Climate Change Vulnerability Assessment

Project Number: 48444
June 2017

PNG: Multi-tranche Financing Facility for the Sustainable Highlands Highway Investment Program

Asian Development Bank

ABBREVIATIONS

BoM	Bureau of Meteorology of the Government of Australia
BRIRAP	Bridges Replacement Program, supported by ADB in PNG
CRVA	Climate risk and vulnerability assessment
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DFAT	Department of Foreign Affairs and Trade of the Government of Australia
DoW	Department of Works of the Government of PNG
ENSO	El Niño Southern Oscillation
EWS	Early warning systems
MFF	Multi-partner financing facility
NWS	National Weather Service of the Government of PNG
OCCD	Office for Climate Change Development of the Government of PNG
PACCSAP	Pacific-Australia Climate Change Science and Adaptation Planning
PNG	Papua New Guinea
PPTA	Project Preparatory Technical Assistance
RRMP	Road Maintenance and Rehabilitation Project (RRMP) supported by the World Bank
SHHIP	Sustainable Highlands Highway Infrastructure Program
TSSP	Transport Sector Support Program, supported by the Government of Australia

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EXECUTIVE SUMMARY

A. Background to the CRVA

1. The proposed Sustainable Highlands Highway Infrastructure Program (SHHIP) is envisaged as a ten- year, multi-partner, multi-tranche financing facility aiming to restore and upgrade the Highlands Highway in Papua New Guinea (PNG). The executing agency is the PNG Department of Works (DoW). The initial climate screening of SHHIP using AWARE determined the Investment Program to be at medium risk to climate and climate change. As a result, ADB procedures require that a climate risk and vulnerability assessment (CRVA) be undertaken during the design stage. This report presents the findings of the CRVA. Additional evidence and methodologies are presented in Annexes; while photographic evidence is presented in the Appendix.

2. Several studies indicate that road transport is amongst the sectors that are most vulnerable to climate change. The ADB has committed to assisting its Pacific Development Member Countries (DMCs) to climate proof projects and to ensure that the outcomes of projects are not compromised by climate change. The CRVA is a key tool for undertaking this task. Specifically, the purpose of this CRVA is to assess the climate and climate change threats to the SHHIP, to assess the adaptation measures that are proposed in the SHHIP design, to determine to what extent the performance and design of SHHIP are vulnerable to climate change, and to recommend measures that will improve the climate resilience of SHHIP. The CRVA covers all aspects of the SHHIP investment program.

3. This CRVA was undertaken as an integral part of the SHHIP preparation and design process in combination with the Project Preparatory Technical Assistance. The approach to the CRVA included making necessary efforts to fully understand the challenges being addressed by the SHHIP, to understand the details of SHHIP's approach and to understand the limitations on the SHHIP. The CRVA is therefore adapted to the SHHIP design. In addition, specific methodologies were developed for two CRVA sub-steps, i.e.: (i) assessing and prioritizing the climate risks associated with SHHIP components and (ii) counting the costs of SHHIP activities that qualify as climate finance.

4. As with many CRVAs, constraining factors were the incomplete meteorological and other geographical data, and the incomplete nature of climate change projections. Further, at the time of preparing this report, the detailed engineering data for the design of SHHIP Tranche 1 was not available. These constraints notably limited the ability to undertake an economic analysis of the impacts of climate change and of adaptation measures.

B. Context of the Sustainable Highlands Highway Infrastructure Program

5. The Highlands of Papua New Guinea (PNG) is a chain of mountains and high valleys stretching in a generally west to east direction from the border with Indonesia in the center of the island to the eastern coast. The mountain valleys of the Highlands have been relatively densely populated for a long time and remain so to this day; it is estimated that some 40% of PNG's population live in the Highlands. The Highlands have many unique geographical characteristics including an extreme tropical climate, highly fragmented watersheds and a predominantly steep relief.

6. The existing Highlands Highway (HH) stretches over 600 km from Lae on the eastern coast to Mendi in Southern Highlands Province. It is a national highway and a major component of PNG's national road network. It is the only terrestrial means of access to the Highlands and is the only road in the Highlands that crosses a provincial boundary. It therefore provides an essential economic, social, educational and cultural lifeline to the

Highlands. The HH is mostly surrounded by small-scale agriculture and associated dwellings. The adjacent land is mostly covered with vegetation, often quite thick, even on the steep slopes, although there are some exceptions and some land is uncovered and exposed to erosion.

