### CLIMATE RISK ASSESSMENT AND MANAGEMENT

#### I. Basic Project Information

Project Titl	Project Title: Road Network Improvement Project		
Project Bu	dget: ADB financing \$70 million, Total cost of Project \$76.7 million		
Location: (	Cambodia (Provinces of Prey Veng, Svay Rieng, and Siem Reap)		
Sector: Roa	ad Transport (non-urban)		
Theme: Ro	ad safety, economic growth and capacity development		
Brief Desci	ription:		
The impact	will be transport infrastructure contributing to the enhancement of national competitiveness and		
people s we	errare developed. The outcome will be transport efficiency increased on the GMS Southern		
Economic C	corridor and connecting project roads. There are four outputs:		
(i)	<b>Output 1: More safe and climate resilient national roads completed</b> . The project will improve about 146.55 km of flood-prone national roads through provision of periodic maintenance and rehabilitation for 97 km of NR1 and 50 km of NR6. The NRs will have $3.5x+1.5x2=10m$ with paved shoulders. The roads are designed to be climate resilient to ensure all year access and to help reduce the communes' vulnerability to climate change.		
(ii)	<b>Output 2: Axle load control enhanced.</b> This will involve (i) improvement of at least 6 existing weigh stations by purchasing required equipment; (ii) help operationalize at least two mobile teams by providing weigh scales and vehicles; and (iii) provision of on-the-job training for staff in weigh stations and mobile teams. The project will also pilot controlling of axle load at three sources and introduce particular conditions to the civil works contract to enforce contractors to obey the load limits.		
(iii) Output 3: Quality assurance for civil works in MPWT strengthened. The project will (i) establish four regional laboratories in Siem Reap, Kampot, Pursat and Kratie provinces equipping it with good quality test equipment and trained and qualified laboratory personal to reduce the costs of collecting and transporting of samples from other provinces to Phnom Penh <sup>1</sup> , (ii) integrate it with the national laboratories, (iii) establish QA system in MPWT, (iv) prepare a Quality Management System Manual to guide the laboratory staff on the policies and procedures to be adopted in the proposed national and regional laboratories for the effective and efficient management of the organization, (v) recruited or re-deployed MPWT staff and train them in the operation of the new QA process and procedural manuals, and (vi) prepare long-term development plan for effective and continual quality control system in road sector; and			
(iv)	<b>Output 4: Road safety along project roads improved.</b> This output focuses on a community based road safety activities through three pillars of: data compilation and analysis, safety school zone, and law enforcement.		

#### II. Summary of Climate Risk Screening and Assessment

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

The project area is in the central region of Cambodia which is characterized as flatland with vast alluvial plains. The area is the floodplain of Tonle Sap that merges with the floodplain of the Mekong River to the southeast. Most of the area is covered by paddy field and is prone to flooding during the wet season by runoff or overflows from Tonle Sap and Mekong River. The section of NR6 to be rehabilitated traverses the northern edge of the floodplain of Tonle Sap and can be exposed to flash flooding from runoff down from the northern Thai mountings to the Tonle Sap lake. Flood events and debris flow are the major climate risks to the project and have historically resulted in damage of the road network, travel disruption and significant economic losses. Climate change impacts are likely to compound existing issues, particularly during the rainy season. Project components and key climate sensitivities include:

<sup>&</sup>lt;sup>1</sup> The locations of laboratories were selected based on the selection criteria: (i) geographical location, (ii) availability of land belongs to MPWT,

Project component: 1. Road pavement; 2. Slopes; 3. Bridge heights; 4. Drainage infrastructure; 5. Construction activities; 6. Frequency of maintenance; and	<ul> <li>Sensitivity to climate/weather conditions and sea level:</li> <li>1. Increase in peak flood height, intensity and frequency of rainfall;</li> <li>2. Increased debris loading; and</li> <li>3. Increased risk of erosion.</li> </ul>		
<ol> <li>Disaster response capacity of operator.</li> </ol>			
<b>B. Climate Risk Screening</b> Initial climate risk screening was carried out using AWARE for Projects and climate change risk was identified as high on the basis of a high risk of increased frequency and intensity of flood events and wild fire and landslide and a medium risk of water stress (see Annex 1). Flood and landslide can result in damage to road infrastructure and disruption of service. Design standards, in particular those for bridges, culverts and drainage may need to be altered, maintenance frequency increased and extreme weather response and			
Risk topic:       D         1. Rainfall increase,       D         2. Increased frequency and intensity of rainfall,       D         3. Increased risk of flood and debris loading, and       D         4. Increased landslide risk       D         5. Wild fire associated with adjacent forest habitats.	<ul> <li>Description of the risk <ol> <li>Pavement, road embankments, slopes, culverts and bridges may be at increased risk of failure;</li> <li>Bridge, culvert and drainage design standards calculated using historic climate data may not have sufficient capacity for projected increases in rainfall intensity and volume;</li> <li>Infrastructure may experience increased debris loading, faster weathering and more regular damage from floodwater and debris requiring more regular routine and major maintenance; and</li> <li>Severe weather events may result in increased incidence of disruption of transport services and there may be a need to improve emergency and disaster response planning and capacity.</li> </ol> </li> </ul>		
Climate Risk Classification High (Annex 1 includes AWARE climate	risk screening report)		
<b>C.</b> Climate Risk Assessment A detailed climate risk and vulnerability assessment (CRVA) was carried out, project roads were evaluated using the Flood Risk Management Interface (FRMI) software developed by MPWT. The frequency and severity of rainfall events and sensitivity of the roads to local rainfall events and flooding were considered. The FRMI methodology consists of identifying road links and parameters based on topographical analysis of road physical parameters and assessing the flooding types that these roads are exposed to. The topographical analysis is derived from Shuttle Radar Topographic Mission (SRTM) data. The road segments from the national road network are sourced from MPWT RAMs 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 RAMS system. Flood impact or damage risk assessment are carried out for four specific types of flood and mapped as a fifth combined flood index consisting of (i) flash flood index, (ii) large drainage area index, (iii) build-up area flooding index, (iv) lowland flooding index, and (v) combined flood risk index. The main input to the flood risk calculation 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. The road resilience factors are then applied in terms of the pavement structure and how efficient the drainage system is under extreme rainfall. Road resilience is assessed in the model through three indicators: (i) pavement surface roughness, (ii) pavement type, and (iii) condition of the drainage structures. Data on meteorology was derived from the Department of Meteorology (DOM) of MOWRAM which has 38 meteorological stations that record rainfall, 23 that record evaporation, and 14 stations that record wind speed. The following key projections were made:			

- a) 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 the dry northeast monsoon occurs. 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. Studies projected an increase in rainfall intensity during rainy days by 2055.
- b) 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 northeast. Smaller 1-day extreme events of 100-145mm occur in the central flat lands and hilly regions in the north. The lowest values are around Tonle Sap.
- c) 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 5-day duration is likely to correspond to the critical flood duration for some of the larger river basins. There is projected small increase in 5-day extreme rainfall over the coastal and other high mountains but a more pronounced increase of 16-20mm per day for the hilly regions to the west of the Mekong in the north of the country. The most pronounced change is a projected decrease of 5-day precipitation over 17mm per day for the flat areas south and southwest of Tonle Sap. It is projected to increase in Svay Rieng.
- d) The 2060 average annual air temperature in the country may increase between 0.7 2.7°C, and total rainfall may increase between -11 and +31% during the rainy season but decrease between 11 and +35% during the dry season.
- e) The 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.
- f) High risk urban (builtup area) flooding is located in Prey Veng and Siem Reap. Due to extremely flat terrain in these areas, weather influences can flood over very large distances on either side of the road alignments.

