Project Climate Risk Assessment and Management

I. Basic Project Information

Project Title: Yunnan Pu'er Regional Integrated Road Network Development Project
Project Budget: ADB financing $200 million, Total cost of Project $589.53 million
Location: People's Republic of China, Yunnan Province
Sector: Road Transport (non-urban)
Theme: Inclusive economic growth, Regional co-operation and integration and inclusive growth
Brief Description: The project will (i) upgrade two regional roads servicing national borders (rehabilitation of 234.07 kilometres (km) of the Ning'er-Jiangcheng-Longfu road and rehabilitation of 48.75 km of the Menglian-Meng'a road; (ii) upgrade 600 km of rural roads to Class IV standard; (iii) involve a spot improvement program to ensure all weather access for 1200km of village roads connected to the project rural roads; (iv) pilot village based public transport services; (v) introduce a gender focused rural roads maintenance program; and (vi) strengthen institutional capacity of the project stakeholder agencies. The road upgrades and transport services will be the project components most vulnerable to climate change effects projected for Yunnan province.

II. Summary of Climate Risk Screening and Assessment

A. Sensitivity of project component(s) to climate/weather conditions and sea level The project area is mountainous characterized by steep slopes and erosion prone soil and is already at high risk from flood, landslide and debris flow during the rainy season. Climate change impacts are likely to compound existing issues, particularly during the rainy season, project components and key climate sensitivities are likely to include:	
Project component: 1. Design of road pavement, 2. Design of slopes, 3. Design of bridges and culverts, 4. Design of drainage, and 5. Maintenance and operation.	Sensitivity to climate/weather conditions and sea level: 1. Winter and summer temperature extremes; 2. Change in peak flood level, intensity and frequency of rainfall; 3. Increased debris loading; and 4. Increased risk of erosion and landslide.
B. Climate Risk Screening Initial climate risk screening was carried out using AWARE for Projects and climate change risk was identified as high particularly in relation to temperature and precipitation increase and increased risk of flooding and landslide. In addition, an EARD study of climate change risk in Yunnan determined that the province is at high risk of increased temperature (2051-60), greater variability in precipitation, severe storms, floods and droughts (2031-60). The risk screening identified that there is potential for an increase in incidences where current design standards will not be sufficient and that a more detailed climate change risk and vulnerability assessment should be carried out to further identify the nature and level of risk and to integrate measures to manage these risks.	
Risk topic: 1. Temperature increase, 2. Rainfall increase, 3. Increased frequency and intensity of rainfall and increased risk of flood and debris loading, and 4. Increased landslide risk.	Description of the risk 1. Pavement and slopes may be at increased risk of failure; 2. Bridge, culvert and drainage design standards calculated using historic climate data may not have sufficient capacity for projected increases in rainfall intensity and volume; 3. Infrastructure may experience faster weathering and require a more regular maintenance regime; and 4. Severe weather events may result in increased incidence

	of disruption of transport services and there may be a need to improve response planning and capacity.

Climate Risk Classification
High (Annex 1 includes AWARE climate risk screening report)

C. Climate risk assessment

A detailed climate risk and vulnerability assessment (CRVA) was funded ($35,000) through the ADB Climate Change Fund, see Annex 2 for Terms of Reference. The application was approved by RSES on 19 June 2014. The detailed CRVA report is included in Annex 3.

The CRVA analysed 40 of the IPCC Fifth Assessment Report General Circulation Models (GCMs). Baseline spatial climatology for the project areas was derived from the WorldCLIM Database which has a spatial resolution of 1 kilometre and site-specific climate conditions from the data from three hydrometeorological observation stations in the project area at Jiangcheng (closest to Ning'er-Jiangcheng-Longfu regional road), Lancang (closest road to Menglian-Meng'a regional road) and Simao (mid-way point). A pattern scaling method was adopted to build a model ensemble to project climate change impacts for the project area, the 50th percentile of the GCM model ensemble was used as the median projection for the future. Given the uncertainty of future greenhouse gas emission rates and climate sensitivity, the CRVA presents projections based on a range of future greenhouse gas scenarios. The median climate change projections are based on the IPCC Fifth Assessment Report Representative Concentration Pathway (RCP) 6.0, which represents mid-climate sensitivity. The low emissions scenario climate change projections are based on RCP4.5, which represents low-climate sensitivity and the high emissions scenario climate change projections are based on RCP8.5, which represents high-climate sensitivity (see Appendix 1 of the detailed report for a full explanation of RCPs). A general extreme value function was applied to the daily observations to investigate extreme rainfall and future changes. A statistical approach was adopted to explore the relationship between peak flow and rainfall of various durations from 1 day to up to 10 day rainfall prior to the peak flow. For the landslide/debris flow, a statistical relationship of 1 day and 6 day rainfall was used to simulate risk of change.

The following key projections were made:

(i) Applying the median projection, annual rainfall change in the area will likely be small, with an average increase of 2-3% by 2050 and 4-8% by 2100. However, severe, intense rainfall events are expected to significantly increase. The 1:50[1] and 1:100[2] year annual maximum daily rainfall of Lancang (closest observation station to Menglian-Meng'a Road) is projected to increase by 10% by 2050 and 19.5% by 2100. This has implications for flood discharge and height which are the key parameters that determine bridge height. Historic data was available for the Nanlei River at Menglian but not for other river catchments. A 10% increase of 1:100 year flood discharge will be 383.9m3/s, which corresponds to a flood height of 958.18 metres above sea level (masl) or a 0.15m increment on the current flood height at the Nanlei bridge location. The current design for the bridges crossing the Nanlei River near Menglian is based on the historic 1:100 year flood height with a 0.5 m factor of safety.

(ii) The current 1:50 year event of the annual maximum 1 day rainfall is 152.83 mm for Simao. The median projection for such an event is 168.34 mm by 2050 and 182.23 mm by 2100, with an associated 9.4% and 18.5% increase in rain intensity. In a high emissions scenario, maximum daily rainfall would increase to 183.75 mm and 222.17 mm for 2050 and 2100 respectively, with an associated rain intensity increase of 20.2% by 2050 and 45.4% by 2100. This change in rainfall intensity is much more significant than the change in maximum daily rainfall.

(iii) As heavy rainfall will become much more frequent, landslide/debris flow risk will significantly increase. Projections indicate that the 1 day rainfall risk[3] could increase by 56.4% by 2050 and 117.9% by 2100 and the 6 day rainfall risk will increase by 145.2% by 2010 and 260% by 2100.

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[1] 1:50 has a 2% probability of occurrence in any given year.
[2] 1:100 has a 1% probability of occurrence in any given year.
[3] The risk of landslide and debris flow increases as the duration and intensity of rainfall events increases.

(iv) The baseline 1:50 year annual maximum temperature is 42.1 ºC and minimum temperature -3.4ºC. An increase of 1.2ºC by 2050 and 2.3ºC by 2100 is projected for annual average air temperature. There will be little change in the difference between maximum and minimum temperature, both will slightly increase. Heat wave will become more intensified and frequent, as indicated by the 7 day average maximum temperature for the three observation stations in the project area, however, this is generally under 45ºC for most scenarios and still under 50ºC by the end of this century. High temperatures combined with humidity can result in asphalt bleeding and increased incidence of slope failure increasing requirements for maintenance.

The CRVA reviewed the key design standards adopted for the project. The projected changes in extreme rainfall and increased flood height imply that standards adopted as the basis of design may not be adequate. The incidence of flood, landslide and debris flow risk will increase which could result in damage to road surfaces, subgrade and slopes, bridges and culverts, and cause road closure and disruption of service.

III. Climate Risk Management Response within the Project

The CRVA recommended that the detailed design takes account of projected climate change impacts and considers adoption of the following adaptation options:

1. The detailed design for the bridges currently incorporates a factor of safety 0.5 m so is likely to be adequate for low and mid emissions scenarios and up to 2050, however, in the event of a high emissions scenario the 1:100 flood height may exceed the design standard by the end of the century. The detailed design of the river crossings should consider costs associated with increasing the factor of safety to take account of a potential high emission scenario to determine whether to adopt a higher flood height as the basis of design. This regional road includes 24 large and medium bridges, so detailed design will need to identify which bridges may be at increased flood risk and may need to adopt a higher factor of safety as basis of design. The design team has indicated that the cost of adopting a higher flood height will depend on the bridge type and number of piers. On average, approximately $1632/pier is expected for every meter bridge height increase. More detailed hydrological analyses will be carried out during the detailed design to determine the bridges at most risk and the need for adoption of higher factors of safety.

2. The design for stormwater drainage included a minimum 10% factor of safety over and above that inherent in the drainage design code. Projections indicate that this may not be adequate in the event of a high emissions scenario and beyond 2050. For any drainage components that would be difficult to replace or repair it is recommended that a higher factor of safety is adopted as the basis for design.

3. More and higher flood discharge may increase risk of damage of road infrastructure. Additional protection of slopes and subgrade may be needed in high risk areas. Detailed design will need to ensure that slope protection design takes account of future increased risk of landslide and debris flow hazards.

4. The Government should develop a comprehensive hydro-meteorological prediction system, early warning system and integrated climate and disaster risk management action plan to ensure that loss of life and damage to infrastructure are minimised and continuity of critical transport services are maintained during a severe weather event.

5. Watershed and ecosystem management are also key. The Government is implementing an ecosystem restoration program in Pu'er which includes planting of deep rooted vegetation in steep erosion prone areas and prohibiting cultivation on steep slopes. Improved ecosystem protection and management should in the long-term contribute to a reduced landslide risk.

These recommendations have been discussed with the Pu'er Municipal Government and the project detailed design team. The Government has agreed to take account of these recommendations in the detailed design and will confirm if/which measures are adopted and if there is an incremental cost of adaptation measures.

01

Introduction

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

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

Project Information

PROJECT NAME:	Yunan Pu'er Reg Int Road Network Dev
SUB PROJECT:	34 road sections
REFERENCE:	x
SECTOR:	Rural transport infrastructure
SUB SECTOR:	Road/ highway/ runway surface
DESCRIPTION:	

02

Chosen Locations

1) China
2) China
3) China
4) China
5) China
6) China
7) China
8) China
9) China
10) China
11) China

03 Project Risk Ratings

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

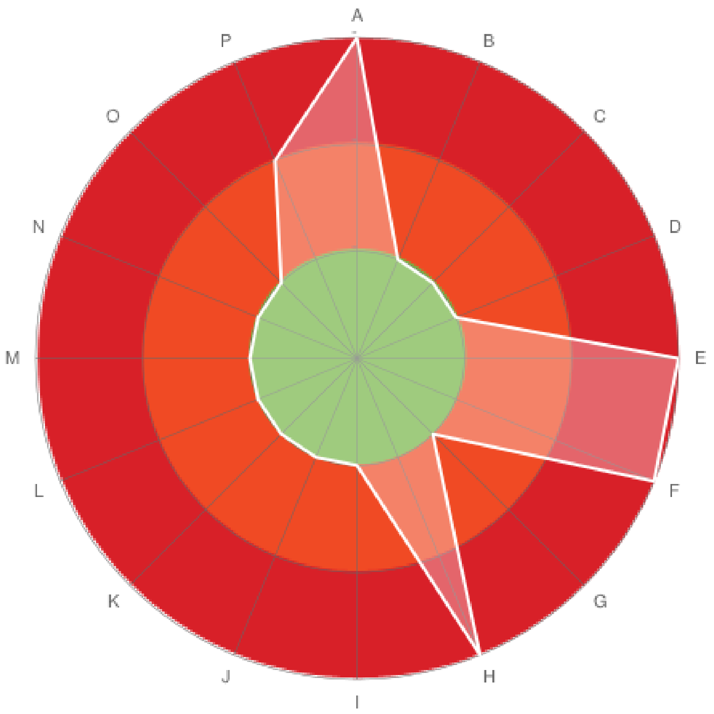
The radar chart provides an overview of which individual risks are most significant. This should be used in conjunction with the final rating to determine whether the project as a whole, or its individual components, should be assessed in further detail. The red band (outer circle) suggests a higher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

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

Final project risk ratings

High Risk

Breakdown of risk topic ratings



A) Temperature increase
B) Wild fire
C) Permafrost
D) Sea ice
E) Precipitation increase
F) Flood
G) Snow loading
H) Landslide
I) Precipitation decrease
J) Water availability
K) Wind speed increase
L) Onshore Category 1 storms
M) Offshore Category 1 storms
N) Wind speed decrease
O) Sea level rise
P) Solar radiation change

04

HIGH RISK

TEMPERATURE INCREASE

ACCLIMATISE COMMENTARY

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

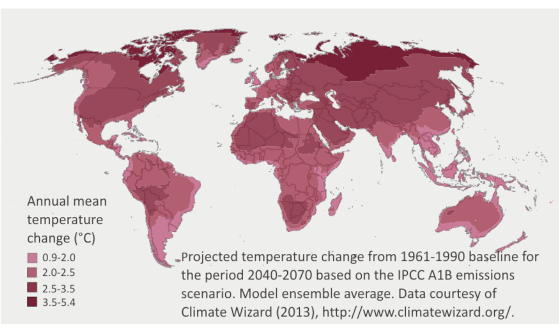
• The project is considered to have high sensitivity to increased temperature and there is a potential for an increase in incidences where current design standards will not be sufficient. See "Critical thresholds" in the "Help and glossary" section for further details on how a changing climate can impact on critical thresholds and design standards.

