cost per km at the expense of the lowest total benefits due to less resilience against flood risk.

The analysis provides a very strong argument for a rural road improvement project to take into account the effect of climate change early in the project from the detailed design phase so that the new road can be climate-resilient under all weather conditions. An earlier economic analysis under Rural Road Asset Management (ADB, 2010) demonstrates that the cost of rural road improvement without taking climate change into account is $87,903 per km (2009 prices). The CBA shows that climate-proofing of a rural road through Adaptation Option 4 only involves additional costs of 11.7%, without taking inflation into account; or even slightly less than the non-climate proof project cost when the inflation rates during 2010-2013 are considered.

When the estimation of benefits is extended to include direct benefits from induced traffic, residual values of the road, and indirect benefits of the road, the results show that the EIRR of adaptation option is raised around 3-4% while the economic NPV is increased by 22-25%. The estimation results further highlight the superiority of Adaptation Option 4 to other options.

Table 7.4 Cost Benefit Analysis Estimation Results for Extended Analysis Scenario

Measure	**Option 1**	**Option 2**	**Option 3**	**Option 4**
Economic IRR	34.7%	32.6%	27.0%	35.9%
Financial NPV	27 425 955	31 322 973	34 109 779	36 507 828
Economic NPV	21 940 764	25 058 378	27 287 823	29 206 263
Benefit Cost Ratio	6.5	6.0	4.8	6.6
Costs ($/km)	75 529	95 166	135 952	98 187
Benefit ($/km)	489 818	568 323	651 205	649 665

Source: CT

If we compare Adaptation Option 2 until Adaptation Option 4 to Adaptation 1 as the on-going construction project using the same performance indicators as in table 7.4., it can be seen that those adaptation options are still worthy investments. Nevertheless, Adaptation Option 3 is very expensive to undertake and Adaptation Option 4 has the best performance. This shows that sufficiently climate-proofing a rural road after it has been reconstructed is a much less efficient effort. Thus, it is best to design and construct a climate-proof road from the beginning as shown by Adaptation Option 4.

Table 7.5 Comparison of Adaptation Option 1 and Other Adaptation Options

Measure	Option 2		Option 3		Option 4	
	Conser-vative	Extended	Conser-vative	Extended	Conser-vative	Extended
Economic IRR ($)	21.2%	23.7%	12.9%	14.9%	36.9%	40.3%
Financial NPV ($)	3 317 292	3 897 018	5 459 996	6 683 824	7 959 996	9 081 873
Economic NPV ($)	2 653 834	3 117 614	4 367 997	5 347 059	6 367 997	7 265 499
Benefit Cost Ratio	3.6	4.0	2.4	2.7	6.3	7.1
Incremental Costs ($/km)	19 637	19 637	60 423	60 423	22 659	22 659
Incremental Benefit ($/km)	69 748	78 505	142 900	161 387	142 900	159 847
Additional costs compared to current construction project	26%	26%	80%	80%	30%	30%

Source: RD (2010)

7.4.2 Sensitivity Analysis

Sensitivity analysis is performed to the Conservative Scenario in order to assess if adaptation options are still worth undertaking when a number of key assumptions that affect the magnitude of benefits and costs are varied to a less favourable level by:

(i) Reducing traffic growth rate by 20%.
Traffic growth rate is a variable that affects the estimation of nearly all direct benefits except maintenance costs and residual values.

(ii) Reducing the effectiveness of adaptation option against flood risk by 20%.
This variable determines the magnitude of direct and non-direct benefits, i.e. reduced potential flood costs and reduced flood impacts to agricultural activities.

(iii) Reducing baseline traffic by 20%.
Similar to traffic growth rate, the baseline traffic affects almost all direct benefits except for maintenance costs and residual values.

(iv) Increasing adaptation costs by 20%;
As the components for adaptation costs are already lumped into one single cost component, the change in adaptation cost can affect key performance indicators, i.e. NPV, EIRR, and benefit cost ratio.

(v) Reducing the risk probability of flood incident by 50% to 0.1.
The effect of flood probability is similar to that of the effectiveness adaptation option.

