Project Climate and Disaster Risk Assessment

April 2018

Cambodia: Rural Roads Improvement Project III

Prepared by the Ministry of Rural Development for the Asian Development Bank. This is the first version of the draft report available.

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ABBREVIATIONS

ADB	Asian Development Bank
CDRA	climate and disaster risk assessment
DBST	double bituminous surface treatment
FRMI	flood risk management interface
GCM	global circulation models
IDF	rainfall intensity duration and frequency curves
km	kilometer
m	meter
mm	millimeter
MRD	Ministry of Rural Development
MPWT	Ministry of Public Works and Transport
MRC	Mekong River Commission
NR	national road
RRIP	Rural Roads Improvement project
RCP	representative concentration pathway
STRM	shuttle radar topographic mission

PROJECT CLIMATE AND DISASTER RISK ASSESSMENT

I. BASIC PROJECT INFORMATION

Project Title: Rural Road Improvement project III

Net Construction Cost: $**39,645,112.72**

Location:
Cambodia; Kampong Cham, Tboung Khmum, Prey Veng, Svay Rieng, Kratie

Sector:
Rural roads

Theme:
Rural roads improvement and upgrading, increasing connectivity, rural access to markets and facilities, promoting gender inclusiveness and equality, and improving resilience to natural hazards and the impact of climate change

II. BRIEF DESCRIPTION

1. The majority of Cambodia's population (85%) lives in rural villages and many of these are rice farmers earning a living through subsistence agriculture. Such livelihoods are vulnerable to climate change both in terms of sustainability of crops and loss of road connectivity. Rural roads play a vital role here.

2. The government of Cambodia is improving the rural population's social and economic conditions through an ongoing program of improvement and maintenance of rural roads. According to the "Strategic Plan for Rural Roads (2007)" published by MRD, economic growth and poverty alleviation of the country are closely correlated with rural road improvement, providing meaningful links to socio-economic wellbeing of the rural population.

3. The Rural Roads Improvement project (RRIP) in 2010 and RRIP II in 2015 are addressing these issues through rural road improvements; rural road asset management; rural road safety and community awareness. The greater portion of the project roads are directly connected to National Roads to provide linkages between population centers and enhance connectivity.

4. The program has now been extended to RRIP III. There will be 22 roads improved in RRIP III and the total length of roads will be 360 kilometers covering 10 provinces. Cambodia is highly susceptible to flooding. Rural roads comprise a pavement, embankment, bridges, box culverts and pipe culverts. All of these can be adversely affected by extreme weather events.

III. SUMMARY OF CLIMATE RISK SCREENING AND ASSESSMENT

A. Sensitivity of project component(s) to climate/weather conditions and sea level

5. Changes in the rainfall regime are the most important factors in climate change that can have an impact on physical infrastructure - much more important than, for example, temperature change.

6. Flooding in Cambodia is a natural occurrence and lifestyles are adapted to seasonal floods. Most people are concerned when the intensity and occurrence changes. There are two major flood types in Cambodia: (i) flashfloods, resulting from heavy downpour upstream on the Mekong River, which affect provinces along the Mekong and the southeastern areas of the country; and (ii) central area large scale floods, resulting from a combination of runoff from the Mekong River and heavy rains around the Tonle Sap Lake, which affect the provinces around the lake and the southern provinces.

7. In rural areas, flooding is a major problem for roads. In some upland areas with significant slopes and a water course, the type of flooding is flash flooding which occurs over several hours. In low-lying areas with no natural gradient flooding can last for weeks or months.

8. While roads should obviously remain above the flood level there are other factors to consider. Roads provide access to communities along the roads. Even if roads are above the flood level agricultural areas and even villages may not be. During floods villagers move their animals to refuges on high ground. Roads provide an escape route in these circumstances.

9. If a road becomes flooded, water will flow across the road. Even if the bituminous surface layer is not damaged water overflowing can damage the embankment and under scour the road. There must be adequate cross-drainage. Major factors to consider for climate resilience are embankments, bridges and culverts.

10. Although these can be designed for climate resilience, to be effective, they must be maintained. Maintenance is a key factor.

11. The project roads are not vulnerable to the effects of sea level rise.

B. Climate Risk Screening

12. The Climate and Disaster Risk Assessment (CDRA) has been carried out and identified the following situations.

1. Kampong Cham (KC)

13. There are 6 roads covering in total a length of 100.60 kilometers. Width varies from 7 meters (m) to 8 m and the proposed pavement is double bituminous surface treatment (DBST).

14. This area is dominated by the flow in the Mekong river which can rise and fall 14 m over the seasons. Roads running along the left bank (easterly) of the river are classed as being at moderate risk of flooding. However, the Kampong Cham town has experienced severe flooding in the past but considerable bank protection and river training civil works have taken place recently to protect the town center. Because of this, roads to west of the town are classed as being at low risk of flooding in the future although the land moving away from the town in a westerly direction is notably flat and should the Mekong river flow exceed its bank full discharge then overtopping waters can travel a long way in a westerly direction. Much evidence of ponding and standing water can be seen on the Flood Risk Map. KC1, 3, 5 and 6 would fall into this category.

15. KC2 is on the western side of National Road (NR) 6 and this location can be vulnerable to overland flow from an expanding Tonle Sap during the wet season when the lake expands its surface area by over 400%. KC4 is in an area of low to moderate risk.

2. Tbuong Khmum (TBK)

16. There are 5 roads covering in total a length of 61.1 km. Width varies from 7 to 8 m and the proposed pavement is DBST.

17. Tboung Khmum is also dominated by the left bank (easterly side) of the Mekong river. The whole of the left bank of the Mekong river is classed as being at moderate risk in the future. This makes TBK1 particularly vulnerable.

18. As one moves away from the Mekong to the east the land rises slightly (a high point is +16 m) which does offer more protection and 2, 5, and 7. These are classified as low risk.

19. TBK 3 is located on the inside of a bend in the Mekong river and this area has experienced severe flooding in the past.

3. Prey Veng (PV)

20. There are 5 roads covering in total a length of 72.2 km. Width varies from 7 to 8 m and the proposed pavement is DBST.

21. Prey Veng is also dominated by overland flow from the Mekong river and has many low lying natural water bodies and ponds. The land between Prey Veng and the Vietnam border (via Svay Rieng) is very flat and there is little opportunity for natural drainage other than the Mekong river, which flows to the south. For this reason, most of the area is classed as being at moderate risk of flooding and this would apply to PV1, 2, 3 and 5

22. Some roads in the center of the province alongside NR1 are classed as being at very high risk of flooding and PV4 could come into that class.

4. Svay Rieng (SVR)

23. There are 5 roads covering in total a length of 64.6 km. Width varies from 7 to 8 m and the proposed pavement is DBST.

24. Svay Rieng province forms a border with Vietnam. It is bisected by NR1 which runs from Phnom Penh over the Mekong River to Vietnam Border. Due to the extremely flat terrain this area of Cambodia is basically downstream of all other weather influences and can flood over very large distances on either side of the NR1 alignment. There are areas of free standing water to the north and south of NR1 and local rainfall has no natural drainage escape route.

25. Most of this area is deemed to be at high risk of flooding. NR1 is classed as being at low to moderate risk because of its embankment.

26. All of the roads from SVR2 to 6 can be classified as high risk of flooding.

5. Kratie (KRT)

27. There is 1 road covering in total a length of 61.3 km. Width is 8m and the proposed pavement is DBST.

28. Kratie province is dominated by the Mekong river which bisects it flowing from north to south. There are also several major tributaries which flow east to west into the Mekong and several minor ones that flow west to east discharging into the Mekong. Due to this extensive drainage network, it is classified as low risk of flooding. The northern end of KRT1 should be considered as vulnerable due to its proximity to the main branch of the Mekong.

C. Climate risk assessment

29. A climate and disaster risk assessment (CDRA) was undertaken, based on site visits and climate change projections for the 5 provinces. Use was made of the Flood Risk Management Interface (FRMI) software developed by the Ministry of Public Works and Transport. This makes climate change projections by downscaling Global Circular Models data and gives results based on RCP8.5 for the years 2030 and 2050 and 2070. These projections are then translated into levels of flood risks. Main conclusions are:

(i) Annual rainfall may remain unchanged, but rainfall will increase more in the wettest months by being of stronger duration. This will lead to longer dry periods. There may be "mini-droughts" during the wet season.
(ii) Precipitation will increase most in the south-west and decrease in the north-east.
(iii) Both the maximum 5-day and 1-day storms are expected to increase. The projected increases are 10% for 2030, 20% for 2050 and 30% or more for 2070.
(iv) The relative increase in rainfall is heavier for short durations.
(v) An increase of 20% on existing rainfall intensity duration and frequency curves (IDF)[1] will allow for a global temperature increase of 2^{o}C. This factor is conservative and is recommended as a design factor.

IV. CLIMATE RISK MANAGEMENT RESPONSE WITHIN THE PROJECT

30. During preliminary design there are five factors considered: pavement, embankment, bridges, box culverts and pipe culverts. The climate resilience measures fall into two categories:
(i) Increasing the embankment to raise up the existing road elevation. This requires a slight vertical lift and as the embankment has sloping sides, a slight widening which means the embankment cross sectional area will increase.
(ii) Additional drainage works to improve water flow and remove constrictions and blockages. This may require replacing existing drainage structures, or if existing structures are in reasonable condition, then widening them.
(iii) Pavement surface will be improved in the project, but this is not considered a climate resilience measure.

31. The cost of climate change adaption for the embankment is calculated by a 45% increment of embankment work to raise up the existing road elevation.

32. Improved drainage includes bridges, box culverts and pipe culverts. Some structures currently are satisfactory and do not require replacement. Widening box culverts may require some additional upstream bank protection against fast flowing currents and some works downstream of the culverts such as energy dissipation structures to slow down the stream and control scouring.

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[1] IDF curves give the amount in mm of rainfall per hour for different return intervals such as a 1 in 10-year event, a 1 in 100-year event and so on. They are an essential tool in the design of drains.

33. Although bridges and box culverts have been checked as part of the condition survey, and the numbers that need to be replaced are given (Table 8-3) the actual works for bridges and box culverts have not been considered further at this stage as this comes under detailed design. If the bridge and box culverts have been damaged they would normally be replaced with similar structures of same size. A hydrological survey and study will be carried out and if they are too narrow they will be extended or widened. If they are in a location identified in the CDRA as being at high risk of flooding the sizing will be increased to accommodate higher rainfall and associated faster stream flows.

34. Pipe culverts have been considered. As a minimum all pipe culverts should have a minimum diameter of 1200mm to aid in cleaning and maintenance. There are over 900 pipe culverts of which possibly over 100 will remain in use unchanged and the rest will have their size increased. This increase will be based on the CDRA.

35. The preliminary design has considered embankments and pipe culverts. These will be verified during detailed design during hydrological studies. Bridges and box culverts have not been considered in detail and these must have climate adaptation included in their specifications. This will be done during detailed design based on hydrological surveys.

36. Additional analysis is required for bridges and box culverts and for pipe culverts in areas identified as High Risk of Vulnerability to climate change induced flooding. These are:

(i) Kampong Cham (KC)
- KC1, 3, 4, 5 and 6 are at low to moderate risk of flooding.
- KC2 is at moderate risk.

(ii) Tboung Khmum (TBK)
- TBK1 and 6 are highly vulnerable.
- TBK 3 is at severe risk.

(iii) Prey Veng (PV)
- PV1, 2, 3 and 5 are at moderate risk.
- PV4 and 6 are at high risk.

(iv) Svay Rieng (SVR)
- SVR1 to 6 are all at high risk of flooding

(v) Kratie (KRT)
- KRT1 is at high risk.
- KRT2 and 3 are at low to moderate risk

(vi) Kampong Chhnang (KCH)
- KCH2 through 7 are at moderate risk

(vii) Kandal (KD)
- All roads KD1 to 12 are at moderate risk.
- KD6, 7 and 8 are highly vulnerable

(viii) Kampong Speu (KSP)
- KSP1 to 7 are at moderate risk but KSP1 is highly vulnerable.

(ix) Takeo (TK)
- TK1 to 6 are at moderate to high risk

(x) Kampot (KP)
- KP1 to 5 are at moderate risk

37. A figure of 10.48% of total construction costs is being allocated to climate change resilience measures.

I. INTRODUCTION

A. Background

1. The majority of Cambodia's population (85%) lives in rural villages and many of these are rice farmers earn a living through subsistence agriculture. By their nature such livelihoods are vulnerable to climate change both in terms of sustainability of crops and in terms of loss of road connectivity. Rural roads play a vital role here.

2. The government of Cambodia is improving the rural populations social and economic conditions through an ongoing program of improvement and maintenance of rural roads.

3. According to the "Strategic Plan for Rural Roads (2007)" published by MRD, economic growth and poverty alleviation of the country are closely correlated with rural road improvement, providing meaningful links to socio-economic wellbeing of the rural population.

4. The Rural Roads Improvement project (RRIP) in 2010 and RRIP II in 2015 are addressing these issues through rural road improvements; rural road asset management; rural road safety and community awareness. The greater portion of the project roads are directly connected to National Roads to provide linkages between population centers and enhance connectivity.

5. The program has now been extended to RRIP III. There will be 22 roads improved in RRIP III and the total length of roads will be 360 kilometers (km). The project will be implemented through to 2020 and beyond. The MRD will be the executing agency for the project.

6. The estimated cost will be US$43,473,590.

B. Design Philosophy

7. The civil works will include the improvement of existing soil or gravel surfaced roads using a double bituminous surface treatment (DBST) and the placement as necessary of sub-base using unbound materials or stabilized materials for the road pavement.

8. The roads will be rehabilitated within their existing width. The works also include the replacement or repair of existing cross drainage structures including box and pipe culverts and small bridges at existing locations and the placement of a number of new culverts at locations still to be identified during engineering surveys.

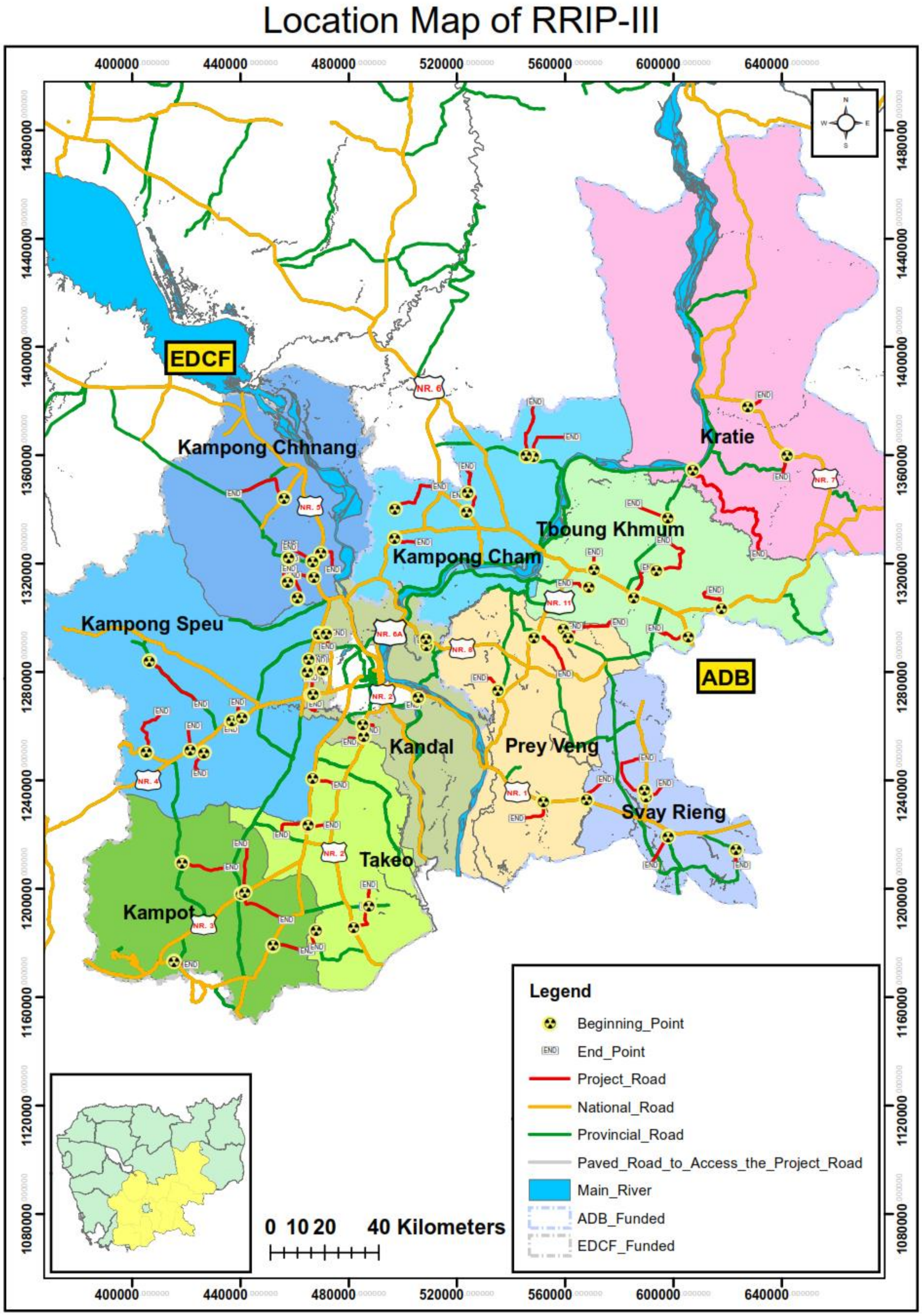

Figure I-1 RRIP III Roads Map updated March 6

C. Climate Change Literature Review

9. The climate risk assessment has been undertaken in accordance with ADB's guidelines and international practices. The consultants have taken account of the following publications:

- Mekong River Commission (MRC), Roads and Floods, MRC Technical Paper No. 35, 2011
- Guidelines for Climate Proofing Investment in the Transport Sector - Road Infrastructure Projects, August 2011, ADB.
- Climate Change Impact and Hydrology, MRD June 2013
- Climate Change Adaptation Options, MRD May 2014
- Climate Change Adaptation Report August, MRD, (Manley, R) August 2014
- Reinforcing Community Flood Resilience, MPWT, August 2014
- Climate Change Resilient Roads, MRD October 2014
- Climate Change Action Plan for Transport Sector 2014-2018 MPWT
- Report on Knowledge Management, MPWT, June 2015
- Non-Mandatory Guidelines for Flood Proofing Roads, MPWT September 2015
- Road Design Standard Changes Report, MPWT September 2015
- Flood Risk Management Interface Manual, MPWT, September 2015
- Vulnerability Mapping Report, MPWT, January 2016
- Climate Modeling Report, MPWT, January 2016
- Flood Risk Management Interface (FRMI) Version 1.2 obtained from MPWT September 2016
- Update Report Flood Risk Management Interface (FRMI) January 2018.

10. These documents reflect the latest state of knowledge and "good practice" on climate change in Cambodia. The FRMI is MPWT's in-house software used for determining the magnitude of flood risk plus indicative costs of adaptation measures based on known unit rates. Version 1.2 was used although it is understood that Version 2.0 has been prepared but not released for general use yet. Extensive use has been made of the MPWT FRMI software in this evaluation.

II. CLIMATE CHANGE SCIENCE

A. IPCC

11. The Intergovernmental Panel on Climate Change (IPCC) is a U.N. scientific body who produce a series of international assessment reports on the current state of climate change knowledge. The IPCC has facilitated comparison of General Circulation Models (GCM) by suggesting standard future CO_2 scenarios and standard input data such as temperature, rainfall, wind speed etc. GCMs are constantly being updated and results from each new model are compared to the outputs from the others. The IPCC carries out an inter-comparison of GCM results.

B. Future Scenarios

12. Accurately forecasting the future climate is not possible because of uncertainties in the interactions between the oceans, atmosphere and biosphere. As a result, GCMs produce a range of modeled future climate situations. These are not attempts to predict the likelihood of what may happen but the consequences of certain concentrations of GHGs. These are called climate scenarios.