#### III. Climate Risk Management Response within the Project

The climate risk and vulnerability studies for the national roads recommend that the detailed design takes account of projected climate change impacts and considers adoption of a number of adaptation options:

- 1. Design adaptation. 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 runoff water away from the road. Factors to consider in engineering adjustments include cost-effectiveness, current climate variability and potential future risk. Adaptation measures include: (i) applying a safety factor, (ii) considering a longer return period for exceptional events when designing hydraulic structure, (iii) considering storm water volumes over a longer period, (iv) reducing the gradients of slopes and taking into account the materials used, (v) protecting the base of fills and discharge structures, (vi) enclosing the materials, (vii) using waterproof materials, (viii) checking the condition of slopes regularly, (ix) regularly checking the condition and function of the drainage system and hydraulic structures, and (x) improving the implementation of alternative routes in the event of a road closure.
- 2. **Elevation.** The recommended crest level for national 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.

- 3. Pavement and Embankments. The MPWT has a new policy statement that national roads should be covered with asphalt concrete or concrete for better sealed pavements and as flood proofing improvement. 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 concrete. In areas where gradients are minimal, even a small flood depth can extend sideways over a very large area. In this case, the only option is to raise the embankment levels. 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. The subbase on embankment shall be constructed to the full width of the subgrade surface. The shoulders shall be constructed same as the pavement structure. The shoulders shall be sealed with an approved bituminous treatment up to the edges of the embankment or where guard rail is constructed, up to the line of guard rail. Each part of the bituminous shoulder treatment which is the same as for the pavement shall be applied simultaneously with the pavement treatment. Rip rap protection is recommended to cover the full surface of embankments of roads at high risks of flash floods and of low land floods.
- 4. Drainage Design. In road sections where there are clearly defined water channels and sufficient gradients for water to flow at all times of the year, the capacity of the cross drainage should be increased by 25% 30%. All cross drains (pipe or box culvert) should be of minimum diameter of 1200mm for easy cleaning and removal of blockages. The rainfall intensity over different time periods at different annual return intervals from MPWT with correction factor will be referred in the drainage calculations. 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.
- 5. **Bridge Standards.** 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 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.
- 6. **Geometry.** The crossfall on sealed roads should be 2% minimum to avoid ponding. In road sections with super-elevation, lateral drains can be constructed on one side only.
- 7. **Maintenance.** Bar screens should be installed on upstream inlets to pies to catch floating debris. Vertical screens are easier to clean by manual labor

The study recommended the design of major roads and bridges to withstand a 1 in 100 year flood with 0.5m freeboard. An increase of 20% on existing rainfall intensity should be allowed for future events.

These climate adaptation measures were discussed and agreed with the MPWT and the project designers during the fact-finding mission in November 2016. Following the detailed design, adaptation measures adopted and the incremental cost of adaptation will be confirmed.

The Project Agreement includes a loan covenant on Detailed Design of the National Roads: *MPWT* and *PMU3* shall ensure that detailed design of the national roads is updated to incorporate the outcomes and recommendations of (a) road safety audit; and (b) climate change adaptation assessment.

#### Annex 1: Aware Climate Risk Screening Report



Section 1 of 11

# 01

#### Introduction

This report summarises results from a climate risk screening exercise. The project information and location(s) are detailed in Section 02 of this report.

The screening is based on the Aware<sup>TM</sup> geographic data set, compiled from the latest scientific information on current climate and related hazards together with projected changes for the future where available. These data are combined with the project's sensitivities to climate variables, returning information on the current and potential future risks that could influence its design and planning.

#### Project Information

PROJECT NAME:	SERD: RNIP Cambodia
SUB PROJECT:	National and Provincial Roads
REFERENCE:	41123
SECTOR:	Rural transport infrastructure
SUB SECTOR:	Road/ highway/ runway surface
DESCRIPTION:	Rehabilitation and maintenance of 195.2km national and provincial roads





#### Section 3 of 11



#### Project Risk Ratings

Below you will find the overall risk level for the project together with a radar chart presenting the level of risk associated with each individual risk topic analysed in Aware<sup>TM</sup>. Projects with a final "High risk" rating are always recommended for further more detailed climate risk analyses.

The radar chart provides an overview of which individual risks are most significant. This should be used in conjunction with the final rating to determine whether the project as a whole, or its individual components, should be assessed in further detail. The red band (outer circle) suggests a higher level of risk in relation to a risk topic. The green band (inner circle) suggests a lower level of risk in relation to a risk topic.

In the remaining sections of this report more detailed commentary is provided. Information is given on existing and possible future climate conditions and associated hazards. A number of questions are provided to help stimulate a conversation with project designers in order to determine how they would manage current and future climate change risks at the design stage. Links are provided to recent case studies, relevant data portals and other technical resources for further research.

#### Final project risk ratings

#### Medium Risk

#### Breakdown of risk topic ratings







#### Section 4 of 11

HIGH RISK

FLOOD

ACCLIMATISE COMMENTARY



Our data suggest that the project is located in a region which has experienced recurring major flood events in the recent past. A high exposure in Aware means that between 1985 and 2010 there have been more than one significant, large-scale flood event in the region. This is based on post-processed data from the Dartmouth Flood Observatory at the University of Colorado.

The risk and type of flooding is dependent on local geographical factors including:

- · Proximity to the coast and inland water courses
- Local topography

 Urban drainage infrastructure
 Up to date information on flood risk worldwide is available online, for example UNEP / UNISDR's Global Risk Data Platform.

1. What the science says could happen in the future and what does this mean for the design of my project?

· Climate change is projected to influence the frequency and intensity of flood events.

 Existing engineering designs may not take into consideration the impact of climate change on the risks from flooding. See "Critical thresholds" in the "Help & glossary" section for further details on how a changing climate can impact on critical thresholds and design standards.

. If flooding is identified as a potential problem for the project, it is recommended that a more localised and in-depth assessment is carried out. This information can then be used to inform the project design process if necessary.

2. As a starting point you may wish to consider the following questions:

Q1 Would the expected performance and maintenance of the project be impaired by flooding? Q2 Is there a plan to integrate climate change into a flood risk assessment for the project? Q3 Will the project include continuity plans which make provision for continued successful operation in the event of floods?

#### 3. What next?

 See the section "Further reading" in "Help and glossary" at the end of this report which lists a selection of resources that provide further information on a changing climate. · Click here or here for the latest news and information relating to floods and climate change.



Section 5 of 11



#### PRECIPITATION INCREASE

Would an increase in precipitation require modifications to the design of the project in order to successfully provide the expected services over its lifetime?

Chosen Answer

Yes - a little. The design of the project may have to be slightly modified to cope with the impact of increased precipitation.

ACCLIMATISE COMMENTARY

1. What does this mean for the design of my project?

 There is a potential for an increase in incidences where current design standards will not be sufficient. See "Critical thresholds" in the "Help and glossary" section for further details on how a changing climate can impact on critical thresholds and design standards.

 The design, operational and maintenance standards should be reviewed - take into consideration current impacts of heavy precipitation events as well as potential future changes.

How could current heavy precipitation affect the project even without future climate change?



 Seasonal runoff may lead to erosion and siltation of water courses, lakes and reservoirs.
 Flooding and precipitation induced landslide events.

 In colder regions, seasonal snow falls could lead to overloading structures and avalanche risk.

 If our data suggests that there are existing hazards associated with heavy precipitation in the region, they will be highlighted elsewhere in the report. This may include existing flood and landslide risks.

3. What does the science say could happen by the 2050s?

 Climate model projections do not agree that seasonal precipitation will increase in the project location which could indicate a relatively high degree of uncertainty (see the section "Model agreement and uncertainty" in "Help and glossary" at the end of this report). On the other hand, this could also mean precipitation patterns are not expected to change or may even decrease (see elsewhere in the report for more details of projections related to precipitation decrease).

 If you want to know more about projected changes in the project location across a range of GCMs and emissions scenarios please refer to The Nature Conservancy's Climate Wizard for detailed maps and Environment Canada's Canadian Climate Change Scenarios Network for scatter plots of expected changes.