The results of sensitivity analysis are presented in Table 7.5. It shows that the changes in the magnitude of key variables above do not significantly affect investment worthiness of adaptation options. Adaptation cost is the variable that affects EIRR the most but EIRR value of all adaptation options is still well above the social discount rate. On the other hand, the NPV is most affected by traffic growth rate and baseline traffic and the effect ranges from 12% to16%.

To assess how sensitive the NPV changes with the change in the key variables, the sensitivity indicator (SI) is estimated. SI compares the percentage change in NPV to the percentage change in the magnitude of a key variable. It represents the elasticity of NPV against the change in the key variable. For instance, an SI of 1 shows that a 1% change in the value of the variable will bring about 1% change in the value of NPV.

Table 7.6 shows that the values of SI for all key variables are less than 1. This means that the change in one unit of key variable causes a less proportionate change in NPV. Traffic baseline is the key variable that brings about the highest SI value, albeit with a magnitude of less than 1.

Thus it can be concluded that the estimation of EIRR and NPV for potential adaptation options in the conservative scenario is fairly robust and not very sensitive to the changes in the key variables.

7.4.3 Applicability of the Results to Other Rural Roads

As pointed out at the beginning of this chapter, it is expected that the results and insights from the CBA estimation can also provide rough guidance on climate-proofing other rural roads. The results from sensitivity analysis provide some insight into how these adaptation options can be applied to other roads. Adjustment for other roads can be done directly by adopting the adaptation cost per km of road and/or by changing other key variables such as the baseline traffic and the traffic growth rate. Thus we can have an idea into how the NPV or EIRR can change.

For illustrative purpose, we take Road 371 in Kampong Cham as an example of another rural road with a high flood risk. This road has a length of 20.8 km and the baseline traffic of 811 passenger car unit (MRD, 2010). If Adaptation Option 4 is implemented on Road 371, the total required adaptation costs will be around $2.04 million. Since the total adaptation cost decreases at a higher rate than the total adaptation benefit compared to Road 2629/ 2KT2, the EIRR of the road is significantly raised to 61.4%; even though the NPV is reduced to $18.5 million. The benefit cost ratio is also significantly increased to 12. This simple exercise shows that climate-proofing rural roads is a highly viable investment

7.5 Recommendations

The economic analysis of adaptation options through the Cost Benefit Analysis highlights a number of recommendations:

1) Climate-proofing rural roads is a highly viable investment project.

Adaptation option of rural roads yields much higher benefits than the required construction costs, even in a conservative scenario that only takes into account the main direct benefits to road users tied to improved traffic conditions. Consequently, the benefits are even greater when the impacts to other community groups are considered.

2) Adaptation Option 4 is the most recommended option to climate-proof rural roads in Cambodia.

   This adaptation option outperforms other options both in the conservative scenario and extended analysis. For the context of Road 2620/"KT2, this option requires 30% higher cost than the on-going construction project. However, in the broader context of Cambodian rural roads, this option is not necessarily more expensive than the costs of ordinary rural road improvement projects.

3) Climate change risks should be incorporated early on into the road design as it is a much more efficient investment than incrementally climate-proofing the road after it has been constructed.

   The difference in investment viability is shown by the difference in performance indicators between Adaptation Option 3 and Adaptation Option 4. Adaptation Option 3 has the lowest EIRR and benefit cost ratio, while Adaptation Option 4 demonstrates the highest ones.

8 Vulnerability Mapping

8.1 Introduction

Vulnerability mapping is a concept to define an entity's sensitivity to risks caused by hazards, and thereby prepare feasible measures to mitigate or terminate negative impact from such hazards.

The United Nations Development Programme (UNDP) defines vulnerability mapping as "Exposure to Hazards and Perturbations x Sensitivity – Adaptive Capacity". In other words: entities exposed to certain hazards and the entity's capacity to tackle any negative impact caused by that specific hazard.