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

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

• Heatwaves put stress on buildings and other infrastructure, including roads and other transport links. In cities, the 'urban heat island' can increase the risk of heat related deaths.
• Warm weather can raise surface water temperatures of reservoirs used for industrial cooling. In addition, this could impact local eco-systems, improving the growing conditions for algae and potentially harmful micro-organisms in water courses.
• Heatwaves can have an impact on agricultural productivity and growing seasons.
• High temperatures can have implications for energy security. Peak energy demand due to demand for cooling can exceed incremental increases on base load in addition to the risk of line outages and blackouts.
• Human health can be affected by warmer periods. For example, urban air quality and disease transmission (e.g. malaria and dengue fever) can be impacted by higher air temperatures.
• Wildfire risk is elevated during prolonged warm periods that dry fuels, promoting easier ignition and faster spread.
• Permafrost and glacial melt regimes as impacted by warm periods.
• If our data suggests that there are existing hazards associated with high temperatures in the region, they will be highlighted elsewhere in the report. This may include existing wildfire risks as well as areas potentially impacted by permafrost and glacial melt.

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



Projected temperature change from 1961-1990 baseline for the period 2040-2070 based on the IPCC A1B emissions scenario. Model ensemble average. Data courtesy of Climate Wizard (2013), http://www.climatewizard.org/.

• Climate model projections do not agree that seasonal temperature will increase beyond 2 ˚C in the project location.
• If you want to know more about projected changes in the project location across a range of GCMs and emissions scenarios please refer to The Nature Conservancy's Climate Wizard for detailed maps and Environment Canada's Canadian Climate Change Scenarios Network for scatter plots of expected changes.

4. What next?

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

I have acknowledged the risks highlighted in this section.

05

HIGH RISK

PRECIPITATION INCREASE

ACCLIMATISE COMMENTARY

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

• The project is considered to have high sensitivity to increased precipitation and there is a potential for an increase in incidences where current design standards will not be sufficient. See "Critical thresholds" in the "Help and glossary" section for further details on how a changing climate can impact on critical thresholds and design standards.

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

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

• Seasonal runoff may lead to erosion and siltation of water courses, lakes and reservoirs.
• Flooding and precipitation induced landslide events.
• In colder regions, seasonal snow falls could lead to overloading structures and avalanche risk.
• If our data suggests that there are existing hazards associated with heavy precipitation in the region, they will be highlighted elsewhere in the report. This may include existing flood and landslide risks.

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

• Climate model projections do not agree that seasonal precipitation will increase in the project location which could indicate a relatively high degree of uncertainty (see the section "Model agreement and uncertainty" in "Help and glossary" at the end of this report). On the other hand, this could also mean precipitation patterns are not expected to change or may even decrease (see elsewhere in the report for more details of projections related to precipitation decrease).
• If you want to know more about projected changes in the project location across a range of GCMs and emissions scenarios please refer to The Nature Conservancy's Climate Wizard for detailed maps and Environment Canada's Canadian Climate Change Scenarios Network for scatter plots of expected changes.

4. What next?

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

☐ I have acknowledged the risks highlighted in this section.

06

HIGH RISK

FLOOD

ACCLIMATISE COMMENTARY

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

• Proximity to the coast and inland water courses
• Local topography
• Urban drainage infrastructure
• Up to date information on flood risk worldwide is available online, for example UNEP / UNISDR's Global Risk Data Platform.

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

• Climate change is projected to influence the frequency and intensity of flood events.
• Existing engineering designs may not take into consideration the impact of climate change on the risks from flooding. See "Critical thresholds" in the "Help & glossary" section for further details on how a changing climate can impact on critical thresholds and design standards.
• If flooding is identified as a potential problem for the project, it is recommended that a more localised and in-depth assessment is carried out. This information can then be used to inform the project design process if necessary.

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

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

3. What next?

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

I have acknowledged the risks highlighted in this section.

07

HIGH RISK

LANDSLIDE

ACCLIMATISE COMMENTARY

• Our data suggest that the project is located in a region which is at risk from precipitation induced landslide events. A high exposure in Aware means that based on slope, lithology, geology, soil moisture, vegetation cover, precipitation and seismic conditions the area is classed as ‘medium’ to ‘very high’ risk from landslides. This is based on post-processed data from UNEP/ GRID-Europe.
• Risk is locally influenced by other factors, for example local slope and vegetation conditions as well as long term precipitation trends. If landslides are identified as a potential problem for the project, it is recommended that a more localised and in-depth assessment is carried out. This information can then be used to inform the design process if necessary.
• Up to date information on landslide risk worldwide is available online, for example UNEP / UNISDR's Global Risk Data Platform.

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

• Climate change is projected to influence landslide risk in regions where the frequency and intensity of precipitation events is projected to increase.
• Existing engineering designs may not take into consideration the impact of climate change on the risk of landslides. Previously affected areas may suffer from more frequent and severe events. See "Critical thresholds" in the "Help & glossary" section for further details on how a changing climate can impact on critical thresholds and design standards.

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

Q1 Would the expected performance and maintenance of the project be impaired by landslides?
Q2 Will assets or operations associated with the project be in elevated areas or close to slopes?
Q3 Is there a history of landslides in the local area where the project is proposed?
Q4 Are there any plans to integrate climate change factors into a landslide risk assessment for the project?
Q5 Will the project include continuity plans which make provision for continued successful operation in the event of landslides?

3. What next?

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

I have acknowledged the risks highlighted in this section.

08
MEDIUM RISK

SOLAR RADIATION CHANGE

ACCLIMATISE COMMENTARY

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

• The project is considered to have medium sensitivity to changes in solar radiation and there is a potential for incidences where current design standards will not be sufficient or met. See "Critical thresholds" in the "Help and glossary" section for further details on how a changing climate can impact on critical thresholds and design standards.

• The design, operational and maintenance standards should be reviewed - take into consideration current impacts of fluctuating solar radiation as well as potential future changes.

2. How could changes in solar radiation affect the project even without future climate change?

Medium (yearly, seasonal) or longer term variations in solar radiation at the Earth's surface can affect for example:
• Agricultural yields. In some cases, the rate of photosynthesis (and therefore growing season) is proportional to the surface solar radiation.
• Solar power potential.
• The rate of degeneration of building materials.

3. What does the science say could happen in the future?

• Future projections of regional 'dimming' or 'brightening' are difficult to predict. This is due largely to the uncertainty surrounding cloud formation under climate change conditions.
• Given future uncertainty it is advisable to carefully assess past variations in solar radiation in the region, bearing in mind that it could change in the future. The UNEP Solar and Wind Energy Resource Assessment SWERA provides a useful global overview of solar radiation information.

4. What next?

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

I have acknowledged the risks highlighted in this section.

09

LOW RISK

PRECIPITATION DECREASE

ACCLIMATISE COMMENTARY

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

• Even though the project is considered to have low sensitivity to decreased precipitation, it is worth considering existing precipitation related hazards in the region where the project is planned.

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

• Decreased seasonal runoff may exacerbate pressures on water availability, accessibility and quality.
• Variability of river runoff may be affected such that extremely low runoff events (i.e. drought) may occur much more frequently.
• Pollutants from industry that would be adequately diluted could now could become more concentrated.
• Increased risk of drought conditions could lead to accelerated land degradation, expanding desertification and more dust storms.
• If our data suggests that there are existing hazards associated with decreased precipitation in the region, they will be highlighted elsewhere in the report. This may include water availability and wildfire.

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

• Climate model projections do not agree that seasonal precipitation will decrease in the project location which could indicate a relatively high degree of uncertainty (see the section "Model agreement and uncertainty" in "Help and glossary" at the end of this report). On the other hand, this could also mean precipitation patterns are not expected to change or may even increase (see elsewhere in the report for more details of projections related to precipitation increase).
• If you want to know more about projected changes in the project location across a range of GCMs and emissions scenarios please refer to The Nature Conservancy's Climate Wizard for detailed maps and Environment Canada's Canadian Climate Change Scenarios Network for scatter plots of expected changes.

4. What next?

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

☐ I have acknowledged the risks highlighted in this section.

10

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

HELP AND GLOSSARY:

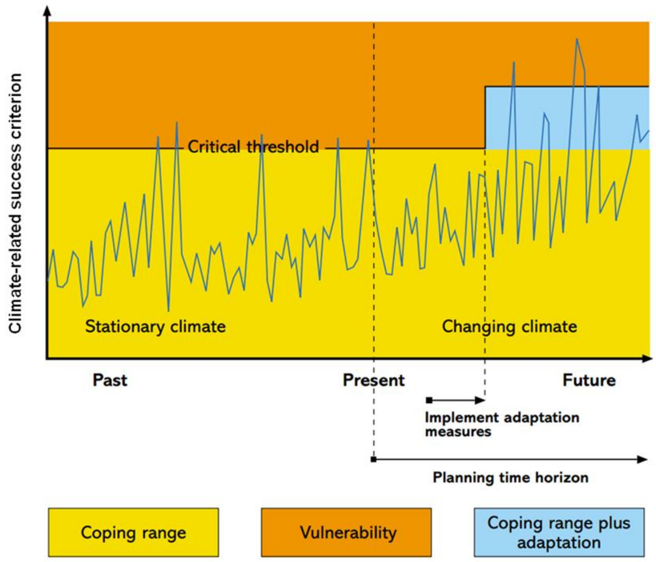
Model agreement and uncertainty:

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

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

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

Critical thresholds:

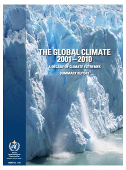
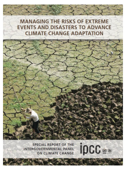
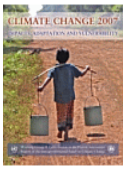


The relationship between a critical threshold and a climate change related success criterion for a project. [Source: Willows, R.I. and Connell, R.K. (Eds.) (2003). ***Climate adaptation: Risk, uncertainty and decision-making*****. UKCIP Technical Report, UKCIP, Oxford].**

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

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

Further reading:

	Report detailing changes in global climate: The Global Climate 2001 - 2010 (PDF)
	IPCC report on climate-related disasters and opportunities for managing risks: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)
	IPCC report on impacts, adaptation and vulnerability: Working Group II Report "Impacts, Adaptation and Vulnerability"
	IFC report on climate-related risks material to financial institutions: Climate Risk and Financial Institutions. Challenges and Opportunities.

Aware data resolution:

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

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

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

Aware data application:

In some instances Risk Topic ratings are only based on Aware data, including:
• Flood
• Permafrost
• Landslides

Country level risk ratings:

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

Glossary of terms used in report

"Climate model projections agree": defined as more than 14 out of 16 GCMs agreeing on the magnitude (e.g. temperature warming of 2 °C) and / or direction of change (e.g. seasonal precipitation).
"Climate model projections do not agree": defined as 14 or fewer out of 16 GCMs agreeing on the magnitude (e.g. temperature warming of 2 °C) and / or direction of change (e.g. seasonal precipitation).
"Significant proportion": defined as at least 25% of locations when multiple locations are selected.
"Large proportion": defined as at least 75% of locations when multiple locations are selected.

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

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Annex 2: Terms of Reference for Climate Change Specialist

Climate Change Specialist (International consultant, 2.0 person-months). The Climate Change Specialist will assess climate change risks and vulnerability of the project components and options for managing identified risks.

Scope of Work. The following tasks will be carried out:

(i) In consultation with the key members of the PPTA team and relevant project documentation, identify project components that are sensitive to climate/weather conditions;

(ii) In consultation with the ADB/PPTA/design team develop a detailed work plan for carrying out a climate risk and vulnerability assessment, including: key study sites/areas, and future timeframe (e.g. 20, 30 or 50 years); climatic/hydrological variables/parameters to be analysed; inventory of data required for the study, and data acquisition plan; methods and techniques for climate scenario analyses; methods for impact assessments; methods for identifying risk management/adaptation options; and a plan for interacting with the PPTA team (including objectives, timeline, relevant team members); and key outputs with milestones;

(iii) The timing of the study should take into account the overall timeline of the detailed design (scheduled for completion 30 September 2014) when results from the study will need to be communicated and considered by the design team;

(iv) Carry out the climate risk and vulnerability assessment, including the development of climate scenarios, assessment of potential risks of climate sensitive project components to projected climate change, and the identification of possible adaptation interventions during design and operation to manage such risks;

(v) Discuss possible adaptation interventions with ADB project leader prior to wider discussion. Conduct a workshop on the findings of the study with key project partners and stakeholders to agree the adaptation options to be taken forward; and

(vi) Prepare a detailed technical report on the study, including the overall methodology, data used, assumptions made, key findings and their implications for the project preparation,[1] caveats/limitations of the study and their implication for the project preparation.

Deliverables. The climate change specialist is expected to provide the following deliverables:

(i) A technical note outlining the sensitivities of project components to climate conditions;

(ii) A technical report on the study, including: an executive summary, key findings and their implications for the design, construction and maintenance of project components; methodological framework; data, scenarios and assumptions underlying the study; key findings including projected climate change in the project sites/areas, potential impacts of projected climate change on project components; possible adaptation interventions to address impacts/risks to ensure climate resilient design, construction, operation and maintenance of project components; and wider implications of climate change and associated impacts for road network development, caveats and limitations of the study; and

(iii) A set of presentational material, with detailed notes, to be derived from the Technical Report described in (iii) above.

Qualifications and experience. The Climate Change Specialist will be a climate scientist with at least 10 years of experiences working in the fields of climate change scenario analysis, climate

[1] Including plans for the design, construction and maintenance of project components.

change impact, vulnerability and adaptation in Asia. He/she will also need to a track record of advising on adaptation options and communicating climate science with multidisciplinary teams and a wide range of audiences.