13. The IPCC report (AR Number 5 is the latest) uses Representative Concentrations Pathway (RCP). These Representative Concentrations Pathway are projections of the change in the balance between incoming and outgoing radiation to the atmosphere. The numbers refer to global energy imbalances, measured in watts per square meter, by the year 2100.

14. RCP 3 (PD) refers to a scenario where CO_2 emissions peak in the near future and then decline. This is optimistic. RCP 8.5 refers to the worst-case scenario where emissions continue to rise until 2100 leading to global temperature increases. This is pessimistic. RCP 4.5 and 6.0 are intermediate scenarios.

15. Recent climate change studies use RCPs of 8.5 for extreme CO_2 future concentrations and values of 3.5 or 4.5 to represent low CO_2 future concentrations. In the projections for MPWT the RCP 8.5 is used. Therefore, this is a pessimistic scenario and will give worst case conditions. It is designated the "extreme scenario".

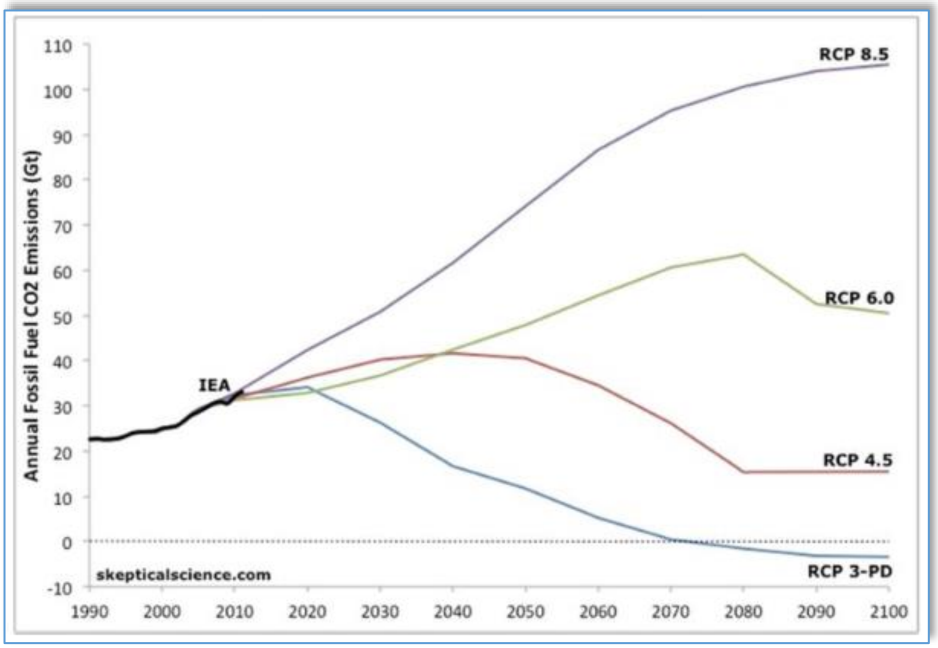

Figure II-1 RPCs from IPCC AR5 (2011)

C. General Circulation Models used in the Region

16. More than 20 different GCMs have been used to model climate change in Cambodia. The suitability can be assessed by comparing modelled results with measured climate data. Models that most accurately predict current monsoon rainfall are the most suitable.

17. While GCMs predict temperature reasonably well the projected extreme precipitation intensities are generally much lower than observed data. The timing of the start and end of the monsoon season are also generally poorly predicted.

18. Rainfall errors are generally between 1.5 to 2.5 millimeters (mm)/day. The worst performing model showed rainfall errors of over 4 mm/day. The most widely used model showed rainfall with errors of less than 1.5 mm/day. This was used in the MPWT project.

D. Downscaling General Circulation Model outputs to regional scales

19. Global models are intended for use with large spatial scales and are too coarse to determine local scale climate variations in precipitation. Downscaling climate data generates locally relevant climate data from GCMs. Downscaling obtains regional weather phenomena that are influenced by the local topography, land-sea-contrast, and small-scale atmospheric features such as convection.

20. The CSIRO modeling is the latest and presents downscaling information at the highest resolution.

E. Projected Temperature change

21. All these models show warming occurring over Cambodia in the future, with the early studies generally projecting warming of 0.01ºC to 0.03ºC per year, and later models projecting warming of 0.03ºC to 0.06ºC per year. This equates to a warming of 0.35ºC to 2ºC by 2050 and 1ºC to 5ºC by 2100.

F. Projected Rainfall Change

22. Climate in Cambodia is traditionally described with reference to two seasons, the wet season, when rain bearing monsoon winds from the southwest predominate and the dry season, when dry northeast monsoon occurs. Climate change could result in changes in the total amount of rain in each season and a change in the onset or end of the wet season. Climate change studies project a shorter wet season in the future with a later start and a longer drier dry season. The results for rainfall change are much more varied than those for temperature.

23. The model projects an overall decrease in rainfall during the wet season, an increase at the start of the wet season and an increase in the amount of rain that falls in extreme events. The first points are significant to farmers. This latter point is significant for drainage design.

G. Rainfall Intensity

24. Climate change studies have projected an increase in rainfall intensity during rainy days by 2055. A decrease in the total yearly rainfall that is projected for some locations is a result of a decrease in the number of rainy days not a reduction in intensity. The CSIRO's CCAM model projected an increase of daily rainfall of 10 to 20mm.

25. While climate models are run at intervals of 1 hour or less the outputs that are generated are at the scale of 1 day. Predictions of rainfall intensity in terms of mm per hour may under estimate maximum rainfall intensity. As a guide, in tropical conditions, hourly rain fall can be assumed to be 20%–40% of daily rainfall.

III. CURRENT AND PROJECTED METEOROLOGICAL DATA

A. Data Availability

26. The Department of Meteorology (DOM) of Ministry of Water Resources and Meteorology has 38 meteorological stations that record rainfall, 23 that record evaporation, and 14 stations that record wind speed. The MRC maintains 12 stations in Cambodia. Key stations send data daily to DOM for weather forecasting. Rainfall, air temperature, wind speed, wind direction and relative humidity are observed by only two main stations at Pochentong and Sihanoukville.

B. Climate data provided for Road Risk Analysis

27. The data in the FRMI consists of:
- Current 1-day extreme rainfall output for the period 1980 - 2000
- Projected 1-day extreme rainfall for the two-decade period centered on 2055 for RCP 8.5
- Current 5-day extreme rainfall output for the period 1980 - 2000
- Projected 5-day extreme rainfall for the two-decade period centered on 2055 for RCP 8.5

28. The projections simulated the extreme event RCP 8.5.

C. Current 1 Day Extreme Rainfall

29. The current 1-day extreme rainfall represents the maximum rainfall output by the models for a 20-year period centered on 1990. The distribution of 1-day extreme rainfall reflects the spatial distribution of annual rainfall with high values of around 200mm in the mountainous region near the coast, in Mondul Kiri and in the far north east. Smaller 1-day extreme events of 100 – 145 mm occur in the central flat lands and hilly regions in the north. The lowest values are around Tonle Sap.

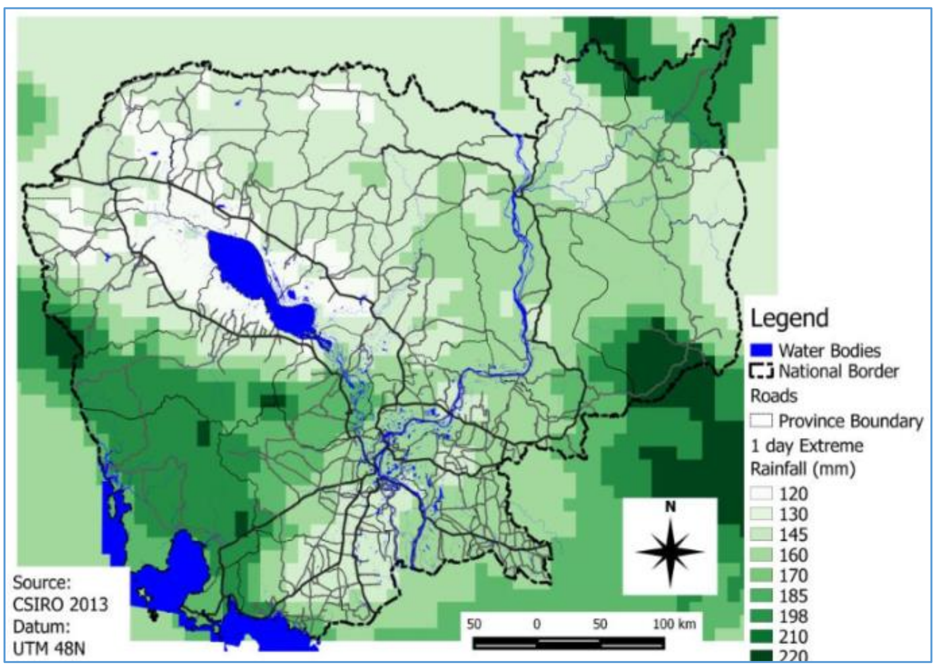

Figure III-1 Current 1-day extreme rainfall from the CCAM model.

D. Projected 1-day extreme rainfall for 2055 with RCP of 8.5

30. The projected 1-day extreme rainfall is the average for a 20-year period centered on 2055 using an RCP of 8.5. The projected change in 1-day extreme rainfall is the difference between current and projected 2055 values. The model projects an increase over the coastal mountains and over the hilly regions in the north of the country. There is no change or only a small change for the central flat areas, except for a small area north east of Phnom Penh.

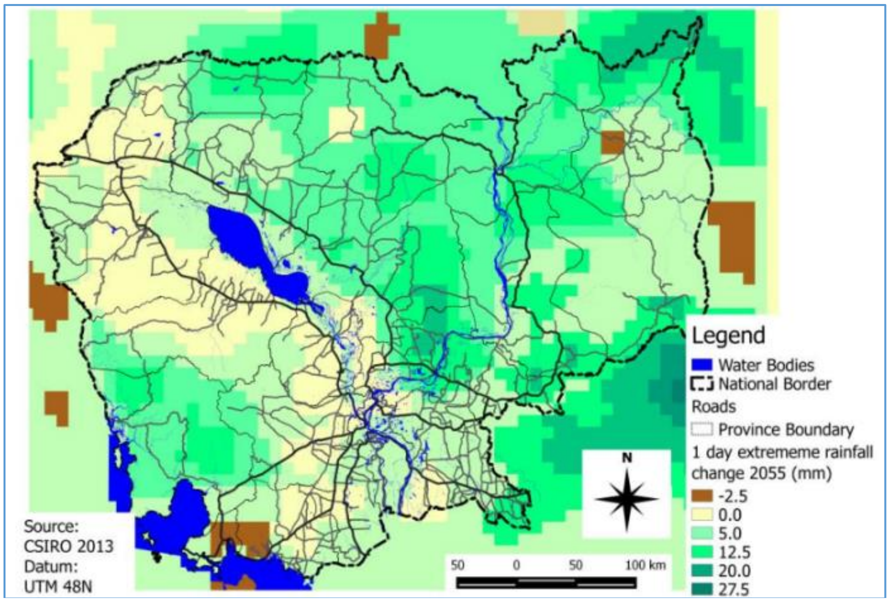

Figure III-2 Projected change in 1-day extreme rainfall for 2055 (RCP 8.5 from CCAM)

E. Current 5-day Extreme Rainfall

31. The 5-day extreme rainfall map is defined as the maximum total rainfall recorded over 5 days for a 20-year interval centered on 1990. The distribution of 5-day extreme rainfall reflects the spatial distribution of annual rainfall with high values of 300mm or more in the mountainous region near the coast, in Mondul Kiri and in the far north east. Smaller 5-day extreme events of 150 – 180 mm occur in the central flat lands and hilly regions in the north. The model shows the lowest values around Tonle Sap.

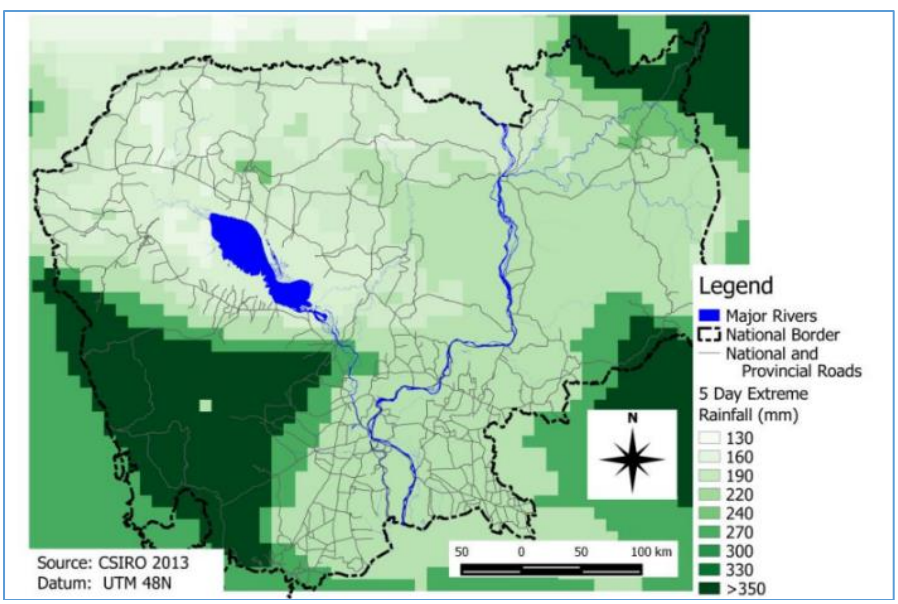

Figure III-3 Current 5-day extreme rainfall from CCAM

F. Projected 5-day extreme rainfall for 2055 with RCP of 8.5

32. The projected 5-day extreme rainfall is the average for a 20-year period centered on 2055

using an RCP of 8.5. The projected change in 5-day extreme rainfall is the difference between current and projected 2055 values. The model projects a small increase in 5-day extreme rainfall over the coastal and other high mountains but a more pronounced increase of 16-20 mm per day for the hilly regions to the west of the Mekong in the north of the country. Little change or a slight decrease is projected to occur in the lower hilly areas east of the Mekong. The most pronounced change is a projected decrease of 5-day precipitation of over 17 mm per day for the flat areas south and southwest of Tonle Sap. It is projected to increase in Svay Rieng.

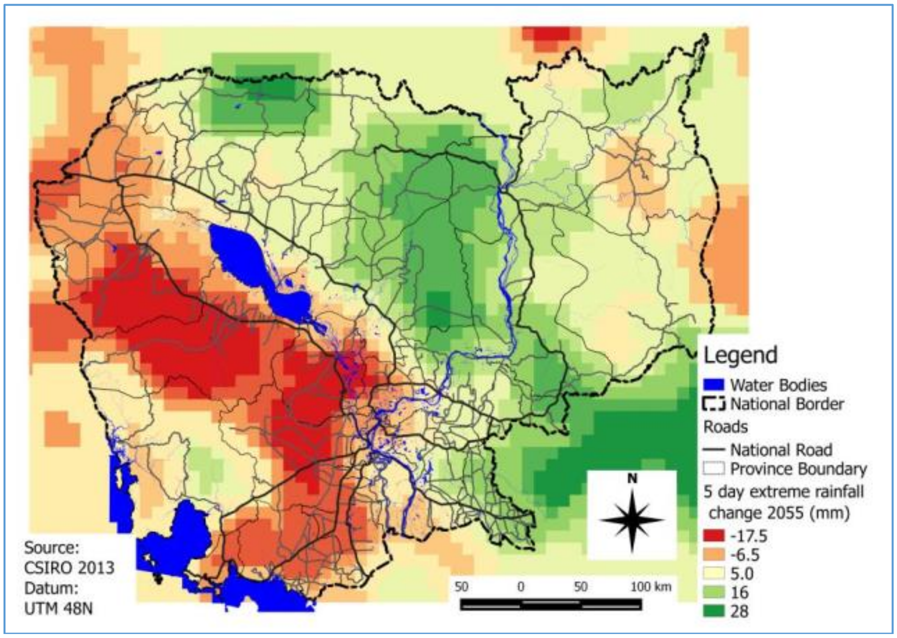

Figure III-4 Projected change in 5-day extreme rainfall for 2055 (RCP 8.5)

G. Changes to 1-day Precipitation

33. The increases are modest for the 2030 projection (6 to 8%) and the 2050 projection (9 to 10%) but larger for the 2070 projection (28 to 34%).

H. Changes to 5-day Precipitation

34. The 5-day maximum precipitation increases for all future time frames; from 9% to 14% for the 2030 projection, from 16% to 20% for the 2050 projection and 29% to 38% for the 2070 projection. The 5-day duration is likely to correspond to the critical flood duration for some of the larger river basins.

IV. FLOODING

A. Floods in Cambodia

35. Changes in the rainfall regime are the most important factors in climate change that can have an impact on physical infrastructure - much more important than, for example, temperature change.

36. Flooding in Cambodia is a natural occurrence and lifestyles are adapted to seasonal floods. Most people are concerned when the intensity and occurrence changes. These events

also create the greatest damage to infrastructure, as seen during typhoon Ketzana in October 2009, which was estimated to cause approximately $15 million in direct damages to the transport sector and a further $11 million in indirect losses through economic loss of access to roads.

37. There are two major flood types in Cambodia: (i) flashfloods, resulting from heavy downpour upstream on the Mekong River, which affect provinces along the Mekong and the southeastern areas of the country; and (ii) central area large scale floods, resulting from a combination of runoff from the Mekong River and heavy rains around the Tonle Sap Lake, which affect the provinces around the lake and the southern provinces.

38. In rural areas flooding is a major problem for roads. In some upland areas with significant slopes and a water course, the type of flooding is flash flooding which occurs over several hours. In low-lying areas with no natural gradient flooding can last for weeks or months. Banteay Meanchey had the longest period of flooding at 68 days.

39. Whilst roads should obviously remain above the flood level there are other factors to consider. Roads provide access to communities along the roads. Even if roads are above the flood level agricultural areas and even villages may not be. During floods villagers move their animals to refuges on high ground. Roads provide an escape route in these circumstances.

40. If a road become flooded water will flow across the road. Even if the bituminous surface layer is not damaged water overflowing can damage the embankment and under scour the road. There must be adequate cross-drainage.

B. Drought and Climate Change

41. Rising temperatures due to climate change increase evaporation rates and increase the capacity of the atmosphere to hold more water for longer periods of time. When the atmospheric water vapour is released as rain the precipitation is more severe and storms are more intense although possibly of shorter duration. If major rains occur after normal rainfall patterns, there has usually been sufficient rain to saturate soils. These are the preconditions for maximum run off and flooding.

42. These longer periods between rainfall increase drought. Drought has devastating effects on agriculture. There are four characteristics of agricultural drought in Cambodia: (i) unpredictable delays in rainfall onset in the early wet season, (ii) erratic variations in wet season rainfall onset, amount, and duration across different local areas, (iii) early ending of rains during the wet season, and (iv) common occurrence of mini-droughts of three weeks or more during the wet season which can damage or destroy rice crops without irrigation. Many farmers report that they fear drought more than flood.

V. FLOOD RISK MANAGEMENT INTERFACE – FRMI

A. Background

43. Cambodia is one of the pilot countries participating in the Pilot Program for Climate Resilience (PPCR). The PPCR provides incentives for scaled-up action and transformational change in integrating consideration of climate risks and resilience in national development planning, consistent with poverty reduction and sustainable development goals.

44. The improvement of access to knowledge, to its dissemination and its conservation was addressed by the development of a knowledge management tool called Flood Risk Management Interface (FRMI). This software provides easy access to information about floods and roads, as well as flood risk maps.

B. FRMI Methodology

45. The FRMI methodology consists of identifying of road links and parameters based on topographical analysis of road physical parameters and assessing the flooding types that they are exposed to. The topographical analysis is derived from Shuttle Radar Topographic Mission (SRTM) data available from public internet sources. Topographical data is based on remote sensing not physical site measurements.

