Draft Climate Risk and Vulnerability Assessment and Evaluation of Adaptation Options
VIE: Support for Border Areas Development Project
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(preliminary draft, not for citation or distribution)

Prepared by:
Charles Rodgers, Senior Advisor Climate Change Adaptation, CCDRM/SDCC
Francis Colledge, (Title) UK Met Office

ABBREVIATIONS and ACRONYMS

ADB	-	Asian Development Bank
AR5		Fifth Assessment Report of the IPCC
CRVA	-	Climate Risk and Vulnerability Assessment
DTR		Daily Temperature Range
GDDP		Global Daily Down-scaled Projections
GEV		Generalized Extreme Value
GHG	-	Greenhouse Gas
GIS	-	Geographical Information System
IPCC		Inter-Governmental Panel on Climate Change
ITCZ		Inter-Tropical Convergence Zone
NASA		National Aeronautics and Space Administration (USA)
NEXX		NASA Earth Exchange
RCP		Representative Concentration Pathway
VCH		Vietnam Central Highlands
VDTA		Vietnam's Development Triangle Area

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Executive Summary

(to be completed)

It will be recommended on the basis of this CRVA that the project climate risk rating be changed to high, due to the concentration of risk in the Kon Tum sub-project area. A risk rating of medium remains appropriate for the other provincial sub-projects.

I. Overview: Climate Risks to Road Transport Infrastructure

Global climate change is relevant to the development of road transport infrastructure through concerns both with mitigation and adaptation. As road transport is a major source of greenhouse gas (GHG) emissions globally[1], mitigation – "*human intervention to reduce the sources or enhance the sinks of greenhouse gases*"[2] – is (or should be) an essential element in the design of transport projects. Low-carbon and inclusive alternatives to the use of private vehicles on roadways should be explored and promoted in situations where they are technically feasible and economically rational; in particular within urban environments. Where road-based transport emerges as the only technically sound and viable approach, road infrastructure should be designed in ways that minimize the emissions of GHG per passenger-mile through e.g., materials specifications, road grade and related design parameters.

The emphasis of this climate risk and vulnerability assessment (CRVA) is on adaptation: "*the process of adjustment to actual or expected climate and its effects … to moderate harm or exploit beneficial opportunities*." ADB has in general taken a risk management approach to adapting infrastructure investments to the likely impacts of climate change. ADB has defined climate risk management, or more colloquially "climate-proofing," in the following terms: "*Climate proofing is a shorthand term for identifying risks to a development project … as a consequence of climate variability and change, and ensuring that those risks are reduced to acceptable levels through long-lasting and environmentally sound, economically viable, and socially acceptable changes implemented at one or more of the following stages in the project cycle: planning, design, construction, operation, and decommissioning.*"[3] The approach to climate risk management that is described in this CRVA is consistent with this definition.

Climate change and variability present risks both to the physical integrity of road transport infrastructure and the delivery of services that road infrastructure are designed to provide. An example of the first is damage and/or premature wear to pavement and roadbed materials from elevated temperatures and more intense precipitation and flooding events. An example of climate risks to the delivery of road transport services is increases in temporary flooding of vulnerable reaches of roadway resulting from precipitation events of increasing frequency and/or intensity. In both cases there are adverse economic consequences that can affect the estimated net present value of the road infrastructure investment. For this reason, ADB has implemented a project risk management framework that is designed to identify climate risks and project vulnerabilities at an early stage in the project cycle; and to identify and evaluate appropriate and effective adaptation strategies to mitigate these risks, to the extent possible and economically justifiable.

This CRVA has been conducted to (i) identify and assess the potential hazards associated with anticipated climate change in the project area; (ii) assess the vulnerability of the project, and of specific components of the project to these hazards; and (iii) to identify adaptation interventions with the potential for reducing these risks.

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[1] References: IEA (2015)?

[2] IPCC AR5 WGII Glossary

[3] ADB (2008) Climate Proofing: A Risk-Based Approach to Adaptation. Manila

Section I of this report provides an overview of climate change risks to road transportation projects. Section II contains a description of the Project, and the project area. Section III describes both current climate in the project area, and projected changes in climate, summarizing data from many sources. Section IV examines the risks to specific components of the project from climate variability and change. Section V contains a discussion of adaptation options relevant to each of the project components found to be vulnerable. Finally, Section VI summarizes the results of this CRVA and provides recommendations for managing climate change risks to the Project.

1.1 Framework for Climate Change Risk Assessment

The basic approach to climate risk and vulnerability assessment used in this CRVA is based on a model of risk commonly used both by the climate change adaptation and disaster risk management communities, respectively. The framework is used to decompose risk into conceptual elements that support systematic risk assessment. The framework is expressed in equation 1:

$$R = H \times \frac{(E \times S)}{A} \qquad (1)$$

In equation 1,

R = *risk*, the expected value of damages (typically expressed in monetary terms)

H = *hazard*, defined by frequency and magnitude (e.g., Q_{100}, the 100-year flood)

E = *exposure*, the extent to which the hazard impacts upon the project or component

S = *sensitivity*, the extent to which the project or component is subject to harm when exposed

A = *adaptive capacity*, the extent to which the project or system can adjust to or recover from harm; moderate potential impacts or cope with consequences.

The three terms on the right are collectively referred to as *vulnerability* (V). This framework allows analytical distinctions to be made between those elements contributing to risk that are identified with climate and climate change itself (H) and those that are associated with the project (V). Risk is understood as a property of the coupled climate and natural or built environmental systems.

1.2 Climate Change Risks to Road Transport Projects

Climate change impacts on road transportation systems are reviewed in a number of recent sources. These include ADB (2011), Regmi and Hanaoka (2011), Nemry and Demirel (2012), IPCC AR5 Chapter 10 (2014) and Neumann et al. (2015).

ADB (2011) identifies a number of the potential impacts of climate change on road transport infrastructure. These include:[4]

- Changes in temperature—both a gradual increase in temperature and an increase in extreme temperatures—are likely to impact road pavements (for example, heat-induced heaving and buckling of joints).

[4] ADB (2011) p. 4.

- Changes in temperature will also impact the behavior of permafrost and thus the infrastructure lying on permafrost.
- Changes in precipitation and water levels will impact road foundations.
- Extreme weather events such as stronger and/or more frequent storms will affect the capacity of drainage and overflow systems to deal with stronger or faster velocity of water flows.
- Stronger or faster velocity of water flows will also impact bridge foundations.
- Increased wind loads and storm strengths will impact long span bridges, especially suspension and cable-stayed bridges.
- Increased storm surges will significantly impact all components of the coastal transportation infrastructure.
- Increased salinity levels will reduce the structural strength of pavements and lead to precipitated rusting of the reinforcement in concrete structures.

These are generic impacts, and not all will be applicable in every project setting. To illustrate, road assets in Viet Nam's Central Highlands are not exposed to storm surge, sea level rise and saline intrusion. In studies of road infrastructure vulnerability in urban settings, the following infrastructure elements were found to be most vulnerable to the likely impacts of climate change:

- bridges and culverts (from increased mean annual rainfall, rainfall intensity, and sea level rise),
- causeways and coastal roads (from sea level rise and increased frequency and intensity of storm surges),
- pavement surfaces (from increased mean annual temperature),
- surface drainage (from increased intensity of rainfall), and
- hillside slope stability (from increased mean annual rainfall and rainfall intensity).

Regmi and Hanaoka (2011) conducted a survey of stakeholders to determine which impacts of climate change on road transport infrastructure are of greatest concern in Asia; and what adaptation strategies have been identified and utilized. The most significant climate change impacts on road transport systems, vulnerable infrastructure and critical design parameters identified through the survey are summarized in Table 1. Among key conclusions of the study are (i) the need to raise awareness of stakeholders concerning climate change and its impacts; (ii) need to review existing road design standards and construction practices in light of anticipated climate impacts; (iii) need for appropriate guidelines for climate change impact assessment; and (iv) the need for stakeholders to co-ordinate for the development of resilient road infrastructure. Regmi and Hanaoka (2011) also conclude that the literature on managing climate risks to road infrastructure in the Asian context is limited, and further research is needed on climate change adaptation within the region.

Table 1: Road Infrastructure, Potential Impacts and Design Parameters

Climate Event	Potential Impacts	Vulnerable Infrastructure and Design Parameters
Temperature	• Extended warm weather can cause pavement deterioration due to liquidation of bitumen, heating and thermal expansion of bridges and buckling of joints of steel structure • Low temperature can affect road transport operations; operation and maintenance costs are likely to increase for additional snow and ice removal as well as additional costs of salts to be used for snow melting	• Pavement: use of stiff bitumen to withstand heat in summer, soft and workable bitumen with solvent in winter, control of soil moisture and maintenance planning • Steel bridges: selection of material, provision of expansion joints, corrosion protection
Rainfall	• Increased intensity of summer and winter precipitation would create floods, affect drainage, road pavement, driving condition and visibility, affect bridges and culverts waterways and clearance, damage bridges and culverts foundation due to scouring • Rainfall can trigger landslides and mudslides in mountainous roads and can create road blocks	• Drains: discharge estimation, size and shape of drain, drain slope • Mountainous road: slope protection work, subsurface drains, catch drains • Pavement: increase road surface camber for quick removal of surface water, frequency of maintenance, design of base and subbase, and material selection
Storms and Storm Surges	• Rainfall and winds associated with storm/ cyclone can create flooding, inundation of embankments, and affect road transport. Disrupt traffic safety and emergency evacuation operations, affect traffic boards and information signs	• Drains and cross drains: capacity enhancement, slope • Road embankment: increase height • Road signs: wind load, structural design, foundation, corrosion protection
Sea Level Rise	• Rise in sea level will affect coastal roads, may be need to realign or abandon roads in affected areas	• Coastal road: protection wall, additional warning signs, realignment of road sections to higher areas, edge strengthening

Source: Regmi and Hanaoka (2011),

Include important observations from:

Nemry and Demirel (2012)

IPCC AR5 Chapter 10 (2014)

Neumann et al. (2015).

II. The Support for Border Areas Development Project

The proposed project is primarily a road transport sector project designed to improve connectivity within five provinces of Viet Nam's Central Highlands: Kon Tum, Gia Lai, Dak Lak, Dak Nong, and Binh Phuoc. This region is known as Viet Nam's Development Triangle Area (VDTA). Improved connectivity in turn is intended to facilitate and enhance the flow of goods, people, and investment capital within the region. By linking farms, forests and plantations more effectively with commodities market chains; and by developing the regional potential for tourism (in particular eco-tourism), the project seeks to increase regional income and to address persistent endemic poverty.

The economy of the VDTA is based on agriculture and plantation forestry, and the crops of greatest importance include coffee, rubber, pepper, cassava and cashew kernels. These commodities are traded in national and international commodity markets. While the VDTA is an area of considerable natural beauty and contains a number of sites that might attract tourists, tourism is currently limited. This is due in part to inadequate and under-developed infrastructure, including but not limited to road infrastructure.

The project is structured around three outputs, of which Outputs 1 and to a lesser extent Output 3 are directly relevant to this CRVA. Each is reproduced here verbatim from the draft RRP:

"Output 1: Improved road infrastructure in five VDTA provinces. The poor condition of critical roads constrains all VDTA economic activity. The project will improve overall connectivity by upgrading national and provincial roads, as well as strategic roads that link border posts to the VDTA road network. To ensure the greatest impact is achieved, the roads were selected through a multi-criteria prioritization filter. Potential traffic demand will be tapped as the road conditions improve, and measures to mitigate the higher risk of accidents will be needed. The project will provide targeted traffic and road safety training to the most vulnerable road users, such as school children and other non-motorized road users."

"This output represents the bulk of the project investment. The indicators for achieving this output are: (i) 236.7 km of national and provincial roads linking to NH14 and NH14C improved; (ii) 26.6 km of provincial roads linking to border crossing stations improved; and (iii) Road safety awareness training for at least 50% of vulnerable road users (factories, communes, schools and markets) along the improved roads conducted."

"Output 3: Strengthened institutional capacity for VDTA investment planning, project design and implementation, and resource management. This output will help improve the efficiency of formulating and implementing investment programs and projects based on the long term development objectives of the VDTA towards becoming a cohesive and strong economic area. Activities include (i) preparation of an implementation action plan for the VDTA Master Plan that mainstreams ecosystem services, climate change, gender and ethnic minority considerations; and (ii) capacity building and training for officials appointed by the VDTA provinces to implement the action plan."

Output 2, which focuses on Transport and Trade Facilitation (TTP) is of potential relevance with respect to climate risk management, since it implicitly encompasses "small infrastructure improvements such as water supply, solid waste and wastewater management facilities, rural access road spot improvements, pathways, trails and drainage" required to improve regional suitability for tourism development. The focus of this CRVA will be on provincial roads, and climate risk assessment of tourism may be conducted separately as required.

Climate change impacts on the project have been assessed as Medium. This assessment may be revised on the basis of finding appearing in this CRVA.

The focus of much of the CRVA will be on the specific projects and their surrounding environment. Candidate sub-projects were identified on the basis of criteria developed for the project. The agreed-upon sub-projects are identified as follows, along with imagery indicating their locations within Vietnamese Central Highlands (VCH).