7. The focus of SHHIP is a 430 km stretch of the HH starting about 40 km outside Lae (near the East coast) and continuing to 20 km before Mount Hagen in the Western Highlands. Approximately, 3% of this stretch is in good condition, 75% in fair condition and 22% in poor condition. This stretch can be divided into five distinct zones as follows:

- Zone 1, covering 101 km from Nadzab airport to Umi Bridge, generally in fair condition;
- Zone 2, covering 208 km to the border with Chimbu Province, generally in fair-poor condition;
- Zone 3, covering 57 km across all of Chimbu Province, generally in poor condition;
- Zone 4, covering 20 km in Jiwaka Province, is generally in fair-poor condition; and,
- Zone 5, covers 42 km from Ambeke Bridge to Kagamuga, generally in fair condition.

8. The existing road pavement exhibits many forms of deterioration. It suffers from potholes, damaged edges, deformations, subsidence, erosion and land and rock slides. In some places these factors have connected up and combined and the pavement surface layer is missing. The base layer is damaged in some short sections and at some points parts of the pavement have collapsed. However, the entire road is passable during most of the year, although delays are regular and chronic damage is caused to vehicles. There is evidence that the deterioration is increasing and it seems likely that major problems may lie ahead and at times after weather events the road is impassable requiring emergency works.

9. Most damage to the pavement is caused by the rain as follows:

- This raises the water table so that it reaches the pavement foundation layers or even the pavement surface. This weakens the foundations and contributes to subsidence, deformation and pothole formation;
- During short-term, intensive rain events, ineffective or absent side drains mean high energy rainwater flows down the road crown and/or the road edge. This weakens the foundations and exacerbates any existing failures;
- During short-term, intensive rain events, rainwater overflows the cross-culverts and crosses the road surface. In addition to damaging the surface, this can erode road foundations near the culvert outlet; and,
- Accumulated rain, from both short-term, intensive events and prolonged rain spells, saturates the soil and contributes to rock and land instability.

C. Climate and climate change threats to the Highlands Highway

10. The greatest climate related threat is extreme rainfall of short duration (within a 24-hour period). Prolonged rainfall also presents a risk as the water accumulates. There are no significant risks associated with high temperatures or strong winds. Both short-term and longer-term rainfalls exhibit strong temporal variability. Further, there is also some evidence of spatial variability in the maximum intensity of short-term rainfall and in annual rainfall. Notably, the storms causing extreme rainfall appear generally small in geographical size.

11. By 2050, the expected changes in these threats due to climate change can be summarized as follows:

- At any site, the average annual rainfall will increase by, at most, 14%;

- At any site, the maximum daily rainfall, for any given return period, may increase by up to 30% (by 2055);
- For any small catchment, the peak rainwater discharge may increase by up to 34% (for any given return period). This would notably influence the required size of drains;
- For any small catchment, the peak water levels in streams and rivers may rise by up to 55% (for any given return period). This would notably influence the required height and design of bridges;
- For larger catchments, it appears likely that: (i) the peak discharges will rise, but probably by less than 34%; and (ii) the peak water level will rise, but probably by less than 55%; and,
- Increases in extreme and prolonged rainfall will most likely lead to increases in soil saturation levels, and in turn to increased slope instability and weakening of the road layers.

D. The SHHIP

12. The SHHIP is envisaged to be implemented in three tranches over a ten-year period. It has four Outputs:

(1) Highlands Highway from Lae Nadzab airport to Kagamuga airport at Mt. Hagen, is restored, effectively maintained, and upgraded as required to be safe, climate- and disaster resilient for all users. This covers the 430 km over the five zones;
(2) Road safety increased and sustained for pedestrians and vehicle passengers on the Highlands Highway;
(3) Transport logistics and services improved in the Highlands region to strengthen value chain for domestic and international trade; and
(4) Program management and institutional capacity improved to deliver the program and sustain its benefits.

13. The first output is the main SHHIP investment and is the main focus of this CRVA.

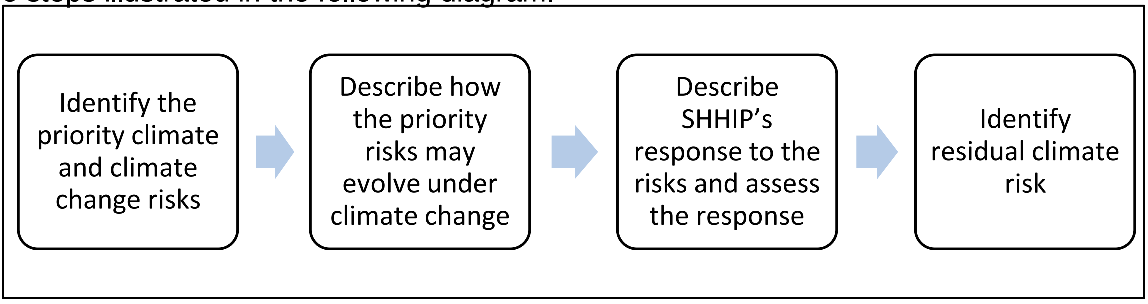
E. Findings of the CRVA (1) – The Overall SHHIP

14. The approach to SHHIP has many positive characteristics in terms of increasing climate resilience. First, the multi-tranche approach facilitates the integration of climate change measures. It allows time and space to collect climate related data, to develop innovative approaches and to convince all decision-makers of the feasibility and necessity of adapting.