46. Road segments from the National and provincial road network are sourced from MPWT's Road Asset Management project data and catchment areas. Other geographical parameters are then calculated for each road segment. Road resilience is derived from its condition level as provided by the Road Asset Management System. Finally, flood impact or damage risk assessments are carried out for four specific types of flood and mapped.

C. SRTM Accuracy

47. The approximate accuracy of a road location and elevation can be obtained from SRTM, but that accuracy is in principle limited by the size of the grid utilized. The SRTM data used in the project was retrieved from a 90 m grid or cell. For such a grid the absolute accuracy of SRTM data ranges from 10 to 20 meters in all directions.

48. The distance of 90 m means that break points, steep slopes or vertical drops would not be traced accurately for countries with significant mountainous terrain, as all slopes are interpolated from point measurements. In low variability terrains like flood plains in Cambodia the overall error in elevation is relatively low. Errors factors of 1 to 2 meters have been established by comparing SRTM data with measured and benchmarked elevations from roads.

D. Road Catchment Area vs. River Catchment Area Method

49. The FRMI uses a road catchment area method rather than a river catchment area method, mainly for effectiveness purpose related to data management and better correlation to road impacts. It is possible to calculate every major river catchment area in the whole country and to organize the gained information according to the river flow network. However, MPWT data is orientated towards the road network, not the river network.

E. Correlation to Road Impacts

50. The road catchment area approach enables one to describe road sections with multiple flooding risk, for example a low-lying road which is susceptible to flash floods if there is a short high intensity rainfall, but which also experiences flooding if there is light rain over a number of days. If the road is located in an urban area it might flood with even less rainfall impact, because the drains might not have been maintained properly. Therefore, the establishment of 4 indicators

for every road section makes it easier to analyze the flooding risk of individual road sections in more detail.[1]

F. Calculation of Catchment Areas

51. The calculation of catchment areas, which drain towards a road section is a normal step in the hydrological and hydraulic design of road drainage systems. The Rational Method or another hydrological estimation technique is then used to estimate the design runoff for certain catchment areas.

52. However, in road design individual catchment areas are calculated and individual structures are designed according to the design runoff. For a normal road section, depending on terrain and road length this can result in hundreds of individual catchment areas and of course the same number of structures. Such degree of detail could not be considered in FRMI due to the large number of catchments involved and due to the insufficient detail of the terrain model.

53. In order to characterize each road section, the combined catchment area was calculated which drains towards a road section from both sides. This enables an analysis according to their flooding potential: a road, which has very little water running towards it has a low potential of being flooded, for example a ridge road, where all water drains away from the road alignment. This compares to a road parallel to a mountain range, where all surface water has to cross the road alignment in order to drain to lower grounds.

G. Flood Risk Damage Maps

54. Flood risk damage maps have been produced for various types of floods. The road vulnerability maps present four road risk flooding damage indexes corresponding to different flood types. Another index combines the risk of the four-flood type for prioritization purposes. It must be noted that experiencing flooding or being subject to flood risk does not necessarily inflict a lot of damage to every road. The overall equation is:

Flood damage risk = Risk of flood occurrence x Road condition factors

55. The flood risk calculation process starts by evaluating the risk of occurrence of the four types of flood. The main input is the 1 day or 5-day extreme rainfall event, the drainage areas, slope and shape. This leads to the buildup intensity next to the road. It then introduces factors to account for the resilience of the road to these floods.

56. Roads properly designed and maintained in good condition will remain at no or at very low risk of flood damage. For example, roads having been recently rehabilitated under major rehabilitation projects will have been upgraded to better withstand flood damages, as prescribed in the Cambodia road standards and in most international road design standards and are likely to be considerably less damaged through flooding than un-rehabilitated roads.

57. The road resilience factors are then applied in terms of the pavement structure and how efficient the drainage system is under extreme rainfall. Four flood indexes are produced which are then combined into one composite index.

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[1] "*Assessment of the susceptibility of roads to flooding based on geographical information – test in a flash flood prone area (the Gard region, France)"* by P.-A. Versini, E. Gaume, and H. Andrieu.

58. The flood risk indexes are:
(i) Flash Flood Index
(ii) Large Drainage Area Index
(iii) Build-up Area Flooding Index
(iv) Low Land Flooding Index
(v) Combined flood risk index

59. The flow chart for this is shown below.

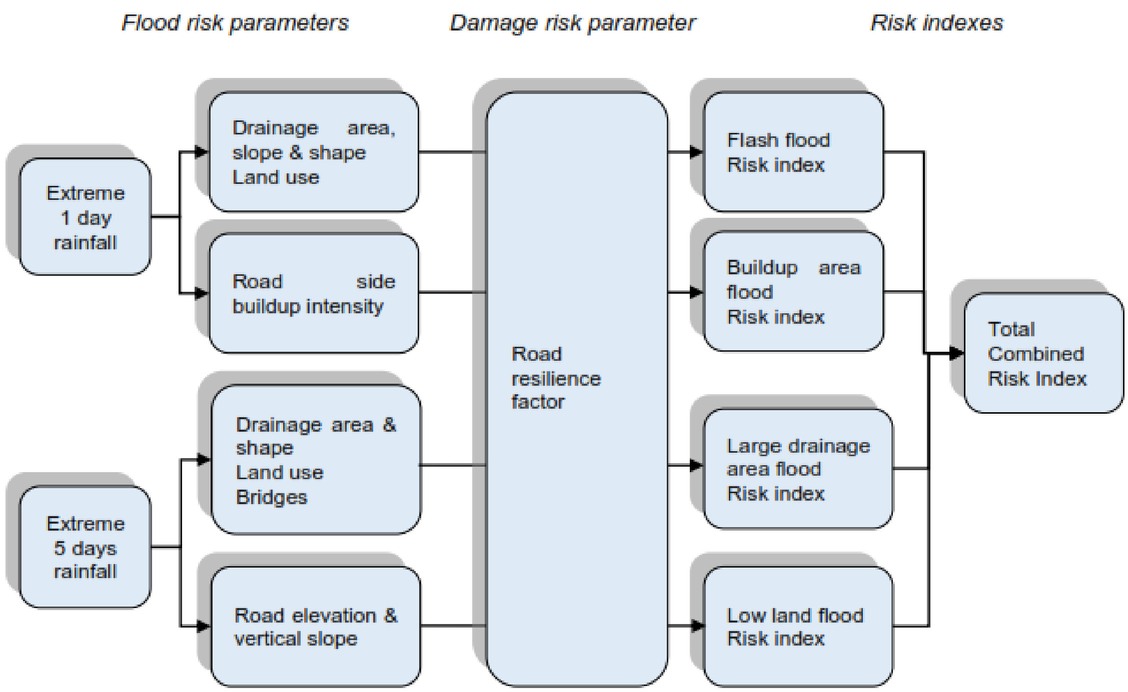

Figure V-1 Flow Chart for Derivation of Flood Index

60. All these indexes are the basic tools for prioritizing the climate proofing of individual road sections. To this is then added the impact of climate change on the flood risk situation. This is projected to the year 2055.

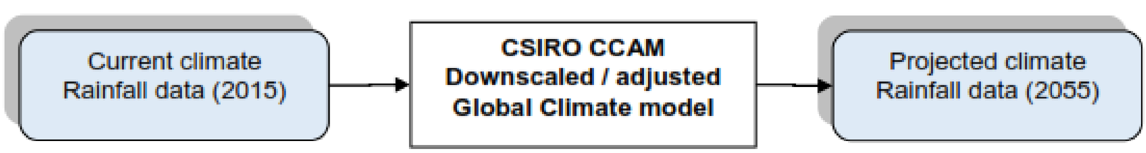

Figure V-2 Climate Change Analysis

61. A climate change scenario calculation using the projected 2055 rainfall data was carried out and the changes compared to the existing situation. The relevant maps have been produced at the national scale and for all the provinces. The types of maps available are:
(i) Road references (Link IDs)
(ii) Flood damage risks – current conditions
(iii) Flood damage risks – future conditions
(iv) Flood damage risk changes in time

62. A flood damage risk map shows the road sections associated with four risk levels, ranging from high (red), moderate (orange), low (yellow) to none (green). Maps of the flash flood analysis show that flash flood risks are located in all provinces where there is mountainous terrain. Highest risk areas are in Mondulkiri, Ratanak kiri and Pursat.

63. Large catchment areas high floods risks are distributed all over the country with no specific patterns as urban flood risk areas and lowland flood risk areas are concentrated along the Tonle Sap and the lower Mekong region. This is where most of the population is located and it is an area of low geographical elevations.

H. Applicability of FRMI Flood Risk Damage Maps to RRIP III

64. The FRMI software covers the whole of Cambodia and is based on topographical information from maps which have a 90 m resolution. This is not suitable for detailed design. However, FRMI is intended to be used as a screening tool, such as is needed in Preliminary Design, not in the later stages of detailed design.

65. The data in FRMI has been collected from knowledge gained in the field relating to National and Provincial Roads. It is not intended to be applied to rural roads. FRMI contains road segments which are part of the National Roads and Provincial Roads networks. As the majority of rural roads connect to provincial or national roads it is a simple matter to find the major road to which a rural road connects, or which lies in the same vicinity. Given the predominantly flat nature of terrain in Cambodia there is not likely to be a significant change in flooding characteristics and vulnerabilities over the short distances between the rural roads included in RRUP III and the nearest main road identified in FRMI.

66. By the same token although the 90m resolution can be considered coarse, given the lack of abrupt changes in gradients in Cambodia and the absence of steep crevasses or rapid changes in slope in mountainous or hilly areas, the given resolution should not significant errors into any conclusions drawn from the use of FRMI.

67. An updated version based on 30 m resolution is under preparation but was not available at the time of this report preparation.

VI. RISK INFORMATION FROM FRMI RELATED TO PROJECT ROADS BY PROVINCE

A. Roads by Province

68. As stated earlier the proposed roads for RRIP III are allocated to ADB and EDCF by 5 provinces each. These are discussed below as shown in Figure 6-1.

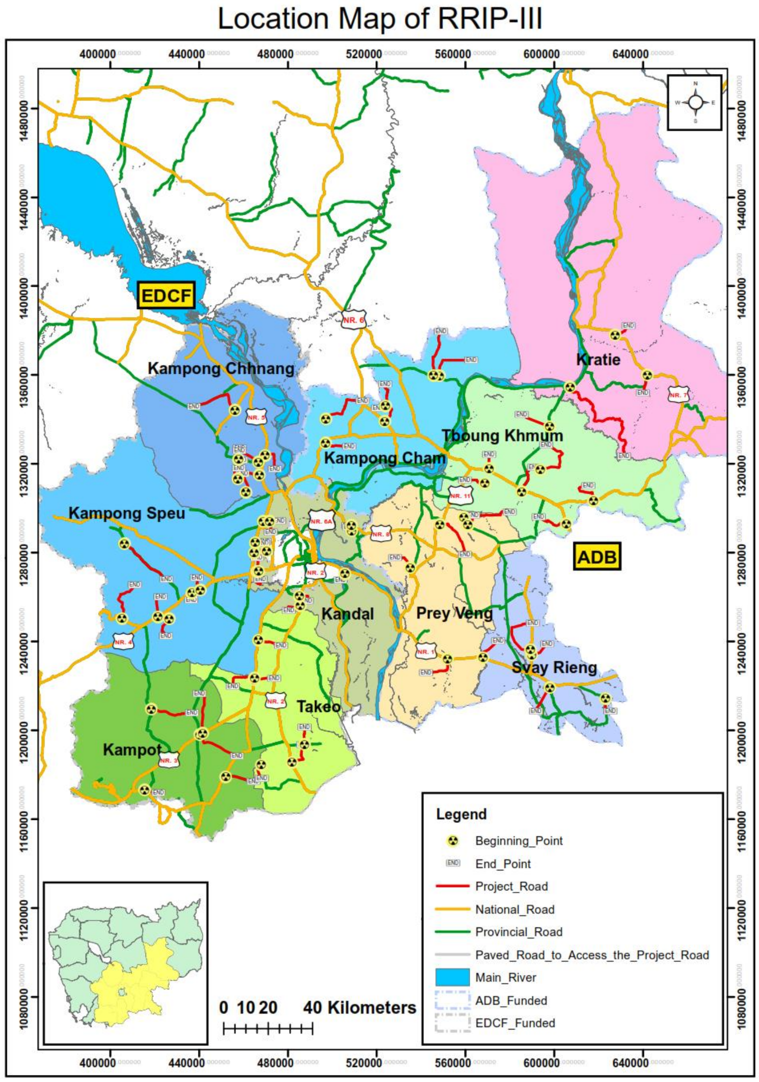

Figure VI-1 RRIP III Roads Map[2]

69. Flood Risk maps are shown for each province. They used the legend below.

70. The flood risk is given for the year 2055 under Climate Change Scenario RCP 8.5. This is pessimistic.

71. The various roads planned under RRIP III in the 10 provinces are discussed below.

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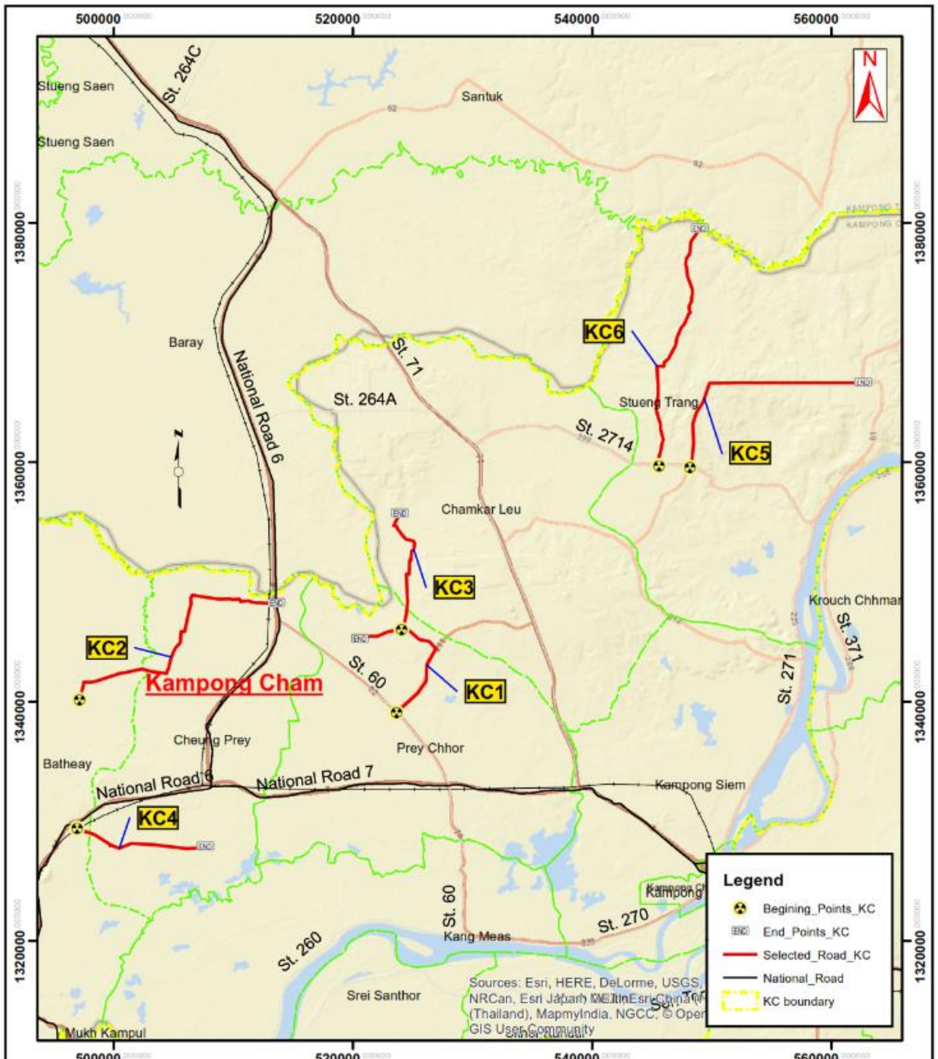
2 Location Map of RRIP-III as update 6 March 2018.

B. Kampong Cham (KC)

72. There are 6 roads covering in total a length of 100.60 km. Width varies from 7 to 8 m and the proposed pavement is DBST.

Kampong Cham



Road ID	District	Road Section		Length(km)	Proposed Width(m)	Proposed Pavement
		Beginning	Ending			
KC1	Prey Chhor	Kor	Tuek Cha	13.50	8	DBST
KC2	Batheay -Cheung Prey	Samdaek	Sampong Chey	23.00	7	DBST
KC3	Prey Chhor- Chamkar Leu	Ou Tathok	Bosthlan	11.30	8	DBST
KC4	Batheay -Cheung prey	Phav	Doun Dam	11.20	8	DBST
KC5	Stueng Trang	Dei kraham	Areak Tnaot	20.10	8	DBST
KC6	Stueng Trang	Mer Sar Chrey	Wat lor	21.50	8	DBST
Total	6 Roads			100.60		

Figure VI-2 RRIP III Roads Kampong Cham

73. This area is dominated by the flow in the Mekong river which can rise and fall 14metres over the seasons. Roads running along the left bank (easterly) of the river are classed as being at moderate risk of flooding. However, the Kampong Cham town has experienced severe flooding in the past but considerable bank protection and river training civil works have taken place recently

to protect the town center. Because of this, roads to west of the town are classed as being at low risk of flooding in the future although the land moving away from the town in a westerly direction is notably flat and should the Mekong river flow exceed its bank full discharge then overtopping waters can travel a long way in a westerly direction. Much evidence of ponding and standing water can be seen on the Flood Risk Map. KC1, 3, 5 and 6 would fall into this category.