#### 4. What next?

 See the section "Further reading" in "Help and glossary" at the end of this report which lists a selection of resources that provide further information on a changing climate.
 Click here or here for the latest news and information relating to water and climate change.



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#### WATER AVAILABILITY

06 MEDIUM RISK

ACCLIMATISE COMMENTARY



 Our data suggest that the project is located in a region where there may be future water stress (2020s - 2050s). A high exposure in Aware means that either water stress is 'extreme' or high seasonal temperatures coincide with relatively low rainfall. Extreme water stress is defined as 'less than 0.5 million litres available per person per year' based on climate information as well as the effects of income, electricity production, water-use efficiency and other driving forces. This is postprocessed data from Alcamo et al., 2007. Away

from populated regions, high exposure also occurs where high seasonal temperatures (above 28 degrees Celsius average over 6 months) coincide with low rainfall (less than 100mm per month average over 6 months). This is based on post-processed data from the Global Precipitation Climatology Centre (GPCC), Climatic Research Unit (CRU) and a range of GCM projections. • The situation may be exacerbated if there is increased competition for water with other users in the area and changes in local demographics.

· An associated reduction in water quality could also have a negative impact on the project.

1. What the science says could happen in the future and what does this mean for the design of my project?

 Climate change is projected to influence water availability. Regions that are already dry may suffer further if future precipitation is projected to decrease. Increased evaporation due to rising temperature will further impact on water availability. Seasonal availability of water may also change whereby there may be a shift in the timing of its availability.

 Existing engineering designs may not take into consideration the impact of climate change on the risks from water availability and design standards may not be met. See "Critical thresholds" in the "Help & glossary" section for further details on how a changing climate can impact on critical thresholds and design standards.

If water availability is identified as a potential problem for the project, it is recommended that a
more localised and in-depth assessment is carried out. This information can then be used to inform
the project design process if necessary.

 If you want to know more about projected changes in water availability in the project location, please refer to: the World Resources Institute's Aqueduct.

2. As a starting point you may wish to consider the following questions:

Q1 How would a lack of water impact the expected performance of the project? Q2 Would a reduction in water supply have consequences for the expected maintenance of the project?

Q3 Will there be a water shortage continuity strategy in place for the project?

Q4 Will it be necessary to carry out water availability risk assessments in any of the project locations? If so, these assessments should take into account climate change?

Q5 Will there be an investment in water efficient technology or practices to help minimise the quantities of water required for its operational processes?

#### 3. What next?

See the section "Further reading" in "Help and glossary" at the end of this report which lists a selection of resources that provide further information on a changing climate.
 Click here or here for the latest news and information relating to water and climate change.



Section 7 of 11

LOW

#### TEMPERATURE INCREASE

Would an increase in temperature require modifications to the design of the project in order to successfully provide the expected services over its lifetime?

Chosen Answer No - modifications are not required. The design of the project would be unaffected by increases in temperature.

#### ACCLIMATISE COMMENTARY

1. What does this mean for the design of my project?

 Even though you have suggested that project designs would not be sensitive to rising temperatures, it is worth considering existing temperature related hazards in the region where the project is planned.

 There is a potential for an increase in incidences where current design standards will not be sufficient. See "Critical thresholds" in the "Help and glossary" section for further details on how a changing climate can impact on critical thresholds and design standards.

 The design, operational and maintenance standards should be reviewed - take into consideration current impacts of high temperatures as well as potential future changes.

2. How could current high temperatures affect the project even without future climate change?

 Heatwaves put stress on buildings and other infrastructure, including roads and other transport links. In cities, the 'urban heat island' can increase the risk of heat related deaths.

 Warm weather can raise surface water temperatures of reservoirs used for industrial cooling. In addition, this could impact local eco-systems, improving the growing conditions for algae and potentially harmful micro-organisms in water courses.

Heatwaves can have an impact on agricultural productivity and growing seasons.

 High temperatures can have implications for energy security. Peak energy demand due to demand for cooling can exceed incremental increases on base load in addition to the risk of line outages and blackouts.

 Human health can be affected by warmer periods. For example, urban air quality and disease transmission (e.g. malaria and dengue fever) can be impacted by higher air temperatures.

 Wildfire risk is elevated during prolonged warm periods that dry fuels, promoting easier ignition and faster spread.

· Permafrost and glacial melt regimes as impacted by warm periods.

 If our data suggests that there are existing hazards associated with high temperatures in the region, they will be highlighted elsewhere in the report. This may include existing wildfire risks as well as areas potentially impacted by permafrost and glacial melt.

3. What does the science say could happen by the 2050s?



 Climate model projections do not agree that seasonal temperature will increase beyond 2 °C in the project location.

 If you want to know more about projected changes in the project location across a range of GCMs and emissions scenarios please refer to The Nature Conservancy's Climate Wizard for detailed maps and Environment Canada's Canadian Climate Change Scenarios Network for scatter plots of expected changes. 4. What next?

 See the section "Further reading" in "Help and glossary" at the end of this report which lists a selection of resources that provide further information on a changing dimate.
 Click here or here for the latest news and information relating to temperature and climate change.



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08

LOW

#### PRECIPITATION DECREASE

Would a decrease in precipitation require modifications to the design of the project in order to successfully provide the expected services over its lifetime?

Chosen Answer No - modifications are not required. The design of the project would be unaffected by decreases in precipitation.

ACCLIMATISE COMMENTARY

1. What does this mean for the design of my project?

 Even though you have suggested that designs would not be affected by a decrease in precipitation, it is worth considering existing precipitation related hazards in the region where the project is planned.

2. How could current heavy precipitation affect the project even without future climate change?



 Decreased seasonal runoff may exacerbate pressures on water availability, accessibility and quality.

 Variability of river runoff may be affected such that extremely low runoff events (i.e. drought) may occur much more frequently.

 Pollutants from industry that would be adequately diluted could now could become

more concentrated. Increased risk of drought conditions could lead to accelerated land degradation, expanding desertification and more dust

storms.

 If our data suggests that there are existing hazards associated with decreased precipitation in the region, they will be highlighted elsewhere in the report. This may include water availability and wildfire.

3. What does the science say could happen by the 2050s?

 Climate model projections do not agree that seasonal precipitation will decrease in the project location which could indicate a relatively high degree of uncertainty (see the section "Model agreement and uncertainty" in "Help and glossary" at the end of this report). On the other hand, this could also mean precipitation patterns are not expected to change or may even increase (see elsewhere in the report for more details of projections related to precipitation increase).

 If you want to know more about projected changes in the project location across a range of GCMs and emissions scenarios please refer to The Nature Conservancy's Climate Wizard for detailed maps and Environment Canada's Canadian Climate Change Scenarios Network for scatter plots of expected changes.

#### 4. What next?

 See the section "Further reading" in "Help and glossary" at the end of this report which lists a selection of resources that provide further information on a changing climate.
 Click here or here for the latest news and information relating to water and climate change.





The sections above detail all High and Medium risks from Aware<sup>TM</sup>. Selected Low risks are also detailed. Local conditions, however, can be highly variable, so if you have any concerns related to risks not detailed in this report, it is recommended that you investigate these further using more site-specific information or through discussions with the project designers.



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#### HELP AND GLOSSARY:

Model agreement and uncertainty:

Although climate models are constantly being improved, they are not good enough to predict future climate conditions with a degree of confidence which would allow precise adaptation decisions to be made. Outputs from different climate models often differ, presenting a range of possible climate futures to consider, and ultimately a wide range of possible actions to take. In Aware, climate projections are described as having potentially higher degree of uncertainty when less than 14 out of 16 GCMs agree on the direction and / or a pre-defined magnitude of change.