The objective and usage of the mapping can, for example, be to allocate vulnerable areas and to mitigate negative impact by implementing proper adaptation options. The outcome data can be used for vulnerability mapping, planning purposes (to highlight sensible factors for a certain region), investment and maintenance plans, research etc. This information is valuable for various actors such as governmental maintenance and development agencies, NGOs such as the Red Cross, National Committee for Disaster Management, research centres including universities, investment banks, developers, etc.

The vulnerability mapping presented in this report handles climate-related hazards and its impact on existing infrastructure and surrounding areas including population, economical and social aspects. The mapping result in this context is a vulnerability classification of roads, which is a tool to be utilised when planning upcoming investments for e.g. maintenance, upgrading and development of, in particular, roads.

This report includes a description of how to undertake the mapping, a vulnerability case study leading the reader through each step of the process, and vulnerability classification of all roads within the Rural Roads Improvement Project (RRIP).

8.2 Climate Change-Related Hazards in Cambodia

Of all climate-related hazards, Cambodia is most exposed to and affected by flooding and to some extent drought. The annual mean temperature in Cambodia is increasing. In a tropical climate zone, such as Cambodia, mean temperature is projected to result in increased rainfall during rainy seasons and longer drought periods during the dry seasons. Subsequently, areas that are affected by flooding and drought today will be even more exposed to flooding and drought in the future.

In general, each degree Celsius of temperature increase can be expected to result in:

- 3-10% increases in the amount of rain falling during the heaviest precipitation events
- 5-10% changes in precipitation
- 5-10% changes in stream flow across river basins
- Risk of very hot summers increases, where “very hot” is defined as the hottest 5% of summers during the 1971- 2000 average
- 5-15% reductions in the yields of crops as currently grown

Photo – (left) Road 2620, submerged and (right) Road 371. Both photos from October 2013

The mean temperature in Cambodia is projected to increase with 1.5^0 C by 2050. With today's average annual rainfall of 1,000-1,500 mm (except south-east where it is 2,500-5,000 mm), this means an increase of up to 150 mm per year. Hence, presently exposed areas will be increasingly exposed and most likely extended to cover bigger areas in the future.

8.3 Vulnerability Mapping - Process

The sought result is gained via a process where historical, existing and projected data are gathered and evaluated. Impact from hazards are studied together with possible mitigation measures. The final steps include visualisation, economical studies, final evaluation and recommendation.

The four key steps of the vulnerability mapping process are

Step 1 – Determine and project hazards and sensitivity

Collecting and summarising existing information, this includes historical data and consequences of climate-related impacts.

Future projections are also undertaken during this initial step.

Step 2 – Determine and project adaptive capacity

Via, in particular, first-hand information (e.g. public meetings), gather information of existing and utilised mitigation measures, social aspects etc., which are relevant for an area's possibility to prevent severe impact from a certain hazard.

Evaluation and summarising of suitable adaptation options are undertaken. This includes preparation of cost estimates for implementation and future maintenance.

Step 3 – Integrate and map vulnerability

Review and evaluation of results collected in steps 1 and 2, with the purpose of identifying areas that are highly vulnerable. This is preferably outlined using GIS tools and expert opinions.

Step 4 – Identify, assess and review adaptation options

Identifying most suitable adaptation options for the specific hazards.

This step shall preferably include economical analyses (Cost & Benefit Analyses) of the various adaptation methods.

8.4 Case Study – Road 2620 and 2KT2 in Kampong Thom Province

8.4.1 Background

The studied road sections have a total length of 66.2 km. The population living along and in the fringe areas of the road is approximately 75,000. The topography is relatively flat and located near the Stung Sen River, which is a catchment river from the northern mountain range. Hence, this area is particularly exposed to flooding.

During the rainy season in 2011, parts of the road sections were submerged by 0.2-0.5 m for nearly 2 months, which among other things resulted in limited accessibility.

Photo – Road 2660, October 2013

The road sections are part of the RRIP, and are subsequently being upgraded. The implemented upgrading design comprises in particular paving the road surface, raising the embankment as well as replacement and new installations of drainage structures and other road furniture.