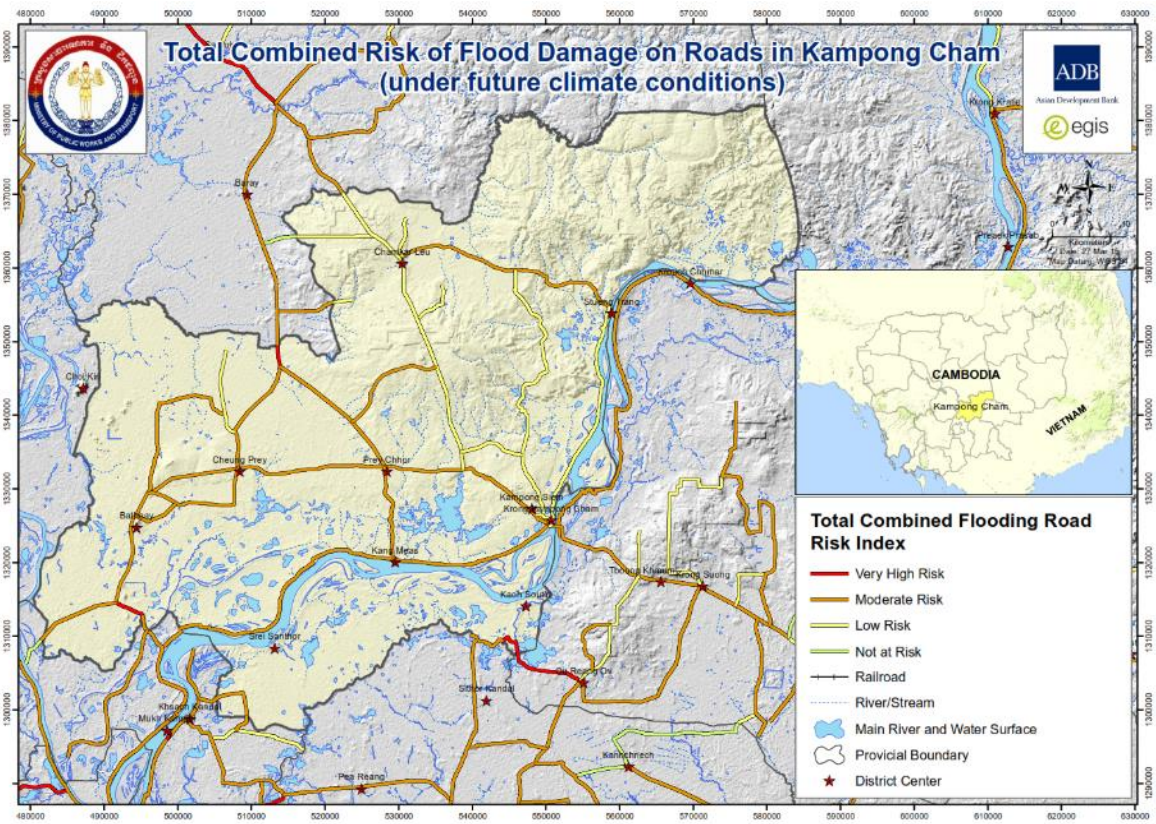


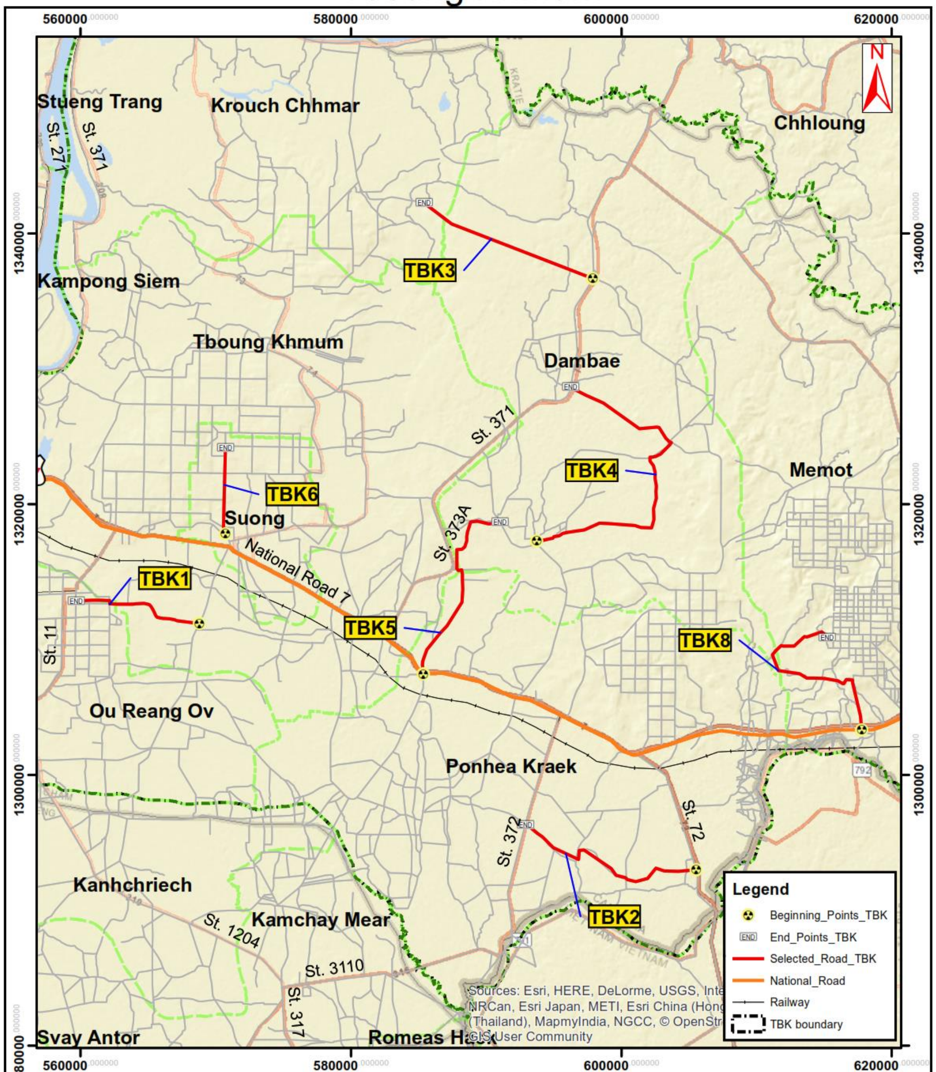
Figure VI-3 Risk of Flood Damaged Roads Kampong Cham Province

74. KC2 is on the western side of NR6 and this location can be vulnerable to overland flow from an expanding Tonle Sap during the wet season when the lake expands its surface area by over 400%. KC4 is considered to be in an area of low to moderate risk.

C. Tboung Khmum (TBK)

75. There are 8 roads covering in total a length of 122.70 km. Width varies from 7 to 8 m and the proposed pavement is DBST.

Tboung Khmum



Road ID	District	Road Section		Length (km)	Proposed Width(m)	Proposed Pavement
		Beginning	Ending			
TBK1	Tboung Khmum	Tuol Kondaol	NR.11	9.90	8	DBST
TBK2	Ponhea krek	Trapeang Phlong	Stueng Toch	16.00	7	DBST
TBK3	Kroch Chmar-Dambe	Chhuk	Sedasenchey	13.70	8	DBST
TBK4	Dambe	Chong Cheach	Dambe	24.80	8	DBST
TBK5	Ponhea krek-Dambe	Kondoal chrum	Char Thum	15.10	8	DBST
TBK6	Suong	Suong	Phnum chan	6.40	8	DBST
TBK8	Memot	Da	Memay	17.50	8	DBST
Total	7 Roads			103.40		

Figure VI-4 RRIP III Roads Tboung Khmum

76. Tboung Khmum is also dominated by the left bank (easterly side) of the Mekong river. The whole of the left bank of the Mekong river is classed as being at moderate risk in the future. This makes TBK1 and 6 particularly vulnerable.

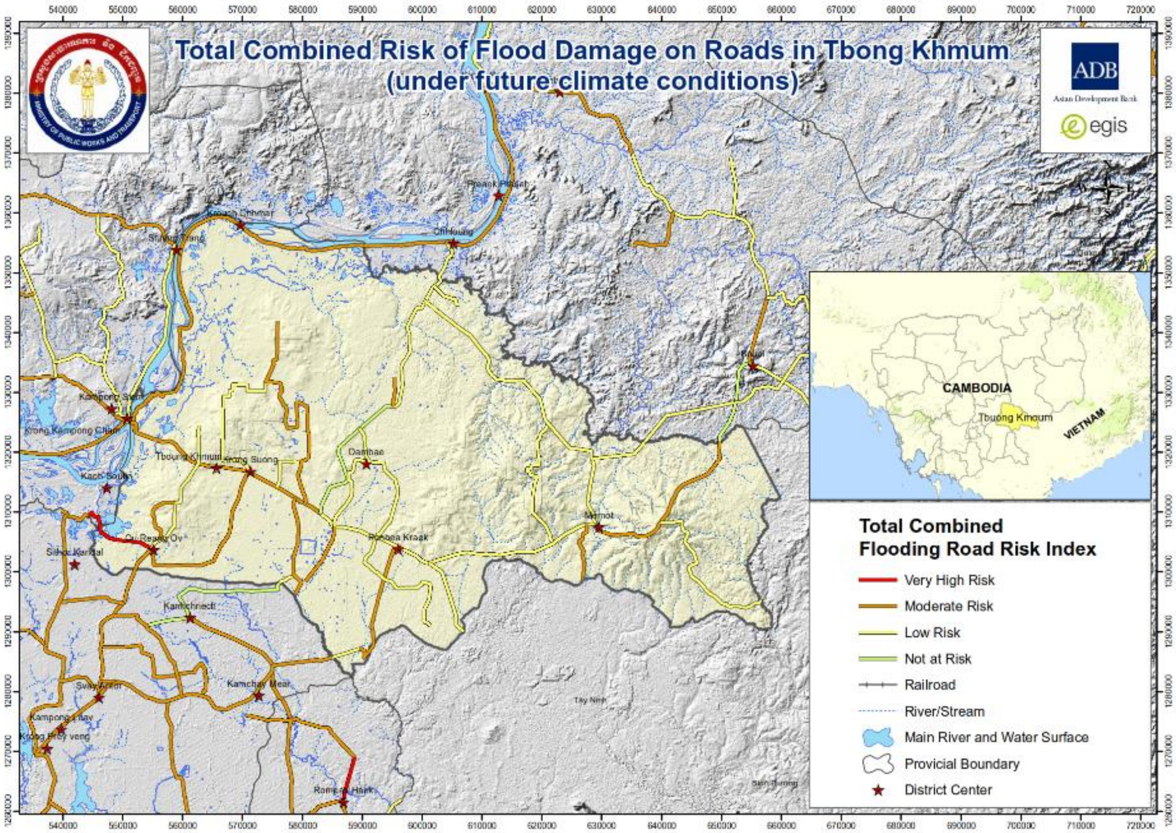


Figure VI-5 Risk of Flood Damaged Roads Tboung Khmum Province

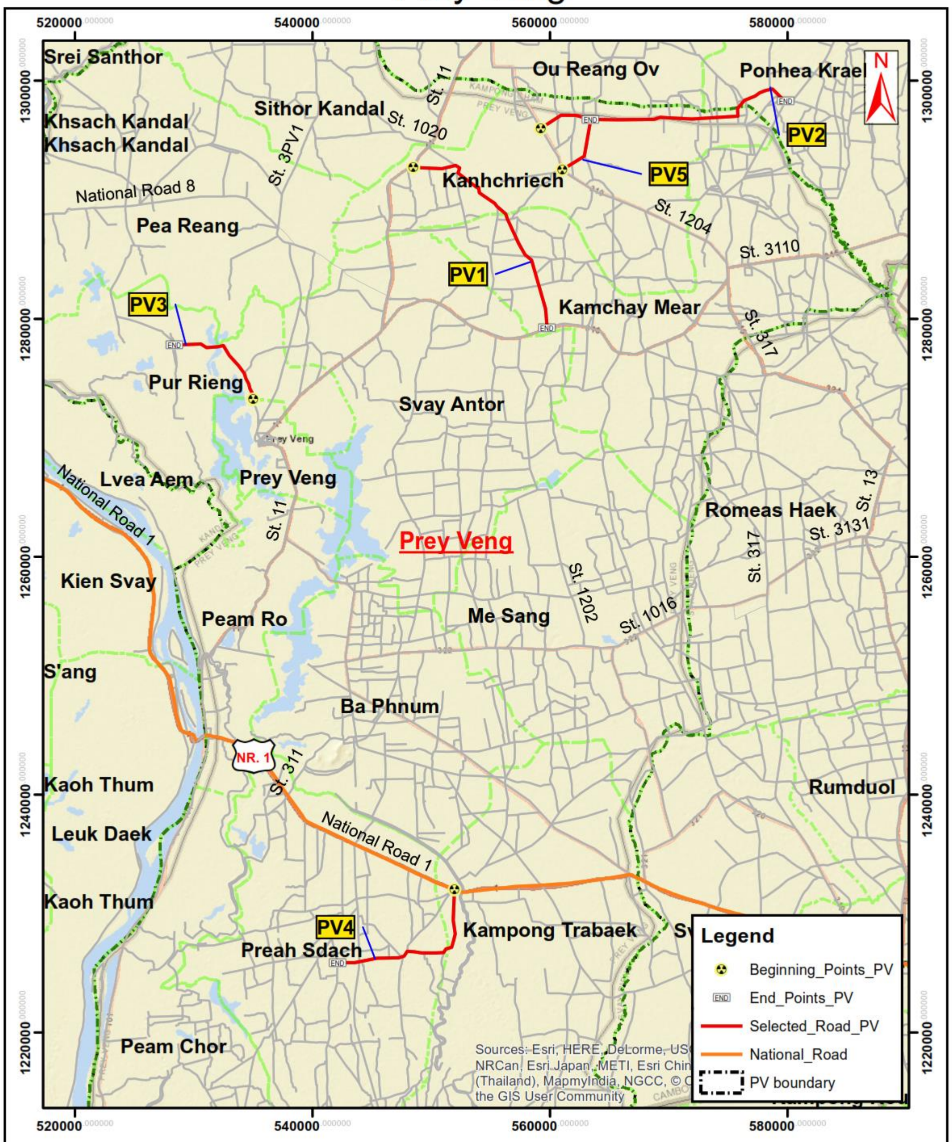
77. As one moves away from the Mekong to the east the land rises slightly (a high point is +16m) which does offer more protection to 2, 4, 5, 7 and 8. These are classified as being at low risk.

78. TBK 3 is located on the inside of a bend in the Mekong river and this area has experienced severe flooding in the past.

D. Prey Veng (PV)

79. There are 6 roads covering in total a length of 81.60 km. Width varies from 7 to 8 m and the proposed pavement is DBST.

Prey Veng



Road ID	District	Road Section		Length (km)	Proposed Width(m)	Proposed Pavement
		Beginning	Ending			
PV1	Kanh Chreach	Lngeun	Boeng Kak	20.20	8	DBST
PV2	Kanh Chreach- Ponhea	Pou Tong	Dountei	22.50	8	DBST
PV3	Prey Veng Town- Pou	Svay Sokhao	Pou Rieng	9.30	8	DBST
PV4	Kampongtrabek- Preah	Kampongtrabek	Preah Sdach	15.00	8	DBST
PV5	Kanh Chreach	Kanh Chreach	Kouk Kongkandal	5.20	8	DBST
Total	5 Roads			72.20		

Figure VI-6 RRIP III Roads Prey Veng

80. Prey Veng is also dominated by overland flow from the Mekong river and has many low lying natural water bodies and ponds. The land between Prey Veng and the Vietnam border (via Svay Rieng) is very flat and there is little opportunity for natural drainage other than the Mekong river, which flows to the south. For this reason, most of the area is classed as being at moderate risk of flooding and this would apply to PV1, 2, 3 and 5

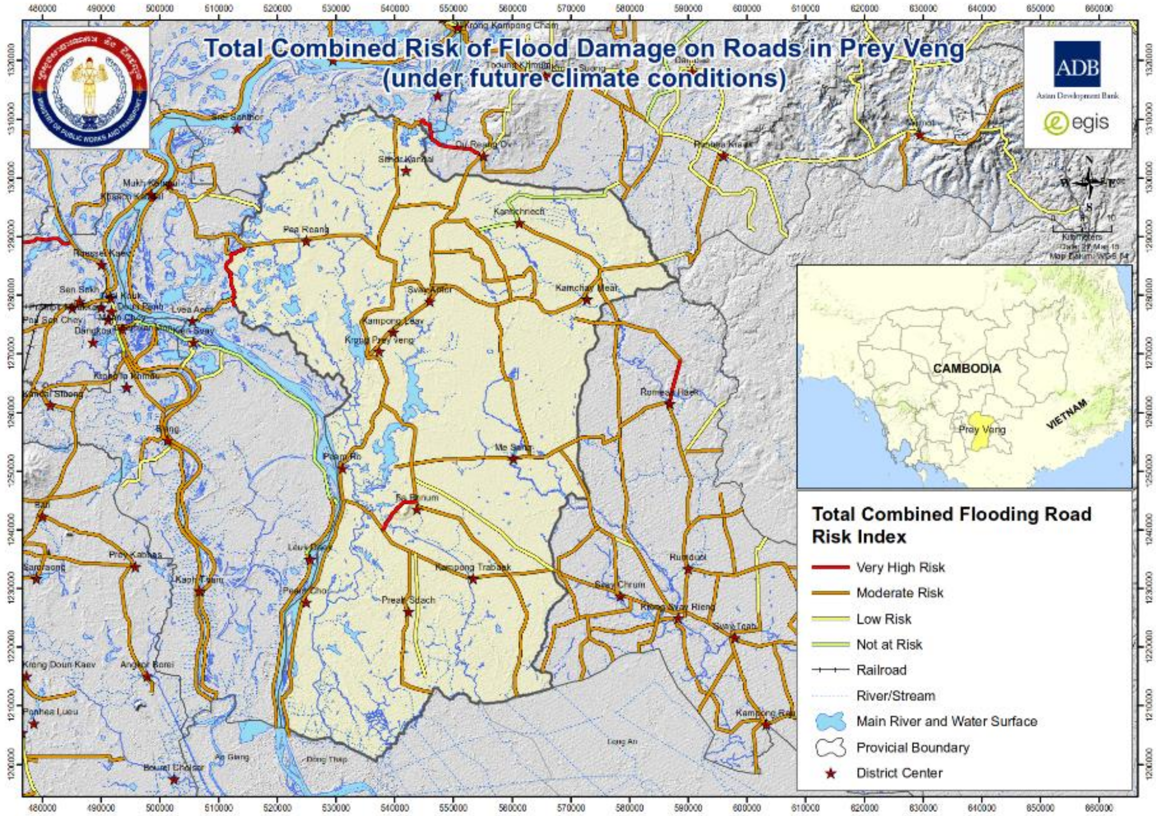


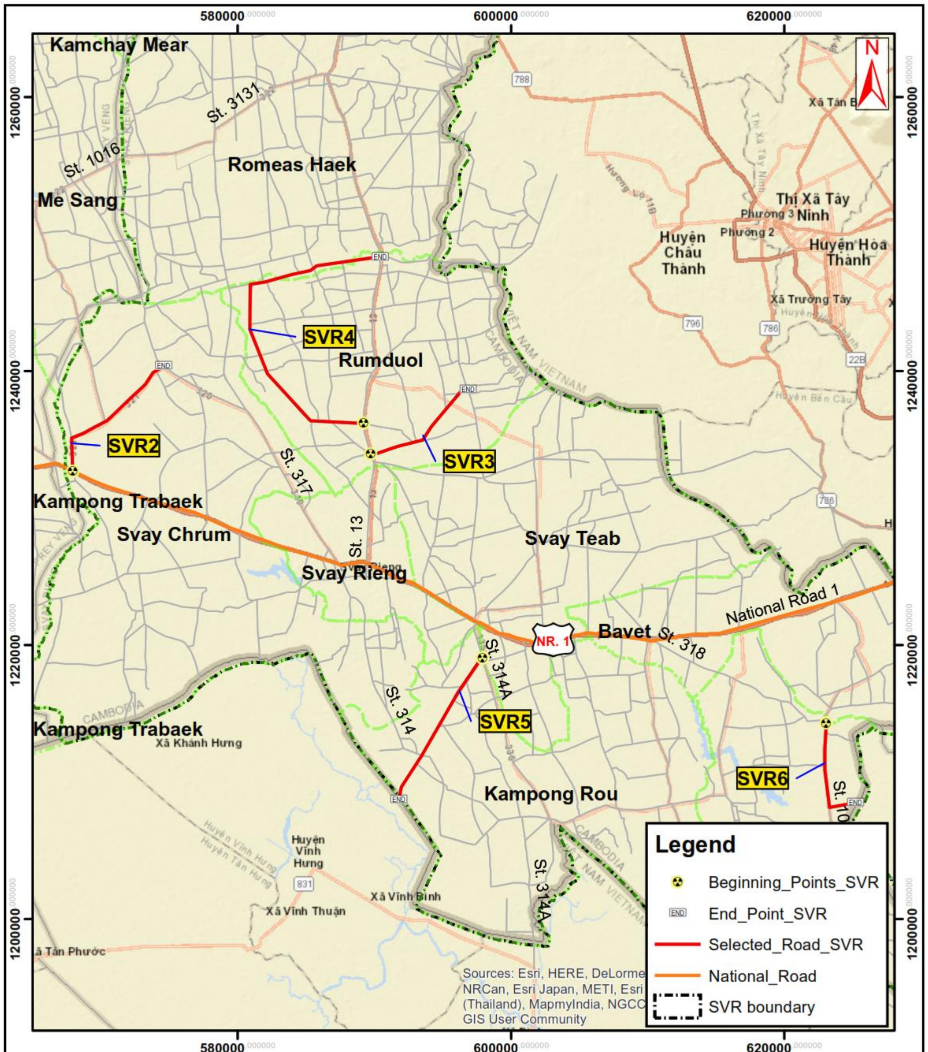
Figure VI-7 Risk of Flood Damaged Roads Prey Veng Province

81. Some roads in the center of the province alongside NR1 are classed as being at very high risk of flooding and PV4 and 6 could come into that class, particularly as PV6 is close to the Mekong river.

E. Svay Rieng (SVR)

82. There are 6 roads covering in total a length of 82.70km. Width varies from 7 to 8 m and the proposed pavement is DBST.