Annex 3: Climate Change Impact Assessment Report

Technical Assistance Consultant's Report

Contract No. 115420-S82962

TA-8149 PRC: Yunnan Pu'er Regional Integrated Road Network Development Project

Climate Change Impact Assessment on Yunnan Pu'er Regional Integrated Road Network Development Projects in People's Republic of China

October 2014

Prepared by Wei Ye

Asian Development Bank

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Abbreviations

ADB	Asian Development Bank
AR5	The Fifth Assessment Report of Intergovernmental Panel on Climate Change
FSR	Feasibility Study Report of Yunnan Pu'er Regional Integrated Road Network Development Projects
GCM	General Circulation Model
GEV	General Extreme Value function
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
PRIRNP	The Yunnan Pu'er Regional Integrated Road Network Development Project
PMG	Pu'er Municipal Government
PMO	Project Management Office of PRIRNP
PPTA	Project Preparatory Technical Assistance of PRIRNP
PRC	The People's Republic of China
RCP	Representative Concentration Pathways of future GHG
V&A	Vulnerability and Adaptation of climate change impact
YTPDI	Yunan Transport Planning and Design Institute
masl	meters above sea level

Executive Summary

Climate change may pose various threats to transport system. The objective of this study is to assess the vulnerability of the Pu’er Regional Integrated Road Network Development Project (PRIRNP) to the impact of projected climate change and to identify adaptive measures to reduce the vulnerability. Pu’er is located in the south western part of the Yunnan Province of the People’s Republic of China (PRC). It borders with Viet Nam, Lao People’s Democratic Republic and Myanmar; hence the PRIRNP has strategic importance by connecting isolated rural communities to the regional road network and provide infrastructure to support trade and regional cooperation between countries.

Geographically, more than 98% of Pu’er consists of mountains. Geologically, sedimentary and alluvial formations are common in Pu’er, with laterite soils in the north and sedimentary and alluvial formations in the south and east. About 25% of Pu’er’s area is erosion prone. Meteorologically, Pu’er is among the areas in China that have the highest precipitation. Characterised by its mountainous topography and abundant precipitation during the rainy season, Pu’er has been under consistent threat of flood and landslide risk. The floods and landslide are caused by torrential or heavy rainfall, which is normally high in intensity but short in duration, and in most times is much localized phenomenon within Pu’er. It has been found that torrential rain and consequently induced river flood and landslide were the highest climate risks to the PRIRNP.

Based on the IPCC AR5 GCM outputs and historical observation from the PRIRNP area, quantitative climate projections and their associated uncertainty for the key climate variables that affect the PRIRNP were generated. From such quantitative and other relevant information, it is then possible to identify adaptation options that could enhance the sustainability (e.g. lifetime) of the project to climate change impact by “climate proofing” the risk sensitive components at the design and construction stages.

Climate scenario analysis has revealed that, by 2050 and towards the end of this century, climate change may have little impact on the total rainfall amount of the dry season, but may lead to noticeable rainfall increases in the rainy season. In contrast to small changes in long-term average rainfall; climate change will manifest largely as changes in the frequency and consequences of extreme rainfall, hence has significant impact on floods and landslide or debris flow disasters. If these adverse impact consequences are not taken into consideration in design, the delivery of the project objective may be impeded.

Several adaptation options are discussed based on the impact assessment and other relevant information. A more comprehensive vulnerability and adaptation (V&A) assessment may be accomplished with more relevant observation data, when/if this become available.

1. Introduction

A transport project is normally designed for providing long term service. Climate poses various threats to a transport system. The long term climatic averages and extreme weather events are important factors which need to be considered in the planning, design, operations, maintenance and management of transport systems. Climate change will likely alter both long term climatic averages and the frequency and severity of extreme weather events. For sustainable transport development, it is thus important to make climate adaptation adjustments to engineering specifications, alignments, and master planning; incorporating associated environmental measures; and adjusting maintenance and contract scheduling (ADB 2010). An effective climate-proofing of a transport system requires project specific climate change impact vulnerability assessment and identifying, evaluating and implementing feasible adaptation measures to strengthen project resilience to future climate change impact. The objective of this study is to conduct climate change impact vulnerability and adaptation (V&A) assessment for the Yunan Pu'er Regional Integrated Road Network Project (PRIRNP) in China.

1.1 Background of the project area

Yunnan is one of the least developed provinces of the People's Republic of China (PRC), and Pu'er is one of the most impoverished cities at prefecture-level of Yunnan. Pu'er is located in the south-western Yunnan province with latitude between 22°02′ to 24°50'N and longitude between 99°09′ to 102°19′E. It has an area of 45385 Km^2, of which more than 98% consists of mountains with altitude ranging between 376 meters above sea level (masl) in the south and 3,306 masl in the north. There are three mountain chains across the city area: Ailao, Wuliang and Nu; which are bisected by three major river systems, the Lancang River, Red River and Nu River. The Lancang River catchment accounts for the largest portion of the city's area at 61.2% or 27776 Km^2, and the Red River and the Nu River account for 33.8% and 5% of city's area respectively. Pu'er is situated in the subtropical humid monsoon climate zone, with mild climate but distinct seasons. Generally, temperatures decline from south to north, but can also have dramatic changes vertically along with altitude change. The annual average temperature is between 15.0ºC in the north to 20.3ºC to the south. Pu'er is one of the areas that have the highest precipitation in China. The average annual precipitation is between 1100 mm to 2780 mm. Geologically, sedimentary and alluvial formations are common in Pu'er, with laterite soils in the north and sedimentary and alluvial formations in the south and east. About 25%, or 10486 Km^2, of the city area is erosion prone. Along with the socio-economic development, the ecosystems in Pu'er have been degraded due to intensified human activities. A large part of the Nanlei River catchment inside Menglian County has been cultivated for agricultural development. The clearance of the natural forest for sugarcane, tea and coffee plantation has significantly changed the landcover and seriously damaged the ecosystems, and subsequently exacerbated the flood, soil erosion and landslide disasters (Menglian Political Consultation Committee, 2013).

Characterised by its unique geographic, geologic and meteorological conditions, Pu'er has been under consistent threat of flood and landslide/debris flow risks (Li et al. 2007; Yang, 2008; Chen, 2014). The floods and landslide/debris flow in Pu'er are triggered by torrential or heavy rainfall, which is normally high in intensity but short in duration, and sometimes is a much localized phenomenon. Long term or large area heavy rainfall is generally rare (Chen, 2014).

However, due to historical reasons, the flood protection measures in Pu'er are relatively poor. About 80% of the rivers of Pu'er either have no flood protection or have flood protection measures which are lacking maintenance. A common observation is that river channels have many twist ad turns, making it difficult for flood water to pass (Li et al. 2007). It is also common to find river channels silted up due to soil erosion. Hence the heavy rainfall and its aftermath have resulted in tremendous economic loss. The 1996 Nanlei River flood in Menglian County caused severe landslides and 50 Km long state road damages (Li et al. 2007). The 1984 flood in Simao and Jiangcheng caused 34 Km long road subgrade damages and affected 10 road bridges (Li et al. 2007). During 2000 to 2005, Pu'er had direct economic losses of CNY 850 million due to flooding, with a death toll of more than 70 (Pu'er Government, 2008).

Pu'er is strategically located at the border of PRC with other three developing countries in the region: Viet Nam, Lao PDR and Myanmar. The PRIRNP will connect isolated rural communities to the regional road network and provide infrastructure to support trade and regional cooperation between countries. The PRIRNP comprises three road components (Figure 1):

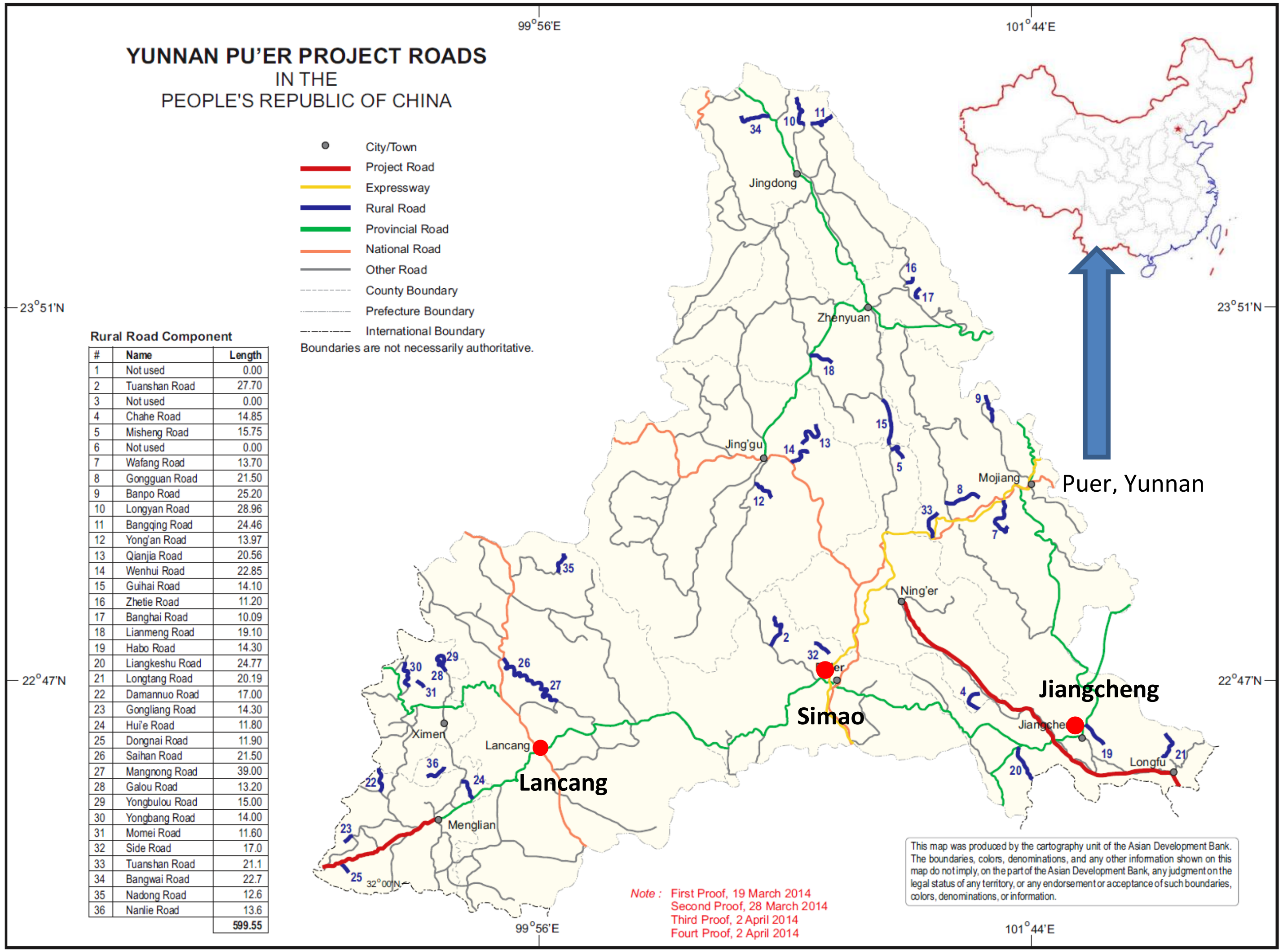
- rural road upgrading, with total 33 road across Pu'er city;
- rehabilitation of the Ning'er-Jiangcheng-Longfu road in the southeast; and
- rehabilitation of the Menglian-Meng'a road in the southwest.

For a sustainable transport system development, all three components require careful consideration of the local climate conditions in the design phase to prevent any disastrous damage to the system by climate hazard. Climate change has the potential to alter the climate condition; hence this study is focused on the climate change impact on the sensitive project components to the climate and the consequent implication in the design process.

1.2 Potential risks of climate change to the proposed project

Transport is vulnerable to climate variability and change. Although most climate factors can influence transport system; for the inland region, the major road damages are derived from temperature and precipitation factors. The influence of the two factors on a transport system is to a large degree manifested by their extremes and aftermath.

In terms of temperature, extreme heat places stress on road infrastructure, softens the asphalt causing traffic rutting and potentially resulting in pavement cracking. Extreme heat can also stress the steel in bridges through thermal expansion and movement of bridge joints. Extremely low temperature can cause fatigue and thermal cracking of the pavement. A wide range of temperatures (the difference between the high and low temperature) will make asphalt binders difficult to span accordingly. Flood triggered by torrential or heavy rainfall can cause severe water damage to roads, including collapse of the slope bed; damage to the subgrade, surface, and key infrastructure components (such as bridges and culverts); damage from landslide and debris flow etc.



Rural Road Component

#	Name	Length
1	Not used	0.00
2	Tuanshan Road	27.70
3	Not used	0.00
4	Chahe Road	14.85
5	Misheng Road	15.75
6	Not used	0.00
7	Wafang Road	13.70
8	Gongguan Road	21.50
9	Banpo Road	25.20
10	Longyan Road	28.96
11	Bangqing Road	24.46
12	Yong'an Road	13.97
13	Qianjia Road	20.56
14	Wenhui Road	22.85
15	Guihai Road	14.10
16	Zhetie Road	11.20
17	Banghai Road	10.09
18	Lianmeng Road	19.10
19	Habo Road	14.30
20	Liangkeshu Road	24.77
21	Longtang Road	20.19
22	Damannuo Road	17.00
23	Gongliang Road	14.30
24	Hui'e Road	11.80
25	Dongnai Road	11.90
26	Saihan Road	21.50
27	Mangnong Road	39.00
28	Galou Road	13.20
29	Yongbulou Road	15.00
30	Yongbang Road	14.00
31	Momei Road	11.60
32	Side Road	17.0
33	Tuanshan Road	21.1
34	Bangwai Road	22.7
35	Nadong Road	12.6
36	Nanlie Road	13.6
		599.55

Figure 1: Project area (Source: ADB)

The PRIRNP will be built in a mountainous area characterised by steep slope and erosion prone soil. The heavy rainfall triggered flood and landslide/debris flow have already caused significant damages to the road networks. The damages are common in Pu'er, especially in the rural area. During the rainy season, many rural roads become impassable due to landslides and poor road surfaces. Almost all susceptible damages are closely related with torrential rainfall.