Agreed list of Subprojects under Output 1:

Province

Binh Phuc	50.16 km of Provincial Road (PR) 756 in Loc Ninh, Chon Thang and Hon Quan Districts.
Dak Lak	40 km of National Highway (NH) 29 in Cu M'Gar and Krong Buk districts;
Dak Nong	37.5 km of PR 686 and PR 681 in Dak Song and Tuy Duc districts;
Gia Lai	65.5 km of PR 665 in Chu Prong district; and
Kon Tum	70.2 km of PR 675 A in Ia H'Drai and Chu Prong districts.

Figure 1: Kon Tum Subproject Area and Location of Proposed Road Rehabilitation

Figure 2: Gia Lai Subproject Area and Location of Proposed Road Rehabilitation

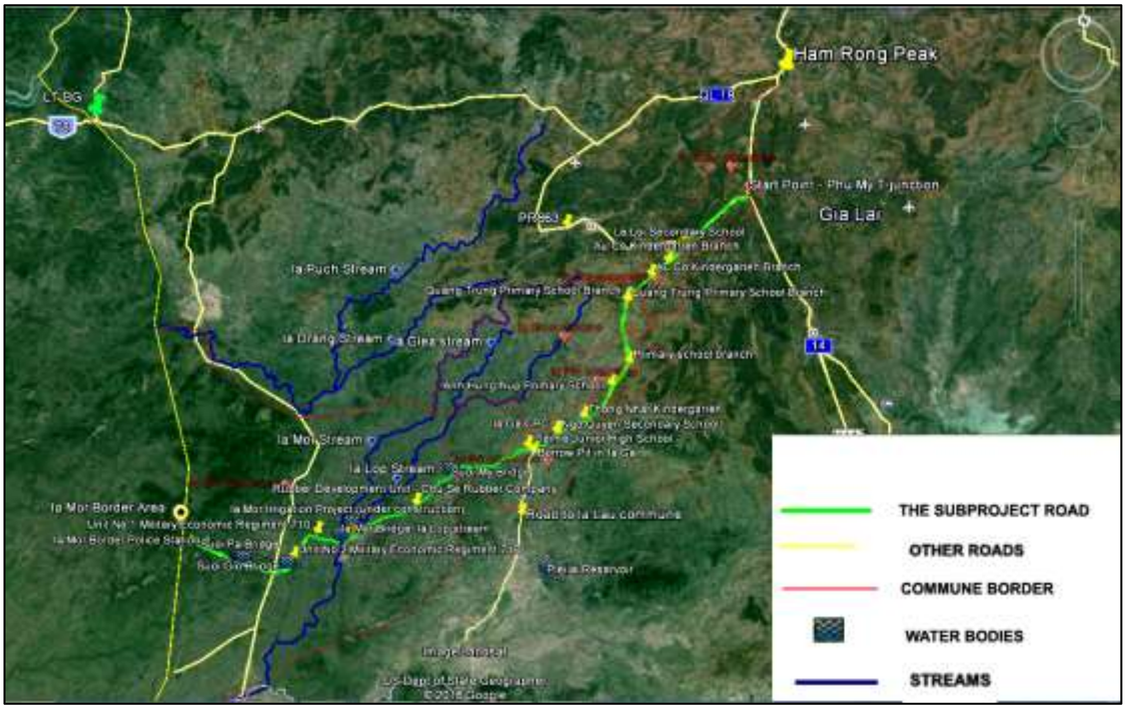


Figure 3: Dak Nong Subproject Area and Location of Proposed Road Rehabilitation

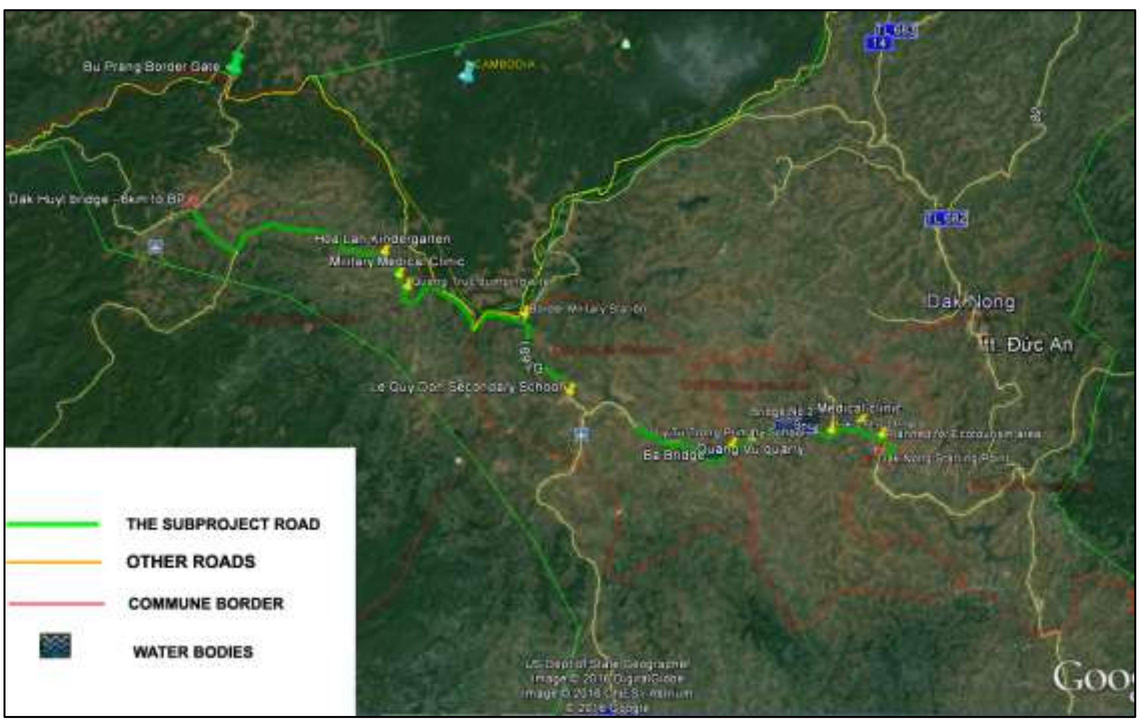
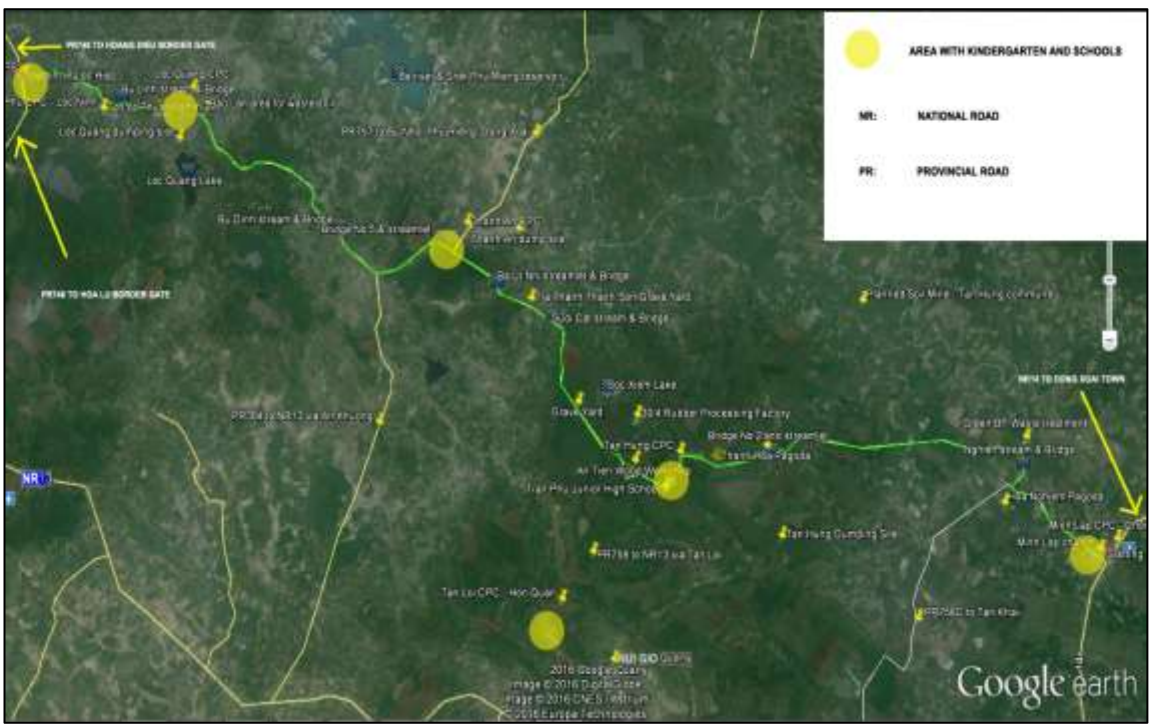


Figure 4: Dak Lak Subproject Area and Location of Proposed Road Rehabilitation

Figure 5: Binh Phuoc Subproject Area and Location of Proposed Road Rehabilitation



III. Climate Change and Impacts in Viet Nam's Central Highlands

3.1 Historical Climate

3.1.1 Climate Overview of the Vietnamese Central Highlands

Vietnam has a typical tropical monsoon climate with a seasonal reversal in winds and precipitation associated with thermal contrast in east-west or land-sea heating. It is located in the center of two main tropical monsoon areas, the South Asian and the East Asian monsoons (Nguyen et al., 2014).

In summer, the climate is dominated by the South Asian monsoon (also known as the south-west monsoon) which is hot and wet, especially in the southern provinces in Vietnam and provides 70 to 80% of the annual rainfall (Nguyen et al., 2007). The full South Asian monsoon normally begins in mid-May and its withdrawal around 18°N in September, from 10°N to 18°N in October, and south of latitude 10°N in November (Nguyen et al., 2007). Winter usually extends from November to March during which the climate is affected by the East Asian monsoon which is cold and dry especially in the North and the Central areas of Vietnam. The transition from the wet to the dry season is characterized by a sudden increase in rainfall in late April.

The project locations lie in the region of the Vietnamese central highlands (VCH) which is located in the southeast of the Indochina Peninsula, between approximately 12-15°N and 107-109°E, and comprises approximately 51800 km2 of rugged mountain peaks, widespread forests, and flat plateaus of basaltic land (Nguyen et al., 2007). The climate of the VCH region will be directly influenced by its largely high altitude nature (mostly 600–2000 m above sea level) and is likely to orographically enhance rainfall and moderate temperatures.

The rainfall over the VCH region during the South Asian monsoon results from the northward migration of the precipitation belt known as the inter-topical convergence zone (ITCZ) (Nguyen et al., 2007). The rainfall maximum during October to November appears in central Vietnam. Chen et al., (2012) found that heavy rainfall in central Vietnam is mainly contributed by cyclonic circulations.

The interannual variation of the South Asian monsoon rainfall over this region is mainly based on disturbances in the local weather caused by westward-propagating weather events such as tropical cyclones and monsoon lows and the influence of El Niño-Southern Oscillation (ENSO) on the atmospheric circulation and the latitudinal position of the ITCZ (Nguyen et al., 2007). The rainfall maximum in central Vietnam exhibits a distinct interannual variation of the rainfall maximum during October to November, with increases (reductions) in the La Niña (El Niño) phase of ENSO an of 174% (52%) of the long term average value (759mm) (Chen et al., 2012).

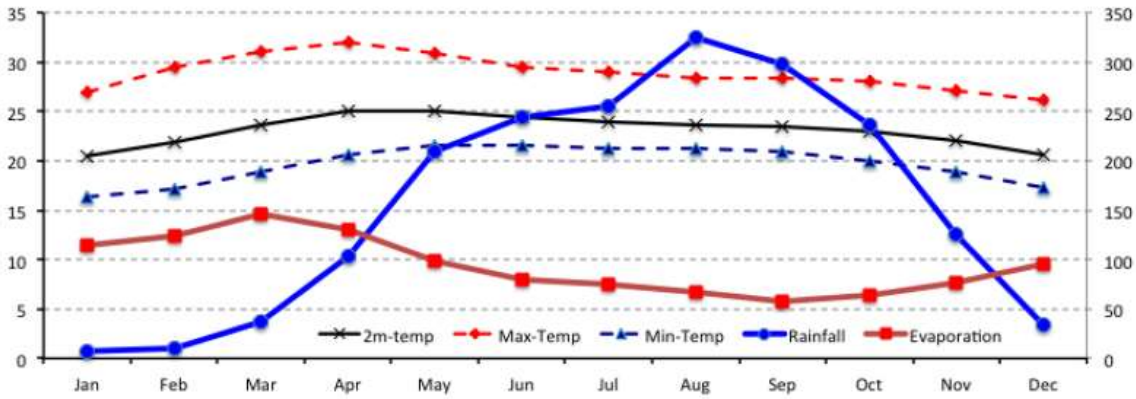
3.1.2 Historical Climate and Trends

To evaluate the effects of climate change on the VCH region it is important to establish the climate baseline. Limited historical complete observational climatic data is available for the region of interest to establish a baseline and trends. Therefore a baseline and associated climatic trends have been established for the region (12°-15°N, 107°-109°E) by reviewing the latest available literature by Harris et al. (2014) and Tan et al. (2013). The baseline and climatic trends are described for average surface, minimum and maximum temperature, and precipitation.