Svay Rieng



Road ID	District	Road Section		Length (km)	Proposed Width(m)	Proposed Pavement
		Beginning	Ending			
SVR2	Svay Chrum	Kroulko	WathSvaypnem	11.00	8	DBST
SVR3	Rumdul	PheasaChork	Pongtek	9.10	8	DBST
SVR4	Rumdul	PreyKearv	KomPongAmpil	24.80	8	DBST
SVR5	Kom Pong Ro	PrasPonlea	SomYong	11.90	7	DBST
SVR6	Chantrea	SalaSrok Chantrea	VietnamBorder	7.80	8	DBST
Total	5 Roads			64.60		

Figure VI-8 RRIP III Roads Svay Rieng

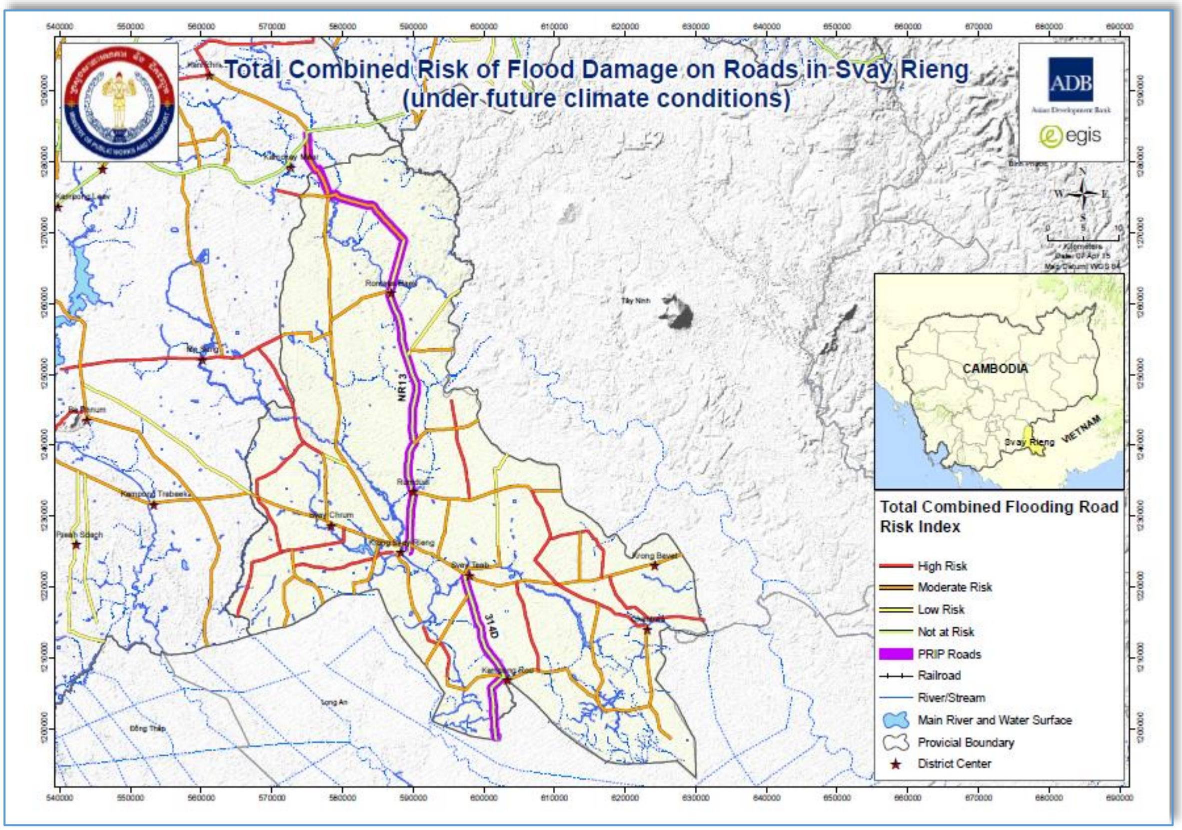


Figure VI-9 Risk of Flood Damaged Roads Svay Rieng Province

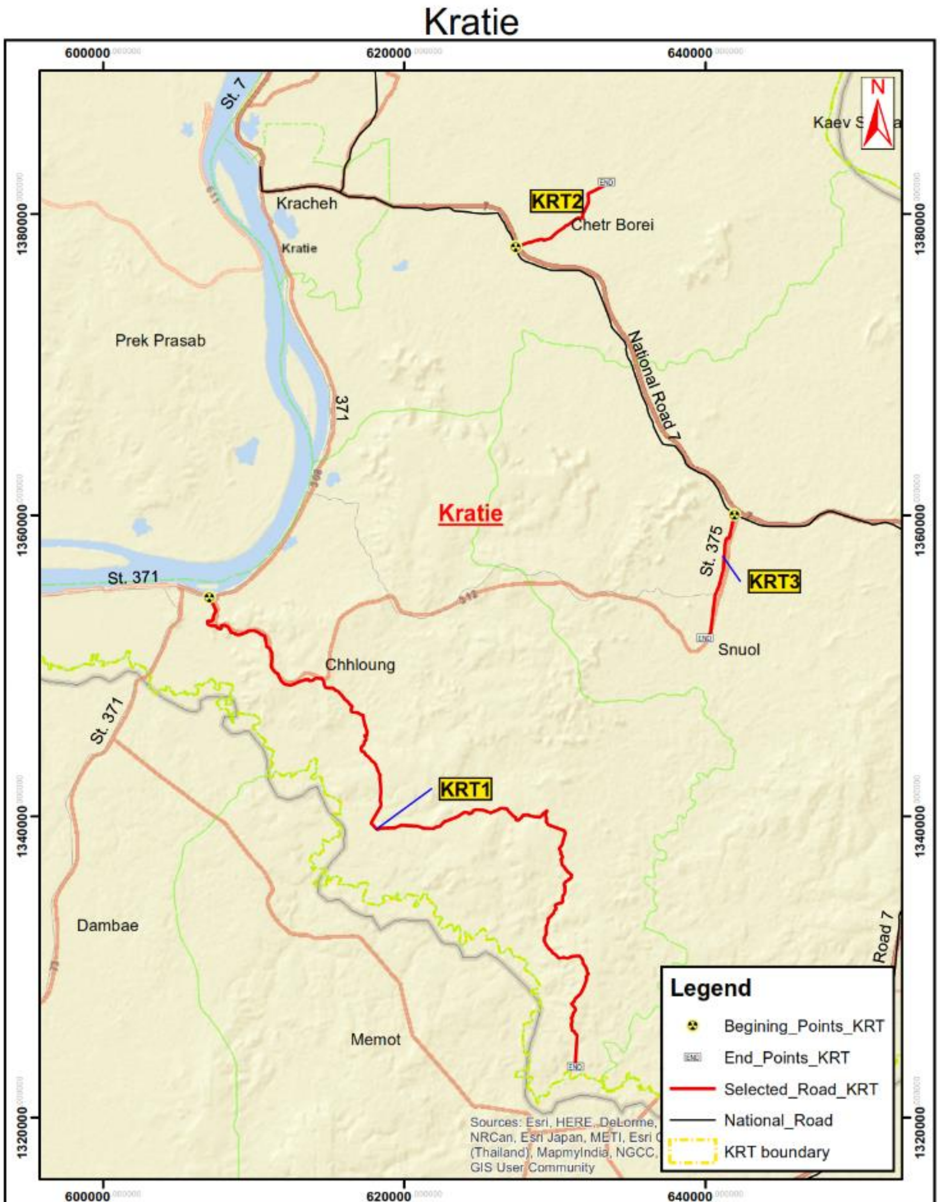
83. Svay Rieng province forms a border with Vietnam. It is bisected by NR1 which runs from Phnom Penh over the Mekong River to Vietnam Border. Due to the extremely flat terrain this area of Cambodia is basically downstream of all other weather influences and can flood over very large distances on either side of the NR1 alignment. There are areas of free standing water to the north and south of NR1 and local rainfall has no natural drainage escape route.

84. Most of this area is deemed to be at high risk of flooding. NR1 is classed as being at low to moderate risk because of its embankment.

85. All of the roads from SVR1 to 6 can be classed as being at high risk of flooding.

F. Kratie (KRT)

86. There are 3 roads covering in total a length of 78.20km. Width is 8m and the proposed pavement is DBST.



Road ID	District	Road Section		Length (km)	Proposed Width(m)	Proposed Pavement
		Beginning	Ending			
KRT1	Chhlong	Chhlong	Prama	61.30	8	DBST
KRT2	Chettraborey	Kantuot	Chroanal	8.20	8	DBST
KRT3	Snoul	Thnal	Rumpuk	8.70	8	DBST
Total	3 Roads			78.20		

Figure VI-10 RRIP III Roads Kratie

87. Kratie province is dominated by the Mekong river which bisects it flowing from north to south. There are also several major tributaries which flow east to west into the Mekong and several minor ones that flow west to east discharging into the Mekong. Due to this extensive drainage network it is classed as low risk of flooding.

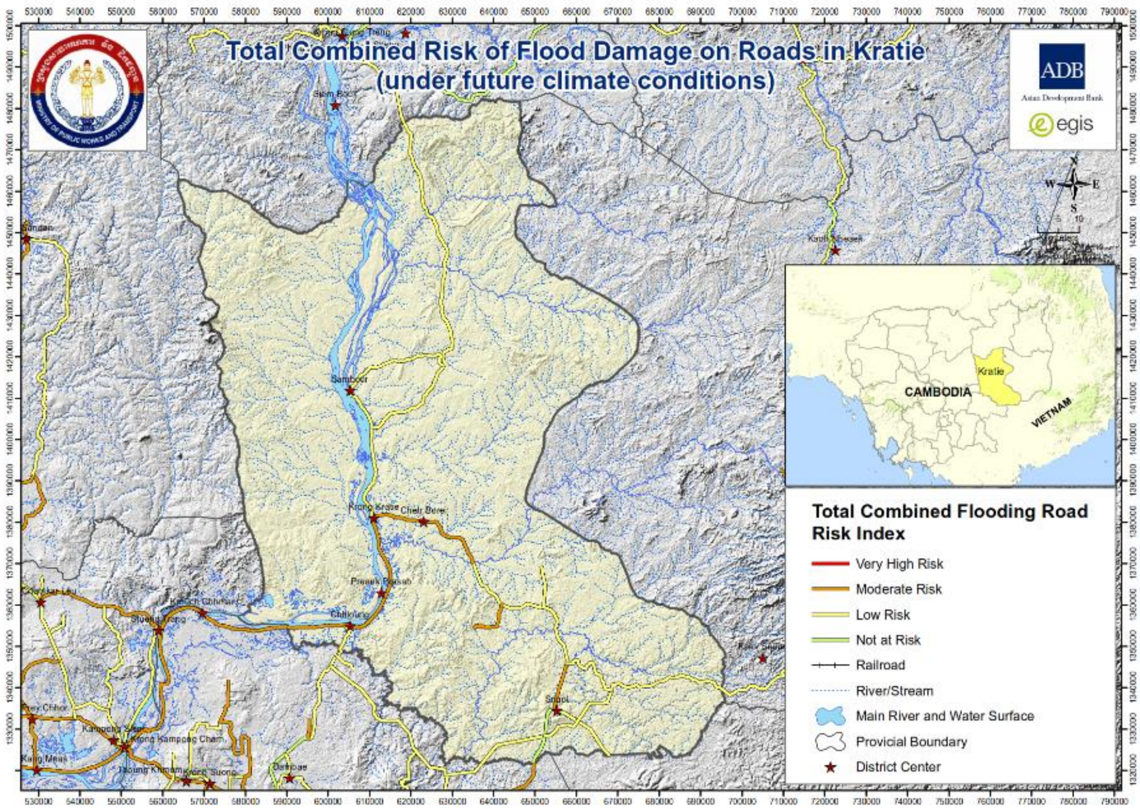


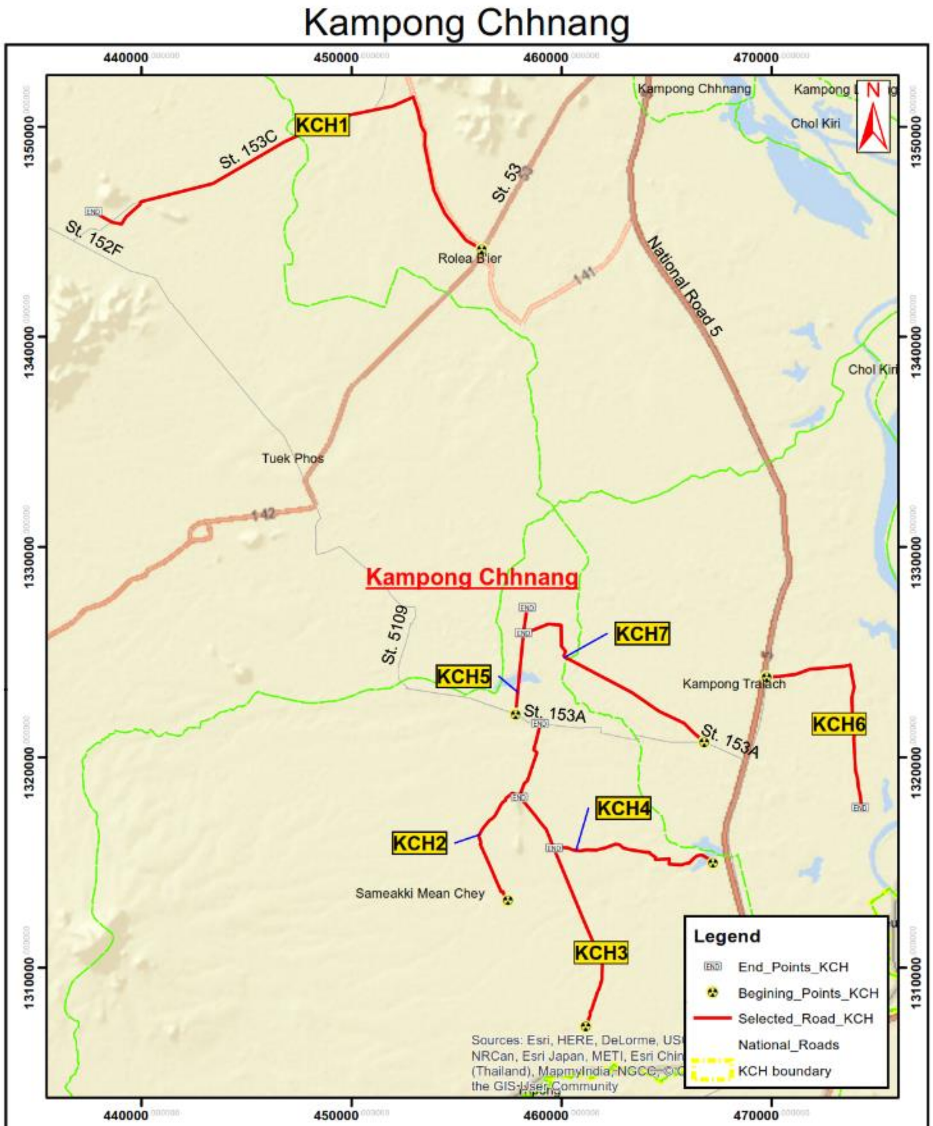
Figure VI-11 Risk of Flood Damaged Roads Kratie Province

88. The northern end of KRT1 should be considered as vulnerable due to its proximity to the main branch of the Mekong.

89. KRT2 and 3 can be considered as at low risk but not entirely absent of risk due to the large number of watercourses. This should be considered when designing cross drainage for these two roads.

G. Kampong Chhnang (KCH)

90. There are 7 roads covering in total a length of 83.20km. Width varies from 7 to 8 m and the proposed pavement is DBST.



Road ID	District	Road Section		Length (km)	Proposed Width(m)	Proposed Pavement
		Beginning	Ending			
KCH1	Rolea Bier , Teuk Phos	Prey Moul	Kraing Skea	25.10	8	DBST
KCH2	Samaki Meanchey	Ra Meanok	Thlork Vien	9.80	7	DBST
KCH3	Samaki Meanchey	Tbeng Khpos	Khnach	9.60	7	DBST
KCH4	Samaki Meanchey	Thlok Russey	Wat Tussapit	11.30	7	DBST
KCH5	Samaki Meanchey	Torp Bos	Tradak porng	5.20	7	DBST
KCH6	Kampong Tralach	Prey Pis	Nak tahang	10.80	7	DBST
KCH7	Kampong Tralach	Deum Popel	Thmor Sor	11.40	7	DBST
Total	7 Roads			83.20		

Figure VI-12 RRIP III Roads Kampong Chhnang

91. Kampong Chhnang is dominated by the influence of Tonle Sap. The big lake lies to the north but the Tonle Sap river which connects the lake to the Mekong river flows through the western portion of the province.

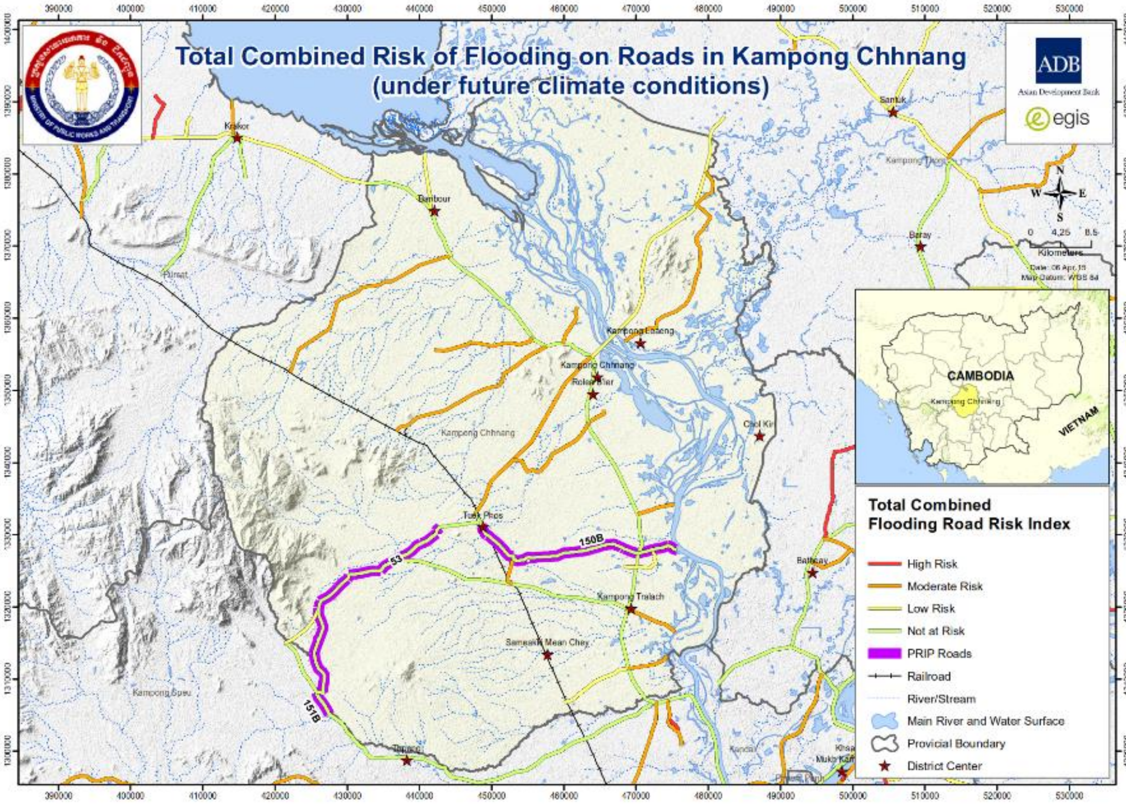


Figure VI-13 Risk of Flood Damaged Roads Kampong Chhnang Province

92. NR5 forms the natural boundary of Tonle Sap in the wet season. This gives some protection to infrastructure to the west of NR5. Consequently, the area is classed as being at low to moderate risk of flooding.