Even with improvements in climate modelling, uncertainties will remain. It is likely that not all the climate statistics of relevance to the design, planning and operations of a project's assets and infrastructure will be available from climate model outputs. The outputs are typically provided as long-term averages, e.g. changes in average monthly mean temperature or precipitation. However, decisions on asset integrity and safety may be based on short-term statistics or extreme values, such as the maximum expected 10 minute wind speed, or the 1-in-10 year rainfall event. In such cases, project designers or engineers should be working to identify climate-related thresholds for the project (see "Critical thresholds" section below) and evaluate whether existing climate trends are threatening to exceed them on an unacceptably frequent basis. Climate models can then be used to make sensible assumptions on potential changes to climate variables of relevance to the project or bottain estimates of upper and lower bounds for the future which can be used to test the robustness of adaptation options.

The key objective in the face of uncertainty is therefore to define and implement design changes (adaptation options) which both provide a benefit in the current climate as well as resilience to the range of potential changes in future climate.

Critical thresholds:



The relationship between a critical threshold and a climate change related success criterion for a project. [Source: Willows, R.I. and Connell, R.K. (Eds.) (2003). *Climate adaptation: Risk, uncertainty and decision-making*. UKCIP Technical Report, UKCIP, Oxford].

A key issue to consider when assessing and prioritising climate change risks is the critical thresholds or sensitivities for the operational, environmental and social performance of a project. Critical thresholds are the boundaries between 'tolerable' and 'intolerable' levels of risk. In the diagram above, it can be seen how acceptable breaches in a critical threshold in today's climate may become more frequent and unacceptable in a future climate.

Climate change scenarios can be used to see if these thresholds are more likely to be exceeded in the future. The simplest example is the height of a flood defence. When water heights are above this threshold, the site will flood. The flood defence height is the horizontal line labelled 'critical threshold'. Looking at the climate trend (in this case it would be sea level or the height of a river) – shown by the blue jagged line – it can be seen that the blue line has a gradual upward trend because of climate change. This means that the critical threshold is crossed more often in the future – because sea levels are rising and winter river flows may be getting larger. So, to cope with this change, adaptation is needed – in this case, one adaptation measure is to increase the height

of the flood defence.

Further reading:



#### Aware data resolution:

The proprietary Aware data set operates at a resolution of  $0.5 \times 0.5$  decimal degrees (approximately 50 km x 50 km at the equator). These proprietary data represent millions of global data points, compiled from environmental data and the latest scientific information on current climate / weather related hazards together with potential changes in the future. Future risk outcomes are based on projections data from the near- to mid-term time horizons (2020s or 2050s, depending on the hazard and its data availability).

Global climate model output, from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset (Meehl et al., 2007), were downscaled to a 0.5 degree grid.

[Meehl, G. A., C. Covey, T. Delworth, M. Latif, B. McAvaney, J. F. B. Mitchell, R. J. Stouffer, and K. E. Taylor: The WCRP CMIP3 multi-model dataset: A new era in climate change research, Bulletin of the American Meteorological Society, 88, 1383-1394, 2007]

Aware data application:

In some instances Risk Topic ratings are only based on Aware data, including:

Flood

Permafrost

Landslides

Country level risk ratings:

These are generated from the data points within a country's borders. For single locations, sitespecific data are used, and for multiple locations or countries, composite data across the portfolio of locations are used.

Glossary of terms used in report

"Climate model projections agree": defined as more than 14 out of 16 GCMs agreeing on the magnitude (e.g. temperature warming of 2 °C) and / or direction of change (e.g. seasonal precipitation).

"Climate model projections do not agree": defined as 14 or fewer out of 16 GCMs agreeing on the magnitude (e.g. temperature warming of 2 °C) and / or direction of change (e.g. seasonal precipitation).

\*Significant proportion": defined as at least 25% of locations when multiple locations are selected. "Large proportion": defined as at least 75% of locations when multiple locations are selected. The above thresholds are used as a means of providing a project-wide risk score where a project may be spread across multiple locations. This requires more than one individual location to be at risk to begin signifying whether there is a risk at the overall project level. However, it is always recommended that individual locations are analysed separately for more accurate, site-specific risk screening. The overall risk score for the project (high, medium or low) is based on a count of high risk topic scores. A project scores overall high risk if greater than or equal to 3 individual risk topics score high. A project scores overall medium risk if between 1 and 2 individual risk topics score high. A project score overall low risk if none of the individual risk topics score high.



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#### DISCLAIMER:

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### Annex 2: Climate Change Impact Assessment Reports for the National Roads

### Road Network Improvement Project – Climate Risk and Vulnerability Analyses

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### Abbreviations

American Association of State Highway and Transportation Officials
Asian Development Bank
Climate Investment Funds
Clean Technology Fund
Digital Elevation Model
Differential Global Positioning System
Flood Risk Management Interface
Global Climate Models
Geographic Information System
Generalized Tropical Flood Model
Rainfall Intensity Duration and Frequency curves
Knowledge Management
Ministry of Water Resources and Meteorology
Ministry of Public Works and Transport
Mekong River Commission
Project Management Unit 3
Pilot Program for Climate Resilience
Provincial Roads Improvement Project
Strategic Climate Fund
Strategic Program for Climate Resilience
Scale Up Renewable Energy Project

#### **Comments on TOR**

1. The TOR requires that "the PPTA assess climate risk vulnerability for the subject corridors. The Team must identify relevant contemporary 'models', refine them to a regional level and define possible impacts on the roadways which are the subject of the proposed rehabilitation. Within the above context, it is necessary to investigate appropriate mitigation and/or adaptation measures to address future extreme weather risks. The results are a list of suggested design allowances and or physical measures that may be considered for inclusion in the project at the future detailed design and construction stages".

2. This section addresses all of the above issues. Extensive use has been made of the MPWT FRMI software in this evaluation.

#### **Literature Review**

3. The TOR require that the consultants undertake a climate risk assessment in accordance with ADB's guidelines and international good practices from which to identify any physical adaptation measures needed. Consequently the consultants have taken account of the following publications:

- 1. Mekong River Commission, Roads and Floods, MRC Technical Paper No. 35, 2011
- 2. Climate Change Impact and Hydrology, MRD June 2013
- 3. Climate Change Adaptation Options, MRD May 2014
- 4. Climate Change Adaptation Report August, MRD, (Manley, R) August 2014
- 5. Reinforcing Community Flood Resilience, MPWT, August 2014
- 6. Climate Change Resilient Roads, MRD October 2014
- 7. Report on Knowledge Management, MPWT, June 2015
- 8. Non Mandatory Guidelines for Flood Proofing Roads, MPWT September 2015
- 9. Road Design Standard Changes Report, MPWT September 2015
- 10. Flood Risk Management Interface Manual, MPWT, September 2015
- 11. Vulnerability Mapping Report, MPWT, January 2016
- 12. Climate Modeling Report, MPWT, January 2016
- 13. Flood Risk Management Interface (FRMI) Version 1.2 obtained from MPWT September 2016

4. The FRMI is the MPWT in-house software used for determining the magnitude of flood risk plus the costs of adaptation measures based on recent known unit rates. These give the latest state of knowledge and "good practice".

## Climate Change Science

#### IPCC

5. 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.(AR5 is the current edition) The release of CO<sub>2</sub> and other greenhouse gasses (GHGs) into the atmosphere will lead to further increases in the average temperature in the future. It is likely that these higher temperatures across the globe will change rainfall patterns. The IPCC has facilitated comparison of GCM (Global Climate Models) by suggesting future CO<sub>2</sub> and other GHGs related forcing 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 all of the others. Then on behalf of the IPCC the World Climate Research Program conducts inter-comparison studies of GCM results.

#### **Future Scenarios**

6.Future climate is contingent on human actions (primarily CO2 emissions) which will depend on societal decisions yet to be taken, so accurately forecasting is impossible in principle. Also caution must be used in attempting to forecast future climate 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 projections.