Van Tan et al. (2013) used daily observational data from 17 meteorological stations and 26 rain gauge stations in five provinces (Kon Tum, Gia Lai, Dak Lak, Dak Nong and Lam Dong) in the central highlands. Figure 1 shows that the annual cycle of temperature (daily mean, minimum and maximum), rainfall, and evaporation over all available stations in the region during the period 1979-2012. The annual mean temperatures at stations in the central highlands range from 20°C to 25°C and the lowest mean temperature occurs in December and January. The monthly mean of maximum temperature is highest in April, while the lowest monthly mean of minimum temperature occurs in January to April. The daily range, which is the difference between maximum and minimum, is largest in February and March and smallest in June and July.

Annual mean and maximum annual daily rainfall records produced by Van Tan et al. (2013) are shown in table A1 in appendix 1. The table shows that most stations across the CVH have annual rainfall from 1800 to 2000mm. The record maximum annual has reached 5202mm in 1998 at Bao Loc (Lam Dong province) and 5202mm in 1981 at P-Dateh (Lam Dong province). Spatial variation was found to be large across VCH where some stations have relatively low rainfall with only 1100-1300mm per year such as the stations at Krongpa (1180mm) and Ayunpa (1284mm) in Gia Lai province, and some stations have annual rainfall of about 3000mm such as Bao Loc (2924mm) and P-Dateh (3092mm) in Lam Dong province.

Figure 6. Monthly mean daily temperature, daily maximum and minimum temperature, monthly total rainfall and evaporation averaged over all the stations. Left axis indicates temperature in °C. The right axis indicates precipitation and evaporation in mm. Number of stations for rainfall and other variables are 43 and 17 respectively (Source: Van Tan et al., 2013, pp19).



3.1.3 Changes in average temperature and rainfall

Surface temperatures across Vietnam on average have warmed at a rate of 0.26°C per decade over the last 40 years. This rate is approximately twice the average rate of global warming, which was estimated to be about 0.13±0.03°C per decade in the last 50 years (Jones et al., 2007; as cited by Nguyen et al., 2014). Nguyen et al. (2014) found that the mean temperature trends for all sub-regions of Vietnam were statistically significant ($p < 0.05$) and that those in the VCH region were similar to the average over the whole country (Table 2). The rise in winter temperatures were found to be around 25% higher than that of summer over the same period (Nguyen et al., 2014).

Table 2. Estimated trends in average temperature anomaly in Vietnam and VCH in last 40 years (unit: °C per 10 years) (Source: Nguyen et al., 2014, pp 253).

	Summer (MJJA)	Winter (DJFM)	All year
VCH	**0.24 ± 0.15***	**0.29 ± 0.17****	**0.25 ± 0.12****
Vietnam	**0.23 ± 0.16**	**0.3 ± 0.17**	**0.26 ± 0.10**

The rate of increase in minimum daily temperature (Tn) is 0.31**±0.16°C per decade** is and is greater than that of the daily maximum (Tx) at 0.19**±0.17°C per decade**. In the south including VCH increases in Tx and Tn are greater in winter than summer (Nguyen et al., 2014).

In contrast, annual precipitation showed statistically significant changes in only two of the sub-regions, not including the VCH region; one in the north shows decreases and the second in the south shows increases (Nguyen et al., 2014). However, the VCH region rainfall does show a significant increase in the dry season of 91 ± 94 mm per decade (Nguyen et al., 2014).

3.1.4 The trends in extreme events

Trends in key extreme indices assessed by Tan et al. (2013) are presented below.

Temperature:

Tx90p – Number of days when Tx > 90th percentile, a measure of hot days

- No dominant increase or decrease trend across the VCH region.
- All stations with data available in Gia Lai province have increase trends.
- Largest increase trend occurs at Kon Tum (~9.9 days per decade) and Pleiku stations (~8.6 days per decade – satisfies 10% significance level).
- Decrease trend experienced at Dak To (~-2.5 days per decade), Buon Ho (~-5.2 days per decade), Lien Khuong (~-19.1 days per decade), and Bao Loc (~ -8.3 days per decade – trend satisfies 10%).

Tn10p – Number of days when Tn < 10th percentile, a measure of cold nights

- Shows a decreasing trend for the entire VCH region (trends att 7/10 stations are significant at the 10% level).
- Strongest trends are at Dak Nong (~ -18.6 nights per decade), Kon Tum (~ -17 nights per decade) and Ayunpa (~ -16 nights per decade) stations.

DTR – Daily temperature range: difference between Tx and Tn

- DTR has a decrease trend over most areas of the VCH region.
- Daily maximum temperatures have increased more slowly than the daily minimum temperatures resulting in decrease of DTR in VCH region.
- At Kon Tim, Ayunpa, Dak Ning and Bao Loc stations the decrease in DTR is about -0.5°C per decade. Nguyen et al. (2014) for the region and 1971-2010 period found it to be -0.21±0.09°C per decade.

Precipitation:

CDD – Maximum number of consecutive days with rainfall < 1mm, a measure of dry spell length

- CDD has a decreasing trend at most stations (16/20) in the VCH region though only 3 are significant. One station has a significant increasing trend.

CWD – number of consecutive days with RR ≥ 1mm, a measure of wet spell length

- Conversely, CWD also has a decreasing trend at half of the stations (10/20) in the VCH region, with 4 of these significant. Again, just one station has an increasing trend.

R50 and R25 – Annual count of number of days when precipitation ≥ 50mm and 25mm respectively

- Most stations in the VCH region do not show significant trends though a few in western VCH have decreasing trends.
- The changes of R50 are from -5 days per decade to 2.2 days per decade. The changes of R25 are from -10 days per decade to 4.7 days per decade.

R95pTOT and R99pTOT – Annual total precipitation from daily rainfall events whose intensities are above the 95th percentile and 99th percentile of daily rainfall events,

- There are few clear trends in R99pTOT though two stations have significant increasing and three significant decreasing trends.
- For R95pTOT more than half of the stations have increasing trends, two of which are significant, but there are also two with significant decreasing trends.

RX1day and RX5day – Monthly maximum 1-day precipitation and monthly maximum consecutive 5-day precipitation

- Trends in RX1day range from -24.3% (ChuProngBD) to +21.6% (Nam Ban) per decade though only at 5 stations are they significant at the10% level.
- For RX5day, trends at only 3 stations are significant at the 10% level.
- The stations with increasing RX5day concentrate in the south-eastern VCH and decreasing trends in the north-western VCH.

3.2 Projected Climate

This section of the report investigates climate projections for Vietnam and VCH region including results from the IPCC AR5 and Vietnams own regional climate projections.

3.2.1 IPCC AR5

This section highlights results summarized in the latest IPCC assessment report, AR5, for the key surface climate variables of average, minimum and maximum temperature, and precipitation.

A new set of emissions scenarios have been developed for use in climate models to explore plausible ranges of future climate change and are known as the Representative Concentration Pathways (RCPs), (Moss et al., 2008; Moss et al., 2010; van Vuuren, et al., 2011). These have been used with the latest generation of climate models to provide the updated set of climate change projections presented in the IPCC AR5 (Collins et al., 2013). The RCPs specify concentrations and corresponding emissions, but are not directly based on socio-economic storylines like the SRES scenarios used in the previous two IPCC reports. The RCPs are based on a different approach and include more consistent short-lived gases and land use changes. However, they are not necessarily more capable of representing future developments than the SRES scenarios (Cubasch et al., 2013). Four RCP scenarios were used within the Coupled Model Intercomparison Project 5 (CMIP5) to generate a wide range of future climate projections; these were RCP2.5, RCP4.5, RCP6, and RCP8.5. The RCPs are described in more detail in Appendix 2.

For the East Asian summer monsoon more than 85% of CMIP5 models show an increase in mean precipitation, while more than 95% of models project an increase in heavy precipitation events throughout the 21st century (Christensen et al., 2014). Increases are also projected for the southern Asian monsoon. However there are limiting factors in the quantitative assessment of monsoon changes including sensitivity to model resolution (Cherchi and Navarra, 2007; Klingaman et al., 2011; as cited by Christensen et al., 2014), model biases (Levine and Turner, 2012; Bollasina and Ming, 2013; as cited by Christensen et al., 2014), poor skill in simulating the Madden–Julian Oscillation (MJO) and uncertainties in projected ENSO changes (Collins et al., 2010; as cited by Christensen et al., 2014) and in the representation of aerosol effects.

As previously discussed the rainfall over the VCH region during the South Asian monsoon can be interpreted as a result of the northward migration of the precipitation belt known as the inter-topical convergence zone (ITCZ). In CMIP5, seasonal mean rainfall is projected to increase on the equatorward flank of the ITCZ (Christensen et al., 2014). However there are known issues with GCMs showing an unrealistic double ITCZ pattern over the tropical Pacific and Atlantic with excessive rainfall south of the equator (Christensen et al., 2014).

Results produced within IPCC (2013) Atlas of Global and Regional Climate Projections in the form of graphics are summarised in table 2 for the VCH region. The information presented in this Atlas is based entirely on all available CMIP5 model output with equal weight given to each model or version with different parameterisations. The graphics represent the variability of results from 42 GCM model simulations and are as follows, the 25th, 50th (median) and 75th percentiles respectively. The results in this Atlas are based upon RCP 4.5 which is described in Appendix 2. For each quartile in table 2, twenty-year averages are presented for the near term (2016-2035), mid-term (2046-2035) and long-term (2081-2100), each relative to a reference period of 1986-2005). Temperature changes are presented for the summer season (MJJA) and winter season (DJFM) and precipitation relative changes are presented for dry season (NDJFM) and wet season (AMJJASO). Where hatching was noted on the plot it means that it can be interpreted as some indication of the strength of the future anomalies from present-day climate when compared to the strength of present day internal 20-year variability. It either means that the change is relatively small or that there is little agreement between models on the sign of the change. In the table where there is hatching these are marked with (*).

TABLE 3. CMIP5 GCM projections for the VCH region under RCP 4.5 emission scenario. (*) Where hatching was noted on the plot it means that it can be interpreted as some indication of the strength of the future anomalies from present-day climate when compared to the strength of present day internal 20-year variability (SOURCE: IPCC, 2013).

SEASON	VARIABLE	2016-2035	2046-2065	2081-2100
MJJA	TEMP °C 25TH	0.5 TO 1.0	1.0 TO 1.5	1.0 TO 1.5
MJJA	TEMP °C 50TH	0.5 TO 1.0	1.0 TO 1.5	1.5 TO 2.0
MJJA	TEMP °C 75TH	0.5 TO 1.0	1.5 TO 2.0	2.0 TO 3.0
DJFM	TEMP °C 25TH	0 TO 0.5	0.5 TO 1.0	1.0 TO 1.5
DJFM	TEMP °C 50TH	0.5 TO 1.0	1.0 TO 1.5	1.5 TO 2.0
DJFM	TEMP °C 75TH	0.5 TO 1.0	1.5 TO 2.0	2.0 TO 3.0
NDJFM	PRECIP %Δ 25TH	0% TO -10%*	0% TO -10%*	0% TO -10%*
NDJFM	PRECIP %Δ 50TH	0% TO -10%*	0% TO 10%*	0% TO 10%*
NDJFM	PRECIP %Δ 75TH	0% TO 10%*	10% TO 20%	10% TO 20%
AMJJASO	PRECIP %Δ 25TH	0% TO -10%*	0% TO -10%*	0% TO -10%*
AMJJASO	PRECIP %Δ 50TH	0% TO 10%*	0% TO 10%*	0% TO 10%
AMJJASO	PRECIP %Δ 75TH	0% TO 10%	0% TO 10%	10% TO 20%

3.2.2 Regional climate projections

High-resolution model simulations are necessary to resolve complex terrain such as in Southeast Asia as these are known to generate localised effects in terms of monsoon rainfall in the VCH region. This section of the report aims to highlight the benefits of downscaled RCM projections for Vietnam and the VCM region. The sources include McSweeney et al. (2010a) 'The UNDP Climate Change Country Profiles Improving the Accessibility of Observed and Projected Climate Information for Studies of Climate Change in Developing Countries' and Vietnams Ministry of Natural Resources and Environment Climate Change and Sea Level Scenarios 2009, 2011 and 2015.

UNDP Climate Change Country Profile

The UNDP Climate Change Country Profile for Vietnam was produced using global climate models; it was a sub-set of 15 models from the 22-member ensemble global models used by the Intergovernmental Panel on Climate Change (IPCC) for the AR4 report, published in 2007.

Key findings from McSweeney et al. (2010b) for temperature and Precipitation:

Temperature:

- The mean annual temperature is projected to increase by 0.8 to 2.7°C by the 2060s, and 1.4 to 4.2 degrees by the 2090s. The range of projections by the 2090s under any one emissions scenario is around 1.5-2.0°C.
- The projected rate of warming is similar in all seasons and regions of Vietnam.
- All projections indicate substantial increases in the frequency of days and nights that are considered ‘hot’ in current climate.
    - Annually, projections indicate that ‘hot’ days will occur on 17-41% of days by the 2060s, and 23-55% of days by the 2090s. Days considered ‘hot’ by current climate standards for their season are projected to increase fastest in summer (MJJ), occurring on 26-87% of days of the season by the 2090s.
    - Nights that are considered ‘hot’ for the annual climate of 1970-99 are projected to increase at a faster rate than hot days, occurring on 25-51% of nights by the 2060s and 34-68% of nights by the 2090s. Nights that are considered hot for each season are projected to increase most rapidly in summer (MJJ) occurring on 55-92% of nights in every season by the 2090s.
    - All projections indicate decreases in the frequency of days and nights that are considered ‘cold’ in current climate. These events are expected to become exceedingly rare, occurring on 0-6% of days in the year, potentially not at all under the higher emissions scenarios by the 2090s.