The latest climate science projects that the climate will change at an increasingly rapid pace over the coming decades. Such change will likely alter the long term climatic averages and, in particular, the frequency and severity of extreme weather events; and subsequently the risk profiles that were adopted for the transport system design. Therefore, it is critical to assess and manage possible changing risks of road infrastructure during the design and construction stage to ensure the viability of the PRIRNP in the future changing climate. The regional road sections have 33 bridges: including 3 major bridges (Class II) and 3 middle (Class III) bridges for the Menglian-Meng'a section; 3 major bridges (Class II) and 24 middle (Class III) bridges for Ning'er-Longfu section. The flood protection design criteria for large bridges (Class II) is above 1:100 year flood levels; and 1:50 year flood levels for middle and small bridges and culverts. It is likely that the flood intensity will not be status-quo in the future due to the climate change impact on rainfall and its extremes. How the flood intensity will change may have impacts for the design of the transport system and affect its serviceability and lifespan.

1.3 Purpose and scope of this study

This study aims to provide an assessment of potential risks posed by climate change to the design of the climate sensitive components of the PRIRNP, and identify options to manage such risks by proposing and analysing a range of adaptive measures. Two future timeslices, i.e. 2050 and 2100 were chosen to demonstrate the V&A assessment processes.

Climate risk assessment will consider changes in temperature and rainfall based on outputs from the latest climate modelling experiments. Consideration of climate risk management options will include both "hard" measures entailing possible adjustments in design specifications, as well as "soft" options of ecological, governance or an institutional learning approach.

The overall objective of the climate change V&A assessment is to minimize road damage and disruptions in road use due to climate change impact. A scoping exercise was carried out to identify the vulnerability of the project to climate change impact. For the PRIRNP, the temperature and rainfall sensitive project components include road subgrade, pavement, bridge structures, slope protection and drainage system. The current design criteria are based on historical data and do not take account of changes in key hydro-met parameters under a changing climate.

Because the focus of this study is on the project vulnerability to changes in temperature and rainfall and its extremes; the required information to support this climate change impact assessment is historical observed temperature and rainfall at the appropriate spatial and temporal scale, in addition to the future climate change projections based on the latest scientific findings. Section 2 below will describe the methodology underlying the climate risk assessments. Details on the baseline and scenario datasets used for climate impacts assessment are provided in Section 3 as well as the impacts of climate change on the various components of the proposed project and implications for the design, construction and operation of the project. Possible options to manage climate risks within the context of the project, as well as a preliminary assessment of such risks, are discussed in Section 4. The report concludes with a set of recommendations on the design, construction and operation of the proposed project.

2. Methodology

A risk is the product of the interactions between hazards, exposure and vulnerability. In this study; hazard is used to denote the threat from climate factors of temperature and rainfall, their extremes and aftermath. Exposure refers to the presence of infrastructure and other assets related to a transport system that could be adversely affected when hazards occur and which, thereby, are subject to potential future harm, loss, or damage. Vulnerability is defined generally as the susceptibility to be adversely affected by climate hazards. Vulnerability can be either physical or socio-economic. The vulnerability of the PRIRNP project is mainly due to the geo-physically flood prone and erosion prone areas of the project. The vulnerability also derives from the serious ecosystem degradation due to human activities in the area. The vulnerability may also come from the inadequate design standard, or the possible economic constraints of constructing and maintaining the road system for the changing climate. Without adequate protection measures, such vulnerability lead to high risk of the road networks across the area to climate-related damage. This section describes the methodology of identifying climate variables that may become hazardous to the project and their future change projections. The climate change projection focuses on the relative changes between historical and future periods by applying an ensemble based pattern scaling approach.

2.1 Overall approach

The first step in climate change impact assessment is the construction of the future climate change scenarios. The construction of climate change scenarios involves the development of the baseline climate condition and the future climate change projections. Depending on the assessment requirements, spatial and/or site specific climate change scenarios are needed for impact studies. In this study, the baseline spatial climatology for the project areas was obtained from the WorldCLIM database (http://www.worldclim.org). The station based observed data collected was used for developing the site specific baseline climate condition.

The future climate change is subject to considerable uncertainty. One important aspect in climate change V&A assessment is to comprehend such an uncertainty range in decision making and policy planning processes. Within this context, any climate change scenario constructed on single Greenhouse Gas (GHG) emission rate and/or individual GCM output is generally considered inappropriate for V&A assessment purposes, because it cannot provide information of the uncertainty range associated with its projection. In this study, to reflect the uncertainties in future GHG emission rates and in climate sensitivity, a combination of different GHG Representative Concentration Pathways (RCPs) and climate sensitivities are used to characterise the future climate change scenario with the associated uncertainty range. RCP6.0 with mid-climate sensitivity represents a middle range future global change scenario, which was used as an indicator of the median projection of the future global change, while RCP4.5 with low-climate sensitivity and RCP8.5 with high-climate sensitivity was used as an indicator of the corresponding low and high bound of the uncertainty range (Table 1). Another important uncertainty in climate change scenario generation is the difference in different GCM simulations. To account for such an uncertainty in V&A assessment, a pattern scaling method was adopted and applied to a wide range of GCMs to build a model ensemble. The average of models' simulation of changes for a climate variable is normally used to capture the middle conditions, as that average often matches better with observed climate than any individual model estimates (Reichler and Kim, 2008). However, in this study the 50 percentile of the GCM model ensemble was used in order to prevent the influence of huge outliers in some GCM simulation on the final change values.

The method was thus termed ‘ensemble based pattern scaling’. Details of the method, as well as the steps of constructing the future climate change scenario, can be found in Appendix 1; while Appendix 2 lists the 40 IPCC AR5 GCMs used for model ensemble.

Table 1: Three climate projections and their input conditions represent the uncertainty ranges

Climate projection	Representative Concentration Pathways	Climate sensitivity
Median scenario	RCP6.0	Mid
Low scenario	RCP4.5	Low
High scenario	RCP8.5	High

2.2 Spatial climate change scenario

Monthly and seasonal climate change impact was assessed spatially over the project areas. The baseline climatology for the project areas was obtained from the WorldCLIM database with a spatial resolution of about 1 Km (http://www.worldclim.org). In generating the climate change scenario for the project areas, the simulation results from 40 GCMs that were assessed in the IPCC AR5 were used (Appendix 2). All 40 models have their monthly simulation results available.

2.3 Site specific climate change scenario

Besides the spatial monthly change projections, site specific climate change scenarios with more detailed temporal scale are usually required for impact assessment. The site specific climate change scenario was constructed by perturbing the station observed daily data using the normalised GCM pattern value from the GCM grid where the climate station is located. In this report, all observation data from a station was used to represent the baseline climate condition for the site.

For site specific extreme value analysis, we first chose an intensity value (such as 1:20 year annual maximum daily precipitation) and then selected its normalised pattern value from the GCM gird where the site is located. The value is then applied to the same precipitation intensity that derived from the observed historical data to generate the future change scenarios.

In the following two sections, the method described above is adopted to generate the change projections for climate variables that may become hazardous to the proposed project. Rainfall and temperature data were collected for 8 stations around the project area and 3 stations were analysed in detail for climate change impact on the project. Table 2 lists the information for the three stations. The locations of the stations can be found in Figure 1. Of the three stations, Simao has the longest observation period and is located in the centre of the project area, Jiangcheng is located in the middle of the regional road of Ning’er-Jiangcheng-Longfu, and Lancang is close to the regional road of Menglian-Meng’a. Simao is also used to represent the upper stream catchment rainfall conditions for the areas of both regional road projects.

Table 2: Location information of the three stations

Station Name	Longitude (°)	Latitude (°)	Altitude (m)	Observation Period
Simao	100.98	22.77	1302.1	1951-2013
Jiangcheng	101.82	22.62	1119.5	1954-2013
Lancang	99.93	22.57	1502.4	1973-2013

3. Climate observation and change projections

3.1 Observational temperature data and their future projections

The temperature related climate variables that have impacts on transport systems include the mean, minimum and maximum temperature; the extreme maximum temperature and related heat waves; and the temperature change range (the difference between minimum and maximum temperature). Appendix 3 lists the baseline temperature related climate variables and their projected future changes in 2050 and 2100 for Pu'er. The median scenario change projection is an increase of 1.2°C and 2.3°C for the annual mean temperature across Pu'er by 2050 and 2100 respectively. The high mountainous area in the north has a slightly higher increase rate than the low altitude area in the south. In terms of extremes, the maximum and minimum temperatures have a similar increase rate as the mean temperature changes. The baseline 1:50 year annual daily maximum and minimum temperatures are 42.1°C and -3.4°C and these values changes to 43.1°C and -2.4°C by 2050 projected by the median scenario, approximately a 1°C increase with an uncertainty range between 0.9°C to 2.6°C. There are little changes in the difference between the maximum and minimum temperature, as both temperatures are projected to increase. Heat wave will likely become more intensified and frequent, as indicated by the 7 day average maximum temperature for the 3 stations, but is generally under 45°C in most change projections and still under 50°C for the high scenario by the end of this century.

3.2 Observational rainfall data and their future projections

The rainfall related climate variables and their aftermath which could become hazardous for the project include torrential rain, flood, landslide and debris flow. Details of the observed rainfall data and their future change projections for the project area are demonstrated in Appendix 4. The key findings are discussed below:

Baseline:

1) The rainfall is characterized by strong variability in terms of both time and space. Spatially, rainfall increase from north to south and is the highest in the southeast area (where the regional road of Ning'er-Jiangchang-Longfu located). The annual average rainfall is around 2000 mm in southeast; more than double in the north where it is around 800 mm. The southeast area, where the regional road of Menglian-Meng'a is located, has an annual rainfall of around1500 mm. In addition, there is a high inter-annual variability in rainfall. The annual average precipitation of Simao is 1486 mm with a coefficient of variation (C_v) of 0.14. Jiangcheng has an annual average of 2213 mm and C_v of 0.16. Lancang has an annual average of 1600 mm and C_v of 0.12. For Simao station, the maximum annual rainfall of 1924 mm was recorded in 2001, while the minimum of 941 mm, which is less than half of the maximum value, was recorded in 1951.

2) Other than large inter-annual variability in annual rainfall, the distinctive feature of the rainfall is the seasonality. For Simao, the average rainfall of the rainy season from May to October is 1293 mm, which accounts for 87% of the annual total. The average rainfall in the dry season of November to April is less than 200 mm, which accounts for only 13% of

annual rainfall. Similar conditions were also found for the other 2 stations. In general, July is the wettest month in a year, and accounts for more than 20% of annual rainfall.

Future projection

3) Applying the method described in the previous section to the area, the median scenario change projection indicates the annual rainfall change in the area will likely be small, with an average increase across the area between 2 to 3% by 2050 and 4 to 8% by 2100.

4) For each station, the monthly rainfall change from the median scenario projection is also small, particularly for the dry season, but becomes noticeable for the rainy season. However, rainfall projection is associated with varied uncertainty ranges. The months in the rainy season generally have large uncertainty range than the months in dry season, and the uncertainty range is skewed to a large rainfall increase from the median climate change projection.

Extreme rainfall and its projection

According to the extreme value theorem, for normalized maxima (minima) of a sequence of independent and identically distributed random variables such as annual daily maximum rainfall, the generalized extreme value (GEV) distribution is the only possible limit distribution, and it is often used as an approximation to model the maxima (minima) of long (finite) sequences of random variables. In this study the GEV distribution was applied to the daily observation to investigate extreme rainfall and their future changes. A detailed method description and analysis process can be found in Ye and Li (2011). The torrential rain in Pu'er is characterised by high intensity and short duration. It is common in the area for 6 hour torrential rain to account for 70-80% of the 24 hour rain total (Yang, 2008). Therefore it was expected that 1 day of torrential rain would have a reasonable correlation with a triggered river flood. More explanation can be found in Appendix 5. For this reason, the annual maximum 1 day rain was analysed in detail for the three stations. Figures A4-4 and A4-5 of Appendix 4 show the result for Simao. The right-shifting of the projected GEV function indicates an increment of torrential rain in terms of both intensity and frequency under climate change impact. The 2050 change is noticeable, with a relative small uncertainty range. The 2100 change is significant, but accompanied with a high uncertainty range. Table 3 lists the baseline and future change projections with uncertainty range of annual daily maximum rainfall for the three stations.

As shown in Table 3, the current 1:50 year event of the annual maximum daily rainfall is 152.83 mm for Simao. The median scenario projection for such an event is 168.34 mm by 2050 and182.23 mm by 2100, which represent 9.4% and 18.5% increase in rain intensity respectively. The high projected change, shown by the high scenario, could reach 183.75 mm and 222.17 mm for 2050 and 2100 respectively, or a rain intensity increase of 20.2% at 2050 and 45.4% at 2100.

In summary, the rainfall change in the project area will noticeable under climate change. The annual rainfall may increase slightly in the future, but the change in extreme rainfall is much more significant than the change in normal rainfall, which implies an increased flood risk in the future.