7.Previous IPCC reports (2000to 2007) have used the Special Report on Emissions Scenarios (SRES) that make different assumptions about global changes in future greenhouse gas pollution, land-use and other driving forces. Some scenarios have assumed very high rapid economic growth and associated high  $CO_2$  future emissions. Others assume a reduction in the use of fossil fuels with proportionally reduced  $CO_2$  levels.

8. The latest IPCC report (Number 5) uses a new description "Representative Concentrations Pathway (RCP)". These RCP scenarios 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.

9.RCP 2.6 (PD) refers to a scenario where  $CO_2$  emissions peak in the near future and then decline. This is optimistic. RCP 4.5 and 6.0 are intermediate scenarios. RCP 8.5 refers to the most severe case of the 4 scenarios considered. where emissions continue to rise until 2100 leading to global temperature increases. This is pessimistic.



Figure 1-1 RPCs from IPCC AR5 (2011)

10.Recent climate change studies use RCPs of 8.5 for extreme  $CO_2$  future concentrations and values of 2.6 or 4.5 to represent low  $CO_2$  future concentrations. In the projections for MPWT the RCP 8.5 is used. This is a pessimistic scenario which although it is no less likely than the other scenarios and not necessarily the worst case it is designated the "extreme scenario".

#### GCMs used in the Region

11.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 were considered the most suitable for flood prediction.

12. 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.

13.Rainfall errors are generally between 1.5 to2.5 mm/day for a rainy day. The worst performing model showed rainfall errors of over 4mm/day. The most widely used model showed rainfall with errors of less than 1.5 mm/day. This was used in the MPWT project.

#### Downscaling GCM outputs to regional scales

14.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 although inherent errors may be carried over from GCMs to local data. Downscaling obtains regional weather phenomena that are influenced by the local topography, land-sea-contrast, and small-scale atmospheric features such as convection. The important downscaling models used in Cambodia are outlined in the table below.

Table Error! No text of specified style in document1	Climate Downscaling carried out in
Cambodia	

Modeling	Comments
MOE for the 2 <sup>nd</sup> National Communication (draft) Carried out with assistance from National Institute of Environmental Studies (NIES), at the Centre for Climate System Research (CCSR) at the	The modeling was carried out in 2009-10 Data from 14 GCMs (pixels ~250 km) was downscaled to smaller pixels Using statistical downscaling Final pixel size 20km
	Older generation IPCC models
Carried out by TA 7610 – CAM Supporting Policy and Institutional Reforms and Capacity Development in the Water Sector Project	The modeling was carried out in 2010 Data from 9 GCMs (pixels 125-400 km) was downscaled to smaller pixels (Data from World Bank Web Portal) Using statistical downscaling

	Final pixel size 50 km Older generation IPCC models		
Mekong River Commission	The modeling was carried out in 2012		
Carried out with assistance from The Commonwealth Scientific and Industrial Research Organisation (CSIRO) and	Data from 1 GCMs - Max Planck Institute for Meteorology's ECHAM4 (pixels ~250 km) was downscaled to smaller pixels		
The South East Asia SysTem for	Using a Regional Climate Model		
Analysis, Research and Training Regional	Final pixel size of 50 km		
Center (SEA START).	Older generation IPCC models		
ADB TA 7459-REG Greater Mekong	The model was developed and run in 2012.		
Subregion Biodiversity Conservation Corridors Project – Pilot Program for	CCAM - This is a regional model that was run specifically for South East Asia.		
Cambodia	It uses 6 GCMs selected for best performance in South Fast Asia		
Carried out by The Commonwealth Scientific and	The model has a pixel size of 10 km		
Industrial Research Organisation (CSIRO)	It uses the latest IPCC standard set of model simulations		

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

#### **Projected Temperature change**

16.All these models show warming occurring over Cambodia in the future, with the early studies generally projecting warming of 0.01°C to 0.03°C per year, and later models projecting warming of 0.03°C to 0.06°C per year. This equates to a warming of 0.35°C to 2°C by 2050 and 1°C to 5°C by 2100. The results of six of the latest model projections for Kampong Chhnang and Svay Rieng are summarized below.

Table 1-2Projected Changes in Svay Rieng and Kampong Chhnang under RCP 8.5 by Year2050

Study	Temperature Change by Year 2050	Wet Season Rainfall change Kampong Chhnang %	Wet Season Rainfall change Svay Rieng %	Seasonal Timing Changes
MOE 1st National Comm 2002	0.7-1	8-12 (all of Cambodia)		
MRC 2009	0.8-1.6	1-5	0-1	
MOE 2nd National Comm 2010	0.5- 1.5	0	-17	Shorter wet season
MOWRAM 2010	2.2	1.5-3.5	1.5-3.5	

Mekong ARCC 2014	2.5-3	7-9		
CSIRO 2013	1.71-2	-8 to -12	0 to -8	Earlier and wetter onset of wet season

#### **Projected Rainfall Change**

17.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 north-east monsoon occur. 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.

18.The CSIRO 2013 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.

#### **Rainfall Intensity**

19.Climate change studies have projected an increase in rainfall intensity during rainy days by2055. 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.

20.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 rainfall is often assumed to be 20-40% of daily rainfall.

#### **Current and Projected Meteorological Data**

#### Data Availability

21. The Department of Meteorology (DoM) of MOWRAM 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.

#### Climate data provided for Road Risk Analysis

22.The data used in CR-PRIP for the FRMI was digitized from the CSIRO CCAM model maps available in published reports and 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 The projections simulated RCP 8.5 which is the most pessimistic (e.g., least success in mitigation) from among the 4 RCPs.

#### **Current 1 Day Extreme Rainfall**

23.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 1-2 Current 1 day extreme rainfall from the CCAM model

### Projected 1 day extreme rainfall for 2055 with RCP of 8.5

24.The projected 1 day extreme rainfall is the maximum 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 modeled current and modeled future (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.



Projected change in 1 day extreme rainfall for 2055 (RCP 8.5 from CCAM) Figure 1-3

### **Current 5 day Extreme Rainfall**

25. 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 1-4 Current 5 day extreme rainfall from CCAM

#### Projected 5 day extreme rainfall for 2055 with RCP of 8.5

26.The projected 5 day extreme rainfall is the maximum 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 Error! No text of specified style in document.-5 Projected change in 5 day extreme rainfall for 2055 (RCP 8.5)

### 1.1.1. Changes to 1-day Precipitation

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%).

### **Changes to 5-day Precipitation**

27.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 2090 projection. The 5-day duration is likely to correspond to the critical flood duration for some of the larger river basins.

### Flooding

### Floods in Cambodia

28.Changes in the rainfall regime are the dominating factor in climate change with respect to physical infrastructure as it affects drainage design. Temperature change can also be important as it may affect pavement consistency, expansion joints and so on.

29.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.

30. There are two major flood types in Cambodia: (i) flashfloods, resulting from heavy downpour upstream on the Mekong River, which affects 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.

31.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 it can last for months. Banteay Meanchey had the longest recorded period of flooding at 68 days.

32.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 in high ground. Roads are an important means of access to these refuge areas.

33.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.

#### **Drought and Climate Change**

34.Rising temperatures due to climate change increase evaporation rates and also 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.

35.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.

### Flood Risk Management Interface - FRMI

#### Background

36.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.

37. 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 developed under the CR-PRIP.

### **FRMI Methodology**

38. 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.

39.Road segments from the national road network are sourced from MPWT RAMS 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 RAMS system. Finally, flood impact or damage risk assessments are carried out for four specific types of flood and mapped.

#### **SRTM Accuracy**

40.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.

41.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.

### Road Catchment Area vs. River Catchment Area Method

42.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. Also repair budgets are attached to established road sections, rather than catchment areas or river sections.

#### **Correlation to Road Impacts**

43. 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 analyse the flooding risk of individual road sections in more detail.<sup>1</sup>

### **Calculation of Catchment Areas**

44.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.

<sup>&</sup>lt;sup>1</sup> "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.