Precipitation:

- Projections of mean annual rainfall from different models in the ensemble are broadly consistent in indicating increases in rainfall for Vietnam. This increase is mainly due to the projected increases in ASO rainfall (-1 to +33% by the 2090s), but is partially offset by projected decreases in FMA (-62 to +23%).
- The proportion of total rainfall that falls in heavy events is projected in increase by all the models in the ensemble, by an additional 2 to 14% by the 2090s. Again, these increases arise mainly due to increases in heavy events in ASO and MJJ rainfall, and are partially offset by decreases in NDJ and FMA.
- All models in the ensemble project increases in the magnitude of 1- and 5-day rainfalls of up to 43mm and 52mm, respectively, by the 2090s.

Ministry of Natural Resources and Environment Climate Change Scenarios

Climate change and sea level rise scenarios for Vietnam were first published by the Ministry of Natural Resources and Environment (MONRE)[5] in 2009 on the basis of synthesizing domestic and international research. However the level of detail provided by these scenarios was confined to information over 7 climatic regions and coastal areas along Vietnam to timely serve ministries, agencies, sectors and provinces to implement the National Target Programme to Respond to Climate Change. The 2009 climate projections were developed using the MAGICC/SENGEN[6] (v5.3) software and statistical downscaling methods. The scenarios that were used to generate these projections were the SRES[7] emission scenarios.

In 2011 a national strategy on Climate Change was issued to identify targets for selected periods and priority projects. Ministry of Natural Resources and Environment updated climate change and sea level rise scenarios based on specific datasets and climatic conditions of Vietnam as well as products of climate models.

Have requested copies of the 2012 report and the Ministry of Natural Resources and Environment, 2009: Climate change and sea level rise scenario for Vietnam

Climate change and sea level scenario for Vietnam version 2015 has been updated according to the defined schedule in National Strategy on Climate Change that aims to provide the latest information about climate changes and trends in the past and climate change and sea level rise scenarios in the 21st century for Vietnam.

The latest version of the scenarios builds on scenarios published in 2012 supplemented by more recent information. The calculation is based on: The new findings in the IPCC (AR5); hydro-meteorological data updated to 2014; recent trends of climate change in Vietnam, results from global climate models and high resolution climate models for Vietnam; related studies from Vietnam Institute of Meteorology, Hydrology and Climate change (including project on climate change coded BDKH43 belonged program coded “KHCN-BDKH/11-15”), the Advisory Council of the National Commission on climate change, research institutes and universities in Vietnam.

With global nations agreeing to keeping global mean temperature increase under 2°C by the end of this century in comparison with pre-industrial levels this report concludes that for short-term planning RCP4.5 is more consistent with this future compared to other higher scenarios therefore it can be used for short-term planning as well as design of infrastructure with shorter life-times. It was also concluded that for longer-lived infrastructure and consideration of the worst case it is appropriate to use RCP8.5.

[5] MONRE has the primary responsibility for the oversight and facilitation of environmental quality standards, land administration, and sustainable natural resources use and conservation, including land use planning and integrated water management at the river basin level.

[6] http://www.cgd.ucar.edu/cas/wigley/magicc/

[7] The IPCC produced a Special Report on Emission Scenarios (Nakicenovic et al., 2000), which identified a number of possible ‘story lines’ which took into account driving forces such as demographic, social, economic, technological, and environmental developments that could alter the climate over decades and centuries. Possible emission (SRES) ‘scenarios’ for the IPCC third and fourth working group reports were defined based on these scenarios.

Key findings from the MNRE (2009) report:

- Climate change projections were developed based on the different SRES emission scenarios for Vietnam in the 21st century, namely low (B1), medium (B2) and high (A2).
- Due to the complexity of climate change and the limited understanding of climate change, both in Vietnam and in the world, together with the social, economic factors, uncertainties of model-estimated scenarios results it was recommended that the most harmonious scenario to implement is the medium scenario for ministries, sectors and provinces/cities to use as an initial basis in climate change impact assessments and in the development of action plans to respond to climate change.
- In the medium emission scenario (B2): By 2050 annual mean temperatures are projected to increase in the central highlands by 0.8°C and by the end of the 21st century 1.6°C relative to the period 1980-1999.
- In the medium emission scenario (B2): In the Central Highlands relative to the period (1980-1999) by the 2050s during Dec-Feb mean temperatures are projected to increase by 0.8°C, Mar-May increase by 0.8°C, Jun-Aug by 0.7°C and Sep-Nov by 0.7°C. By the end of the 21st century mean temperatures are projected to change during Dec-Feb by 1.8°C, Mar-May 1.8°C, Jun-Aug 1.4°C, and Sep-Nov 1.5°C.
- Rainfall in the dry season is projected to decrease in most climate zones, especially southern zones. Rainfall in the rainy season and the total annual rainfall is projected to increase in all climate zones.
- In medium emission scenario (B2): annual rainfall is projected to increase relative to the period 1980-1999 by about 0.7% by the 2050s and by 1.5% in the central highlands by the end of the 21st century.
- In medium emission scenario (B2): Relative to the period (1980-1999) rainfall in the central highlands in Dec-Feb by 2050 is projected to decrease by -7.7%, Mar-May decrease by -9.1%, Jun-Aug increase by 0.2%, and Sep-Nov increase by 6.5%. By the end of the 21st century is projected in Dec-Feb to decrease by -14.8%, Mar-May decrease by -17.4%, Jun-Aug increase by nearly 0.5%, and Sep-Nov increase by approximately 12.5%.

These national climate projections are yet to be released?? however as part of deriving national climate projections for Vietnam a report was commissioned by UNDP entitled 'Technical Support in Development of Climate Scenarios in Vietnam – Preparation of National Projections.' A work package ran by the Met Office Hadley Centre generated high resolution climate projections at a resolution of 25km for Vietnam the PRECIS 2.1 model were configured to downscale three GCMs from the Coupled Model Intercomparison Project Phase 5 (CMIP5) including HadGEM2-ES, GFDL and CNRM. The three CMIP5 models were driven by historical and RCP4.5/RCP8.5 emission scenarios. The simulations undertaken for this study provide complementary results to those generated using CSIRO's CCAM variable resolution model to downscale 6 CMIP5 GCMs (Katzfey et al., 2014).

This UNDP report produced top level climate information for a whole host of climate indices from the three downscaled GCMs. Further work could be carried out subject to licensing agreements, of the data to understand the specifics found for the VCH region.

3.2.2 NASA Earth Exchange Global Daily Down-scaled Projections (NEX-GDDP)

To support subproject site-specific analysis of climate change at timescales relevant to project design; and in particular to assess the impacts of climate change on the frequency and magnitude of extreme temperature and precipitation events, an additional source of climate projections data was utilized for this CRVA. The requirements were that data be resolved at spatial and time scales consistent with both sub-project spatial scale and the timescale of specific events.

In June 2015 the U.S. National Aeronautics and Space Administration (NASA) de-classified the NASA Earth Exchange (NEX) Global Daily Downscaled Projections (GDDP) dataset. The dataset was produced in support of the IPCC AR5, and consists of daily projected values from 21 General Circulation Models (GCM) of three primary climatic variables – maximum and minimum temperature and precipitation – at 0.25 degree horizontal resolution (equivalent to approximately 25 km near the equator) for the entire globe.

Projections are made for the historical period (1950-2005) and for 2006–2100 for two representative concentration pathways (RCP): RCP4.5 and RCP8.5 (see Annex 2). The historical period is taken from the CMIP hindcast experiments and the 21st century projections from the long-term experiments (Taylor, et al., 2011). RCP4.5 is consistent with a relatively optimistic vision of progress in GHG mitigation, while RCP8.5 is equivalent to a “business as usual” scenario and consistent with current global GHG emissions patterns.

Down-scaled projections are obtained using the bias-correction spatial disaggregation (BCSD) approach (Maurer and Hidalgo, 2008) applied to 21 of the CMIP5 models for which daily projections were produced and distributed. The stated purpose of the GDDP is “… to provide a set of global, high resolution, bias-corrected climate change projections that can be used to evaluate climate change impacts on processes that are sensitive to finer-scale climate gradients and the effects of local topography on climate conditions” (Thrasher and Nemani, 2015).

At 0.25 degree resolution, the rectangular domain containing the central and northern parts of Vietnam’s Central Highlands extends from 12.25 degrees N Lat to 15.0 degrees N Lat and 107.25 degrees E Lon to 108.5 degrees E Lon approximately, and consists of 72 rasters (pixels) of roughly 600 square kilometer (km^2) each. At this resolution a more detailed view of projected climate change in the VCH, including N-S and E-W temperature and precipitation gradients, is possible to achieve, although projected climatic variables downscaled using BCSD are still constrained by the skill of projections from the parent GCM.

Due to constraints on time and resources required to process the NASA NEX-GDDP files into formats suitable for desk-top analysis, only a sub-set of this dataset has been acquired and processed at the time this report was prepared. Specifically, down-scaled outputs from five GCMs have been analyzed. These GCMs are NorESM1-M, MPI-ESM-MR, MIROC5, GFDL-ESM2M and CanESM2.

The general approach to the use of these projections in climate risk analysis is typically referred to as the delta method. The delta method assumes that while GCM outputs (and down-scaled projections based on these output) may not always demonstrate a high level of skill in reproducing the historical levels (values) of specific climate variables, they are relatively more skillful in simulating changes in the values of these variables over time as a consequence of e.g., GHG forcings. Thus, in applying the delta method we are evaluating changes based on model-simulated projections of future conditions relative to model-simulated historical data.

For the analysis conducted for this CRVA, the following reference 20-year time periods were utilized:

Historical: 1986-2005 (CMIP5 hindcast experiments)

Projection: 2041-2060 (mid-21st century)

Figure 7 indicates the location of the NASA NEX GDDP projections over the VCH (drawing is free-hand based on Google Earth latitude and longitude readings and thus approximate).

Figure 7 – NASA Earth Exchange (NEX) Global Daily Down-scaled Projections Grid for the Central Highlands

The 72 0.25º x 0.25º rasters cover much of the Central Highlands. For the purposes of this assessment, only data in rasters containing proposed project roadways was analyzed in detail. The following are the rasters associated with each proposed Provincial subproject site, identified by the co-ordinates of the raster centroid:

Binh Phuc:	not included within high-resolution grid
Dak Lak:	1: 12.875 degrees N Lat., 107.875 degrees E Lon
	2: 12.875 degrees N Lat., 108.125 degrees E Lon
Dak Nong	1: 12.375 degrees N Lat; 107.375 degrees E Lon
	2: 12.375 degrees N Lat; 107.625 degrees E Lon
Gia Lai	13.625 degrees N Lat; 107.875 degrees E Lon
Kon Tum	1: 14.125 degrees N Lat., 107.375 degrees E Lon
	2: 14.125 degrees N Lat., 107.625 degrees E Lon

IV. Vulnerability of the Project to Projected Climate Change

4.1 The Impact Pathways Approach

Built infrastructure is inherently sensitive in varying degrees to a range of climatic variables, and the behavior of these variables has implications for the design and performance of infrastructure. Important climatic variables include temperature (mean, maximum, minimum, rate of change, extremes), precipitation (mean, distribution in time, extremes), windspeed and direction, humidity, and solar radiation. Climate change holds the potential to alter each of these, although the projected direction and magnitude of change over a given time interval is subject to uncertainty. Impact assessment must therefore be concerned with causal linkages between the level and behavior of specific climatic variables and the design and performance of specific infrastructure components. These causal linkages can be described through climate impact pathways (see, for example ADB 2014b).

Climate impact pathways are analytical tools that help to identify adaptation choices by linking the impact and vulnerability assessments, addressing the following questions:

- Which climate change impacts are we concerned with in our project?
- Which infrastructure components and/or functions are exposed to these impacts?
- How sensitive is each component to specific changes in climatic conditions?
- Are there critical vulnerability thresholds?
- What type(s) of adaptation intervention will reduce exposure, sensitivity and/or increase adaptive capacity?