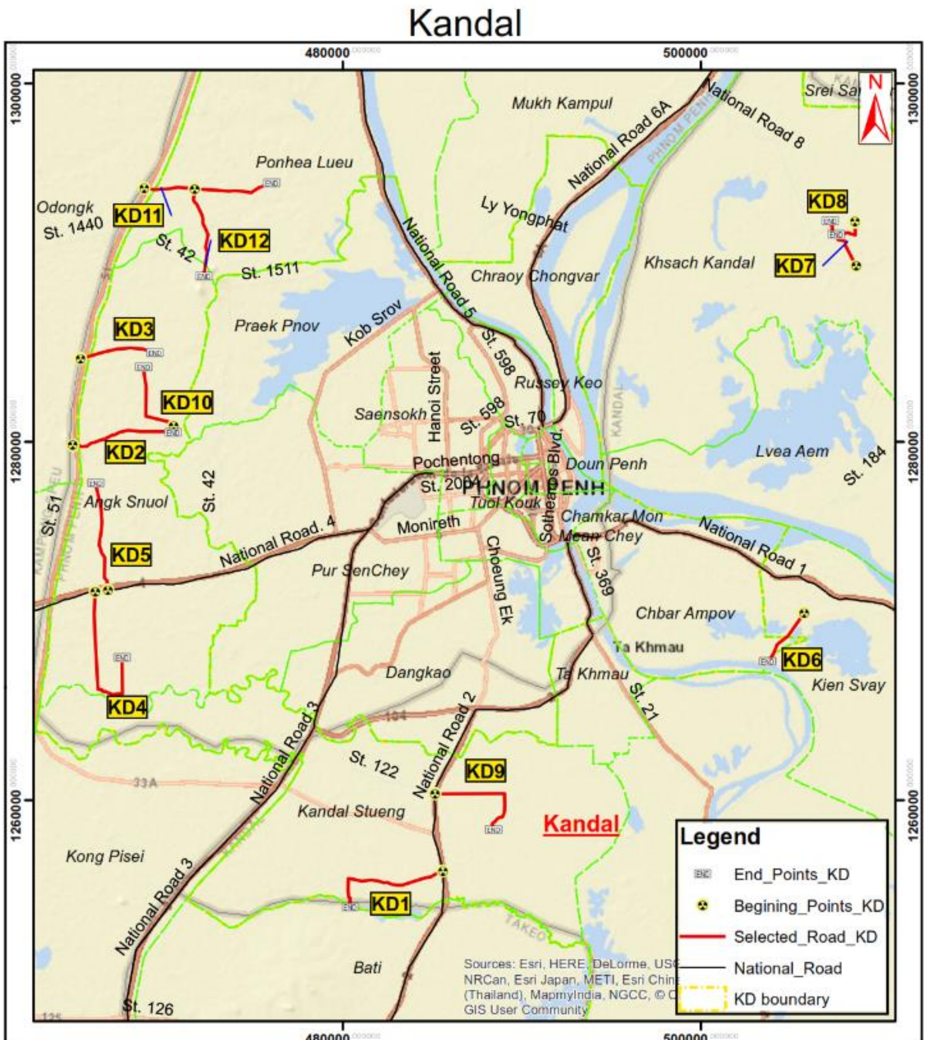
93. KCH1 is well to the west of NR5 and protected by some intervening high ground so is unlikely to flood.

94. KCH2 through 7 interlink to form a small network. They are protected by NR5 to their east but there are several free-standing water bodies which suggest the land is low lying and poorly drained. They should be considered to be at moderate risk of flooding.

95. The province can be influenced by heavy rain falling on the Cardamon mountains to the west. In times of intense rainfall flash floods could occur and cross drains should take account of this.

H. Kandal (KD)

96. There are 12 roads covering in total a length of 64.20km. Width varies from 7 to 8 m and the proposed pavement is DBST.



Road ID	District	Road Section		Length (km)	Proposed Width(m)	Proposed Pavement
		Beginning	Ending			
KD1	Kandal Steung	Phsa daem ampil	Trapang skun	7.10	7	DBST
KD2	Ang Snoul	Wat Tmat Pong	Wat Phor	5.70	7	DBST
KD3	Ang Snoul	Ang Taset	Orng Ka	4.20	8	DBST
KD4	Ang Snoul	Prey Chamkar	Yosmetrey	8.80	7	DBST
KD5	Ang Snoul	R/N4	Domnakorkhos	5.90	8	DBST
KD6	Ken Svay	Don Sor	Cher Teal	3.70	8	DBST
KD7	Khsach Kandal	Chey Thom	Sala RoTA	3.20	7	DBST
KD8	Khsach Kandal	Prolay Pring Eb	Wat TroPheng Prey	1.80	8	DBST
KD9	Kandal Steung	Sem Rap	Chey Reryong	7.30	7	DBST
KD10	Ang Snoul	Tol Khlong	Ten Lop	4.30	7	DBST
KD11	Ponhear Leu	Stok Chouk	Ta Peat	7.20	7	DBST
KD12	Ponhear Leu	Pum Ton Say Svet	Takork	5.00	7	DBST
Total	12 Roads			64.20		

Figure VI-14 RRIP III Roads Kandal

97. Kandal province experiences the double effects of the Mekong river flowing north to south through Phnom Penh and the Tonle Sap river which reverses its flow depending on the season. The two rivers have a confluence at Phnom Penh where they form another two rivers, the Mekong main branch and the Bassac which both flow down into Vietnam.

98. The variability of these flows and the sometimes unpredictability of the combined effects makes this area be deemed moderate to high risk of flooding.

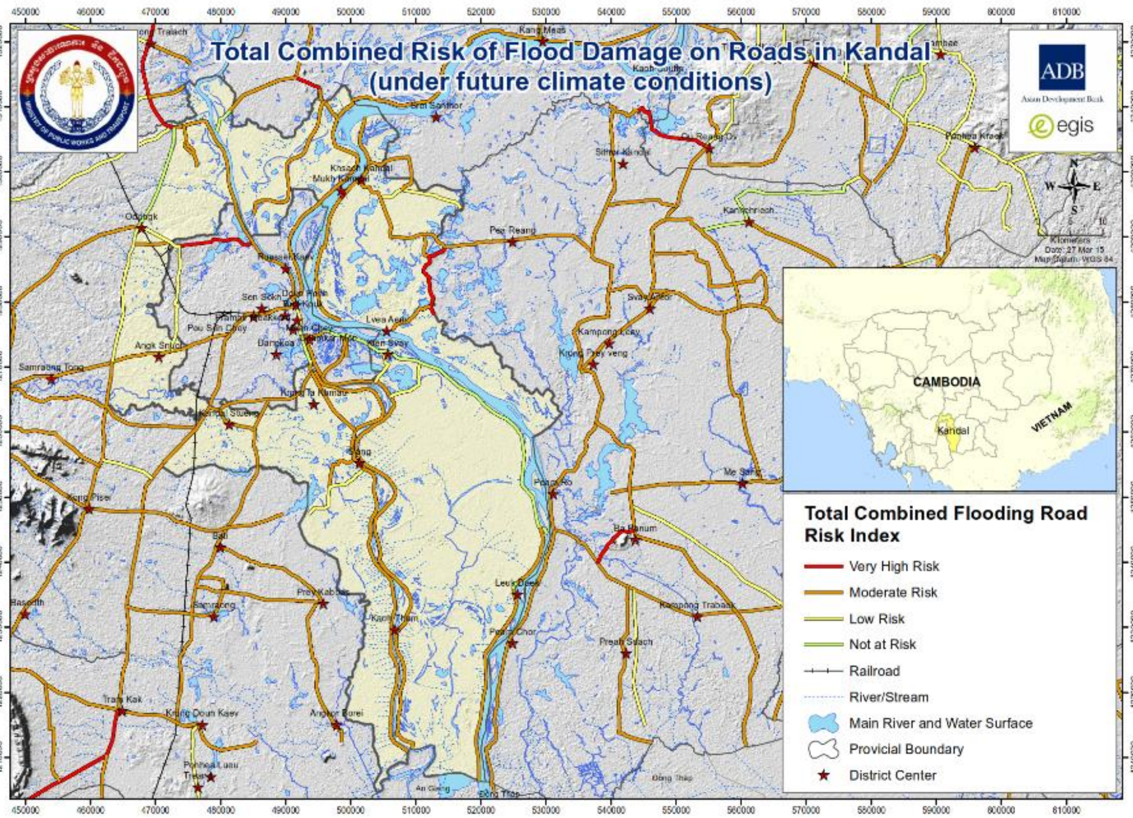


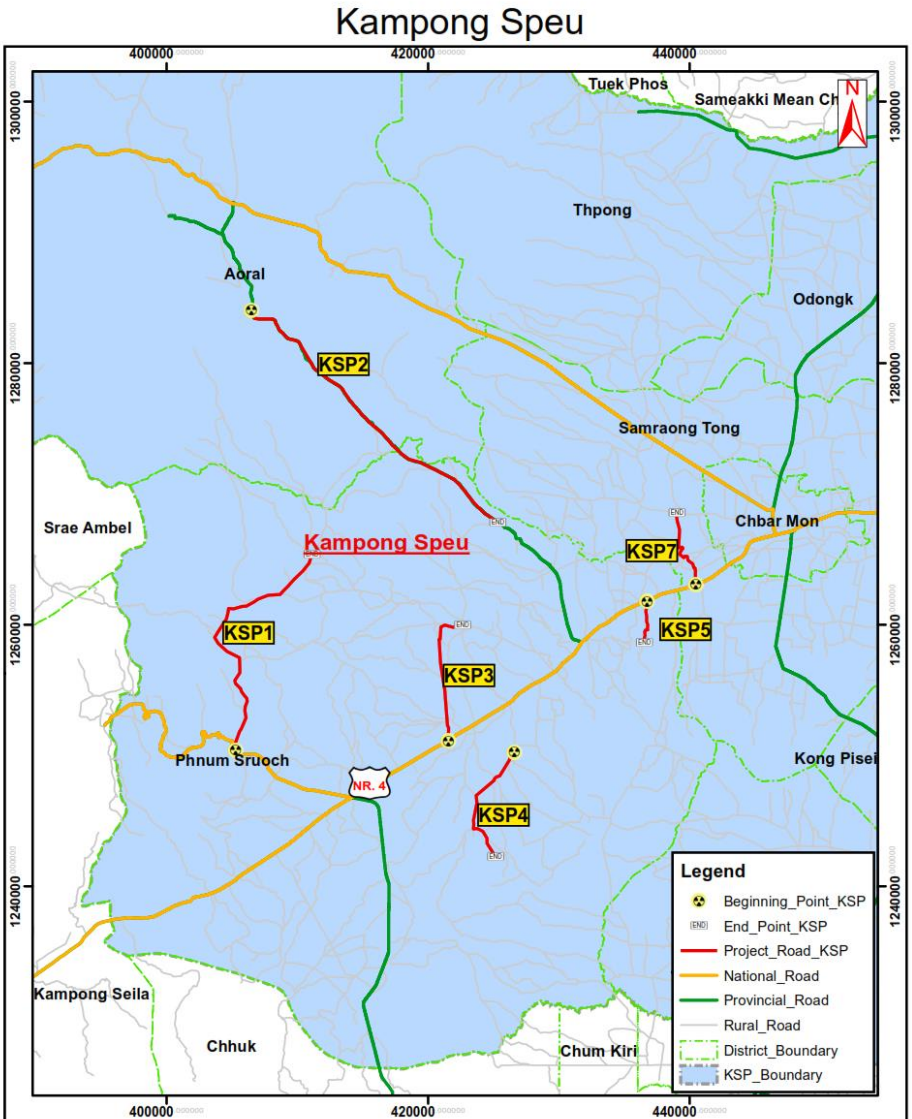
Figure VI-15 Risk of Flood Damaged Roads Kandal Province

99. The province surrounds Phnom Penh, so it could be considered partly urban which causes rapid runoff from impermeable surfaces during heavy rain.

100. All the roads KD1 to 12 should be considered at moderate risk of flooding but in particular KD6, 7 and 8 are in low lying land and may be vulnerable to flooding from both sides due to nearby water ponds impeding cross drainage.

I. Kampong Speu (KSP)

101. There are 6 roads covering in total a length of 77km. Width varies from 7 to 8 m and the proposed pavement is DBST.



Road ID	District	Road Section		Length (km)	Proposed Width(m)	Proposed Pavement
		Beginning	Ending			
KSP1	Phnom Sruch	Ousamchort	Dorkk por	20.60	8	DBST
KSP2	Oral - Phnomsruch	Prey Mean	Krangthom	25.56	7	DBST
KSP3	Phnom Sruch	Prey	Kandal	10.60	8	DBST
KSP4	Phnom Sruch	Damnaktrach	Trapeangtotem	10.00	7	DBST
KSP5	Phnom Sruch	Kbalthnal	Banttop	3.30	8	DBST
KSP7	Samrungtong	Champey	Vorprenh	6.80	7	DBST
Total	6 Roads			76.86		

Figure VI-16   RRIP III Roads Kampong Speu

102. Kampong Speu province forms a catchment in the foothills of the Cardamon mountains which contains Mount Aural the highest peak in Cambodia. Relatively speaking, when compared to the rest of Cambodia, it is considered hilly and contains many streams and watercourses.

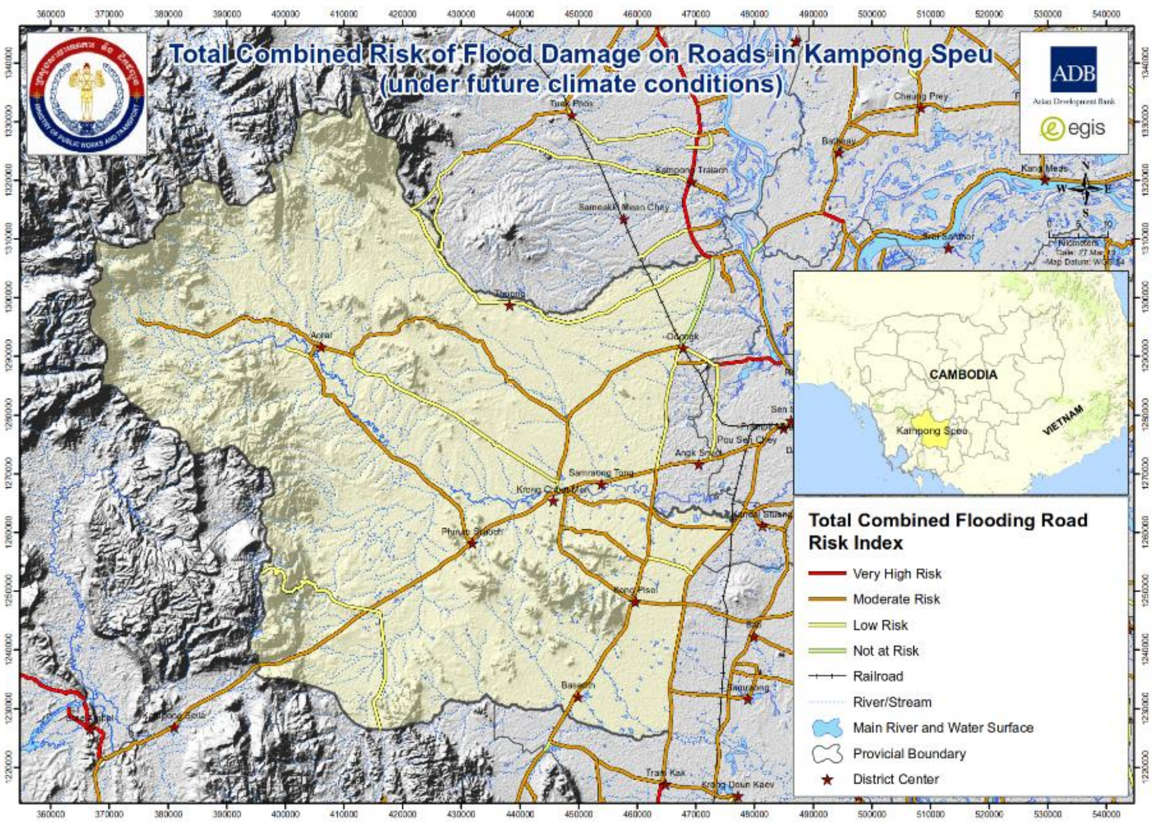


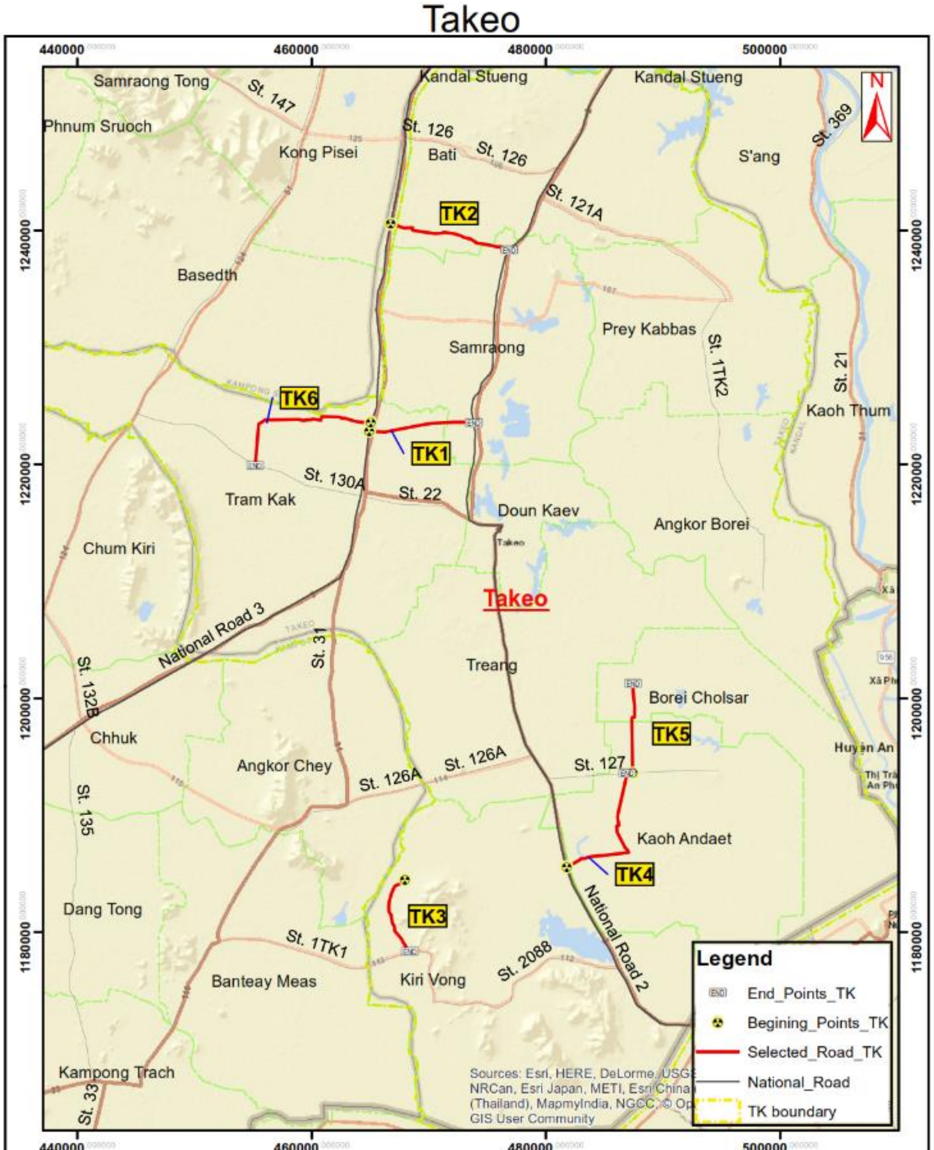
Figure VI-17 Risk of Flood Damaged Roads Kampong Speu Province

103. It is considered at moderate risk of flooding as flash floods can occur in the streams if heavy rains fall in the higher altitude mountains. Any roads crossing existing streams must take this into account when designing cross drains, lateral drains or bridges.

104. These comments apply to all the roads KSP1 to 7 but in particular to KSP1 which are close to steep slopes and may suffer from sudden runoff.