Table 3: The GEV results of annual maximum 1 day rainfall and its future projections

Stn Name	Return period (years)	Annual maximum daily rainfall changes (%)						
		Baseline	2050 scenario			2100 scenario		
			Low	Median	High	Low	Median	High
Siamo	20	132.06	6.7	9.2	18.9	9.1	18.0	43.1
	50	**153.83**	6.9	9.4	19.5	9.4	18.5	44.4
	100	170.99	7.1	9.8	20.2	9.7	19.1	46.1
Jiang-cheng	20	227.85	6.4	8.7	17.9	8.6	17.0	40.8
	50	**325.15**	6.5	8.9	18.3	8.88	17.4	41.7
	100	429.62	6.7	9.1	18.9	9.1	18.0	43.2
Lancang	20	122.96	7.0	9.6	19.8	9.5	18.8	45.1
	50	**140.81**	7.2	10.0	20.6	9.9	19.5	47.1
	100	154.59	7.6	10.4	21.5	10.3	20.4	49.3

3.3 Climate change impact on the PRIRNP and the implication to the project design

The climate change information needs to be related to the project components that are sensitive to the climate, to support the vulnerability assessment and adaptation options identified. In the context of this project, the target sensitive project components include:

- Change in maximum temperature of the pavement;
- Change in minimum temperature of the pavement;
- Change in the range of temperature of the pavement;
- Change in the heavy rainfall intensity which will affect the drainage design; and
- The change of 1:100 year flood water level; which is the criterion for big bridge design and 1:50 year flood height which is the criterion for middle size bridge design

The pavement temperature has a linear relationship with the air temperature, so the increase in air temperature will lead to increase of pavement temperature. The baseline annual average air temperature of Pu'er is relatively mild. An increase of 1.2°C by 2050 or 2.3°C by 2100 will not cause significant impact to the transport system. Heat wave may become more severe and longer lasting. Nevertheless, the 7 day average maximum temperature of 2050 for all 3 stations will still be around 40°C, even from high scenario projection. Thus the temperature change may not have significant effects on the project. Special modification of the asphalt binders may be required if the difference between high and low temperature is more than 90°C. In Pu'er, the difference between high and low temperature is much less than 90°C currently and in the future. Thereby, no special impact concern is expected from the temperature changes in the future.

In contrast to temperature, the heavy rainfall and its consequent induced flood, landslide or debris flow pose a much greater risk to road systems. For the purpose of assessing climate change impact on flood, landslide or debris flow, it is essential to have insightful understanding of their relationship with rainfall. Normally hydrological or hydraulic models, either physically or statistically based, are used to simulate the rainfall – flood and rainfall – landslide processes. Long term observed meteorological and hydrological data are required for model calibration/validation in such model development. However, the hydrologic observations for the PRIRNP area are largely unavailable.

For the project area, the only available data is the 54 years observed annual maximum river discharge of the Nanlei River at Menglian hydrometric station, which is 40 Km at the downstream of the Lancang Metrological station. No significant statistical relationship could be found between the Menglian annual maximum flow data and the rainfalls at Lancang, either from individual daily rainfall and or combination of multiple day rainfalls. The reasons are twofold: firstly it is because of the complexity of the local geo-hydrological conditions; second and more importantly, because of the extensive human intervention to the Nanlei River systems, such as man-made changes to the river channels and the landcover in the river catchment. Such conditions are by and large common to most areas in Pu'er, so in the absence of reliable hydrological observations for a more sophisticated model development, the one day maximum rainfall may be used as a surrogate in investigating the climate change impact on river flood, as it was expected that the flood discharge and the one day heavy rainfall would have a reasonable linear relationship. For the landslide/debris flow, a statistical relationship of 6 day rainfall was used to simulate its risk changes as well as 1 day rainfall. Appendix 5 described the details of reasoning and development of these methods.

With regard to climate change impact on flood assessment, the 1:50 and 1:100 year annual maximum daily rainfall of Lancang will likely have a 10% and 19.5% increment by 2050 and 2100 respectively, based on the median scenario projection (Table 3). This implies a corresponding increment of flood discharge of 10% by 2050 and 19.5% by 2100. During the bridge design, it would be desirable to examine if the design still meets the increased flood risk in 2050 and in 2100. Field surveying may be required to obtain the information about the river channel, such as the shape and area of the cross section, at the bridge site, in order to calculate the flood height. Hu (2009) rectified the flood discharge and flood height relations for the Nanlei River at Menglian, as shown in Table 4. A regression model can be obtained from Table 4, as shown in Figure 2:

$$y = 0.0041x + 956.61 \qquad (1)$$

where: y is the flood height (masl); x is the flood discharge (m^3/s).

A 10% increase of 1:100 year flood discharge will be 383.9 m^3/s, and it corresponds to a flood height of 958.18 masl, or a 0.15 metre increment of current flood height. Similarly, a 20.6% increase of flood discharge by 2050 projected by the high scenario will lead to a 0.31 metre increment of the current flood height. For Menglian-Meng'a Road, the current design for the bridges crossing the Nanlei River near Menglian is based on the historical flood survey of 1:100 year flood height with a 0.5 metre safety factor. Thus the safety factor of the current design may offset of the climate change induced height increase by 2050. It may become inadequate toward the end of this century, when more than 0.68 metre will add to the current 1:100 flood height under the high scenario projection.

For the landslide and debris flow risks, the 6 day total rainfall of 140, 180 and 230 mm, as well as daily rainfall of 70, 90 and 100 mm were used as an indicator for the risk profile changes.

Table 4: The relationship between flood discharge and flood height at Menglian (source: Hu, 2009)

	Flood frequency				
	20%	10%	5%	2%	1%
Q (m^3/s)	200	237	274	316	349
h (masl)	957.42	957.58	957.75	957.90	958.03

Q: flood river discharge
h: flood height.

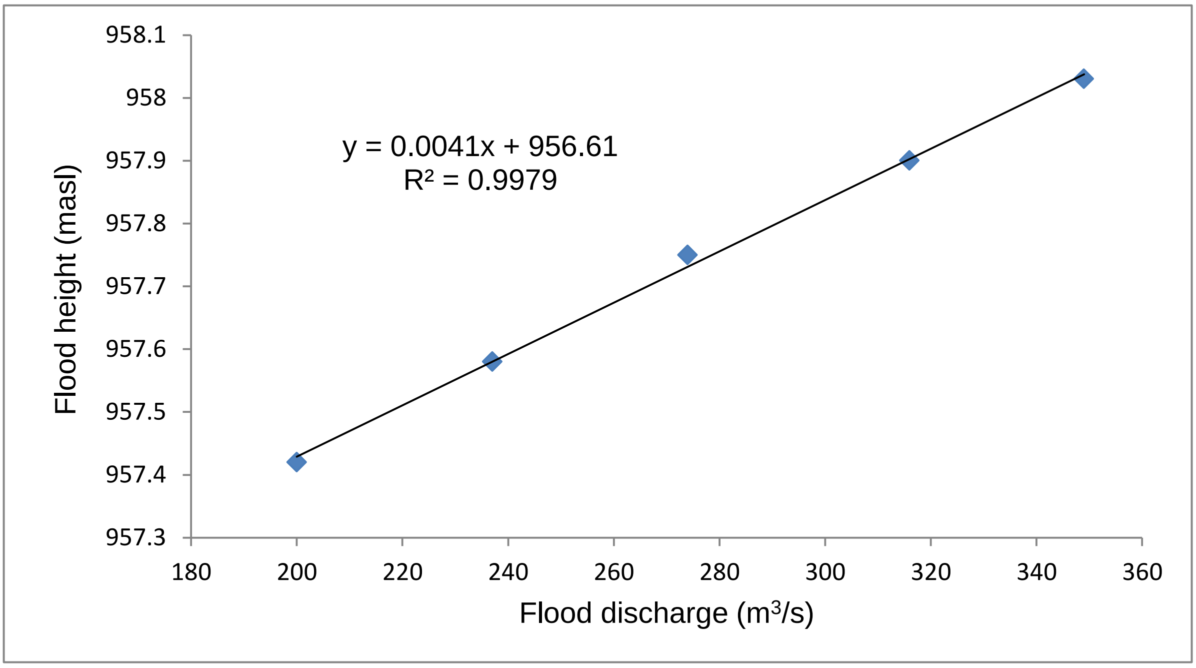


Figure 2: the regression model of flood discharge and flood height at Menglian.

The GEV function was applied to analyse the annual maximum rainfall of 6 consecutive days for the three stations. Again, future climate change scenario was generated for such a climate variables and the result is shown in Table 5. According to Table 5, it is most likely that the heavy/torrential rain will become much more frequent in the future, and so do the landslide/debris flow risks, especially for the for 6 day triggered landslide or debris flow. As shown in Table 6, the baseline frequency of 1 day rainfall corresponding to high risk landslide for Lancang is 1:6.1 years, and its median scenario change projections are 1:3.9 and 1:2.8 years by2050 and 2100 respectively, which implies a 56.4% and 117.9% frequency increase. In comparison, the 6 day rainfall risk increase will even larger, as the frequency increase 145.2% and 260.0% by 2050 and 2100 respectively. Great attention should be paid at design stage to ensure the slope protection is sufficient of future climate change impact on landslide and debris flow hazards.

Table 5: The rainfall frequencies corresponding to low, medium, high landslide risk and their future projections under climate change impact.

Rainfall (mm)	Station name	Frequency as return period (years)				
		Baseline	2050 median scenario	Change	2100 median scenario	Change
Daily						
70	Simao	1.6	1.3	23.1	1.1	45.5
	Jiangcheng	1.1	<1	N/A	<1	N/A
	Lancang	1.6	1.3	23.1	1.1	45.5
90	Simao	3.3	2.3	43.5	1.8	83.3
	Jiangcheng	1.6	1.3	23.1	<1	N/A
	Lancang	3.7	2.5	48.0	1.9	94.7
100	Simao	5.0	3.4	47.1	2.5	100.0
	Jiangcheng	2.1	1.6	31.3	1.3	61.5
	Lancang	6.1	3.9	56.4	2.8	117.9
6 day total						
140	Simao	1.4	1.2	17.9	1.1	30.2
	Jiangcheng	<1	<1	N/A	<1	N/A
	Lancang	1.3	1.1	13.6	1.0	23.8
180	Simao	2.6	1.9	37.2	1.5	74.7
	Jiangcheng	1.2	1.0	12.5	<1	N/A
	Lancang	3.0	1.9	61.6	1.4	113.5
230	Simao	8.0	5.0	59.9	3.4	132.8
	Jiangcheng	2.1	1.5	33.8	1.2	66.1
	Lancang	16.4	6.7	145.2	4.6	260.0

4. The adaptation options

Given the likely changing climate in the future, managing climate risks in road transport sector will require effective adaptation of infrastructure, operations and maintenance, in order to avoid costly repair and/or replacement in the future. Proper adaptation measures can effectively alleviate vulnerability and reduce the potential damage from the climate change impact. As discussed in the previous sections, the flood and landslide/debris flow are the two major climate induced risk to the PRIRNP. In this section, the adaptations that are identified based on literature review and/or from the discussion with the staff from the Project Management Office (PMO) and the Yunnan Transport Planning and Design Institute (YTPDI) are provided as options with brief discussion:

4.1 “Hard” options: adjustments to design of relevant project component(s)

- Enhanced flood drain system to reduce the water flood risk on the road surface. Staff from YTPDI have indicated that high standard was used in the water drain system design, such as the side ditch, culvert size etc. A safety coefficient of 1.1 (10% higher than required design standard) was adopted, and it is even higher in some places. The 10% capacity increment may be adequate by 2050 under median scenario projection, but could become insufficient for 2050 high scenario projection or beyond 2050. A 20% capacity increment may be more appropriate based on the extreme rainfall projections.
- For road section along the rivers, the design process should take the future increased flood discharge into account. More flood discharge not only means an increased flood height, but also an increase in flood speed, so that increase damage risk of the flood water flushing away the subgrade materials. Engineering techniques should be designed or planned, either to enhance the stability of the road subgrade or to reduce the flood speed.
- Climate change will manifest most impact effects on rural road. However, the current rural road development is based on existing road structure, which limits the “Hard” adaptation choices. It would be desirable to examine all the aspects involved in rural road design and adopt as much as possible the design standard for climate sensitive components, such as slope protection, and drainage systems. Almost all the rural roads are located in the mountainous area. Flood in this area are generally characterised by fast happening but short in duration. For sections that are susceptible to flood but are also difficult to raise the subgrade, it may be economical to adopt design standard using special materials to ensure the robustness of the road when it is submerged by flood water.
- Bridge design is based on the observed historical highest flood level as the design standard with an extra of 0.5 to 1.0 meter as safety factor. The climate change will likely produce 10% and 20% more flood discharge by 2050 and 2100. An examination of the current design standard is needed to ensure the safety factor is adequate for the extra flood discharge. As shown in this study, the 0.5 metre safety factor may be adequate to offset the median scenario change induced flood height increase at Menglian, but may become inadequate at the end of this century or for high climate change scenario. Further increase the bridge height may be necessary, which will introduce additional construction cost. The total cost will depend on the

bridge type and the number of piers. On average, approximate CNY10000/pier (US$1632/pier) is expected for every metre bridge height increase (per comm. YTPDI).
- Heavy rainfall triggered landslide risk will likely become more frequent. Special design consideration should be given to the road sections that have steep slope on the side of the road. Proper slope stabilization techniques, including engineering methods, should be adopted or planned for future implementation.

4.2 "Soft" measures: ecological solutions, institutional and technical capacity building to enhance risk awareness and ability for ongoing risk assessment & management, knowledge management to improve risk assessment as new information emerges

- Human activities have an important role to play in terms of ensuring the road network is maintained in good working order. The PRIRNP is located in an area that are characterised by high soil erosion. The river channel siltation is rather common in this region; hence regular dredging and/or clearing of the river channels can significantly reduce the risk of flood and landslide risks.
- Heavy rainfall is weighted at only 20% in total landslide risk. Landcover accounting for 30% in total landslide risk, is an even larger weighting factor. Prohibiting cultivation along the steep slope land and planting deep rooted vegetation in the erosion prone area will effectively prevent landslide from occurring. The government has made great effort in ecological restoration in Pu'er and, as indicated by the staff from both PMO and YTPDI, there has been steady improvement in ecosystem restoration and protection in Pu'er. However in the short term the landslide will still present a considerable threat to the road network in Pu'er, particularly to the rural road.
- The Pu'er government has placed flood protection as one of its priorities for future development. It is expected that most of the work under government hydraulic plan will significantly benefit the PRIRNP.