Similarly, for each infrastructure component, it is useful to consider if changes in climatic parameters are likely to result in any of the following consequences (and possibly others):

- Damage to physical assets
- Reduced service lifetime of assets
- Increased operation, maintenance costs
- Reduction in reliability; interruption of services
- Increasing input; operating costs
- Reduction in efficiency

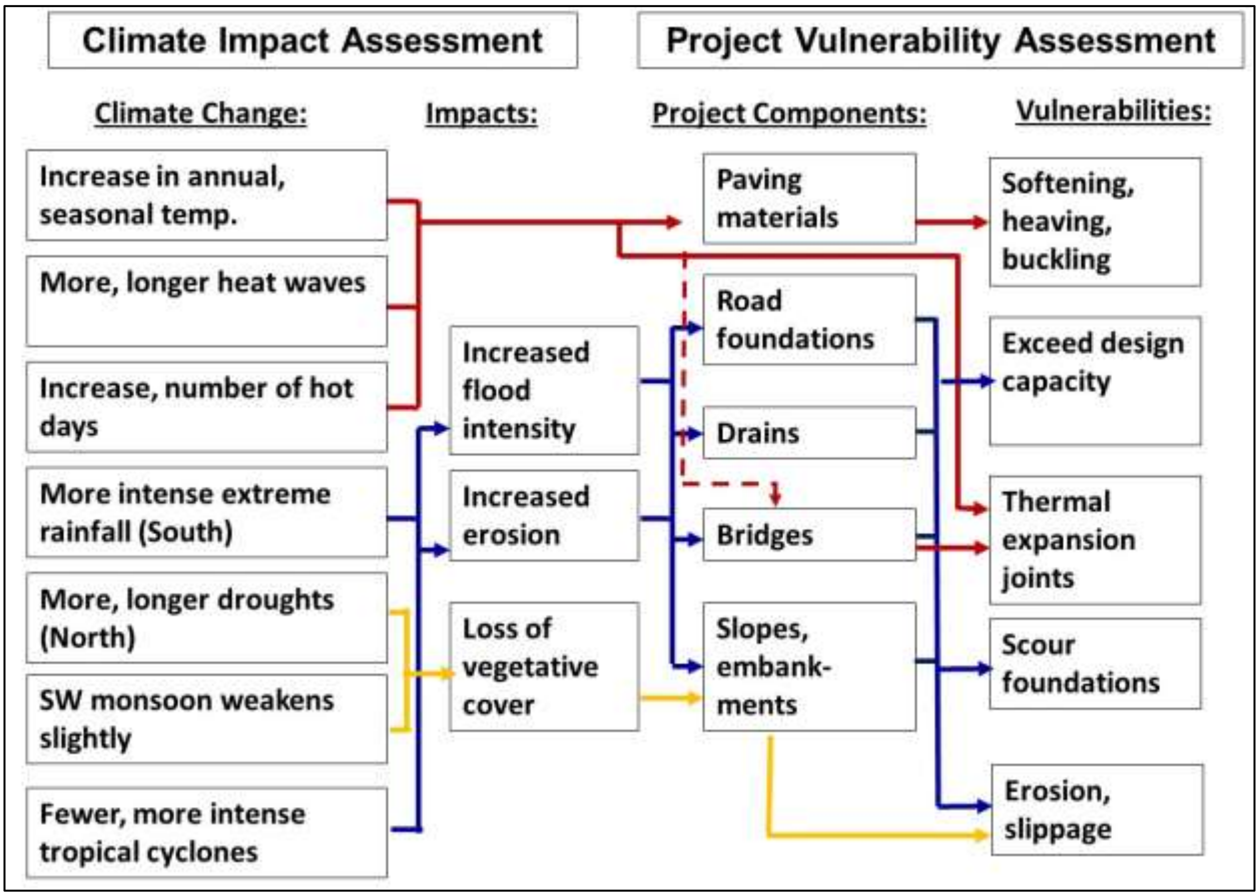
A partial set of climate impact pathways is represented in Figure 8. The projected manifestations of climate change in the Central Highlands reflected in Figure 8 are summarized in IMHEN (2014) and in Section 3 of this document. The most important projected changes include the following:

- Annual temperature is projected to increase by about 1.4 to 4.5°C by end-of-century.
- Little change in annual rainfall amounts is projected, although seasonal changes are apparent.
- The number of heatwaves is projected to increase in the southern part of this region, while heatwaves are projected to last longer throughout the region. The number of hot days in lower-lying parts of this region is projected to increase.
- Extreme rainfall amounts are projected to increase in the southern part of this region

- Droughts are projected to be more frequent and longer in the northern part of this region
- The length and intensity of the southwest monsoon are projected to decrease slightly.
- Projections indicate that the number of tropical cyclones may decrease. Other studies have also suggested some increases in intensity

These changes are linked in Figure 8 to primary components of road infrastructure within the project region assessed to be vulnerable to one or more of these changes. Note that Figure 8 does not explicitly represent temporary loss of services due to e.g., flooding or slope failure as an additional risk pathway, although these and related impact pathways are implied.

Figure 8 – Climate Impact Pathways on Road Infrastructure in the Central Highlands



4.2 Changes in Temperature Extremes at Project Locations

In this section, the results of an analysis of changes in extreme high temperatures are presented with reference to each of the project locations. The NASA NEX GDDP are the basis of this analysis. For each of the 0.25º x 0.25º rasters associated with each provincial road rehabilitation, the annual maximum daily temperature was extracted for each of the 20 years in the historical baseline period (1986-2005) and the mid-21st century projection period (2041-2060). The mean of annual daily maxima and the period (20-year) maxima are compared. Note that Binh Phuc Province lies outside of the NASA NEX GDDP high-resolution grid developed for this analysis, and is thus not included in the following section. Results for the closest included province, Dak Nong, will be assumed to generalize to Binh Phuc Province.

For each location, the results for each individual GCM are presented, along with the average over models, and the corresponding change between the projection and the historical periods.

Dak Lak Project Location:

Table 4a: Projected Changes in Temperature Extremes, Western Dak Lak Site

Dak Lak 1	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
			Historical			
mean	35.6	36.0	35.8	36.2	35.6	35.8
st dev	0.8	0.8	1.5	1.3	1.0	
max	37.2	37.3	38.4	38.9	37.0	37.8
			Projection			
mean	37.2	38.3	37.1	37.5	38.5	37.7
st dev	0.9	1.0	1.2	1.3	0.8	
max	39.0	39.6	39.0	39.9	40.5	39.6
			Difference			
mean	1.6	2.2	1.3	1.3	2.9	1.9
st dev	0.1	0.2	-0.3	-0.1	-0.1	
max	1.8	2.3	0.6	1.0	3.5	1.8

Table 4b: Projected Changes in Temperature Extremes, Eastern Dak Lak Site

Dak Lak 2	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical					
mean	33.7	34.2	34.1	34.5	33.7	34.0
st dev	0.6	0.8	1.5	1.3	0.9	
max	35.0	35.6	36.6	37.0	35.1	35.9
	Projection					
mean	35.3	36.4	35.4	35.6	36.6	35.8
st dev	1.1	0.8	1.2	1.3	0.8	
max	39.1	37.8	37.3	38.0	38.5	38.1
	Difference					
mean	1.6	2.2	1.2	1.2	2.8	1.8
st dev	0.5	0.0	-0.3	0.0	-0.1	
max	4.1	2.2	0.7	0.9	3.4	2.3

Dak Lak project location is described by two NASA NEX GDDP rasters. Dak Lak 1 lies immediately to the West of Dak Lak 2 (refer to Figure 7). Within each raster, the five GCMs present a reasonably consistent picture of both (modeled) historical and projected annual maximum temperatures. The mean of annual maximum temperatures is around 35.8 ^{o}C in the west and slightly lower (34.0 ^{o}C) in the Eastern part. Period of record maxima are also slightly higher in the Western area. Although results differ to some degree by GCM, the general pattern is that both mean annual maximum temperature and period maximum (equivalent to the 1 in 20-year, or 5% exceedance probability maximum, approximately) increases by around 2.0 ^{o}C over the 55-year period (1995/96 – 2050). The highest temperatures projected by any of the 5 GCMs for the mid-21st century in general do not exceed 40.0 ^{o}C, with one exception.

Dak Nong Project Location:

Table 5a: Projected Changes in Temperature Extremes, Western Dak Nong Site

Dak Nong 1	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical					
mean	33.6	34.0	32.9	33.4	33.3	33.4
st dev	1.1	1.2	1.6	1.3	1.2	
max	35.4	35.9	36.4	35.9	34.9	35.7
	Projection					
mean	35.4	35.9	34.2	34.7	36.1	35.3
st dev	1.6	1.3	1.3	1.3	0.8	
max	40.4	38.1	36.3	37.5	38.0	38.1
	Difference					
mean	1.8	1.9	1.3	1.3	2.8	1.8
st dev	0.6	0.0	-0.3	0.0	-0.4	
max	5.0	2.2	-0.1	1.7	3.1	2.4

Table 5b: Projected Changes in Temperature Extremes, Eastern Dak Nong Site

Dak Nong 2	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical					
mean	33.5	33.6	32.7	33.2	33.1	33.2
st dev	1.0	1.1	1.6	1.3	1.0	
max	35.2	35.7	36.0	35.6	34.6	35.4
	Projection					
mean	35.3	35.5	34.1	34.5	35.7	35.0
st dev	1.6	1.1	1.2	1.2	0.8	
max	40.2	37.4	36.1	37.0	37.7	37.7
	Difference					
mean	1.8	1.9	1.3	1.4	2.7	1.8
st dev	0.6	0.0	-0.4	-0.1	-0.2	
max	5.0	1.8	0.1	1.4	3.1	2.3

The Dak Nong project location is the southern-most among the locations evaluated (Binh Phuc Province lies to the South and West, but is not included in this analysis). Both mean of annual maxima and period maxima are significantly lower than Dak Lak, and rates of change over the (roughly) 50-year projection period are similar: around 1.8 ^{o}C for mean of annual maxima and slightly greater (2.3 ^{o}C) for the period maxima. Only one of the GCMs included (NorESM1-M) projects mid-21st century maxima above 40 ^{o}C. The other models project substantially lower, around 37.0 to 38 ^{o}C.

Gia Lai Project Location:

Table 6: Projected Changes in Temperature Extremes, Gia Lai Site

Gai Lai	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical					
mean	35.5	35.8	35.8	35.6	35.1	35.6
st dev	0.9	0.8	1.4	1.3	0.9	
max	37.7	37.7	38.1	38.5	36.5	37.7
	Projection					
mean	37.0	38.3	37.3	37.1	38.2	37.6
st dev	1.0	1.0	1.5	1.4	1.0	
max	39.3	40.0	39.9	40.3	40.6	40.0
	Difference					
mean	1.5	2.5	1.4	1.5	3.1	2.0
st dev	0.0	0.2	0.0	0.2	0.1	
max	1.6	2.3	1.8	1.8	4.1	2.3

Gai Lai project area lies largely within one 0.25^{o} x 0.25^{o} raster. The pattern is very similar to Dak Lak and Dak Nong, with both mean of annual maximum temperatures increasing by around 2.0 degrees. The period maxima increase by slightly more: 2.3 ^{o}C in roughly 50 years. Thus, while historical maxima are nearly identical to Dak Lak (1), by the mid-21st century, the one-in-20-year event is now projected to exceed 40.0 ^{o}C by three of the five GCMs.

Kon Tum Project Location:

Table 7a: Projected Changes in Temperature Extremes, Western Kon Tum Site

Kon Tum 1	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical					
mean	37.0	36.9	36.7	36.4	36.2	36.6
st dev	1.3	0.9	1.4	1.4	1.1	
max	39.7	38.3	38.8	39.3	38.5	38.9
	Projection					
mean	38.4	39.6	38.7	38.0	39.4	38.8
st dev	1.2	1.2	1.6	1.5	1.0	
max	40.3	41.7	41.6	41.3	41.9	41.3
	Difference					
mean	1.4	2.7	2.0	1.6	3.2	2.2
st dev	-0.2	0.3	0.1	0.0	-0.1	
max	0.6	3.4	2.8	1.9	3.4	2.4

Table 7b: Projected Changes in Temperature Extremes, Western Kon Tum Site

Kon Tum 2	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical					
mean	34.9	34.6	34.5	34.0	33.9	34.4
st dev	1.3	0.9	1.4	1.4	1.0	
max	37.7	36.2	36.7	37.1	35.7	36.7
	Projection					
mean	36.4	37.2	36.3	35.7	37.0	36.5
st dev	1.2	1.1	1.6	1.4	1.0	
max	39.2	38.9	39.5	39.1	39.6	39.3
	Difference					
mean	1.5	2.7	1.8	1.6	3.2	2.2
st dev	0.0	0.2	0.2	0.1	0.1	
max	1.6	2.6	2.8	2.0	3.9	2.6

Kon Tum 1 is identified as the project location with both the highest projected extremes. In the western raster (Kon Tum 1), projected 20-year maxima for all GCMs exceeds 40.0 ^{o}C, in some cases by almost 2.0 ^{o}C. In addition, rates of change in both Eastern and Western rasters are the highest among the project locations.

To provide an additional perspective, Table 8 summarizes the frequency of hot days in each project location exceeding each of three absolute temperature thresholds: 36.0 ^{o}C, 38.0 ^{o}C and 40.0 ^{o}C. The table indicates the simulated number of events (days with maximum temperature equaling or exceeding the threshold) under both simulated historical conditions and mid-21st century conditions, per decade. It is observed that projected climate change in the Central Highlands will greatly increase the number of hot days (equaling or exceeding 36.0 ^{o}C), and generate a substantial number of events exceeding 38.0 ^{o}C and 40.0 ^{o}C, respectively.

Thee impacts of such events can only be evaluated with respect to the vulnerability of systems to absolute temperature thresholds.