45.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 was not considered in FRMI due to the large number of catchments involved and due to the insufficient detail of the terrain model.

46.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.

### **Classification of Road Links**

47. The classification of road links was based on topographical analysis of road physical parameters. The topographical analysis has been carried out as a drainage area analysis, calculating the drainage area and slope of this area towards a specific road link. However, contrary to habitual hydrological practice, emphasis is not focused on the propagation of the flow of water from sub-catchment to larger catchments, but rather upon the issue of a characterization of every road link in view of its drainage characteristics.

48.In order to characterize the drainage situation of each road link the following parameters were calculated for approximately 550 road links registered in the RAMS (Road Asset Management Project) database of the MPWT, representing about 11,500 km of roads. The length of the segments varies i.e. it is not standardized to 1 km segments and is based on the MPWT reference road links database, for purpose of compatibility with MPWT other datasets. The results for individual road drainage areas are stored in the FRMI database installed in the MPWT mapping department computer that links the flooding data with the RAMS data.

49. The following analytical steps were carried out for every road link:

- Definition of the road link as part of the road network.
- Overlaying of the road network layer with the 90 m Shuttle Radar Topographic Mission (SRTM) digital terrain model.
- Definition of the drainage area upstream of the relevant road link.
- Calculation of the relevant geometrical parameter concerning the road link and the drainage area.
- Visual verification of the topographic analysis on the basis of topographic maps, satellite imagery and field observations.
- Storing of the relevant road specific GIS layer for use in a computer application aimed at serving as a tool for improved flooding management and resilience development.

The following parameters were extracted from the SRTM with this method:

Road Geometry
Average road elevation level
Max. slope of road
Average slope of road
Length of road section
Upstream Drainage Area Parameters
<ul> <li>Surface area which drains towards the target road</li> </ul>
Max. slope of drainage area
Average slope of drainage area
<ul> <li>Average elevation of drainage area</li> </ul>
Perimeter of drainage area
Information on drainage structures, available in the RAMS
database
Type of structures
Location of structures
<ul> <li>Length and number of spans etc.</li> </ul>

50.The analysis of the drainage areas has been carried out subsequently for all the registered road links. All catchments were calculated using Global Mapper and 30m resolution DEM files. Drainage area maps (also call catchment maps) have been produced for all the road links. The following aspects have to be considered when discussing the analytical results:

- The analyzed areas cannot be considered as 'catchment areas' in the classical sense. In fact, the resulting areas represent the aggregated area from where water drains towards the relevant road link. This water can flow towards the road from both sides, from one side only, or not at all.
- If the analysis was to be carried out with a more detailed elevation model such as a LIDA Rscan or drone survey- it would be possible to detail the analysis into sub-drainage areas and designate a specific drainage structure (culvert or bridge) to individual sub-drainage areas.

However, in order to obtain such degree of accuracy it is recommended that this be conducted at the detailed design stage of the road rehabilitation, or of new road construction.

#### **Output of FRMI**

#### Flood Risk Damage Maps

51. 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

52.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. Road resilience is assessed in the model through three indicators, **the pavement surface roughness**, **the pavement type and the condition of the drainage structures**.

53.Roads properly designed and maintained in perfect condition will remain at no or at very low risk of flood damage. For example, roads having being 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.

54. 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.

The flood risk indexes are:

- Flash Flood Index
- Large Drainage Area Index
- Build-up Area Flooding Index
- Low Land Flooding Index
- > Combined flood risk index

The flow chart for this is shown below.



Figure 1-6 Flow Chart for Derivation of Flood Index

55.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 1-7 Climate Change Analysis

56.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:

- Road references (Link IDs)
- Flood damage risks current conditions
- Flood damage risks future conditions
- Flood damage risk changes in time

57.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.

58.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.

#### **Multiple Flood Vulnerability by Province**

59.For each province the number of kilometers of each road that are classed as being at risk from multiple risks has been calculated. The analysis was carried out on the basis of road sections so the entire length of any section may not be susceptible to each flood risk factor and the lengths shown can be an over estimation.

Table 1-4Length and percentage of roads by province being at moderate or high risk of acombination of flood types (Current conditions)

PROVINCE	Total (km)	Nb of Km at high risk	% at high risk	Nb of km at moderate risk	% at moderate risk
Banteay Meanchey	425	33	8%	84	20%
Battambang	706	149	21%	131	19%
Kampong Cham /Tbong Khmum	1212	201	17%	232	19%
Kampong Chhnang	462	0	0%	189	41%
Kampong Speu	464	0	0%	204	44%
Kampong Thom	551	31	6%	175	32%
Kampot	497	62	12%	239	48%
Kandal	640	178	28%	233	36%
Кер	74	36	49%	32	43%
Koh Kong	238	54	23%	8	3%
Kratie	460	0	0%	66	14%
Mondul Kiri	218	0	0%	0	0%
Oddar Meanchey	294	0	0%	18	6%
Pailin	145	45	31%	40	28%
Phnom Penh	180	0	0%	86	48%
Preah Sihanouk	99	31	31%	0	0%
Preah Vihear	804	12	1%	105	13%
Prey Veng	643	91	14%	315	49%
Pursat	636	104	16%	228	36%
Ratanak Kiri	456	0	0%	0	0%
Siem Reap	954	37	4%	266	28%
Stung Treng	245	0	0%	0	0%
Svay Rieng	593	139	23%	352	59%
Takeo	450	120	27%	204	45%

60.The table shows that Kampong Cham has the largest number of kilometers of roads classed as being at very high damage risk from multiple floods, i.e. 201 km (17%). The next is Kandal with 178 km (28%) and Battambang with 149 km (21%). The roads in the provinces of Prey Veng and

Svay Rieng, where NR 1, is located has 14% and 23% at high risk to flooding, respectively. Meanwhile, the Siem Reap roads have 4% vulnerability to high risk of flooding.

#### Mapping of Change of Flooding Risk due to Climate Change

61.A second round of risk mapping had the rainfall input figures changed according to the projected climate change data. The change was in extreme 1-day rainfall and change in total 5 day rainfall. Road conditions were unchanged to be able to visualize only the climate change effects. The four different risk parameters are affected to a different degree and in a different way by these climatic changes.

#### Analysis of Road Flood Risk by Province

62.The following table summarizes the number of kilometers of roads in each province that are at a high risk of being impacted by each of the four identified types of flooding. The table looks at the current conditions and presents predicted values for 2055 under a high  $CO_2$  climate change scenario (RCP 8.5).

Table 1-5Number of Km of roads per province rated at high risk of flooding for future climateconditions

Province	Flash Flooding	Large Area Drainage	Urban Flooding	Lowland Flooding
Banteay Meanchey	0	4	11	73
Battambang	0	57	153	226
Kampong Cham / Tbong Khmum	0	0	198	262
Kampong Chhnang	37	0	0	122
Kampong Speu	84	45	0	0
Kampong Thom	0	78	31	101
Kampot	88	20	13	219
Kandal	0	18	207	398
Кер	27	11	14	67
Koh Kong	49	0	0	54
Kratie	61	31	69	0
Mondul Kiri	201	0	0	0
Oddar Meanchey	0	18	0	0
Pailin	56	0	46	0
Phnom Penh	0	11	82	81
Preah Sihanouk	9	22	0	0
Preah Vihear	43	0	12	0
Prey Veng	0	38	131	486
Pursat	119	11	50	196
Rotanak Kiri	69	0	0	0
Siemreap	27	25	52	102
Stung Treng	0	0	0	0
Svay Rieng	0	31	81	521
Takeo	28	7	28	287
Total	898	427	1178	3195

#### **Flash Floods**

63.Due to its mountainous terrain, Mondul Kiri has over 200km of roads that are at very high risk from flash flooding. Pursat has over 100 km of roads at very high risk from flash flood while Kampot, Ratanak kiri, Kampong Speu, and Kratie have just under 100 km of roads at very high risk. As the flash flood indicator is heavily weighted towards the catchment slope, the smaller input from rainfall means that there is no change projected to occur for this indicator due to climate change.