J. Takeo (TK)

105. There are 6 roads covering in total a length of 61.10km. Width varies from 7 to 8 m and the proposed pavement is DBST.



Road ID	District	Road Section		Length (km)	Proposed Width(m)	Proposed Pavement
		Beginning	Ending			
TK1	Tramkok	Svay prei	Dam nak ta sek	9.60	8	DBST
TK2	Bati	Tram Tbal(NR3)	Phum thmey(NR2)	10.70	7	DBST
TK3	Kirivong	Au ansar	Han tea	7.20	8	DBST
TK4	Koh Andet	Phlouvcheat lek2(NR2)	Thlea pror chum	12.70	8	DBST
TK5	Koh Andet	Thlea pror chum	Phum roung	7.90	8	DBST
TK6	Tramkok	moeurng char	Ang roka	13.00	8	DBST
Total	6 Roads			61.10		

Figure VI-18 RRIP III Roads Takeo

106. Takeo province lies in the foothills of the mountains to the west and can experience heavy runoff. The province is itself fairly flat with many large streams and standing water bodies. Natural drainage is constrained to the east by the Bassac and Mekong rivers so a combination of heavy rains in the mountains and high river levels can lead to flash flooding. For this reason, the roads in the province are classed as being at moderate to high risk of flooding.

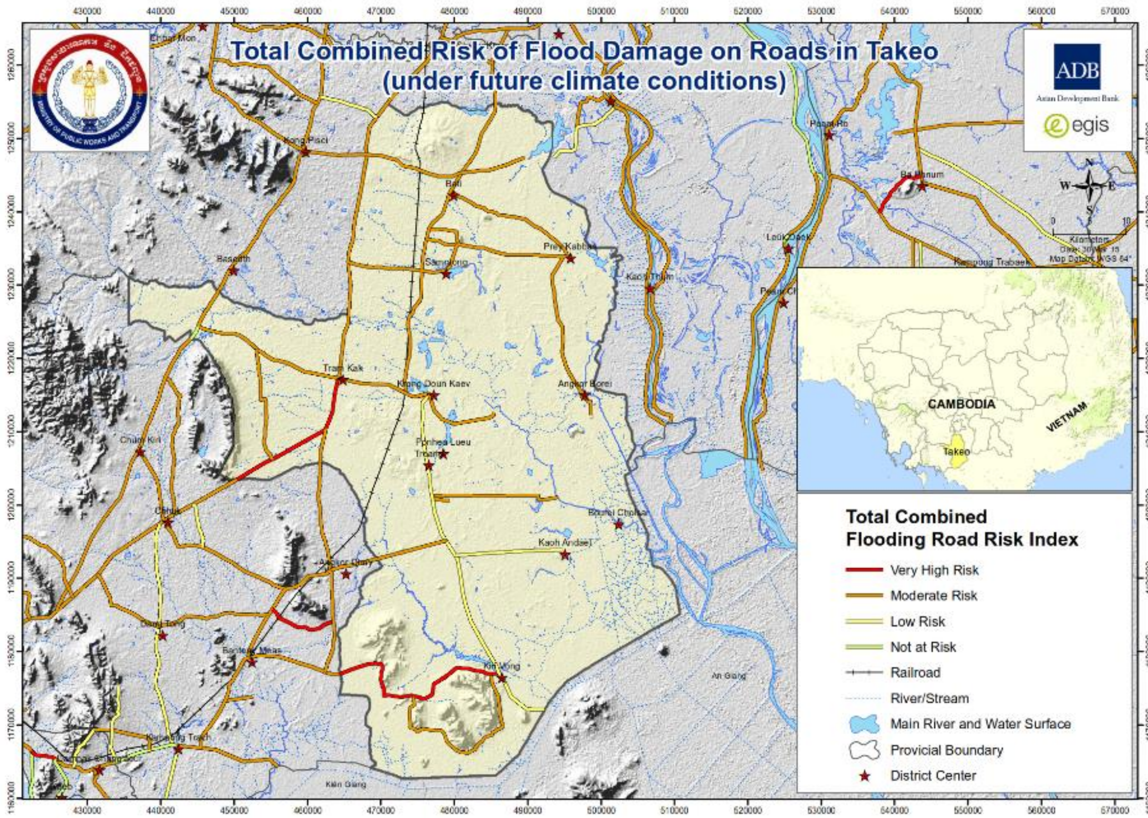


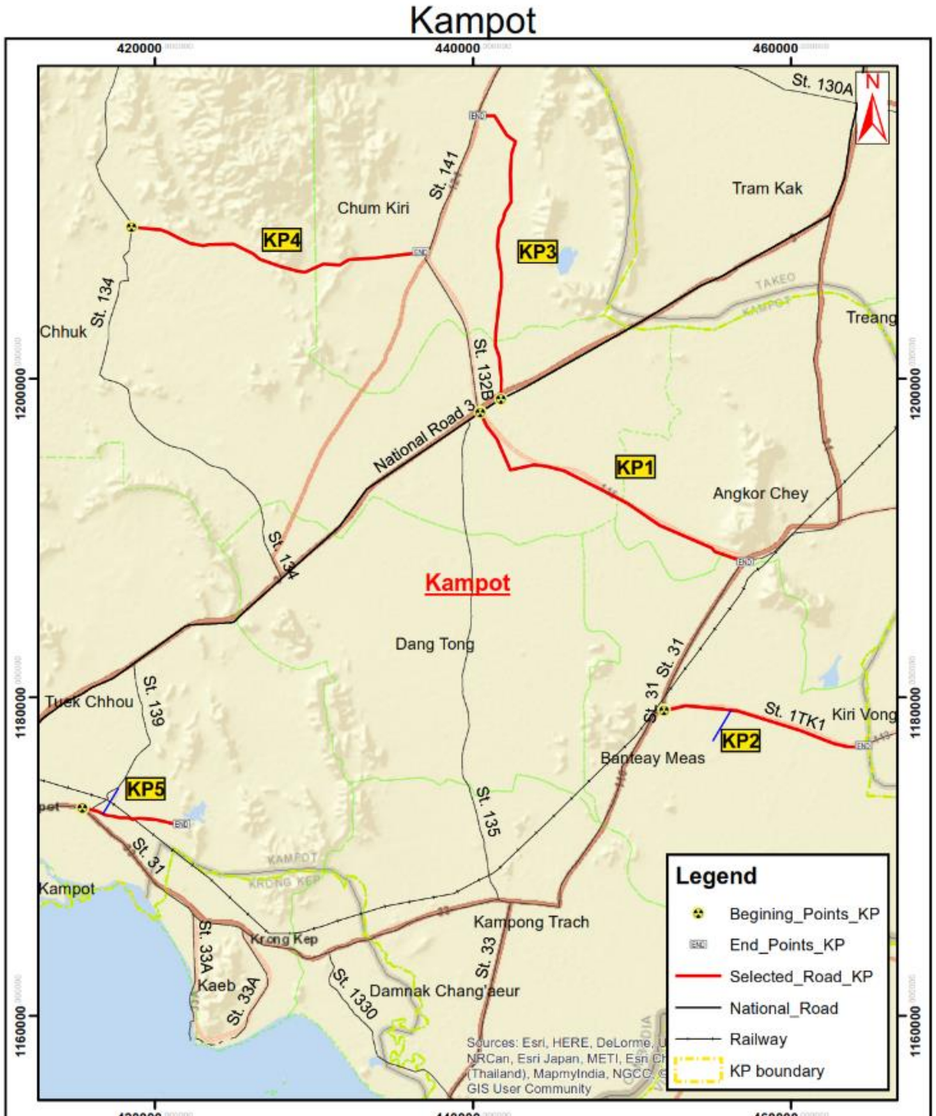
Figure VI-19 Risk of Flood Damaged Roads Takeo Province

107. Two major highways NR2 and NR3 pass though the province and lead to the south coast.

108. Most of the project roads TK1 to 6, except for TK3, act as feeder roads to these national highways. Such highways maybe elevated on embankment and have enlarged drainage to preclude flooding due to the embankment acting as dam and impeding natural drainage. The connecting project roads must be consistent with these designs.

K. Kampot (KP)

109. There are 5 roads covering in total a length of 78.30km. Width varies from 7 to 8 m and the proposed pavement is DBST.



Road ID	District	Road Section		Length (km)	Proposed Width(m)	Proposed Pavement
		Beginning	Ending			
KP1	Chhouk/ Angkor Chey	Chhouk	Chrok Siem	20.20	8	DBST
KP2	Banteay Meas	Touk Meas	Potasu	13.00	8	DBST
KP3	Chhouk, ChhumKiry	Wath steung thmea (Road No3)	Sre Cheng (Road No41)	19.90	7	DBST
KP4	Chhouk, ChumKiry	Taken (Road No43)	Trapaing Raing (Road No41)	19.00	8	DBST
KP5	Toeuk Chhu	Kampot (RoadNo33)	Phnom Kaunsath	6.20	7	DBST
Total	5 Roads			78.30		

Figure VI-20 RRIP III Roads Kampot

110. Kampot province forms part of the seaward side catchment draining form the Mount Bokor national park into the sea. It is crossed by many streams and watercourses including several big rivers. The gradients of the slopes are quite high as evidenced by the hydroelectric potential being exploited there.

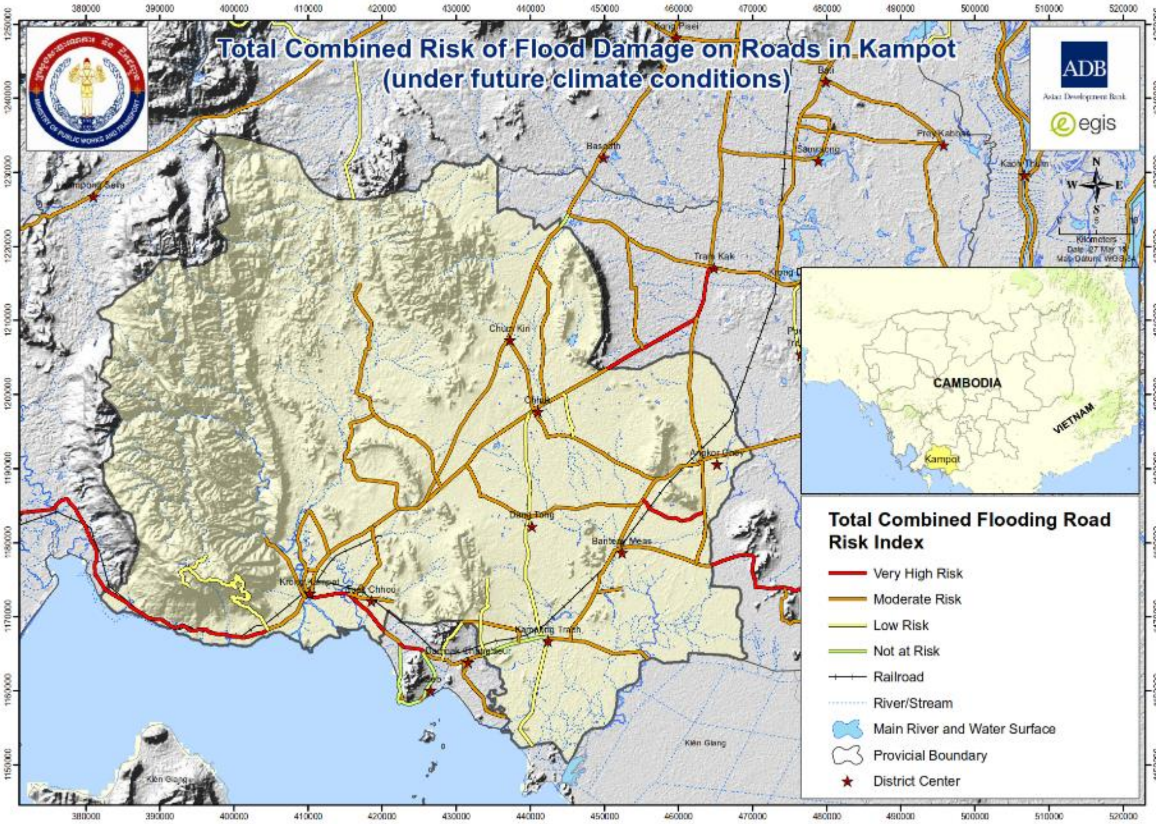


Figure VI-21 Risk of Flood Damaged Roads Kampot Province

111. When the southwest monsoon blows bringing in moisture from the sea the clouds are forced to rise over the mountains which form the hinterland of Kampot and shed their rain. This leads to high seasonal rainfall in the province. The precipitation drains back into the sea in watercourses which cross the coastal roads. These effects lead to the roads in the province being classed as at very high risk to flooding.

112. The coastal roads are also susceptible to sea level rise although apart from the bridges in Kampot town itself, the coast roads (NR33) are well set back from the coastline and well elevated above sea level.

113. All of the roads (KP1 to 5) act as connector roads or feeders to national or provincial highways.

114. The main concern here is the heavy rain which may fall and runoff in the catchment to sea. All cross drains, lateral drains and bridges must be designed to accommodate intense short duration rain fall in the future.

VII. APPROACH TO CLIMATE CHANGE IN DETAILED DESIGN

A. Rainfall

115. Knowing what rainfall intensity and duration figures apply is absolutely fundamental in any road design. This applies not only to the drainage but also to the elevation of the wearing course above any likely flood levels. (This is known as freeboard.)

116. Rainfall duration and intensity must be known as a basis of design. Detailed Design requires an IDF (Intensity Duration Frequency) Curve. This must be projected to include climate change. This is only likely to be available during Detailed Design.

B. Projections of Annual Precipitation

117. The overall conclusion is that annual precipitation in the project area will rise slowly, if at all.

C. Monthly Increase during Flood Period

118. The main change in rainfall will occur in the three wettest months of the year, August to September. In low lying areas flooding is generally caused by the rainfall in the wettest months of the year and lasts for several weeks. In such a case, changes in monthly rainfall are of more importance than rain falling over a shorter period. Projections suggest that the will be little, if any, increase by 2030 but could increase by over 20% by 2070.

D. Storm Projections

119. A paper by O'Gorman in Nature Geoscience Letters[3] related increases in precipitation to increases in temperature and shows that for extreme storm events (0.01% probability of occurrence or less) precipitation increases by 10% for each degree of increase in temperature.

120. As temperature increases are hoped not to exceed 2^{o}C by the end of this century then an addition of 20% on intensity of short duration extreme storms would account for climate change.

E. Overview of Precipitation Changes

121. The following table summarises the expected change to precipitation for different periods. They are based on the average of 4 models for RCP6.0 projection.

Table VII-1 Change in Rainfall % (RCP 6.0)

Year	Annual	Rainy season	Month	5-day	1-day
2030	-1	-3	-1	12	7
2050	0	3	12	19	10
2070	4	7	8	35	32

122. The main conclusions from the above as they relate to precipitation are:

- (i) Annual rainfall may remain unchanged, but rainfall will increase more in the wettest months by being of stronger duration. This will lead to longer dry periods. There may be "mini-droughts" during the wet season.
- (ii) Precipitation will increase most in the south-west and decrease in the north-east.
- (iii) Both the maximum 5-day and 1-day storms are expected to increase. The projected increases are 10% for 2030, 20% for 2050 and 30% or more for 2070.
- (iv) The relative increase in rainfall is heavier for short durations.
- (v) An increase of 20% on existing IDF curves will allow for a global temperature increase of 2^{o}C. This factor is conservative and is recommended as a design factor.

[3] 'Sensitivity of tropical precipitation extremes to climate change' in Nature Geoscience Letters, September 2012.

F. Climate Resilient Design Adaptation

123. Climate resilience related adjustments can be made to civil works through (i) the design of road embankments and roadside ditches which are susceptible to erosion, (ii) using less moisture susceptible materials or hydraulically-stabilized materials usually with cement or lime within the road structure so that structural layers do not lose significant strength upon flooding and soaking, and (iii) by using green engineering to improve the water conservation characteristics of the watershed and to divert run-off water away from the road.

124. Factors considered in making engineering adjustments include cost-effectiveness, current climate variability and potential future risk. Climate change projections do not have a known scientific probability of future climate change and, therefore, the civil engineering adjustments based on expected future changes are difficult to calculate exactly. A margin of safety risk factor should be applied. The risks to roads from climate change include:

(i) Damage to roads, tunnels and drainage system due to flooding
(ii) Increase in scouring of roads, bridges, and support structures
(iii) Damages due to landslide and mudslide
(iv) Loss of structural integrity of roads due to increase in soil moisture levels.

125. Adaptation measures include : (a) applying a safety factor; (b) considering a longer return period for exceptional events when designing hydraulic structures; (c) considering storm water volumes over a longer period; (d) reducing the gradients of slopes and taking into account the materials used; (e) protecting the base of fills and discharge structures; (f) enclosing the materials; (g) using waterproof materials or treating them to make them so; (h) checking the condition of slopes regularly; (i) regularly checking the condition and function of the drainage system and hydraulic structures; and, (j) improving the implementation of alternative routes in the event of a road closure.

G. Adaptation Measures

126. Adaptation to climate change in highway design may require intervention at several stages. Some modifications can be introduced at preliminary design, other items will be required at detailed design phase.

Table VII-2 Climate Change Adaptation Measures

Highway Design Component

Roadways
- Increased height of embankment above High Water Level (HWL)
- Modification of side slope ratios
- Use all-weather wearing course / running surfaces e.g. DBST, surface seals.

Hydrological Studies
- Coordination of data collection/recording systems e.g. rainfall, stream gauges
- Adjustment of design criteria to account for increased flows
- Allowances for effects of future dam and irrigation schemes.

Drainage Design
- Additional waterway opening at bridge sites
- Additional cross-culvert capacity

- Debris defectors and energy dissipaters
- Install Debris Deflectors
- Sub-drainage systems.
- Turf surfaces on side slopes.

Erosion Controls

- Anti-scour provisions at bridge sites
- Channel training / riprap bank protection
- Side ditch linings in areas of high flow velocity
- Retaining walls and gabions to stabilize slopes
- Bioengineering of embankments

Operations and Maintenance

- Regular inspection and repair of road, shoulders, drainage systems
- Regular cleaning of culverts and side ditches
- Regular cleaning of box and pipe culvert systems
- Cleaning of culverts before known storms or typhoons
- Quick restoration of items following major flood events.

H. Specific Recommendations from MPWT

127. MPWT have produced a series of Design Guide Recommendations that incorporate climate resilience. For full details reference should be made to the MPWT Guidance Note (see Section 1.3 Literature Review.)

I. Field Work and Ground Truthing

128. Engineers must visit the site areas and enquire for local characteristics of floods and update flood information from the relevant authorities before deciding on a design elevation. Historical extreme flood elevation maps and 100 Year flood depth maps should be used for general guidance only.

J. Elevation

129. The recommended crest level for National roads and Provincial roads should be a minimum height of the water level of floods with a recurrence interval of 1 in 100 years, plus an additional 0.5 meters for wave overtopping due to wind.

130. For district and local roads, the crest level should be a minimum height of the water level of floods with a recurrence interval of 1 in 10 years plus 0.25 meters.

K. Flood Calculations

131. Flood calculations are based on flow in one direction only. Where area-wide flooding is possible, other methods will be applicable. The commonly used Rational Method can only be applied to catchment areas less than $10km^2$. For larger areas, the Generalized Tropical Flood Model developed by Fiddes and Watkins (1984) should be used.

L. Pavement and Embankments

132. Pavements are normally designed solely on the basis of traffic levels. Theoretically, a “perfect“ road, with an adequate level for clearing floods, with proper embankment materials, with adequate drainage structures, with fully compliant compaction and structural materials and which is perfectly maintained does not require pavements standards higher than those given in current design codes.

133. In Cambodia, special measures must be taken for additional protection from floods. One flood proofing improvement is the use of better sealed pavements such as asphalt/concrete or concrete. It has been recommended by Climate Resilience Provincial Roads Improvement project[4] as a new road policy statement for MPWT that national and provincial roads should be covered with asphalt concrete, or concrete where a road lies on a soft subgrade, is to carry heavy traffic, and is expected to be regularly submerged for appreciable periods, the pavement is recommended to be of asphalt concrete or preferably concrete.