The road sections are part of the RRIP, and are subsequently being upgraded. The implemented upgrading design comprises in particular paving the road surface, raising the embankment as well as replacement and new installations of drainage structures and other road furniture.

8.4.2 Vulnerability Mapping

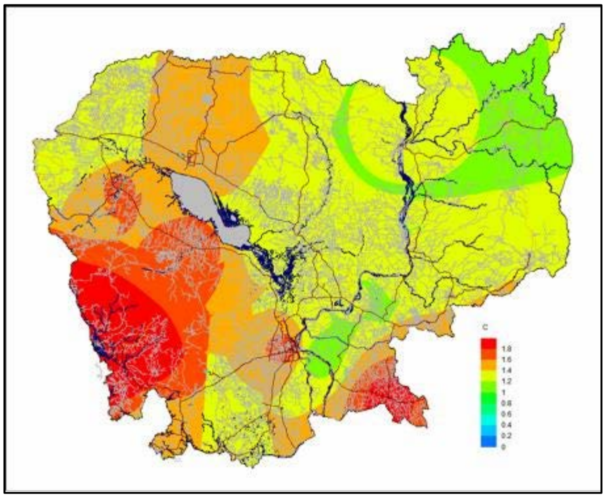
Step 1 – Determine and project hazards and sensitivity

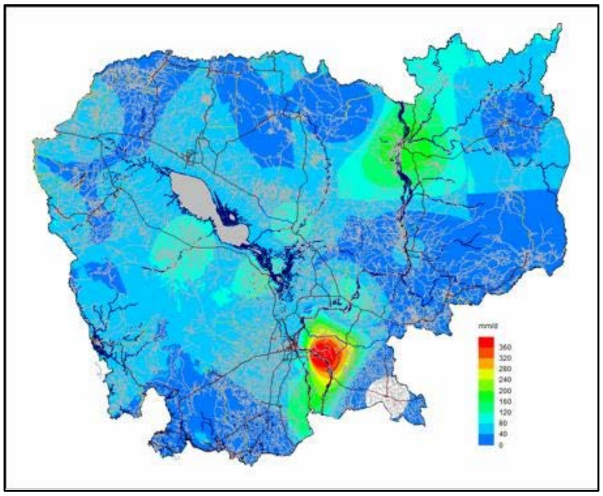
Available historical and existing climate-related data were gathered, a phase which was followed by climate modelling for projections and hydrological modelling for existing and projected scenarios.

The climate modelling included five main activities namely:

1) Collection and processing of historical hydro-meteorological data
2) Collection and processing of global and regional climate change data
3) Downscaling to monitoring stations
4) Dynamic interpolation of the weather data
5) Information synthesis and visualisation utilising GIS

(Detailed description and outcomes of the climate modelling are in particular described in the report "Climate Change Vulnerability Modelling" dated December 2013.)





Picture – Extracts from GIS database; (left) Change in temperature by year 2050 Scale reaching from 0 - 1.8^0 C and (right) Change in 100 years rainfall by year 2050 Scale reaching from 0-360 mm/day

The hydrological modelling concentrated on the determination of flows in river streams and flooding. Simulations were undertaken of flows and levels in streams using existing data and projected data from the climate modelling.

(Detailed description and outcomes of the hydrology modelling are described in the reports "Climate Change Impact and Hydrology" dated June 2013 and "Simulation of flows and levels using projected climate values" dated December 2013.)

Step 2 – Determine and project adaptive capacity

Evaluation of the existing situation with a focus on currently used methods to mitigate negative impacts from climate-related hazards. Feasible future adaptation and mitigation options will be developed and/or determined based upon existing system and existing as well as predicted future capacity.

Surveys of the project sites were undertaken, this included consultations with local authorities, communities and local NGOs to gather information on natural and social resources, including exposure and vulnerability to climate-related hazards as well as adaptation measures in use.

(Details and outcomes from this work are presented in the report "Vulnerability and Environmental Assessment" dated December 2013, wherein consultations and outcomes from all consultations in the seven provinces included in the RRIP are summarised.)