#### Large Area Floods

64.Kampong Thom has around 80km of roads at very high risk from large area catchment flooding, while Kampong Speu and Battambang have around 50 km each at high risk. In Kandal, climate change is projected to result in an increase in the length of roads highly exposed to large area catchments floods from 7 to 18km.

#### **Builtup Area Flooding**

65.Most of the high risk urban (builtup area) flooding is located in four provinces, Battambang, Kampong Cham, Kandal and Prey Veng. Climate change is projected to increase the length of roads at very high risk of urban flooding by 57km in Battambang and 15 Km in Siem Reap.

#### Low Land Flooding

66.As would be expected the provinces covering the central plains have a large amount of roads that are at risk from low land flooding. Prey Veng and Svay Rieng have around 500 km of roads at high risk each. Climate change is projected to increase the exposure to lowland flooding for two provinces, Pursat and Siem Reap.

Province	Type of flood	Nb of Km at high risk 2013	Nb of km at high risk 2055	Increase in km
Battambang	Buildup area	153	210	57
Kandal	Large drainage area	7	18	11
Pursat	Low land	196	222	26
Svay Rieng	Buildup area	81	96	15
Siem Reap	Low land	102	163	61

 Table 1-6
 Km of roads per province at high risk changed by climate conditions

#### **Exposure to Multiple Flood Risk Factors**

67.Some provinces are rated as being at high risk of flooding from a combination of flooding types. Two provinces, Kandal and Kampong Cham have nearly 200 km of roads at high risk of flooding from multiple types of flood each.

68. Three more provinces, Battambang, Pursat, Svay Rieng and Takeo have over 100 km of roads at high risk of flooding from multiple types of flood. Three provinces, Kampot, Koh Kong and Prey Veng have over 50 km at risk from multiple types of flood.

69. The remaining provinces have a small amount of kilometers of roads at risk but the 36 kilometers in Kep that are at risk represents half of the province's provincial and national roads. Two provinces, Kampong Chhnang and Svay Rieng, are projected to have new road segments classified as being at high risk by 2055. Takeo risks are projected to decrease slightly.

Table 1-7Length of road per province rated at high risk of flooding from a combination offlooding types – Current and future conditions

	Baseline	2055
Province	Km	Km
Banteay Meanchey	34	34
Battambang	149	234
Kampong Cham / Tbong Khmum	202	202
Kampong Chhnang	0	0
Kampong Speu	0	17
Kampong Thom	31	31
Kampot	62	62
Kandal	178	178
Koh Kong	54	54
Kratie	0	0
Кер	36	36
Mondul Kiri	0	0
Oddar Meanchey	0	0
Pailin	45	45
Phnom Penh	0	0
Preah Sihanouk	30	30
Preah Vihear	12	12
Pursat	104	104
Prev Veng	92	92
Rotanak Kiri	0	0
Siemreap	37	37
Stung Treng	0	0
Svay Rieng	139	155
Takeo	119	110
Total	1324	1433

This table above represents the total risks of flooding under present and future conditions allowing for climate change.

#### **Summary of Climate Change Effects**

#### **FRMI Model Limitations**

70.The models used for flood risk assessment have limitations. Changes in floods and in flood damage are driven by many factors other than rainfall. Changes in flood risks are not directly proportional to increases in rainfall and may proportionally exceed them. Equally precedent conditions can slow down the onset of flash floods.

71.Future variations in Tonle Sap and Mekong levels will depend on water level manipulations at dams and on future timber cutting of lands. The comparison of flood damage risks to roads under current climate condition and of the same risks under future climate conditions is approximate and can be carried out only to illustrate the magnitude of changes.

72. Due to the limitations of availability of flood data in Cambodia, the FRMI method uses geographical and land use characteristics as well as rainfall data. Local investigations and traditional hydraulic analysis are needed to give final floodproofed designs.

#### **Risk Increases**

73.Only three sections of road show an increase in the risk of flooding from a combination of flooding types from moderate to high, in Svay Rieng, in Kampot and in Kampong Speu. Five sections of road across the country show an increase in the risk of flooding from a combination of flooding types from low to moderate and nine sections from no risk to low risk.

#### **Risk Decreases**

74. Four road sections show a decrease in the risk of flooding from a combination of flooding types. This reflects the climate change projection of a small decrease in extreme rainfall for a few areas around the country.

#### **Combined Risks**

75.The risk level has been assigned to all national roads of the current Cambodian road network, using 550 individual road sections covering about 11,500 km linked to the MPWT Road Asset Management Output (RAMO) data, which is the fundamental basis for current road maintenance practice.

76.The number of roads that potentially show a change in the combined road risk index due to climate change are very limited, as predicted by the rainfall model and the vast majority of the network shows no change in risk level.

77.Notwithstanding the above many segments of road are already at risk from flooding and climate change will make this worse.

#### **Risk Information from FRMI related to Project Roads**

#### NR 6 Siem Reap to Kralanh

78. The section of road on NR6 from Siem Reap to Kralanh is shown at a province level and in detail below. The road segment is rated at "Moderate" level of flood risk in 2055 under RCP 8.5.

79.As this road segment is bounded on one side by Tonle Sap Lake and on the other side facing the catchment runoff from the Dangrek Escarpment it may be inundated on both sides and face flash floods in the watercourses crossing the road.



Figure 1-8 Risk of Flood Damaged Roads Siem Reap Province



## Total Combined Flooding Road Risk Index

- Very High Risk
- Moderate Risk
- Low Risk
- Not at Risk
- Figure 1-9 Risk of Flood Damage to NR6

### 1.1.1. NR 1 Mekong River to Cambodia Vietnam Border

The section of road on NR1 from Mekong River Bridge to the Cambodia Vietnam border is also shown and a province level and in detail below. The road segment is rated at "Low Risk" level of flood risk then "Moderate" in 2055 under RCP 8.5.



Figure 1-10 Risk of Flood Damaged Roads Svay Rieng Province



## Total Combined Flooding Road Risk Index

Very High Risk

Moderate Risk

Low Risk

— Not at Risk

Figure 1-11 Risk of Flood Damage to NR1

80.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 alignment. There are areas of free-standing water to the north and south of the alignment and local rainfall has no natural drainage escape route.

#### Road information in the FRMI Database

81.Basic road infrastructure data such as bridges, culverts and road alignments can be retrieved from the MPWT RAMO database. There are 550individual road links and 13,000 bridges, culverts and other drainage related structures.

All relevant road characteristics road condition data and drainage structures are stored in the RAMO database. Other information such as catchment areas or land use along the road is stored in the FRMI program. This contains the following road data:

- Geometric road parameters
- Road Alignment
- Length
- Vertical Alignment of terrain
- Slopes
- Flood Risk Indices
- Catchment area maps
- Inventory and condition of culverts, bridges and drainage structures
- Road condition International Roughness Index
- Land use
- Pavement type (Pavement surface)
- Recent major rehabilitation details

#### **Rehabilitation Costing Scenarios**

82.A budgeting tool is available for a preliminary estimation of flood proofing initiatives. Road segments can be selected for rehabilitation and flood proofing measures such as road raising, replacement of culverts, adding embankment protection and using A/C pavements. A number of combinations can be compared. These would require further investigation during detail design.

#### **Overall Approach and Detailed Design**

#### **Overall Approach**

83.Once the flood risk has been established the appropriate adaptation measure can be selected and costed.



Figure 1-12 Overall Flood Proofing Process for Roads

Documents have been published by MPWT giving guidance in revising design standards. The key aspects to be considered in Detailed Design are discussed below.

#### Rainfall

84.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.)

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.