Table 8: Simulated Frequency of Hot Days, Historical (1986-2005) and Projected (2041-2060)

Threshold	Period	Dak Nong 1	Dak Nong 2	Dak Lak 1	Dak Lak 2	Gai Lai	Kon Tum 1	Kon Tum 2
36	historical	0.1	0	22.5	0.8	13.6	51.1	1.2
	projected	22.1	16.3	198.6	26.9	165.3	324.8	55.8
38	historical	0	0	0.3	0	0.2	3	0
	projected	1.7	1.3	20.4	1.8	17.5	64.2	5.3
40	historical	0	0	0	0	0	0	0
	projected	0.1	0.1	0.8	0	0.6	7.5	0

4.3 Changes in Precipitation Extremes at Project Locations

In this section, the results of an analysis of changes in extreme daily precipitation are presented with reference to each of the project locations. The NASA NEX GDDP are once again the basis of this analysis. As with extreme temperatures, for each of the 0.25° x 0.25° rasters associated with each provincial road rehabilitation, the annual maximum daily precipitation was extracted for each of the 20 years in the historical baseline period (1986-2005) and the mid-21st century projection period (2041-2060). The mean of annual daily maxima and the period (20-year) maxima are compared for each project location. Note once again that Binh Phuc Province lies outside of the NASA NEX GDDP high-resolution grid developed for this analysis and has not been included in this section. In this instance results for the closest included province (Dak Nong) should not be assumed applicable to Binh Phuc Province due to greater spatial variability of precipitation relative to temperature. Again, for each location, the results for each individual GCM are presented, along with the average over models, and the corresponding change between the projection and the historical periods. In these tables all units are mm per day.

Although twenty year time slices should in general be sufficient to capture systematic changes in the values of variables such as annual maximum daily precipitation due to climate change, a 20-year record is still in many ways inadequate for many types of statistical analysis. There is, for example, the possibility that period means and extremes are disproportionately influenced by individual extreme values. This is anticipated when working with model- (GCM-) generated projections. Ideally, each GCM run should be viewed as a sample pathway that might differ from other pathways generated by the same GCM under identical GHG forcing and over the same time period due to differences in e.g., initial conditions such as sea surface temperatures; and the inherently chaotic nature of the climate system. A large number of runs would be required to obtain stable estimates of the values of representative variables, but only a single set of runs for each GCM and GHG emissions trajectory (RCP) is available.

In particular, if we interpret the highest daily precipitation event in a simulated 20-year time window as an empirical estimate of the 20-year recurrence event (equivalent to the p=0.05 or 5% annual exceedance value), this interpretation does not take into consideration the overall distribution of the sample data. A 20-year period may contain no “true” 20 year events; or it may contain a 100-year event (with roughly 18% probability). A method is required to estimate daily precipitation quantiles from the simulated data which are more robust than empirical frequency estimates.

Daily precipitation quantiles are defined as the magnitude of events with a specified probability of occurrence. Based on the simulated 20-year time slices, parameters of the Generalized Extreme Value (GEV) distribution are fitted using the method of L-moments (Hosking and Wallis, 2005) and used to develop parametric estimates of extreme precipitation quantiles. The L-moment approach is often used with limited sample sizes since it is relatively robust in comparison to other quantile estimation methods when used on small samples.

For each of the project locations, annual daily maximum rainfall quantiles were estimated for recurrence intervals of 2, 5, 10 and 25 years, to permit a more systematic comparison of changes in the projection period relative to the (simulated) historical. These results will be presented along with the simple statistics.

Dak Lak Project Location:

Table 9a: Projected Changes in Precipitation Extremes, Dak Lak Site

Dak Lak 1	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical					
mean	69.6	85.9	90.5	69.9	61.1	75.4
st dev	17.6	32.1	44.2	41.1	28.1	
max	107.3	160.5	169.7	161.5	142.6	148.3
	Projection					
mean	77.8	86.3	78.0	96.6	86.7	85.1
st dev	34.0	29.4	35.4	53.8	37.4	
max	165.4	164.4	189.7	246.2	196.2	192.4
	Difference					
mean	8.2	0.4	-12.6	26.8	25.6	9.7
st dev	16.3	-2.7	-8.8	12.7	9.3	
max	58.1	3.9	20.0	84.7	53.7	44.1

Table 9b: Projected Changes in Precipitation Extremes, Dak Lak Site

Dak Lak 2	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical					
mean	72.4	89.3	93.5	66.4	60.8	76.5
st dev	28.9	27.3	51.2	30.6	21.3	
max	129.7	158.6	225.8	130.2	104.7	149.8
	Projection					
mean	79.0	106.4	87.5	98.0	86.2	91.4
st dev	23.4	56.7	54.2	56.8	32.1	
max	124.7	233.7	282.0	254.7	155.2	210.1
	Difference					
mean	6.5	17.0	-6.0	31.6	25.4	14.9
st dev	-5.4	29.3	3.0	26.2	10.8	
max	-5.0	75.1	56.3	124.4	50.5	60.2

The five GCMs are relatively consistent in simulating both mean annual and series maximum daily precipitation. Although not all models agree with the direction of change, the majority of model results suggest increases in both annual average and more extreme daily precipitation events as a consequence of climate change in the region. For the Western project site (Dak Lak 1) annual average maximum precipitation is projected to increase by around 13%, while (empirical) one-in-20 year maximum daily precipitation increases by around 30%, which is substantial. For the Eastern pixel (Dak Lak 2) the corresponding changes are slightly larger: 20% for annual daily maxima and 40% for 20-year maxima.

An analysis based on GEV quantiles provides additional information on the likely changes in precipitation extremes. In the Western project area, daily maximum precipitation quantiles from 2 to 25 years are projected to increase by around 11% to 14%, averaging across individual GCM results. Note that there is considerable variation across GCMs, with some (e.g., MIROC5) projecting decreases relative to historical and some (e.g., CanESM2) projecting very large increases. Note also that the largest event in the (simulated) historical period, 148 mm/day, corresponds with a 25-year event.

Projected changes in the Eastern part of the project zone (Dak Lak 2) are larger, ranging from 13% to 29%, averaging across GCM results. Again, there is considerable variation across GCMs, with some (e.g., MIROC5) projecting decreasing daily precipitation intensity.

Table 10a: Estimated Annual Daily Maximum Precipitation Quantiles, Dak Lak Site

Dak Lak 1	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical (1986-2005)					
2 Year	68.2	77.3	82.4	58.7	54.0	68.1
5 Year	84.7	105.8	123.1	95.0	78.1	97.3
10 Year	94.1	128.0	150.7	123.4	96.7	118.6
25 Year	104.5	160.5	186.2	165.3	123.6	148.0
	Projected (2041-2060)					
2 Year	70.0	78.4	67.5	83.8	79.1	75.7
5 Year	100.5	103.7	94.1	131.7	112.2	108.4
10 Year	122.8	123.7	117.3	167.3	135.6	133.3
25 Year	153.7	153.3	154.6	217.4	166.9	169.2
	Change (% of Historical)					
2 Year	2.6%	1.4%	-18.0%	42.7%	46.3%	11.2%
5 Year	18.6%	-2.0%	-23.5%	38.6%	43.7%	11.4%
10 Year	30.4%	-3.4%	-22.2%	35.5%	40.3%	12.4%
25 Year	47.1%	-4.5%	-16.9%	31.5%	35.0%	14.3%

Table 10b: Estimated Annual Daily Maximum Precipitation Quantiles, Dak Lak Site

Dak Lak 2	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical (1986-2005)					
2 Year	67.4	85.0	79.2	62.5	57.5	70.3
5 Year	94.6	110.0	121.7	91.1	77.4	99.0
10 Year	112.6	126.2	156.1	108.7	90.1	118.8
25 Year	135.2	146.3	208.6	129.6	105.8	145.1
	Projected (2041-2060)					
2 Year	78.8	86.4	70.4	82.3	80.1	79.6
5 Year	100.1	126.4	106.0	131.4	109.5	114.7
10 Year	110.9	164.9	139.6	170.4	129.7	143.1
25 Year	121.6	233.4	198.4	228.8	156.0	187.6
	Change (% of Historical)					
2 Year	16.9%	1.5%	-11.1%	31.7%	39.2%	13.2%
5 Year	5.8%	14.9%	-12.9%	44.2%	41.5%	15.9%
10 Year	-1.5%	30.6%	-10.6%	56.8%	43.9%	20.5%
25 Year	-10.0%	59.5%	-4.9%	76.6%	47.4%	29.3%

Dak Nong Project Location:

Table 11a: Projected Changes in Precipitation Extremes, Dak Nong Site

Dak Nong 1	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical					
mean	62.3	80.4	75.0	57.4	52.1	65.4
st dev	25.0	26.7	29.1	28.3	20.1	
max	126.7	124.0	160.0	132.6	115.2	131.7
	Projection					
mean	67.0	96.6	68.0	74.8	83.4	78.0
st dev	21.8	30.1	29.1	39.3	30.4	
max	123.0	160.6	141.2	180.8	154.2	152.0
	Difference					
mean	4.7	16.2	-7.0	17.4	31.3	12.5
st dev	-3.2	3.5	0.1	11.0	10.3	
max	-3.7	36.7	-18.9	48.2	39.0	20.3

Table 11b: Projected Changes in Precipitation Extremes, Dak Nong Site

Dak Nong 2	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical					
mean	64.9	79.2	73.9	57.8	53.0	65.7
st dev	24.3	25.8	28.3	29.3	21.0	
max	125.0	122.6	146.4	126.6	119.1	127.9
	Projection					
mean	70.4	93.6	67.8	75.3	83.2	78.0
st dev	23.6	28.3	29.1	39.5	30.7	
max	132.3	144.2	153.8	180.7	157.9	153.8
	Difference					
mean	5.6	14.4	-6.1	17.6	30.1	12.3
st dev	-0.8	2.4	0.8	10.2	9.7	
max	7.3	21.6	7.4	54.2	38.8	25.8

Results at Dak Nong are in many ways similar to Dak Lak. Most (but not all) models project increases in precipitation intensity both for annual average maximums and for period maximum. Annual maxima are projected to increase by around 20% (mean of GCMs) in both East and West. Period maxima are projected to increase by about 15% in the Western part of the project region, and around 20% in the Eastern part. Projections are, again, reasonably consistent across models.

A quantile-based analysis indicates somewhat larger increases at all recurrence intervals than in Dak Lak. Quantiles increase by around 18% - 20% (mean of GCMs), although once again there are individual models that indicate reductions in daily peak precipitation intensity. The GCM MIROC5 characteristically simulates decreasing precipitation intensity, although when averaged these are offset by the very large increases projected by CannESM2, up to 70% at all recurrence intervals.

Table 12a: Estimated Annual Daily Maximum Precipitation Quantiles, Dak Nong Site

Dak Nong 1	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical (1986-2005)					
2 Year	56.0	74.9	69.6	49.4	46.4	59.3
5 Year	77.6	99.5	95.5	73.7	62.0	81.7
10 Year	94.1	116.7	113.3	93.3	75.1	98.5
25 Year	118.0	139.5	136.4	122.8	95.7	122.5
	Projected (2041-2060)					
2 Year	62.5	95.1	60.0	63.0	77.4	71.6
5 Year	82.4	122.8	85.6	94.6	105.6	98.2
10 Year	96.4	137.9	105.7	121.5	125.1	117.3
25 Year	115.0	153.8	135.7	164.2	150.7	143.9
	Change (% of Historical)					
2 Year	11.5%	27.0%	-13.8%	27.5%	66.7%	20.8%
5 Year	6.2%	23.5%	-10.4%	28.4%	70.3%	20.3%
10 Year	2.4%	18.2%	-6.7%	30.3%	66.6%	19.1%
25 Year	-2.6%	10.2%	-0.5%	33.7%	57.5%	17.5%

Table 12b: Estimated Annual Daily Maximum Precipitation Quantiles, Dak Nong Site

Dak Nong 2	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical (1986-2005)					
2 Year	59.3	73.9	68.2	49.9	47.5	59.8
5 Year	81.2	97.6	94.0	76.0	64.5	82.7
10 Year	97.2	114.1	112.0	96.2	78.1	99.5
25 Year	119.2	136.0	135.8	125.8	98.8	123.1
	Projected (2041-2060)					
2 Year	66.8	90.9	59.5	63.7	77.9	71.8
5 Year	88.4	117.5	83.9	96.8	106.3	98.6
10 Year	102.3	133.0	103.8	124.1	125.1	117.7
25 Year	119.6	150.4	134.3	166.4	148.8	143.9
	Change (% of Historical)					
2 Year	12.6%	23.0%	-12.8%	27.7%	64.1%	20.1%
5 Year	8.9%	20.4%	-10.8%	27.4%	64.9%	19.3%
10 Year	5.3%	16.5%	-7.3%	29.0%	60.1%	18.2%
25 Year	0.3%	10.5%	-1.1%	32.2%	50.6%	16.8%

Gia Lai Project Location:

Table 13: Projected Changes in Precipitation Extremes, Gia Lai Site

Gai Lai	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical					
mean	74.5	107.4	119.7	72.6	68.6	88.6
st dev	32.7	47.0	61.6	34.7	37.9	
max	141.5	208.8	271.5	159.4	168.4	189.9
	Projection					
mean	93.8	96.1	95.5	106.9	91.1	96.7
st dev	29.5	36.0	64.3	61.2	41.2	
max	161.7	180.2	339.8	224.6	201.1	221.5
	Difference					
mean	19.3	-11.3	-24.2	34.2	22.5	8.1
st dev	-3.2	-11.0	2.8	26.5	3.3	
max	20.2	-28.6	68.4	65.2	32.7	31.6

Changes in Gia Lai are consistent with other project sites: annual maxima increasing by around 10% and period maxima by around 16% (mean of GCMs). Quantile analysis indicates relatively modest increases on average across models, ranging from 12% for 2-year events down to only 4% for 25-year events. MIROC5, which has projected decreasing intensity of precipitation at most project sites, presents significant decreases of almost 30% at Gai Lai, although other models (e.g., GFDL) project very large increases.