Suitable and feasible adaptation options are identified to mitigate any negative impact from the hazards in the specific context. Costs for the various adaptation options, including initial investment and maintenance, are estimated.

Each adaptation option will be further evaluated and tailor-made in later steps when additional specific studies have been undertaken.

(Evaluation of possible adaptation options including costs and other relevant information are presented in this report, see chapter 4 "Adaptation Options".)

Step 3 – Integrate and map vulnerability

Study and evaluate the result from Step 1 and Step 2 with the purpose to identify most vulnerable areas. This is preferably done by visualising the data either on maps and/or via matrices.

All data collected, in particular climate change projections, were arranged in a tailor-made GIS database comprising of raster and vector files, from where data can be extracted, evaluations undertaken, maps prepared and studies carried out. The baseline data is supported by various other data that is also incorporated into the GIS database; this includes among other things technical road data, average daily traffic, road accident data, road networks, 3D contour lines and photos.

More than 150 raster files have been generated covering basic data and frequency. The baseline data used are from the period 1984-2005 and projections have been prepared for year 2044-2069.

(Additional information is available in the GIS database, which has been widely distributed within the MRD organisation).

Step 4 – Identify, assess and review adaptation option

Detailing of previous steps by identifying the most feasible adaptation option for the specific context including detailed costs and preferably by carrying out cost and benefit analyses.

The most feasible mitigation measures were decided by combining the capacity of MRD and the context of the hazard and its connected risks. For the case study roads, the main problem is flooding, not flash floods but long-lasting floods that submerge the roads and thereby limits accessibility to communities during rainy seasons. The most feasible adaptation options in this specific context are to raise the road embankment, pave the road surface and upgrade and/or clean drainage structures.

An economical cost and benefit study was prepared for the case study road using HDM4 modelling. Four adaptation options were evaluated. All options are based on raising the embankment and paving the road. The evaluated options are:

Baseline

Laterite road with specification of road 2620/2KT2 Adaptation Option 1 - Current road improvement project Cost 5.0 MUSD

Adaptation Option 2 - Road level is raised 0.5 m for 13.7 km, after construction of Adaptation Option 1.

Cost 6.2 MUSD

Adaptation Option 3 - Road level is raised 1m above projected water level from the climate change modelling, after construction of Adaptation Option 1

Cost 8.6 MUSD

Adaptation Option 4 - The design for Adaptation Option 3 is planned and constructed from the beginning to laterite road.

Cost 6.5 MUSD

The evaluations handled two scenarios for each adaptation option, namely:

1. Conservative - Travel time saving, VOCs, maintenance costs and reduced flood costs for normal and generated traffic.
2. Extended analysis - Residual values of road, induced traffic for tourism, reduced health costs from dusts and other socio economic impacts

Table - Result from HDM4 Evaluations

Measure	Option 1	Option 2	Option 3	Option 4
Economic IRR	31.0%	29.6%	24.9%	32.4%
Financial NPV ($)	21 962 550	25 279 842	27 422 546	29 922 546
Economic NPV ($)	17 570 040	20 223 874	21 938 037	23 938 037
Benefit Cost Ratio	5.4	5.1	4.20	5.6
Costs ($/km)	75 529	93 656	129 909	98 187
Benefit ($/km)	407 289	477 037	550 190	550 190

An investment is seen as financially viable if the IRR is >12%. Subsequently, all adaptation options evaluated are highly worthy investments. The result from the extended analysis scenario improves the investment ability of each adaptation option by around 5%.

The study shows that adaptation option 4 is the most feasible adaptation option when the context is similar to the case study road.

8.5 Vulnerability Classification of Roads

One way to utilise the vulnerability mapping data is for various classifications. Vulnerability classification in regards to climate-related impact on roads have been undertaken for the RRIP roads.

The classification is divided into three categories: Class 1-3, where a Class 1 road is considered to have low and a Class 3 road high vulnerability for climate impacts.