As discovered by the PPTA team, the current operation of the road network still has much space for improvement, in terms of both 'hard' engineering options and 'soft' measures. Good climate resilience can also be achieved through institutional and technical capacity building to enhance risk awareness and ability for ongoing risk assessment & management. It is also worthwhile to note that not all adaptation needs to be implemented immediately. In fact, by taking economic into consideration, as long as good plan has been in place, some adaptation can be implemented in the future as climate change is also a gradual process. The above adaptations are mostly discussed against their targeted vulnerable components. However, one adaptation will not only strength the resilience of target component, but will likely also benefit all components across the project.

5. Conclusion

The objective of the PRIRNP development is to facilitate growth and regional integration by connecting isolated rural communities to the regional road network and providing infrastructure to support trade and regional cooperation between the PRC, Viet Nam, Lao PDR, and Myanmar. Climate change may have a significant impact on the serviceability and usable life of the project. Actions should be taken to include effective and efficient adaptations as an integral part of project design and construction to alleviate any negative climate change impact consequences. Incorporating effective adaptation measures in project design and construction will prevent costly infrastructure remedy and/or re-construction and also expedite the long term economic benefits for which the project is designed.

This study produces quantitative climate change information relevant to the project by making use of the pattern scaling based GCM ensemble method. The advantage of this method is that it not only takes the key uncertainties in climate change science into future projection into consideration, but also treats these key uncertainties independently. Therefore climate change projections and their associated uncertainty range can be produced consistently through a combination of the different scenarios. A quantitative impact assessment can then be conducted by linking the relevant climate factors to the key vulnerable components of the project, and targeted adaptation options can subsequently be identified and evaluated.

As revealed by the study, the biggest climate related risk to the project is river flood and landslide/debris flow caused by heavy rainfall event. The climate change scenario analysis indicated enhanced risks for both hazards. Several adaptation options were identified and discussed. Despite the importance of taking necessary ‘hard’ adaptation measures in project design and construction, it is worthwhile to emphasise that the ‘soft’ options could be much cost effective and equally efficient. The deforestation in the mountainous area and the blocking of the waterway system have both contributed to the increased vulnerability of the project to flood. Therefore ecosystem restoration should be considered as a long term adaptation option to enhance the resilience of the project to climate change impact.
This study was constrained by a number of limitations:

- The impact assessment was conducted on the basis of available data. Though we considered this data adequate for this study, a properly developed impact model would reveal the detailed relationship between torrential rain and the flood or landslide. For example, a time series river flow data would assist in developing proper hydrologic and hydraulic models so that the impact on flood due to changing in rainfall could be explored; a rainfall - landslide model built on detailed topography, soil information and vegetation cover information would provide valuable adaptation management options.
- No flood height data or analysis can be found for the Ning’er-Jiangchen-Longfu regions road section. The design of bridges in this section may take the recommendation of Menglian-Meng’a in this study as a reference.
- The adaptation options discussed were presented as initial recommendation. No economic data was available to investigate the cost-benefit of implementing such adaptation options. However, we recommend selection of appropriate adaptations and/or their combination to be considered in projects design wherever feasible.

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Appendix 1: Climate change scenario generation

The uncertainties in climate change scenario generation

The future climate change projection includes uncertainties, particularly at the regional and local level. The major sources of uncertainties come from: 1) the difference of spatial change projections modelled by different GCMs; 2) the future Greenhouse Gas (GHG) emission rates; and 3) different GCM model parameterisation due to the unknown or not fully understood mechanism and feedbacks in the climate systems. A thoroughly studied uncertainty by the scientific community is the difference in GCM model parameterisation, or the climate sensitivity. The climate sensitivity is conventionally defined as the equilibrium change in global mean surface temperature following a doubling of the atmospheric (equivalent) CO_2 concentration simulated by a GCM. It has been found that the uncertainty range is between 2.0°C to 4.5°C (Solomon et al., 2007).

To reflect the uncertainty of future GHG emission rates, a new process has been used for future global climate change projection since IPCC AR5. In this process, GHG emissions and socioeconomic scenarios are developed in parallel, building on different trajectories of radiative forcing over time to construct ***pathways*** (trajectories over time) of radiative forcing levels (or CO_2-equivalent concentrations) that are both ***representative*** of the emissions scenario literature and span a wide space of resulting GHG ***concentrations*** that lead to clearly distinguishable climate futures. These radiative forcing trajectories were thus termed "Representative Concentration Pathways" (RCPs). A RCP was simulated in an Integrated Assessment model to provide one internally consistent plausible pathway of GHG emissions and land use change that leads to the specific radiative forcing target. The full set of RCPs spans the complete range of integrated assessment literature on emissions pathways and the radiative forcing targets are distinct enough to result in clearly different climate signals.

In this study, three RCPs: RCP4.5, RCP6.0 and RCP8.5, are used to characterise the possible climate change scenario for the project area and uncertainty range. RCP6.0 with mid-climate sensitivity represents a GHG concentration reaching 850 ppm and stabilized after 2100, it is a middle range future change scenario. Similarly, RCP4.5 (650 ppm GHG and stabilized at 2100) with low-climate sensitivity and RCP8.5 (concentration larger than 1370 ppm at 2100 and still rising) with high-climate sensitivity represents the low and high bound of the uncertainty range of future global change scenarios as shown in Table 1. The three RCPs represent rising radiative forcing to 4.5, 6 and 8.5 W/m^2 by 2100 respectively.

The General Circulation Model (GCM) is the most reliable tool in generating the future climate change scenarios at large to global scale. However, given the current state of scientific understanding and limitations of GCMs in simulating the complex climate system, for any given region in the world, it is still not possible to single out a GCM that outperforms all other GCMs in future climate change projection. Future climate change projection based on the analysis of a large ensemble of GCM outputs is more appropriate than using any individual GCM outputs (Wilby et al. 2009). This is particularly important if such a projection is used for impact assessments; a large ensemble of GCM simulations can provide a reliable specification of the spread of possible regional changes by including samples covering the widest possible range modelling uncertainties (Murphy et al. 2004, Sortberg and Kvamsto 2006, Murphy et al. 2007, Räisänen 2007). A single GCM projection of future climate made with even the most sophisticated GCM can be of limited use for impact assessment as it lacks the ability to provide information on the range of uncertainties. Within an ensemble approach; provided the members of the ensemble are independent, a larger ensemble size could lead to a more reliable statistical result (Sterl et al. 2007). In this study, the 50 percentile value from the model ensemble sample was used in generating future climate change projections.

The pattern scaling method

The pattern-scaling method (Santer *et al*., 1990) is based on the theory that firstly, a simple climate model can accurately represent the global responses of a GCM, even when the response is non-linear (Raper et al. 2001), and secondly, a wide range of climatic variables represented by a GCM are a linear function of the global annual mean temperature change represented by the same GCM at different spatial and/or temporal scales (Mitchell, 2003, Whetton et al. 2005). Constructing climate change scenarios using the pattern-scaling method requires the following information:

a) regional patterns of changes in climate (e.g. for precipitation) by specified timeframe (e.g. month) from GCM results, which are normalized to give a spatial pattern of change per degree of global-mean temperature change;
b) time-dependent projections of global-mean temperature change projected by a selected RCP under a selected “climate sensitivities”
c) baseline climate variables derived from observational records.

In generating a “time-slice” scenario for a future year, the normalised pattern (a) is scaled by a time dependent projection of global-mean temperature change (b). The resultant scenario of climate change is then used to perturb the underlying observed spatial climatology (c) to give a “new” climate for the year in question. In this way, the three key uncertainties – the GCM spatial patterns of change, the future GHG emission rates and the climate sensitivity – can be treated independently and combined flexibly and quickly to produce future climate scenarios (as per Wigley, 2003).

The pattern scaling method is also extended to analyse the climate change impact on climate variability, such as the extreme precipitation event. A general extreme value (GEV) function was applied to the daily precipitation data from historical observations and GCM outputs to derive precipitation intensity values. Similar to a normalised pattern for monthly precipitation, normalised patterns of a series of precipitation intensities, such as 1:20 year maximum daily precipitation, are calculated for a GCM following the steps discussed previously. In generating the normalised patterns, the GCM simulated period of 1975 to 2005 was used as GCM baseline.

Out of the 40 GCMs 22 have their daily simulation outputs publically available (see Appendix 2). For the GCM with available daily data, a linear regression method was used to process them in order to derive the normalised pattern for the precipitation intensity series. A more detail discussion of the extreme precipitation change scenario generation can be found from Ye and Li (2011).

Appendix 2: IPCC AR5 GCMs used in this scenario generation and their horizontal and vertical resolutions. Models with daily data available are used for extreme rainfall event scenario generation

Model label	Resolution (longitude°× latitude°)	Daily	Institution
ACCESS1.0	1.875×1.25	No	Commonwealth Scientific and Industrial Research Organisation/Bureau of Meteorology (CSIRO-BOM) Australia
ACCESS1.3	1.875×1.25	Yes	Commonwealth Scientific and Industrial Research Organisation/Bureau of Meteorology (CSIRO-BOM) Australia
BCC-CSM1.1	2.8125×2.8125	No	Beijing Climate Center (BCC) China
BCC-CSM1.1(m)	2.8125×2.8125	No	Beijing Climate Center (BCC) China
BNU-ESM	2.8125×2.8125	No	Beijing Normal University (BNU) China
CanESM2	2.8125×2.8125	Yes	Canadian Centre for Climate Modelling and Analysis (CCCma) Canada
CCSM4	1.25×0.9375	Yes	National Center for Atmospheric Research (NCAR) USA
CESM1(BGC)	1.25×0.9375	Yes	National Center for Atmospheric Research (NCAR) USA
CESM1(CAM5)	1.25×0.9375	No	National Center for Atmospheric Research (NCAR) USA
CMCC-CM	0.75×0.75	Yes	Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC) Italy
CMCC-CMS	1.875×1.875	Yes	Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC) Italy
CNRM-CM5	1.4×1.4	Yes	Centre National de Recherches Météorologiques (CNRM-CERFACS) France
CSIRO-Mk3.6.0	1.875×1.875	Yes	Commonwealth Scientific and Industrial Research Organisation (CSIRO) Australia
EC-EARTH	1.125×1.125	No	EC-EARTH consortium published at Irish Centre for High-End Computing (ICHEC) Netherlands/Ireland
FGOALS-g2	2.81x1.66	No	Institute of Atmospheric Physics, Chinese Academy of Sciences(LSAG-CESS) China
FGOALS-s2	2.81x1.66	No	Institute of Atmospheric Physics, Chinese Academy of Sciences(LSAG-IAP) China
GFDL-CM3	2.5 × 2.0	No	Geophysical Fluid Dynamics Laboratory (GFDL) USA
GFDL-ESM2G	2.5x2.0	Yes	Geophysical Fluid Dynamics Laboratory (GFDL) USA
GFDL-ESM2M	2.5x2.0	Yes	Geophysical Fluid Dynamics Laboratory (GFDL) USA
GISS-E2-H	2.5×2×L40	No	NASA Goddard Institute for Space Studies (NASA-GISS) USA
GISS-E2-H-CC	2.5×2×L40	No	NASA Goddard Institute for Space Studies (NASA-GISS) USA
GISS-E2-R	2.5×2×L40	No	NASA Goddard Institute for Space Studies (NASA-GISS) USA
GISS-E2-R-CC	2.5x2×L40	No	NASA Goddard Institute for Space Studies (NASA-GISS) USA
HadCM3	3.75x2.5	No	Met Office Hadley Centre (MOHC) UK

HadGEM2-AO	1.875 × 1.2413	No	National Institute of Meteorological Research, Korea Meteorological Administration (NIMR-KMA) South Korea
HadGEM2-CC	1.875 × 1.2413	No	Met Office Hadley Centre (MOHC) UK
HadGEM2-AO	1.875 × 1.2413	No	National Institute of Meteorological Research, Korea Meteorological Administration (NIMR-KMA) South Korea
HadGEM2-CC	1.875 × 1.2413	No	Met Office Hadley Centre (MOHC) UK
HadGEM2-ES	1.875 × 1.2413	Yes	Met Office Hadley Centre (MOHC) UK
INM-CM4	2x1.5	Yes	Russian Academy of Sciences, Institute of Numerical Mathematics (INM) Russia
IPSL-CM5A-LR	3.75x1.875	Yes	Institut Pierre Simon Laplace (IPSL) France
IPSL-CM5A-MR	2.5x1.25874	Yes	Institut Pierre Simon Laplace (IPSL) France
IPSL-CM5B-LR	3.75x1.875	Yes	Institut Pierre Simon Laplace (IPSL) France
MIROC-ESM	2.8125x2.8125	Yes	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology (MIROC) Japan
MIROC-ESM-CHEM	2.8125x2.8125	Yes	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology (MIROC) Japan
MIROC4h	0.5625x0.5625	No	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology (MIROC) Japan
MIROC5	1.40625 × 1.40625	Yes	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology (MIROC) Japan
MPI-ESM-LR	1.875x1.875	Yes	Max Planck Institute for Meteorology (MPI-M) Germany
MPI-ESM-MR	1.875 × 1.875	Yes	Max Planck Institute for Meteorology (MPI-M) Germany
MRI-CGCM3	1.125x1.125	Yes	Meteorological Research Institute (MRI) Japan
NorESM1-M	2.5x1.875	Yes	Bjerknes Centre for Climate Research, Norwegian Meteorological Institute (NCC) Norway
NorESM1-ME	2x2	No	Bjerknes Centre for Climate Research, Norwegian Meteorological Institute (NCC) Norway

Appendix 3: Temperature related observed climate variables and their future projections