Table 14: Estimated Annual Daily Maximum Precipitation Quantiles, Gia Lai Site

Gai Lai	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical (1986-2005)					
2 Year	65.9	96.7	106.0	64.3	56.9	78.0
5 Year	95.3	139.7	161.9	94.7	87.8	115.9
10 Year	117.8	170.9	202.2	117.5	114.2	144.5
25 Year	150.3	213.7	257.1	149.9	156.3	185.5
	Projected (2041-2060)					
2 Year	94.2	89.0	76.8	95.0	81.8	87.4
5 Year	119.9	122.5	116.9	152.2	118.6	126.0
10 Year	132.5	145.5	154.3	191.2	145.4	153.8
25 Year	144.7	175.6	219.2	241.9	182.3	192.7
	Change (% of Historical)					
2 Year	42.9%	-7.9%	-27.6%	47.8%	43.8%	12.1%
5 Year	25.8%	-12.3%	-27.8%	60.7%	35.1%	8.8%
10 Year	12.5%	-14.9%	-23.7%	62.7%	27.3%	6.4%
25 Year	-3.8%	-17.8%	-14.8%	61.4%	16.6%	3.9%

Kon Tum Project Location:

Table 15a: Projected Changes in Precipitation Extremes, Kon Tum Site

Kon Tum 1	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical					
mean	78.1	108.5	103.5	89.2	72.2	90.3
st dev	32.7	42.5	47.1	46.1	43.0	
max	148.2	219.8	223.1	195.7	163.6	190.1
	Projection					
mean	94.3	124.0	91.3	144.2	120.0	114.8
st dev	42.4	56.4	37.5	88.7	92.5	
max	177.9	251.8	179.3	379.4	401.8	278.0
	Difference					
mean	16.2	15.4	-12.2	55.0	47.7	24.4
st dev	9.7	14.0	-9.7	42.7	49.5	
max	29.7	32.0	-43.8	183.7	238.2	88.0

Table 15b: Projected Changes in Precipitation Extremes, Kon Tum Site

Kon Tum 2	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical					
mean	82.4	111.0	106.8	94.4	76.8	94.3
st dev	37.2	47.0	51.5	52.1	45.7	
max	165.7	233.9	228.5	221.8	171.7	204.3
	Projection					
mean	98.6	125.2	96.1	150.3	122.7	118.6
st dev	44.7	57.3	44.3	88.4	97.8	
max	176.9	250.5	202.1	361.9	434.0	285.1
	Difference					
mean	16.3	14.3	-10.7	55.9	45.8	24.3
st dev	7.5	10.4	-7.2	36.4	52.1	
max	11.2	16.5	-26.4	140.1	262.4	80.8

The highest simulated daily precipitation intensities, and the greatest projected increases in intensity are found in the Kon Tum subproject area. Period maxima of 190 (West) to 200 (East) mm/day are simulated, and projected increases in annual mean maximum precipitation are around 26% to 27% (mean of models). For the period maximum, increases range from 40% (East) to 46% (West).

Quantile analysis also indicates significant increases in precipitation intensity, both in East and West pixels, of around 24% for two-year events up to almost 36% for 25-year events. In this location, variation across GCMs is also extreme. While MIROC 5 (predictably) projects decreasing peak daily precipitation intensity, other models project increases of up to 80% for the 25-year event.

Table 16a: Estimated Annual Daily Maximum Precipitation Quantiles, Kon Tum Site

Kon Tum 1	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical (1986-2005)					
2 Year	72.4	97.4	93.7	79.3	58.6	80.3
5 Year	103.2	133.5	137.1	121.9	92.6	117.7
10 Year	123.5	161.8	167.5	152.1	122.3	145.4
25 Year	149.1	203.6	208.1	192.5	170.7	184.8
	Projected (2041-2060)					
2 Year	84.1	116.0	86.9	122.9	86.5	99.3
5 Year	122.7	169.1	121.6	202.4	140.9	151.3
10 Year	151.2	202.3	142.7	261.6	197.9	191.1
25 Year	191.1	242.4	167.2	344.6	307.8	250.6
	Change (% of Historical)					
2 Year	16.1%	19.2%	-7.2%	55.0%	47.4%	23.7%
5 Year	18.9%	26.7%	-11.3%	66.0%	52.1%	28.6%
10 Year	22.4%	25.0%	-14.8%	72.0%	61.7%	31.4%
25 Year	28.1%	19.0%	-19.6%	79.0%	80.3%	35.6%

Table 16b: Estimated Annual Daily Maximum Precipitation Quantiles, Kon Tum Site

Kon Tum 2	NorESM1-M	MPI_ESM-MR	MIROC5	GFDL_ESM2M	CanESM2	Mean
	Historical (1986-2005)					
2 Year	76.5	97.4	95.2	81.2	63.3	82.7
5 Year	111.6	136.4	142.3	128.1	101.3	123.9
10 Year	134.2	168.5	176.2	163.7	133.0	155.1
25 Year	162.0	218.0	222.5	214.4	182.3	199.8
	Projected (2041-2060)					
2 Year	88.1	117.7	87.2	130.6	87.9	102.3
5 Year	128.7	171.4	126.5	211.5	147.9	157.2
10 Year	158.6	204.6	154.1	269.7	209.2	199.2
25 Year	200.2	244.1	190.9	349.1	324.7	261.8
	Change (% of Historical)					
2 Year	15.1%	20.8%	-8.4%	60.8%	39.0%	23.7%
5 Year	15.3%	25.7%	-11.1%	65.1%	46.0%	26.8%
10 Year	18.2%	21.4%	-12.5%	64.8%	57.3%	28.5%
25 Year	23.6%	12.0%	-14.2%	62.8%	78.1%	31.0%

Two observations can be made on the basis of this analysis. First, the intensity of extreme precipitation events has the potential to increase in this region, and possibly by significant amounts. The second observation is that GCM-simulated changes cover a wide range of projections, encompassing both negative and positive projected changes, making it difficult to make unequivocal statements about future climate hazards in this area. One GCM in particular (MIROC5) is consistent in its projections of decreasing intensity, while other models, with equal consistency, project significant or large increases.

In the absence of specific information on the relative skill of individual models in simulating key attributes of regional climate, it is accepted practice to view all members of a GCM ensemble as equally credible. Re-stated, projections generated by different GCMs under common assumptions (such as GHG emissions trajectories) are viewed as equally likely future states of the world. Under these circumstances, risk management requires that attention be paid to the more “difficult” projections, those that project conditions which would be the most challenging to adapt to.

Projected changes in Kon Tum are of particular concern. In this subproject area, the terrain is often steep, and road grades require extensive excavation, leaving relatively steep slopes adjacent to roadways. Steep terrain is also more likely to generate severe flooding that can develop very rapidly. Kon Tum is also the location of many of the largest projected increases in precipitation intensity. In combination with the region’s steep terrain and frequent stream crossings, both flash flooding and slope de-stabilization could be increasing concerns in this sub-project area.

4.4 Implications of Increasing Temperature and Precipitation Extremes on Paving Materials

The primary risks to paving materials associated with temperature extremes are related to the fact that asphalt pavement behaves differently at different temperatures. If temperatures experienced by road surfaces exceed those used in design assumptions, particularly for prolonged periods, pavement can deteriorate due to liquidation of bitumen. As a result, the pavement may be subject to rutting, heaving, longitudinal cracking and/or fatigue cracking or otherwise degrade in the short run, and in the long run the design lifetime of the road surface may be reduced relative to its potential assuming design assumptions were correct (Qiao et al., 2013).

Heat-related degradation of asphalt may be exacerbated by increases in the frequency and/or intensity of high-intensity rainfall events. Water may enter sub-grade through new cracks in the asphalt, and unpaved shoulders may erode from local flooding, further weakening the asphalt surface. Excess water can also cause loss of adhesion (stripping) between asphalt and the underlying aggregate (Willway et al., 2008). Concrete pavement is less susceptible to damage from elevated temperatures.

The following is a preliminary examination of the vulnerability of the proposed road renovations, specifically paving materials, based on descriptions of these materials found in technical project documentation.[8]

Kon Tum:

“The road will be built ***in cement concrete*** (emphasis added) and will serve Ia H’Drai District whose population is predominantly ethnic minority and where the poverty rate is high. It will enable year-round access for rubber plantations and cassava cropping and is expected to lead to increased agricultural production generating additional employment.”

Gia Lai:

“The Subproject upgrades 65.87km of provincial road No.665 to Vietnamese Standard Road Grade IV – Mountainous - with the surface width of 5.5 m and base width of 7.5 m. ***The road***

[8] Verbatim from EconomicAnalysisDL.doc

surface material is asphalt concrete (emphasis added) with design speed of 40 km/h. The road provides a strategic east-west connection from NR 14 at Phu My Junction to NH 14C in the west and border post 729 (Gia Lai – Cambodia Border). The project road serves the districts of Chu Prong. Chu Prong is the biggest rubber producing district and second biggest coffee producer in Gia Lai. It is also high ranking in the production of the other export crops. The ethnic minority proportion, at 47% and the incidence of poverty at 12.4% are high, but not the highest in the province."

Dak Lak:

"The subproject in Dak Lak will upgrade NH-29. The subproject will upgrade 40km of National road No.29 to Vietnamese Standard Road Grade III – Mountainous (TCVN 4054-05) with the surface width of 7.5 m and base width of 9.0 m. ***The road surface material is asphalt concrete***. (emphasis added) The designation as NH29 for what is currently a minor provincial road reflects the Province's intention that this will form part of an eventual link from the Cambodian border at Dak Rue to the east coast port of Nha Trang. The section being improved under the project is of particular significance for Dak Lak province and primarily serves Cu M'Gar district, although it passes through the district of, Krong Buk and serves Ea Sup district indirectly. Cu M'Gar is the province's biggest coffee producer, it also is one of the larger producers of rubber, cashew and pepper. With Kong Buk it has one of the highest proportions of ethnic minorities and median level poverty within the province."

Dak Nong:

"The subproject in Dak Nong will upgrade the provincial road from NR No.14 to Bu Prang Border Gate (Section Km3-Km17 of PR No.686 and Section from Tuy Duc District Center to Dak Huyt Bridge) – Dak Nong Province. The Subproject will upgrade about 44 km to connect National Road No.14 (at Km817) to the end point at Bu Prang Border Gate, Tuy Duc district. The subproject will goes through the area of Nam N'Jang; Dak N'Drung communes – Dak Song district and Dak Buk So; Quang Truc communes in Tuy Duc district. Dak Song is the largest coffee and pepper producing district, while Tuy Duc and Dak Song have the second and third highest poverty rate respectively for the province." (no specific mention of paving materials).

Binh Phuoc:

"The Subproject in Binh Phuc will upgrade 50.3 km of provincial road No.756 to Grade III – Mountain in accordance with TCVN 4054:2005. The road links the productive agricultural districts of Loc Ninh, Chon Thanh and Hon Quan with Hoa Lu and Hoang Dieu border crossings in the north and the main route to Ho Chi Minh City in the south. The start point is the Minh Lap junction with National Road No14 in Chon Thanh district. It goes through Minh Lap commune – Chon Thanh district; Tan Hung, Tan Loi, Thanh An communes – Hon Quan district; Loc Quang, Loc Phu, Loc Hiep communes – Loc Ninh district. The end point is the junction with provincial road No. 759B at the center of Loc Hiep commune at a distance of 22 and 31 km to Hoa Lu and Hoang Dieu international border gates respectively. The districts served by the road account for 47% and 53% of the province's rubber and pepper production respectively and 45% of the ethnic minorities." (no specific mention of paving materials).

In the same document, the following addresses “Selection of Options” for paving materials and design” (paragraph references removed):

“Two road pavement options were selected for testing and were compared with a do minimum option that assumed general maintenance but no major work. Incremental analysis was used to compare the options. Under incremental analysis, a more expensive option is favored if comparing the incremental benefits to the incremental costs gives a return greater than the target 12%.

“The options for all except Kon Tum were:

(i) Single asphalt concrete layer: for new work or where the existing pavement is completely replaced, the pavement would be formed using a single asphalt layer with two layers of crushed stone base course. Where the new pavement is on top of an existing pavement, the crushed stone layers are reduced depending on the calculated strength of the existing.

(ii) Double asphalt layer: As above, but with separate asphalt concrete base course and wearing course layers. The crushed stone layer is consequently reduced.