The roads were classified using a scoring system, 1-3, in nine categories. All categories have different weight depending on each category's relevance. The categories and weight used are:

Table – Classification Categories and Weights

Category	Weight	Minimum	Maximum
Length	1	1	3
Width	2	2	6
ADT	9	9	27
Surface	6	6	18

Usage	5	5	15
Population	8	8	24
Flood	10	10	30
Drought	5	5	15
Projection	8	8	24
Sum		**54**	**162**

When the scoring is completed, the total score is divided by 9 (i.e. the number of categories). The score will be in the range between 6 and 18. The score for each road class is:

Vulnerability Class 1 <9

Vulnerability Class 2 9-15

Vulnerability Class 3 >15

All relevant data should preferably be summarised prior to the actual classification. All roads included in the RRIP have been summarised in a matrix. The summary matrix for the case study road is presented below:

Table – Data Matrix for Road 2620 and 2KT2

Province	Kampong Thom
Road	Road 2620 and Road 2KT2
Length*[1]*[2]	66.2 km
Width*[1]	7 m
ADT*[2]	863
Specific road users/usage	Availability to social services and transport of goods
Population*[4]	75,000

Road accidents*5	111 fatalities in the province during 2012. Considerable decrease since 2008-2009 when >200 died. 89% of fatalities accidents occurred on straight road section. 41% of fatal accidents involve motorbikes.
Exposure*3	The area is rather flat and located in the fringe of the Stung Sen River, which is a catchment river from the northern mountain range. Hence, this area is very exposed to flooding. The existing roads and storm water system are in poor condition.
Historical facts*3	Parts of the roads were submerged between 0.2 and 0.5 m for 1-2 months during and after the rainy season in 2011. 9 people lost their lives due to the flooding in 2011. Furthermore, more than 100 domestic animals died due to the flooding in 2011.
Projections*6	The average daily maximum temperature increases 1.37oC in dry and 1.44oC in wet season. The maximum rain-fed water on the ground increases by over 54mm in the projection. Erosion is projected to increase by about 27%.
Sensitivity*3	Flooding, erosion
Consequence	Limited accessibility during and after rainy seasons. Casualties due to flooding.
Adaptive capacity	Limited adaptive capacity. Presently a warning system is in place and managed by MOWRAM, NCDM, Red Cross, etc. Shelter is available in pagodas (normally located on highlands).
Adaptation options	Raising road profiles, proper pavement of roads, upgrading storm water drainage system, implementation of spillways.
Vulnerability Class 1-3	Class 3 (both roads are Class 3)*7

*1 Data from survey
*2 Data from report “Preparing the provincial/rural asset management project” dated March 2012.
*3 Information gathered via public hearing consultations
*4 Data from census 2008, National Institute of Statistic, Ministry of Planning
*5 Data from Road Safety study carried out within the RRIP
*6 Projection data from climate change modelling prepare
*7 Relates to the situation prior to the RRIP road improvement

The vulnerability classification of the case study roads, 2620 and 2KT2, was carried out by the CCA team and scored as follows:

Table – Classification of Road 2620

Category	Weight	Score	Result
Length	1	3	3
Width	2	2	4
ADT	9	2	18
Surface	6	3	18
Usage	5	3	15
Population	8	3	24
Flood	10	3	30
Drought	5	3	15
Projection	8	3	24
Sum		**25**	**151**

Table – Classification of Road 2KT2

Category	Weight	Score	Result
Length	1	1	1
Width	2	2	4
ADT	9	2	18
Surface	6	3	18
Usage	5	3	15
Population	8	3	24
Flood	10	3	30
Drought	5	3	15
Projection	8	3	24
Sum		23	149

Dividing the total score with the number of categories (9) results in a score of 16.8 for road 2620 and 16.6 for road 2KT2. Subsequently, both roads are classified as vulnerability Class 3 roads (>15).

Observe! The evaluation is done with road details and conditions prior to the ongoing upgrading within the RRIP.

The following table shows a full classification of all roads within the RRIP. This classification can be used as a guideline for future classifications.