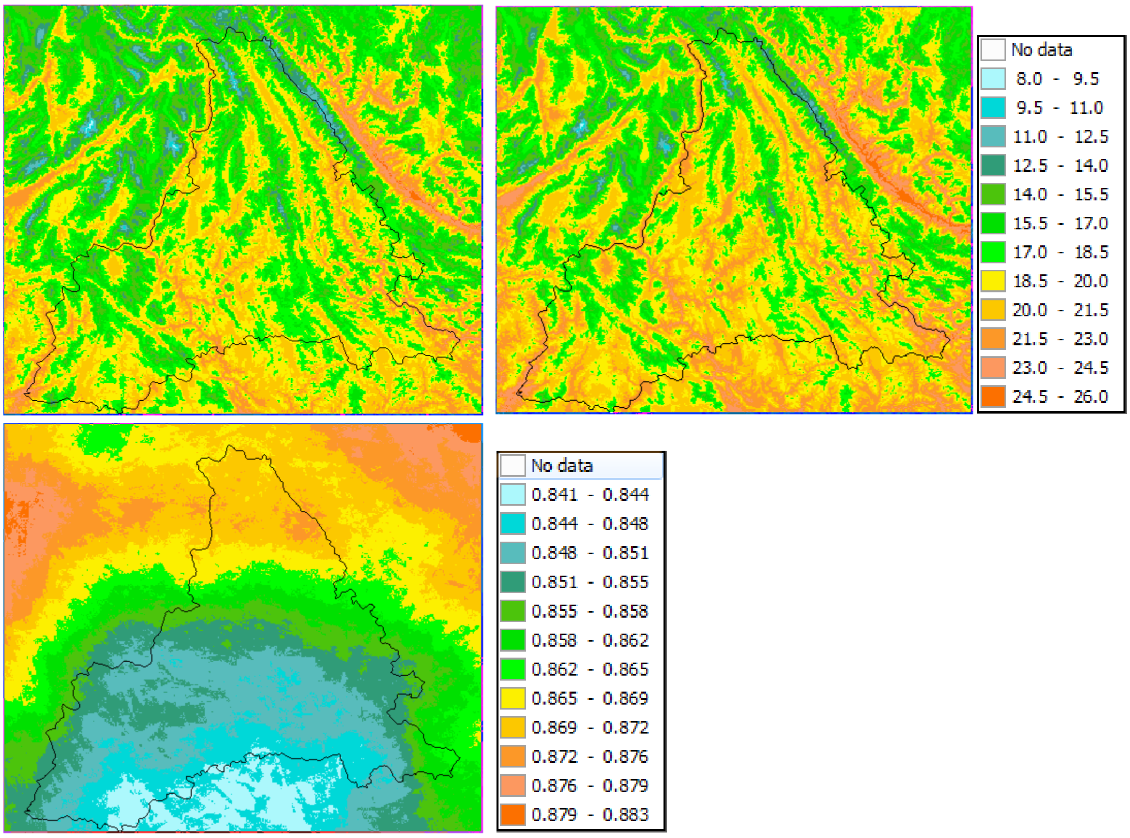

Figure A3-1: Baseline annual mean temperature (°C) and its 2050 change based on the median scenario projection.

Table A3-1: Observed extreme temperatures and their future change projections for Jiangcheng and Lanchang.

	Return period (year)	Baseline	2050			2100		
			Low scenario	Median scenario	High scenario	Low scenario	Median scenario	High scenario
Jiangcheng	Annual daily maximum temperature (°C)							
	20	39.248	40.091	40.402	41.624	40.392	41.503	44.651
	50	42.077	42.846	43.129	44.277	43.120	44.164	47.113
	100	44.578	45.263	45.513	46.585	45.505	46.480	49.224
	Annual daily minimum temperature (°C)							
	20	-2.062	-1.301	-1.025	0.038	-1.034	-0.064	2.572
	50	-3.366	-2.644	-2.389	-1.424	-2.397	-1.513	0.711
	100	-4.229	-3.540	-3.300	-2.418	-3.308	-2.496	-0.632
Lancang	Annual daily maximum temperature (°C)							
	20	36.928	37.760	38.068	39.284	38.058	39.164	42.332
	50	37.369	38.178	38.478	39.662	38.468	39.545	42.636
	100	37.637	38.429	38.722	39.885	38.713	39.770	42.807
	Annual daily minimum temperature (°C)							
	20	-0.304	0.489	0.779	1.906	0.770	1.795	4.692
	50	-1.202	-0.483	-0.223	0.783	-0.231	0.684	3.280
	100	-1.841	-1.190	-0.958	-0.065	-0.965	-0.152	2.152
Jiangcheng	Annual 7 day maximum temperature (°C)							
	20	33.21	34.18	34.52	35.84	34.51	35.71	39.13
	50	33.57	34.57	34.90	36.22	34.89	36.09	39.49
	100	33.78	34.79	35.13	36.44	35.12	36.32	39.70
	Annual 7 day minimum temperature (°C)							
	20	1.03	1.78	2.06	3.12	2.05	3.02	5.73
	50	-0.92	-0.23	0.02	0.97	0.01	0.88	3.26
	100	-2.55	-1.92	-1.69	-0.86	-1.70	-0.93	1.12
Lancang	Annual 7 day maximum temperature (°C)							
	20	35.16	36.00	36.32	37.57	36.31	37.50	41.53
	50	35.38	36.20	36.51	37.74	36.50	37.68	41.92
	100	35.49	36.29	36.60	37.83	36.59	37.77	42.15
	Annual 7 day maximum temperature (°C)							
	20	1.32	2.21	2.53	3.81	2.52	3.68	6.97
	50	0.40	1.29	1.62	2.91	1.61	2.78	6.14
	100	-0.28	0.63	0.96	2.26	0.95	2.13	5.55

Appendix 4: Precipitation related observed climate variables and their future projections

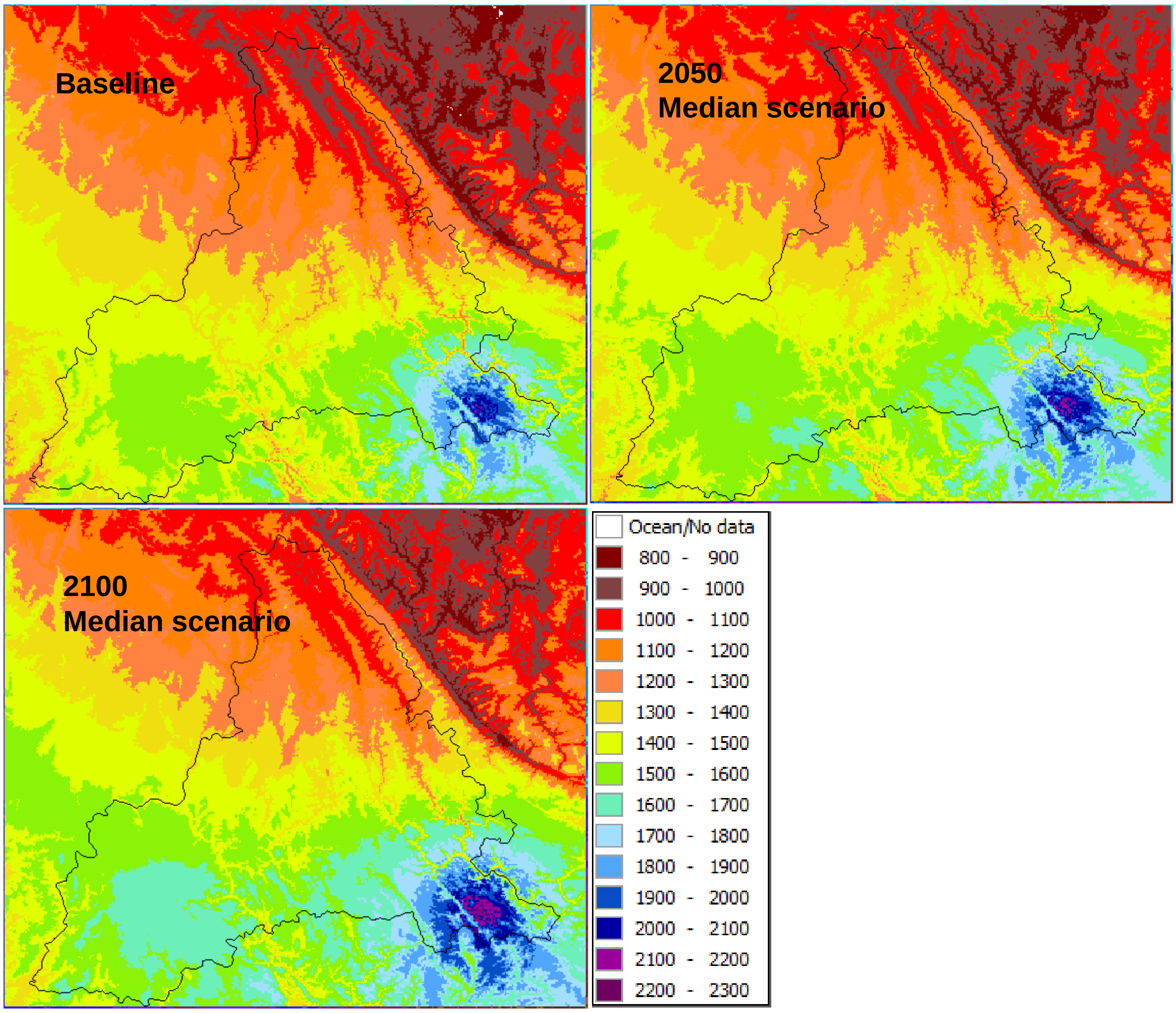

Figure A4-1: Pu'er annual rainfall distribution (mm): baseline and 2050, 2100 median scenario projection

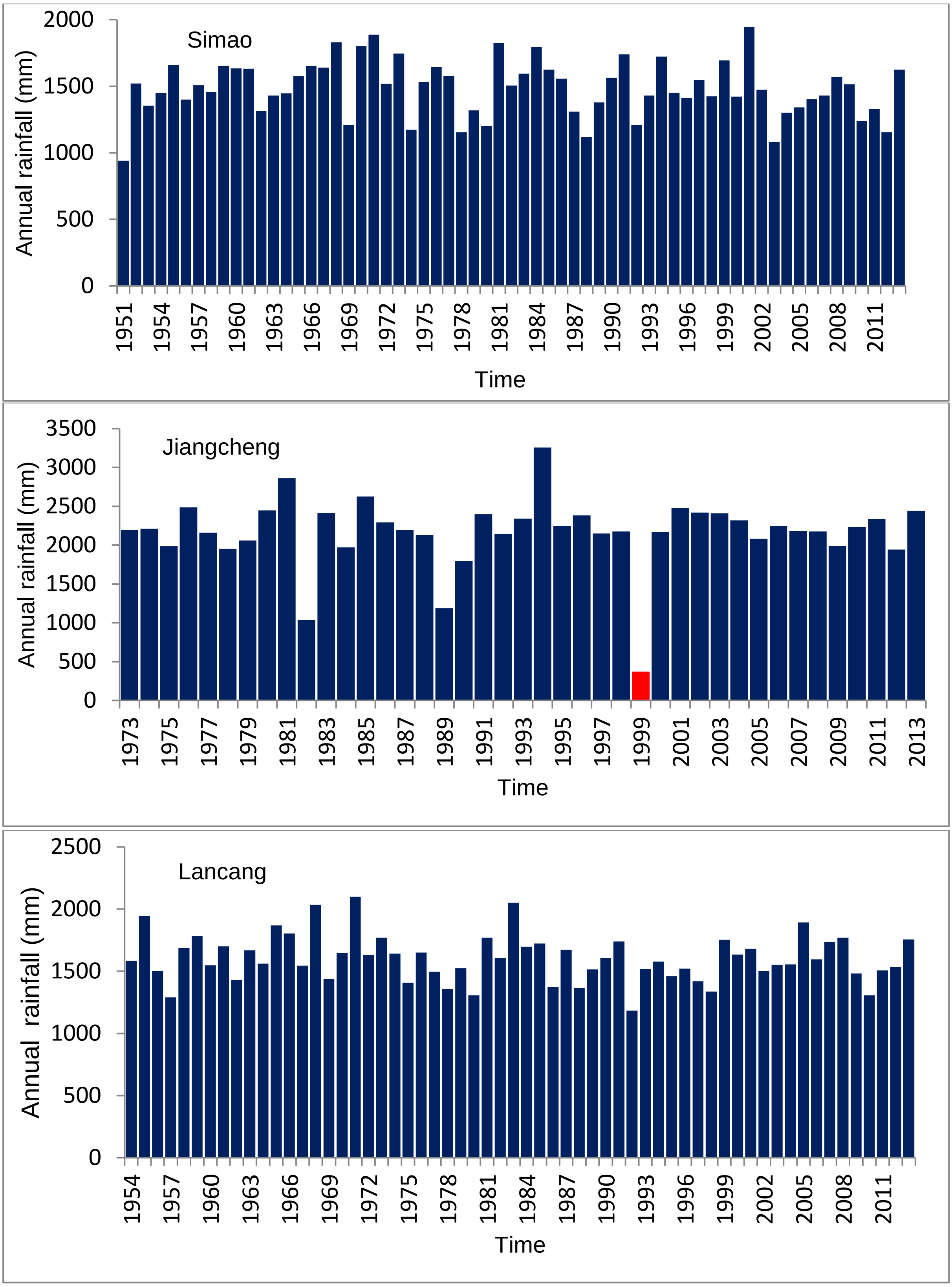

Figure A4-2: Observed annual rainfall of Simao, Jiangcheng and Lancang (Jiangcheng has missing data for 1999)