134. If the cost of raising a road on embankment plus extra drainage costs is excessive then a climate resilient road that can withstand occasional inundation maybe more cost effective if the occasional loss of connectivity is acceptable.

135. When determining CBR values test samples shall be soaked for a period not less than 7 days. Materials with a CBR value less than 3 shall be considered unsuitable. Lime stabilization and additional compaction may be employed to increase structural strength under inundation.

136. In areas where gradients are minimal, such as near NR1, even a small flood depth can extend sideways over a very large area. Where that is the case the only option is to raise embankment levels.

137. For new roads the side slopes of embankments shall not be steeper than 1 vertical on 2 horizontal for embankment covered with rip rap and 1 vertical on 2.5 horizontal for those without rip rap cover.

138. For existing roads increasing road embankment heights after a road has been built is costly. Agricultural land and properties both tend to get as close to roads possible, so any future increase in elevation and width of an embankment could lead to resettlement issues which must be considered.

139. A gentler slope is more stable than a steep slope. However, a 5-meter high embankment of slope 1:3 (1 vertical to 3 horizontal) as compared to a slope 1:2 (1 vertical to 2 horizontal) embankment is wider and needs 10 m more road corridor and 50 % additional earth works. This will add to costs and may encroach outside the Right of Way, so requiring compensation.

140. A layer of soil shall be constructed over the completed and trimmed side slopes of embankments. A complete dense cover of growing grass shall be established on the soil covering the side slopes. Where the side of an embankment is subject to wave action, a hedge of shrubs shall be established growing on a line 1.2 m in elevation below the top edge of the roadway.

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[4] MPWT. 2015. *Climate Resilience Provincial Roads Improvement project.* Egis Consultants.

M. Drainage Design

141. Raising the road elevation must always be conducted in parallel to increases in drainage capacity. Otherwise, the hazard of a road on a high embankment, intended to be flood-free can be much worse than for a low-level road, if a flood overtops the road. The risk of this happening needs to be reduced by a combination of higher embankment level and increased drainage capacity in the culverts and under the bridges, all of which add to costs.

142. Inadequate cross drainage can not only pose a hazard to the road itself but can also cause localized flooding to nearby property.

143. In places where there are clearly defined water channels and sufficient gradients for water to flow always, then the capacity of the cross drainage should be increased by around 25%–30%.

144. All cross drains (pipe or box culvert) should be of minimum diameter 1200mm to make for easy cleaning and removal of blockages.

145. Drainage calculations require knowledge of rainfall intensities over different time periods at different Annual Return Intervals. These can be in the form of tables or IDF curves. The following tables relevant to this project are provided by MPWT.

146. Climate studies showed that peak rainfall intensity will vary generally in the range of -7% (for annual) to +25% (for short term storms) compared with intensities in the current standard for road and bridge design. Therefore, the following table can be used with this correction factor.

Table VII-3 Rainfall Intensity Pochentong Airport – Current

Pochentong Rainfall Intensity (mm / hr.)					
Time (hours)	Frequency (Return Period) (Years)				
	5 yr.	10 yr.	20 yr.	50 yr.	100 yr.
0.5	98.6	111.0	122.7	137.7	149.2
1	60.9	68.6	75.8	85.1	92.2
3	26.5	29.8	32.9	36.9	40.0
6	15.2	17.1	18.9	21.2	22.9
12	8.6	9.6	10.6	11.9	12.9
18	6.1	6.8	7.6	8.5	9.2
24	4.9	5.5	6.1	6.8	7.3
48	2.9	3.2	3.6	4.0	4.3
72	2.2	2.5	2.8	3.1	3.4
96	2.0	2.3	2.5	2.9	3.2

Table VII-4 Rainfall Intensity Siem Reap – Current

Siemreap Rainfall Intensity (mm / hr.)					
Time (hours)	Frequency (Return Period) (Years)				
	5 yr.	10 yr.	20 yr.	50 yr.	100 yr.
0.5	128.5	146.7	164.0	186.2	203.2
1	79.1	90.3	101.0	114.6	125.1
3	32.7	37.4	41.8	47.4	51.7
6	18.0	20.6	23.0	26.1	28.5
12	9.8	11.2	12.5	14.2	15.5
18	6.8	7.8	8.7	9.9	10.8
24	5.3	6.0	6.7	7.5	8.2
48	3.2	3.6	4.0	4.5	4.9
72	2.4	2.7	3.0	3.4	3.6
96	2.0	2.3	2.5	2.8	3.0

Table VII-5 Rainfall Intensity Kampong Thom – Current

Kampong Thom Rainfall Intensity (mm / hr.)					
Time (hours)	Frequency (Return Period) (Years)				
	5 yr.	10 yr.	20 yr.	50 yr.	100 yr.
0.5	93.4	100.5	107.3	116.0	122.6
1	59.1	64.6	69.8	76.5	81.6
3	26.2	29.1	31.8	35.3	37.9
6	15.2	16.9	18.6	20.7	22.3
12	8.6	9.7	10.6	11.9	12.9
18	6.1	6.9	7.6	8.5	9.2
24	4.9	5.5	6.0	6.7	7.3

Kampong Thom Rainfall Intensity (mm / hr.)					
Time (hours)	Frequency (Return Period) (Years)				
	5 yr.	10 yr.	20 yr.	50 yr.	100 yr.
48	3.2	3.7	4.1	4.7	5.1
72	2.5	2.8	3.2	3.6	3.9
96	2.6	3.0	3.3	3.7	4.1

147. For all stations, the one-hour rainfall is about 35% of the total daily rainfall. However, the study of exceptional rainfall events in Cambodia has revealed that a 24-hour storm water rainfall of 69 mm can be reached in as little as 1 hour. In Phnom Penh the average 1 hour to 24-hour rainfall ratio is of the order of 60% so in that case the current IDF curves strongly underestimate short term rainfall intensities.

148. For convenience MPWT have produced a graph linking all daily rainfall figures to hourly figures, although this gives high hourly values.

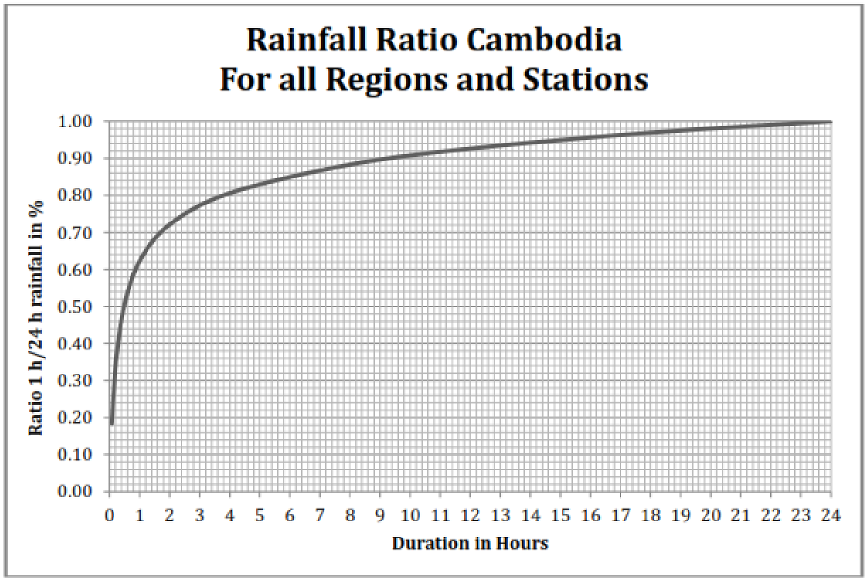

Figure VII-1 Rainfall Ration 1 Hour to 24 Hours

149. IDF curves must be used very cautiously in design. Error factors of 2 to 1 are common. However, overestimating the anticipated rainfall will give a higher safety factor in the design of the drains.

N. Bridge Standards

150. The most important change to bridge design will be a slight increase in spans to allow for larger storm flows from more extreme rainfalls. The ideal bridge design is a single span. The soffit of bridges must be 0.5m clear of the 1 in 100 Year flood level to clear floating debris such as logs and branches which could damage the bridge.

151. Minor changes due to wind loads and temperature changes may be needed. For bridge design the historical maximum shade air temperatures for bridge design should be increased by 3^{o}C.

152. Average wind speed will increase in winter, spring and autumn months, but decrease in the summer months (MONRE 2011). The projected changes in meters per second are very small.

O. Geometry

153. Crossfall on sealed roads should be 2% minimum to avoid ponding. It is reported that Super-elevation seems to be inadequate for curves for 80 km per hour operating speed. In road sections with super-elevation lateral drains can be constructed on one side only. This gives a cost saving but the drains must be sized to carry twice the normally expected road surface runoff.

P. Construction Materials

154. The MPWT Central Laboratory proposed the following pavement composition for roads on embankment above the expected flood level:

- Sub-grade: 570 mm from a borrow area with PI 7%, MDD 2.1g/cc and CBR>10
- Subbase: 250 mm laterite stabilized with 3% cement in some sections if necessary

- Base: 200 mm crushed aggregate
- Wearing course – 20 mm DBST with 19/12 mm aggregates & slow curing emulsion.

155. Bitumen can deteriorate in sunshine and oxidize, losing its polymerization properties and crack. Cracking is exacerbated by high axle loads and potholes result. This in turn leads to ponding which worsens the road surface roughness. Maintaining a sealed surface is imperative. The wearing course surface dressing should extend to the edge of the shoulders to assist in runoff and avoid downward percolation. The wearing course surface should be maintained sealed to discourage upwards movement of water through capillary action. The cement stabilization is intended to strengthen the subbase in the event of flood inundation.

Q. Maintenance

156. The importance of maintenance cannot be over emphasized. No matter how good the design a lack of maintenance will render it ineffective. As indicated above cross drains should be increased in diameter to be a minimum of 1,200 mm to make for ease of clearing debris.

157. Many drains are reported to be choked due to silt and rubbish. Bar screens should be installed on upstream inlets to pipes to catch floating debris. Vertical screens are easier to clean by manual labor.

158. Local communities can be hired for drain cleaning and grass cutting. This only needs unskilled labor and providing of some simple tools. The community sense of ownership can improve the efficiency of maintenance.

R. Incremental Costs for Climate Change Adaptation

1. Elevation

159. The costs for including rises in road elevation are significant. Examples quoted from MPWT documentation are given below.

160. The cost of the Baseline Road to which the percentage increase applies is an elevation of 0.75 m above grade as a minimum at a slope of 1 vertical to 2 horizontal, with no road widening, width 11 m and with sodding, costed at $160/m of road.

Table VII-6 Estimated cost increases for geometry adjustments

Situation	Increase in cost
Road rise of 0.75 m (min) – slope 1:2.5	8%
Road rise of 0.75 m (min) – slope 1:3	16%
Road rise of 1 m – slope 1:2.5	20%
Road rise of 1 m – slope 1:3	29%
Road rise of 2 m – slope 1:2.5	26%
Road rise of 2 m – slope 1:3	35%

2. Cross Drains

161. Cost increments do not allow for additional cross drainage which is site specific. However, based on Australian standards, as a minimum on flat terrain cross drains should be provided at

least at 300 m intervals. In the above case they would be at least 11 m length plus wing walls and minimum sizing of 1,200 mm. This will allow costing at current unit prices.

162. Overestimating the anticipated rainfall will give a higher safety factor in the design of the drains. This MPWT "new method" based on rainfall ratios for Cambodia can be used in design. This gives the cost increases given below.

Table VII-7 Estimated Cost Increases for Drainage Adjustments

Situation	Increase in cost
Large drainage area using new method	- 15%
Using updated rainfall data – rural areas	+5%
Using updated rainfall data – with buildup areas (i.e. urban drainage)	+15%

3. Pavement

163. The costs of improvements of the pavement surface are substantial, and on par with changes to road elevation rises and extension of side slopes. The increase in costs for a pavement upgrade are given below relative to a Baseline case of DBST 20 mm not including shoulders.

Table VII-8 Estimated cost increases for pavement type upgrades

Pavement type	Increase in cost
A/C 30 mm (including shoulders)	100%
A/C 40 mm (including shoulders)	200%
A/C 50 mm (including shoulders)	260%
Concrete 250 mm (including shoulders)	1400%

4. Detailed Costs

164. The FRMI software can calculate costs but it considers road sections of possibly 10km or more in length. Only a smaller section of road may require additional climate resilience measures such as cross drains, not the whole road. This issue of costs needs to be addressed at the detailed design stage to give more precise cost figures.

VIII. CLIMATE CHANGE ADAPTATION COSTS

A. Costs of RRIP III

165. RRIP III will refurbish 22 sections of roads in 5 provinces covering 360 km. The total cost is $43,473,590.

166. These costs include an allowance for climate change adaptation. This is discussed further below.

B. Climate Resilience Measures Adopted in Preliminary Design

167. During preliminary design there are five factors considered: pavement, embankment, bridges, box culverts and pipe culverts. The climate resilience measures fall into two categories:

- Increasing the embankment to raise up the existing road elevation. This requires a slight vertical lift and as the embankment has sloping sides, a slight widening so the embankment cross sectional area will increase.
- Drainage and protection works for better water flow. This may require replacing of existing drainage structures or widening of existing if existing can be used.

168. Pavement is improved but is not considered a climate resilience measure.

C. Estimated Incremental Cost of Adaptation

169. The cost of climate change adaption for the embankment is calculated by a 45% increment of embankment work to raise up the existing road elevation.

170. Drainage and protection work for better water flow include bridges, box culverts and pipe culverts. Some structures currently are satisfactory and do not require replacement. Other must be replaced.

171. Although bridges and box culverts have been checked as part of the condition survey, the actual works for bridges and box culverts have not been considered further at this stage as this comes under detailed design. If the bridge and box culverts have been damaged they would normally be replaced with similar structures of same size. A hydrological survey and study will be carried out and if they are too narrow they will be extended or widened. If they are in a location identified in the CDRA as being at high risk of flooding the sizing will be increased to accommodate higher rainfall and associated faster stream flows.

172. Pipe culverts have been considered. As a minimum all pipe culverts should have a minimum diameter of 1200mm to aid in cleaning and maintenance.

173. There are over 900 pipe culverts of which over 100 will remain in use unchanged and the rest will have size increased.

174. The total costs for climate change adaptation are given below (table 8-1).

Table VIII-1 Total Costs of Climate Change Adaptation

Description	Kampong Cham (CW-A)	Tboung Khmum (CW-B1)	Tboung Khmum (CW-B2)	Prey Veng (CW-C)	Svay Rieng (CW-D)	Kratie (CW-D)	Total
No. of Roads	6	5	2	5	5	3	26
Length (kilometers)	100.6	79.8	23.6	72.2	64.6	78.2	419.0
Earthwork and Allied activities	935,576	744,681	223,795	690,779	602,439	752,688	3,949,961
Drainage and Protection Works	95,902	137,991	41,848	133,636	122,184	109,116	640,681
Total Climate Change Adaption							4,590,642
Sub-total Road Construction Costs	9,702,676	7,931,515	2,378,943	7,879,949	6,636,140	8,845,364	43,374,590

175. This equates to 10.48% of total construction costs being allocated to climate change resilience measures.

D. Measures for Further Consideration During Detailed Design

176. The road design involves four parameters:

- Pavements
- Bridges
- Box culverts
- Pipe culverts

177. The preliminary design has included a condition survey that examined all of these and identified those which needed replacement and those which were in satisfactory condition.

178. Pavement replacement is not considered as a climate change related factor. Although bridges and box culverts have been checked as part of the condition survey, and the numbers that need to be replaced given, the actual works for bridges and box culverts have not been considered further at this stage.

179. If the bridge and box culverts have been damaged they would normally be replaced with similar structures of same size. A hydrological survey and study will be carried out and if they are too narrow they will be extended or widened. If they are in a location identified in the CDRA as being at high risk of flooding, the sizing will be increased to accommodate higher rainfall and associated faster stream flows.

180. Pipe culverts have been considered in detail. There are 984 existing pipe culverts of which 112 will remain unchanged and 872 will be replaced. As a minimum all replaced pipe culverts should have a minimum diameter of 1200mm to aid in cleaning and maintenance. A hydrological study will be carried out based on existing rainfall data amended for climate change and the culverts sized accordingly.

E. Additional Analysis Needed to be included in PAM TORs

181. Additional analysis is required for bridges and box culverts and for pipe culverts in areas identified as High Risk of Vulnerability to climate change induced flooding. All drainage structures will be subjected to a design review and the sizing based on the hydrological study. The IDF curves used in the detailed design must be amended to include climate change. An increase of 20% on existing IDF curves will allow for a global temperature increase of 2^{o}C. This factor is conservative and is recommended as a design factor.

182. Special attention must be given to roads at risk which, as stated in the CDRA report are:

(i) Kampong Cham (KC)

- KC1, 3, 4, 5 and 6 are at low to moderate risk of flooding.
- KC2 is at moderate risk.

(ii) Tboung Khmum (TBK)

- TBK1 and 6 are highly vulnerable.
- TBK 3 is at severe risk.

(iii) Prey Veng (PV)

- PV1, 2, 3 and 5 are at moderate risk.
- PV4 and 6 are at high risk.

(iv) Svay Rieng (SVR)

SVR1 to 6 are all at high risk of flooding

(v) Kratie (KRT)

- KRT1 is at high risk.
- KRT2 and 3 are at low to moderate risk

(vi) Kampong Chhnang (KCH)

- KCH2 through 7 are at moderate risk

(vii) Kandal (KD)

- All roads KD1 to 12 are at moderate risk.
- KD6, 7 and 8 are highly vulnerable

(viii) Kampong Speu (KSP)

- KSP1 to 7 are at moderate risk but KSP1 is highly vulnerable.

(ix) Takeo (TK)

- TK1 to 6 are at moderate to high risk

(x) Kampot (KP)

- KP1 to 5 are at moderate risk

IX. CONCLUSIONS

183. Flooding does not necessarily inflict damage to a road. Roads properly designed and maintained in good condition will remain at no or at very low risk of flood damage. Roads recently rehabilitated will better withstand flood damages and are likely to be considerably less damaged through flooding than un-rehabilitated roads.

184. The main conclusions on precipitation are:

(i) Annual rainfall may remain unchanged, but rainfall will increase more in the wettest months by being of stronger duration. This will lead to longer dry periods. There may be “mini-droughts” during the wet season.

(ii) Precipitation will increase most in the south-west and decrease in the north-east.

(iii) Both the maximum 5-day and 1-day storms are expected to increase. The projected increases are 10% for 2030, 20% for 2050 and 30% or more for 2070.

(iv) The relative increase in rainfall is heavier for short durations.

(v) An increase of 20% on existing IDF curves will allow for a global temperature increase of 2^{o}C. This factor is conservative and is recommended as a design factor.

185. If hourly or short-term data on rainfall is lacking daily rainfall figures can be used to estimate hourly rainfall for drainage design calculations. In general, the one hourly rainfall figure is 20%–40% of daily although figures of 60% have been recorded around Phnom Penh. When in doubt a higher figure should be used.

186. Climate change will cause an increase in short term intense rainfall. An increase of 20% on existing rainfall intensity should be allowed for future events.

187. The MPWT FRMI software has been used to assess flood risk to roads. The level of risk is based on a future projection to 2055 with RCP 8.5. FRMI considers sections of roads. These may be longer than the actual stretch of road likely to be damaged.

188. The most vulnerable provinces are Prey Veng, Svay Rieng, Takeo and Kampot.

189. MPWT publish engineering design guides that cover all classes of roads from national highways down to rural roads. These can be used for all types of road design. MRD do not publish such documents. There are a large number of climate change adaptation design guides now issued by MRD and MPWT. These can be used when considering climate change adaptation measures. (See section 1.3)

190. Major roads and bridges should be designed to withstand a 1 in 100-year flood level with 0.5m freeboard.

191. Provincial and district roads should be designed to withstand a 1 in 10-year flood level with 0.25m freeboard.

192. Maintenance is essential. All culverts should be a minimum of 1200mm diameter to facilitate cleaning.