“For the Kon Tum road, three options were tested being:

(i) surface dressing (3cm bituminous surface),

(ii) single layer asphalt concrete and

(iii) cement concrete.”

As noted in Sections 4.2 and 4.3 above, the Kon Tum sub-project is exposed to the greatest risks, and the greatest projected increases in risks, from both extreme temperatures and extreme precipitation. The first two options identified, (i) 3 cm bituminous surface dressing and (ii) single layer asphalt concrete, are both inherently sensitive and thus potentially vulnerable to projected changes in extreme temperatures. (option 3, cement concrete paving, is relatively insensitive to changes in extreme temperatures, at least within the range projected). Recalling (Section 4.2) that temperatures by mid-21st century may exceed 40 ^{o}C on occasion, it is recommended that the selection of paving materials and their technical specification be informed and guided by climate change projections on the order of those presented in Section 4.2.

A noted in Section 4.3, the Kon Tum subproject area may be subject to significant increases in the intensity of peak precipitation events. Some projections have the 25-year daily maximum precipitation event increasing by almost 80% relative to the historical baseline, and even the mean of model projections suggests a 30% increase in the 25-year event by mid-century. Intense rainfall and associated damage to roadbeds and paving materials will exacerbate temperature-related stresses if not managed properly (see section following).

It is also important to acknowledge that the design lifetime of the upgraded Provincial roads is not likely to extend to mid-century (2041-2060, the climate projection period) so that the temperatures in excess of 40 ^{o}C projected for that period may not have materialized before the next cycle of road upgrade occurs. As a result, for planning purposes the projections presented in Sections 4.2 and 4.3 likely represent relative upper bounds on the conditions which paving materials must accommodate.

4.5 Implications of Increasing Precipitation Intensity on Structure Design

The most dramatic among the projected impacts of climate change within the project is the potential for significant increases in design rainfall events. This is particularly true in the Kon Tum subproject area, as noted above.

Other factors exacerbating risks associated with increasingly intense precipitation in Kon Tum are steep topography and exposed embankments, both of which contribute to the intensity of local flash flooding given increased rainfall intensity. The design and effectiveness of both pavement composition and roadway configuration, and the design and capacity of drainage structures will largely determine the extent to which increases in heavy precipitation events lead to damage accelerated depreciation of road assets in Kon Tum.

Among aspects of road design potentially affected by changes in precipitation patterns are elevation of the sub-grade relative to the calculated groundwater level (Section 7.3.3 of the Design Code) and planning of the drainage facilities system (Section 9.1). Section 9.1 instructs that:

"… a master plan of completed drainage system should be done, including drainage facilities such as intercepting ditch, side ditch, and water receiving ditch, bridge, culvert, underground drain, pit, and evaporation pond etc., these facilities must cooperate closely to each other. Locations, dimensions of the drainage facilities must be reasonable and suitable with the regional drainage plan in order to ensure high effectiveness and low cost.

Arrangement of ditches and canals for subgrade drainage must ensure ability to receive and collect water in order to prevent water from running freely into the subgrade; must incorporate with arrangement of drainage culvert and bridge on the highway, and determine direction of runoff from ditch and canal draining to bridge, culvert or watercourses; methods for connecting drainage ditches with bridge, culvert or watercourses are necessary needed. In contrary, when arranging bridge, culvert, it's necessary to consider requirement of fast draining from ditches and canals.

Arrangement of the drainage facilities on the highway shall take irrigation and drainage requirements into consideration. At the same time flood drainage after highway construction must be considered as well."

Specific hydrologic design events are also specified for roadway structures including (i) embankments and protection works, (ii) large and medium bridges, (iii) small bridges and culverts and (iv) intercepting and side ditches. Design events are given in Table 17 (based on Table 30 of the Design Standards). The 100-year event is the design standard for major bridges in all road classes, and the 25-year event is the design standard for small bridges, culverts and intercepting ditches for class III roadways.[9]

[9] Note that sub-project roadways in Kon Tum will be upgraded to Vietnamese Standard Road Grade III – Mountainous, for which the 25-year design standard applies.

Table 17- Calculated Hydrological Frequency for Structures on the Highway (Unit is given in %)

Structures	Expressway	I, II	III to VI
Embankment, protection work	According to calculated frequency for bridges and culverts		
Large, medium bridges	1% (100 year)	1% (100 year)	1% (100 year)
Small bridges; culverts	1% (100 year)	2% (50 year)	4% (25 year)
Intercepting and side ditches	4% (25 year)	4% (25 year)	4% (25 year)

Source: Table 30 in Vietnam Design Standards (full citation required)

It is evident that structures designed for hydrologic events of 25 year recurrence interval (p=0.04) on the basis of retrospective (historical) hydro-meteorological records carry the risk of under—design if the increases in peak rainfall intensity projected by a range of GCMs for the region materialize within the project design lifetime. A general recommendation of this CRVA is that the calculation of the design event (in most instances it will be the 25-year event) should reflect the evidence presented in Section 4.3. In the Kon Tum subproject area, it would be prudent to increase the design event calculated on the basis of historical information by at least 20% and possibly higher, since small bridges and culverts have design lifetimes that exceed the road pavement, likely by decades.

A partial survey of the Provincial road upgrading in Kon Tum indicated that many of the drainage structures for this roadway have already been constructed. Figure 9 shows one such structure. While this particular structure appears to possess robust discharge capacity, the basis on which it was designed (magnitude of design event, upstream contributing area) is not known, so that it is not clear that it would function to prevent local flooding of the roadway if the design event increased by more than e.g., 35% relative to historical assumptions.

Figure 9: Circular Culvert on PR 675 A, Kon Tum Subproject Area

4.6 Implications of Increasing Precipitation Intensity on Soil and Slope Stability

A third aspect of the proposed road upgrading project that is vulnerable to the projected changes in temperature and precipitation extremes described in Sections 4.2 and 4.3 is the slopes and embankments associated with the roadway. The primary concern is an increase in the erosive power of precipitation of increasing intensity. There are additional concerns that are linked to the potential for drought events to increase in frequency, duration and/or intensity within the project area, leading to adverse consequence for the management of slope vegetative cover (see Figure 8).

(to be completed)

V. Recommendations for Design

(to be completed)

The goal of the adaptation assessment is to identify and prioritize the most appropriate and cost-effective adaptation measures to incorporate into the project. These can include:

- Modifications in project location and/or scale
- Modifications in engineering materials and designs
- Alternative technology choices
- Biophysical- and Ecosystem-based measures
- Community-based adaptation
- Policy and Social options (institutional re-design)
- Business-as-usual (“do nothing”)

In many project settings, a combination of approaches may be most effective

VI. Next Steps

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APPENDIX A – HISTORICAL METEOROLOGICAL DATA FOR THE PROJECT AREA

STATIONS	LON	LAT	HEIGHT (m)	Average Annual Rain	Min. Annual Rain	Year	Max. Annual Rain	Year	Heaviest Daily Rainfall	Year	Day of year
DAKTO	107.83	14.65	620	1845.2	777.6	2010	2430.5	1999	254.9	2009	272
KONTUM	108.00	14.33	536	1881.2	1189.2	1991	2521.1	2004	157.9	2004	138
YALY	107.75	14.20	547	1845.3	1149.4	2002	2728.8	2011	137.2	2004	175
PLEIKU	108.02	13.97	779	2232.7	1452.3	1998	3094.5	1984	227.8	1979	172
ANKHE	108.65	13.95	422	1546.8	685.4	1982	2238.0	1998	240.8	1987	323
AYUNPA	108.45	13.38	159	1284.2	786.1	2001	1766.2	1983	250.5	1980	306
EAHLEO	108.20	13.22	615	1925.1	1155.7	2003	3093.1	2009	207.4	2007	217
BUONHO	108.27	12.92	707	1548.7	1128.9	2012	1971.5	2009	280.5	2007	217
MDRAK	108.77	12.73	419	2103.9	915.1	1982	4227.0	2008	443.4	1996	323
BMTHUOT	108.05	12.67	470	1883.4	1348.0	2004	2599.8	1981	285.6	2006	179
DAKMIL	107.62	12.45	760	1862.5	1299.0	2004	2340.6	2007	137.9	2003	123
LAK	108.20	12.37	423	1999.4	1311.6	2004	2575.5	2009	264.5	2000	283
DAKNONG	107.68	12.00	631	2574.5	1939.2	2010	3775.1	1999	489.1	1986	136
DALAT	108.45	11.95	1509	1814.0	1431.5	1998	2382.1	1997	113.9	1997	283
LIENKHUONG	108.38	11.75	957	1586.4	1162.0	2008	1981.9	1983	122.4	1998	136
BAOLOC	107.82	11.53	841	2923.7	2196.0	1986	5272.1	1998	235.7	2000	227
EAKMAT	108.13	12.68	516	1895.2	1194.8	2003	2602.4	1998	690.0	2011	207
P-BANDONTV	107.73	12.90	-99	1343.0	530.3	2001	1930.6	1987	157.8	1982	238
P-BIENHO	108.02	14.05	-99	1938.3	1378.5	1992	2341.2	1983	169.6	1985	215
P-CAU14TV	107.93	12.62	-99	1701.5	1168.4	2001	2292.4	1981	194.4	1993	277
P-CHUPRONGBD	107.85	13.65	-99	2327.5	1411.2	2002	3765.4	1984	357.2	1979	226
P-CHUSE	108.08	13.70	-99	1614.8	987.5	1979	2675.6	1984	175.0	1986	232
P-DAKGLEI	107.73	15.07	-99	1517.7	1089.8	1987	2394.0	1991	191.2	1994	265
P-DAMRONG	108.27	12.17	-99	1896.3	1362.3	1994	2297.7	1996	142.3	1996	316
P-DANHIM	108.58	12.12	-99	1689.2	641.3	1986	2441.8	1991	106.5	1993	111
P-DATEH	107.5	11.57	-99	3092.0	2398.6	1993	5202.0	1981	252.1	1987	233
P-DUCXUYENTV	107.83	12.30	-99	1913.1	1383.9	1991	2403.7	1992	137.3	1990	167
P-EAHDINH	108.04	12.89	-99	1764.7	1486.3	1994	2063.7	1993	217.7	1993	277
P-EAKNOP	108.45	12.80	-99	1450.4	801.7	1989	2258.6	2001	287.2	1993	276
P-EASUP	107.88	13.07	-99	1573.1	1090.9	1994	2225.6	1990	149.5	1993	276
P-GIANGSONTV	108.2	12.50	-99	1891.6	1246.3	1991	2469.8	1995	243.4	1993	277
P-KBANG	108.62	14.17	-99	1614.8	987.5	1979	2675.6	1984	175.0	1986	232
P-KONPLONGTV	108.2	14.47	-99	1822.0	1286.7	1982	2567.0	1979	170.0	1985	314
P-KRONGBUKTV	108.38	12.77	-99	1433.0	1090.7	1997	1783.5	1998	241.0	1993	277
P-KRONGPA	108.7	13.30	-99	1179.8	440.1	1999	2103.7	2001	296.0	1980	306
P-NAMBAN	108.33	11.85	-99	1704.6	1024.0	1980	3089.6	2006	154.5	2007	303
P-POMORETV	108.35	14.03	-99	1862.7	1273.2	1995	2406.6	1981	227.0	1988	291
P-SATHAY	107.78	14.42	-99	1778.7	965.1	1999	2429.5	1997	161.5	1993	240
P-SUOIVANG	108.37	11.98	-99	2069.1	1648.0	1992	2640.9	1979	126.9	1980	230
P-THANHBINHTV	108.3	11.77	-99	1581.8	1057.8	1996	2203.0	1979	108.3	1981	109
P-THANHMYTN	108.5	11.77	-99	1290.7	940.3	1995	1876.3	1983	217.5	1979	322
P-THON4	108.13	14.00	-99	1614.8	987.5	1979	2675.6	1984	175.0	1986	232
P-XALAT	108.42	12.05	-99	2061.0	1275.6	1983	3008.2	1989	270.5	1992	227

APPENDIX 2 - Representative Concentration Pathways

The Representative Concentration Pathways (RCP) are not new fully integrated scenarios unlike SRES, i.e. they are not a complete package of socioeconomic, emissions, and climate projections (Collins et al, 2013). They are consistent sets of projections of only the components of radiative forcing (the change in the balance in between incoming and outgoing radiation to the atmosphere caused primarily by changes in atmospheric composition) that are meant to serve as input for climate modelling. Central to the process is that any single radiative forcing pathway can result from a diverse range of socioeconomic and technological development scenarios. Four RCPs were selected, defined and names according to their total radiative forcing in 2100 and are described in table A2.

RCP	Description
RCP8.5	Rising radiative forcing (RF) pathway leading to 8.5Wm^{-2} in 2100 and implies rising RF beyond that.
RCP6	Stabilization without overshoot pathway to 6Wm^{-2} at stabilization after 2100.
RCP4.5	Stabilization without overshoot pathway to 4.5Wm^{-2} at stabilization after 2100.
RCP2.6 or RCP 3-PD2	Peak in radiative forcing at approximately 3Wm^{-2} before 2100 and decline.

Table A2. Overview of Representative Concentration Pathways (Source: https://www.wmo.int/pages/themes/climate/emission_scenarios.php).