Table – Classification of all RRIP Roads*[1]

Roads	L	W	A	S	U	P	F	D	P	Score	Road Class
Kampong Speu											
1KS3	3	2	3	3	3	3	2	2	3	16.1	**3**
1KS4	2	2	2	3	3	3	2	2	3	15	**2**
Kampong Cham											
370	2	2	3	3	3	3	2	1	3	15.4	**3**
371	2	2	2	3	3	3	3	1	3	15.6	**3**
373C	2	2	2	3	3	3	1	2	1	12.1	**2**
373C-1	1	2	2	3	3	3	1	2	1	12	**2**
Kampong Chhnang											
1KCH2	2	2	2	3	3	3	1	1	3	13.3	**2**
115C	2	2	3	3	3	3	1	1	3	14.3	**2**
1KCH3	2	2	2	3	3	3	1	1	3	13.3	**2**
Pursat											
152E	1	2	2	3	3	3	3	2	2	15.1	**3**
154D	1	2	1	3	3	3	3	2	2	14.1	**2**
155C	2	2	2	3	3	3	1	2	2	12	**2**
155D	2	2	2	3	3	3	1	2	2	13	**2**
1PS2	2	2	2	3	3	3	1	2	2	13	**2**
Battambong											
1BB1	2	2	2	3	3	3	2	3	3	15.6	**3**
1BB2	2	2	2	3	3	3	2	2	3	15	**2**
1BB3	1	2	2	3	3	3	1	1	3	13.2	**2**
1BB4	2	2	2	3	3	3	3	2	3	16.1	**3**
Siem Reap											
266E	2	2	2	3	3	3	2	3	3	15.6	**3**
266D and 2SR2	3	2	3	3	3	3	2	3	3	16.7	**3**
Kampong Thom											
2620	3	2	2	3	3	3	3	3	3	16.8	**3**
2KT2	1	2	2	3	3	3	3	3	3	16.6	**3**

*[1] The classifications are done based on road data and condition prior to the RRIP road upgrading

8.6 Summary

The historical and existing data collected in combination with the projected climate-related scenarios comprises the baseline for future vulnerability mapping and classification. The data are conveniently accessible for evaluations via the tailor-made GIS database, which can be utilised either via a full GIS software license or via free GIS viewers available from the world wide web.

The classifications undertaken within this study can be used as a guideline for future similar classifications.

The data are relevant for more actors than MRD and should be shared with all parties having any interest in accessing and using the material.

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Table 7.6 Sensitivity Analysis

Key variable for sensitivity analysis	Option 1				Option 2				Option 3				Option 4			
	EIRR	Economic NPV	Change in NPV	SI	EIRR	Economic NPV	Change in NPV	SI	EIRR	Economic NPV	Change in NPV	SI	EIRR	Economic NPV	Change in NPV	SI
Trafficgrowth rateisreducedby 20%	29,4%	15 421 676	-12,2%	0,61	28,0%	17 805 175	-12,0%	0,62	23,4%	19 388 794	-11,6%	0,65	30,8%	21 068 794	-12,0%	0,60
Effectiveness of hazard impact reduced by 20% forOption1to Option4	30,9%	17 503 690	-0,4%	0,02	28,7%	19 869 580	-1,8%	0,09	23,2%	21 259 735	-3,1%	0,15	31,6%	23 259 735	-2,8%	0,14
Baseline traffic is reduced by 20%	28,0%	15 293 379	-13,0%	0,65	26,1%	17 383 682	-14,0%	0,70	20,9%	18 498 249	-15,7%	0,78	28,9%	20 498 249	-14,4%	0,72
Adaptation costs increased by 20%	26,2%	16 770 040	-4,6%	-0,23	24,5%	19 215 874	-5,0%	-0,25	19,6%	20 498 037	-6,6%	-0,33	27,4%	22 898 037	-4,3%	-0,22
Flood risk probability is reduced to 10%	30,8%	17 404 164	-0,9%	0,02	28,1%	19 338 141	-4,4%	0,09	22,3%	20 242 283	-7,7%	0,15	30,5%	22 242 283	-7,1%	0,14