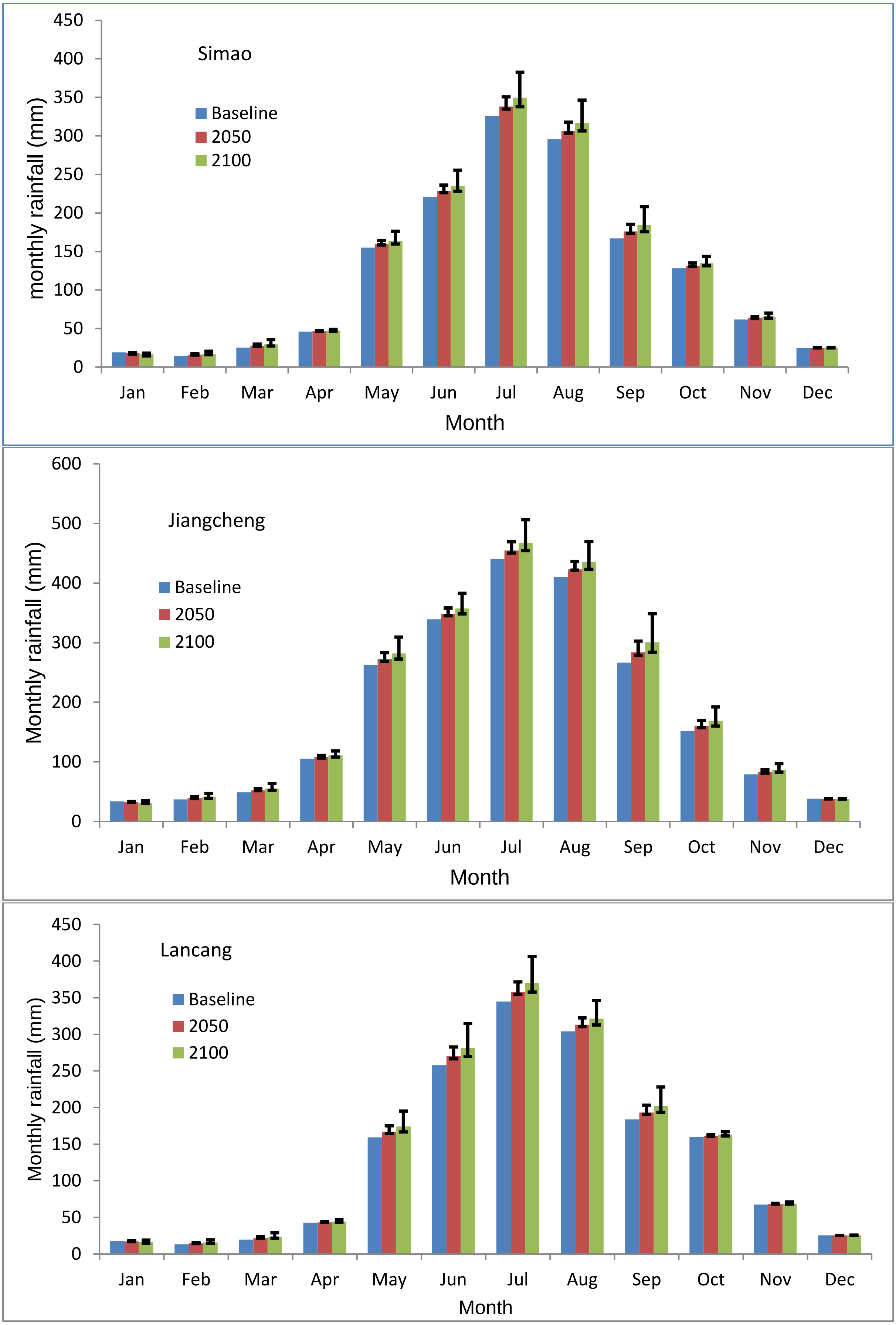

Figure A4-3: Station monthly normal rainfall and future projection. The bar indicates the uncertainty range of the climate change projection as defined in Table 2

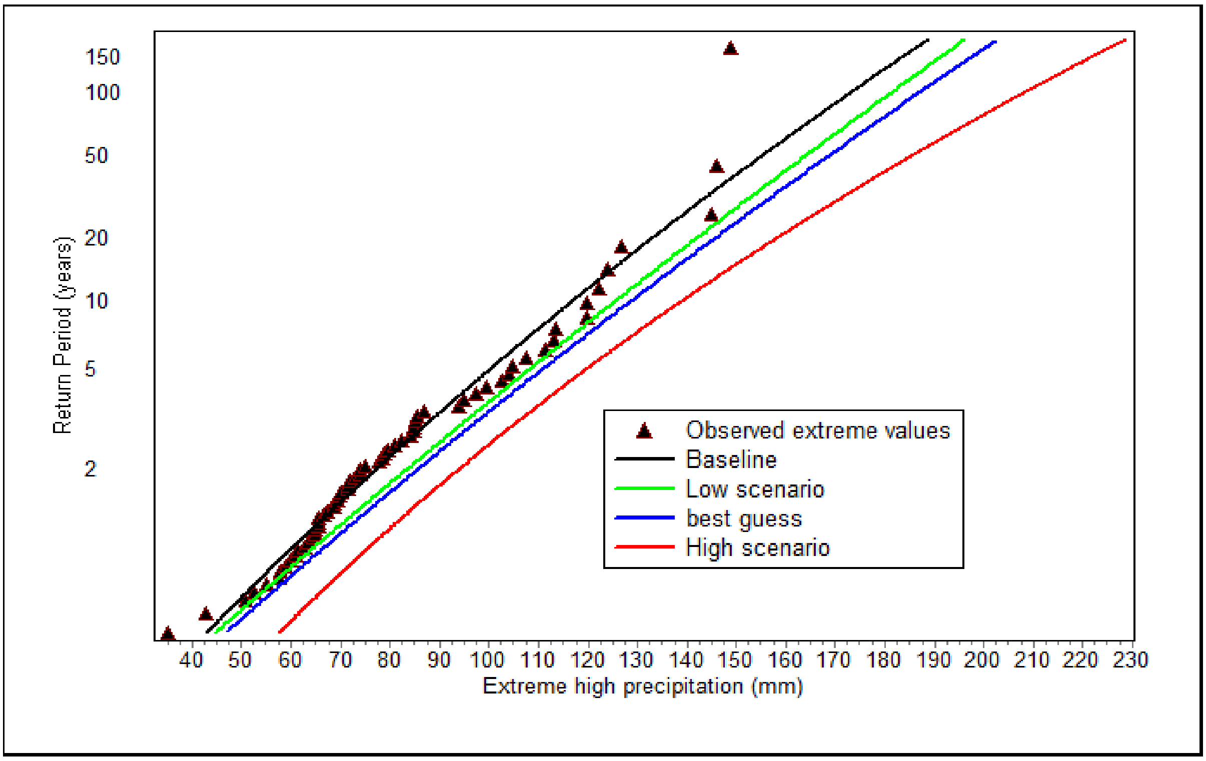

Figure A4-4: Simao annual maximum 1 day rainfall GEV distribution and 2050 projection. Black line is the baseline from historical data; blue and red lines represent the uncertainty range as defined in Table 2; green line is low projection; red line is high projection. The horizontal difference between green and red lines indicates the uncertain range of rainfall intensity for a given rainfall frequency; the vertical difference between green and red lines indicates the uncertain range of rainfall frequency for a given rainfall intensity

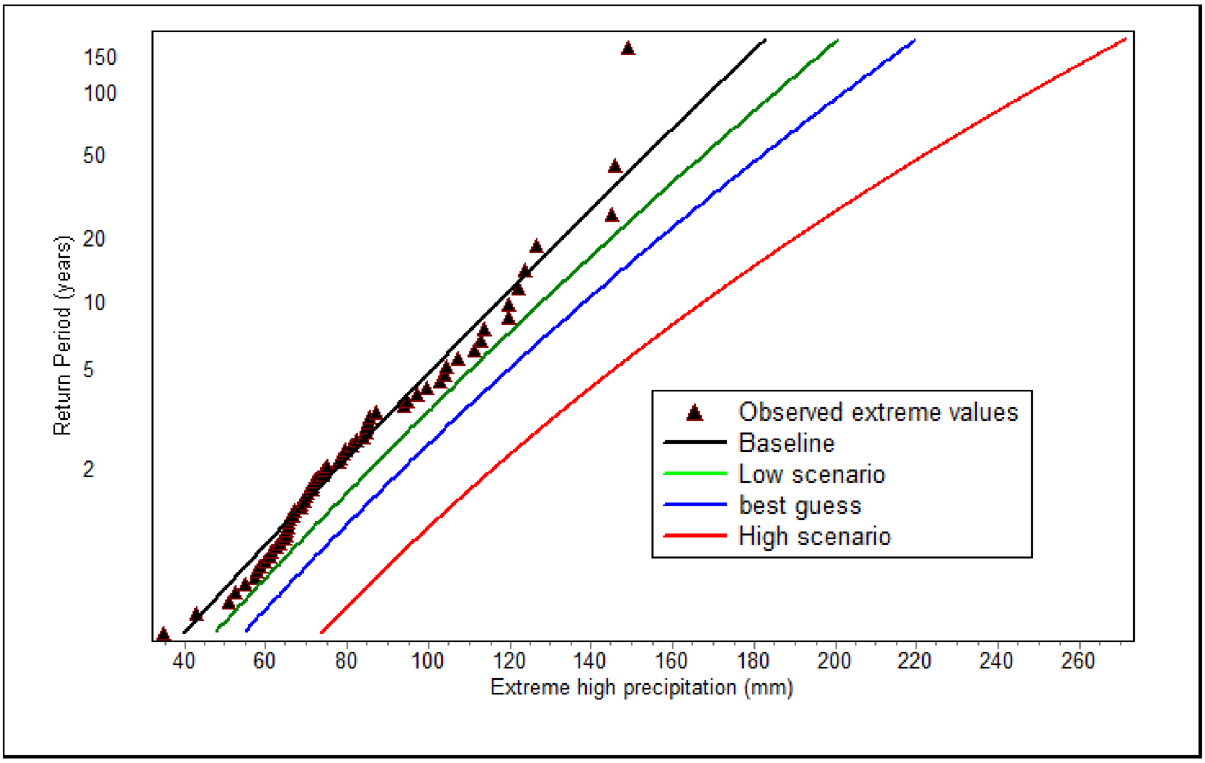

Figure A4-5: Same as Figure 4 but for 2100 projection

Appendix 5: Discussion of the relations of rainfall - flood, rainfall - landslide for Pu’er project climate change impact assessment

There is a lack of hydrologic data in the PRIRNP area for proper hydrologic or hydraulic model development. Only a 54 years annual maximum peak flow data of 1959 to 2013 was collected for the Menglian hydrometric station for the Nanlei River, which is a major tributary to the Lancang River. The Menglian station is about 40 Km west of the Lancang meteorological station. The Lancang Station is in the direction of upper stream of the Nanlei River, but outside of the catchment area. A statistical approach was adopted to explore the relationship between the Menglian peak flow and the Lancang rainfall of various durations from 1 day to up to 10 day rainfall prior to the peak flow. No significant statistical relationship could be found between the peak flow and the rainfalls, either from any individual rainfall duration or from the combination of various durations.

The reason are twofold: firstly it is because of the complexity of the local geo-hydrological conditions; second but also more importantly is because of the extensive human intervention to the river systems, such as man-made changes to the river channels and the extensive cultivation at the river catchment. Such conditions are by and large common to most area in Pu’er. This is evident from the Nanlei River at Mengliang, which is the start point of the Menglian-Meng’a Regional Road for this project. The river channels at Menglian have undergone a number of rehabilitations, which has greatly altered the hydrology of the river flow. The 2006 flood is a typical example: during October 8-10, Menglian had a total three day rainfall of 276.6 mm, the largest in history for Pu’er. The peak flow data observed at Menglian station was 958.11 masl, which was even 0.17 metres below the flood warning height (958.28 masl) . However, the torrential rain had triggered a 1:50 year flood at downstream of Nanlei River downstream and caused CNY 40 million damages and 1 death (Hu, 2011). Thus it has been a great challenge to develop proper hydrological or hydraulic models to simulate the rainfall and flood for Pu’er. In the past, most rainfall – flood research has been focused on either single event analysis or on the qualitative bases. Zhang et al. (2011) thus used directly the rainfall to study the water damage to the road system of Yunnan.

On the other hand, however, the heavy and, in particular, the torrential rainfall of Pu’er is characterised by high intensity and short duration. The steep mountainous topography makes the triggered flood responding quickly to the rainfall and also characterised in short duration in general. Almost all rainfall becomes runoff and goes to river channels (Luo and Jing, 2009). Li et al. (2007) pointed out that there was good spatial and temporal agreement between torrential rain and flood in Pu’er, with a flood event normally last 20 to 30 hours. Hence it is expected that the flood discharge and the 1 day heavy rainfall would have a reasonable good linear relationship. In the absence of reliable hydrological observations for the project area, the 1 day torrential rain may be used as a surrogate in investigating the climate change impact on river flood, i.e., it was assumed that the flood discharge will vary linearly with the 1 day rainfall change. The assumption is hold particularly well for high intensity flood event.

Another biggest climate risk is the heavy rainfall induced landslide. The PRIRNP is located in a high soil erosion prone area. Human activities have also caused serious land degradation. The landslide and debris flow disaster is severe in both frequency and intensity. While slope is the dominated factor contributed to landslide risk, a study on the project area revealed that it only accounts for 50% of the total landslide risk (Yan et al. 2001). The heavy rainfall contributes 20%, and landcover accounts for the rest 30% of the total landslide risk in the PRIRNP area. Tang and Zhu (1999) conducted a survey study in the Lancang catchment, and provided a quantitative relationship between rainfall amount and landslide risk in the area, as shown in Table A5-1.

Table A5-1: Landslide risk area classification for the middle and downstream area of Lancang River (Tang and Zhu. 1999)

	Landslide risk level		
	Low	Medium	High
Rain amount in 1 day (mm)	60-80	80-100	≥100
Total rain in previous 5 day + rain of current day (mm)	100-120 +40	120-150 +60	≥150+80

Based on their results, for the project area it was expected that the 1 day rainfall of 70, 90 and 100, or 6 day total rainfall of 140, 180 and 230 mm would have reasonable good relationship with landslide risk of low, medium and high. Thus these values were used as indicators for future landslide/debris flow risk changes under climate change impact.