### **Projections of Annual Precipitation**

85.The overall conclusion is that annual precipitation in the project area will rise slowly, if at all. However this is based on the average of several models which tends to minimize projected changes relative to individual projections, so a conservative approach in design is advocated.

### Monthly Increase during Flood Period

86. 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 time period. Projections suggest that the will be little, if any, increase by 2030 but could increase by over 20% by 2090.

#### **Storm Projections**

87.A paper by O'Gorman in Nature Geoscience Letters<sup>1</sup> related increases in precipitation to increases in temperature and shows that for extreme storm events (0.01% annual probability of occurrence or less) precipitation increases by 10% for each degree of increase in temperature.

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

#### **Overview of Precipitation Changes**

88. 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.

Year	Annual	Rainy season	Month	5-day	1-day
2030	-1	-3	-1	12	7
2050	0	3	12	19	10
2090	4	7	8	35	32

Table Error! No text of specified style in document.-8 Change in Rainfall % (RCP 6.0)

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

- Annual rainfall may remain unchanged but rainfall will increase more in the wettest months by being of stronger duration. Rainy days will have more intense rain but the number of rainy days may decrease. The periods in between rainy days will lengthen leading to longer dry periods. There may even be "mini-droughts" during the wet season.
- > Precipitation will increase most in the south-west and decrease in the north-east.
- > Both the maximum 5-day and 1-day storms are expected to increase.
- The relative increase in rainfall is heavier for short duration rainfall in storms of higher ARI value
- An increase of 20% on existing IDF curves will allow for a global temperature increase of 2°C. This corresponds to a time horizon of 2055 and applies to short duration storms (1 hour or less) at higher ARIs. (e.g.1 in 50. 1 in 100). This factor is conservative and is recommended as a design factor.

### **Climate Resilient Roads**

### **Design Adaptation**

90.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.

91.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

<sup>&</sup>lt;sup>1</sup> 'Sensitivity of tropical precipitation extremes to climate change' in Nature Geoscience Letters, September 2012.

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
- (v) Temperature impacts on asphalt paving materials and expansion joints

92.Adaptation measures include : (a) applying a safety factor in the design of embankment heights and conveyance capacities of cross drains, culverts and bridges; (b) considering a longer return period for exceptional events when designing hydraulic structures; (c) consider long term changes in the volume of storm water ; (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.

### **Adaptation Measures**

93.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 1-9 Climate Change Adaptation Measures

### **Highway Design Component**

### Roadways

- Increased height of embankment above 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

### **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.

### Specific Recommendations from MPWT

94.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 X.2 Literature Review)

### Field Work and Ground Truthing

95.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 100Year flood depth maps should be used for general guidance only.

#### Elevation

96.The recommended crest level for National 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. The extra freeboard also acknowledges the fact that estimates of design events, and in particular low-frequency events like 100-year floods, are subject to both statistical error and uncertainty due to climate change.

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.

### **Flood Calculations**

97.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<sup>2</sup>. For larger areas the Generalised Tropical Flood Model (GTFM) developed by Fiddes and Watkins (1984) should be used.

### **Pavement and Embankments**

98.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.

99.In reality in Cambodia special measures have to 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 CR-PRIP as a new road policy statement for MPWT that national roads should be covered with asphalt concrete, or concrete

100.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.

101.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. This loss of connectivity may be acceptable on rural roads but is unlikely to apply to NR1 and NR6 where the road is expected to be open and passable at all times and under all conditions.

102. 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.

103.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.

104.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.

105.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.

106.If a slope of 1:3 is considered it must be investigated from economic and policy points of view. A 5 meter high embankment of 1:3 as compared to a1:2 embankment needs 10 m more road corridor and 50 % additional earth works. This could require substantial resettlement or compensation actions.

107. The sub-base on embankments shall be constructed to the full width of the subgrade surface. The shoulders shall be constructed same as the pavement structure. The shoulders shall be sealed with an approved bituminous treatment up to the edges of the embankment or, where guard rails constructed, up to the line of guard rail. Each part of the bituminous shoulder treatment which is the same as for the pavement shall be applied simultaneously with the pavement treatment.

108.Rip Rap protection is recommended to cover the full surface of embankments of roads at high risks of flash floods and of low land floods. For full coverage of embankments of roads at high risk of flash floods and of low land floods, a minimum thickness of 200 mm shall be used.

109. 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.

#### Drainage Design

110.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.

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

112.In places where there are clearly defined water channels and sufficient gradients for water to flow at all times of the year, then the capacity of the cross drainage should be increased by around 25% - 30% relative to a design based on current known rainfall.

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

114.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.

115.Climate studies showed that up to the year 2055 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.

	Pochentong Rainfall Intensity (mm / hr.)						
Time	Frequency (Return Period) (Years)						
(hours)	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 1-10
 Rainfall Intensity Pochentong Airport – Current

	Siemreap Rainfall Intensity (mm / hr.)						
Time	Frequency (Return Period) (Years)						
(hours)	5 yr.	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 1-11
 Rainfall Intensity Siem Reap – Current

Kampong Thom Rainfall Intensity (mm / hr.)					
Time Frequency (Return Period) (Years					s)
(hours)	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
к	ampong T	hom Rainfa	all Intensity	y (mm / hr.	)
Time	F	requency (	Return Per	riod) (Years	s)
(hours)	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

116.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 1hour. 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.

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



Figure 1-13 Rainfall Ration 1 Hour to 24 Hours

117.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.

#### **Bridge Standards**

118. 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.

119. 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°C.

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

#### Geometry

121.Crossfall on sealed roads should be 2% minimum to avoid ponding. It is reported that Superelevation seems to be inadequate for curves for 80 km/h 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.

#### **Construction Materials**

122. 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 20mm DBST with 19/12mm aggregates & slow curing emulsion.

123.Bitumen can deteriorate in sunshine and oxidise, losing its polymerization properties and crack. Bitumen is also sensitive to changes in temperature, with high-temperature events leading to both rutting and cracking. Bitumen composition should reflect warmer future temperatures. 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.

#### Maintenance

124. 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 1200mm to make for ease of clearing debris.

125.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.

126.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.

#### Costs

### Elevation

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

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

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%

 Table 1-13
 Estimated cost increases for geometry adjustments

#### **Cross Drains**

129.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 300m intervals. In the above case they would be at least 11m length plus wing walls and minimum sizing of 1200mm. This will allow costing at current unit prices.

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 1-14	Estimated Cost Increases for Drainage Adjustments
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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%

#### Pavement

130. 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 is given below relative to a Baseline case of DBST 20 mm not including shoulders.

 Table 1-15
 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%

#### **Detailed Costs**

The FRMI software considers risk in general terms where road sections are possibly 1km in length. In reality only a smaller section of road may require additional climate resilience measures. A FRMI subroutine will carry out these calculations but it is very site specific. This needs to be addressed at the detailed design stage.

#### Summary and Conclusions

131.Flooding does not necessarily inflict damage to every road. Roads properly designed and maintained in perfect 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.

132.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. The FRMI costs subroutine allows for calculating costs of shorter lengths of road.

133. The roads NR1 and NR6 are all rated as being at "Moderate" risk in the future. Variations in Tonle Sap and Mekong levels will depend on water level manipulations at dams and on future timber cutting of lands. The comparison of flood damage risks to roads under current climate condition and of the same risks under future climate conditions is approximate and can be carried out only to illustrate the magnitude of changes.

134.Using FRMI Road Resilience is assessed through three indicators, the pavement surface roughness, the pavement type and the condition of the drainage structures.

135.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.

136.Technical specifications can be varied to improve climate resilience. Details are given in this chapter. Maintenance is essential. All culverts should be a minimum of 1200mm diameter to facilitate cleaning.

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

138. If data on rainfall is lacking daily rainfall figures can be used to estimate hourly rainfall for drainage design calculations. In general 1 hourly is 20-40% of daily although figures of 60% have been recorded around Phnom Penh. When in doubt a higher figure should be used.

139. 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.