Notes: EIRR = Economic Internal Rate of Return; SI = Sensitivity Indicator Source: CT

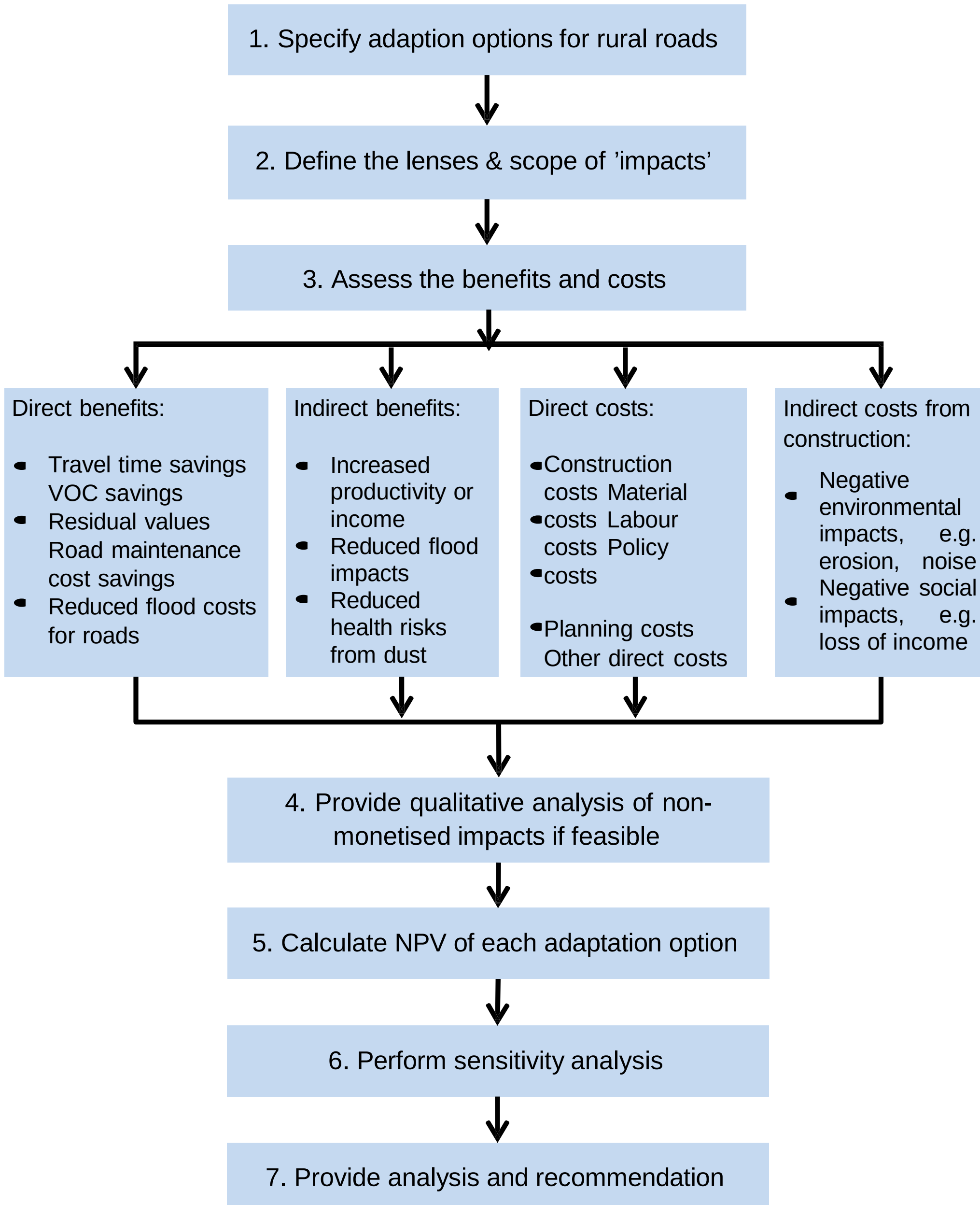

Figure 4. Methodology for Cost Benefit Analysis of Rural Road Adaptation

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