15. Second, two alternative approaches to implementation were considered. The first (to fully rehabilitate and substantially upgrade small sections of the highway, while, due to financial limitations, cutting down on maintenance activities elsewhere) was rejected. The second (to provide comprehensive and sustained maintenance whilst progressively undertaking appropriate upgrading) was selected. The selected alternative gives more flexibility. It therefore allows adaptive responses to climate change to be developed when needed and when available. It also provides for more maintenance and emergency response – thereby both preventing climate impacts and creating the capacity to respond to climate impacts after they happen. It is more climate resilient.

F. Findings of the CRVA (2) – Output 1 (*Highlands Highway from Lae Nadzab airport to Kagamuga airport at Mt. Hagen, is restored, effectively maintained, and upgraded as required to be safe, climate- and disaster resilient for all users*)

16. Output 1 consists of 17 different types of activity, categorized as either ‘maintenance’ or ‘investment’. For each activity type, the climate risk and vulnerability was assessed using the steps illustrated in the following diagram.



17. The detailed findings are presented in Table 4 of the main text. In summary:

- Four of the types of activity to be implemented by SHHIP are to be implemented purely in response to climate threats. Based on best available knowledge and understanding, these appear reasonable and adequate;
- Seven of the types of activity to be implemented by SHHIP have been adapted to increase the resilience to climate change. Based on best available knowledge and understanding, these appear reasonable and adequate;
- For the other five types of activity, there is no significant climate change risk;
- Hence, the measures taken by SHHIP to climate proof are considered adequate and appropriate;
- Despite the measures taken to climate proof, the uncertainties associated with climate change mean that the measures cannot guarantee to provide full climate resilience in all circumstances. There is a residual climate change threat. In response, SHHIP has built in a flexible and effective adaptive response measure - through the maintenance systems and emergency response mechanisms; and
- SHHIP could explore the utilization of more ecosystem based approaches to adaptation, such as bioengineering and catchment management.

G. Findings of the SHHIP CRVA (3) – Output 2 (*Road safety increased and sustained for pedestrians and vehicle passengers on the Highlands Highway*)

18. Output 2 does not include the construction of infrastructure that is at risk to climate hazards or vulnerable to climate change. Output 2 does not include entry points through which adaptation measures can be introduced.

H. Findings of the SHHIP CRVA (4) - Output 3 (*Transport logistics and services improved in the Highlands region to strengthen value chain for domestic and international trade*)

19. Output 3 does not include the construction of infrastructure that is at risk to climate hazards or vulnerable to climate change. Output 3 does not include entry points through which adaptation measures can be introduced.

I. Findings of the SHHIP CRVA (5) - Output 4 (*Program management and institutional capacity improved to deliver the program and sustain its benefits*)

20. Output 4 includes measures to ensure that the SHHIP and DoW benefit from best available technical support and from capacity development related to designing and implementing the restoration, upgrading and maintenance of the Highlands Highway. Currently, in DoW, there appears to be little understanding of basic climate change concepts

and no evidence of in-depth knowledge of climate change. Output 4 provides an entry point to provide that capacity (see Recommendations below).

J. Conclusions

21. Limited data, knowledge, models and understanding mean a classical approach to designing adaptation measures is not possible. By classical approach it is meant: determining current parameters, projecting future climate change, determining impacts on the project of climate change, and recommending specific adaption approaches and measures. The limited data, knowledge, models and understanding are major constraints to doing this. This is compounded by the great variability of rainfall. This and uncertainty associated with projections for climate change over the coming decades, make it impossible to precisely project the future climate and how it may affect road infrastructure.

22. Extrapolation from past climate impacts on the road provides an appropriate complementary approach to identifying adaptation needs. As the road has existed for several decades, the impacts of previous climate hazards can be easily observed. By extrapolating from these, and using available climate change projections, it is possible to project the climate risks facing each section of the highway in the future. This method was used by the PPTA team and in this CRVA.

23. The climate in the PNG Highlands is challenging; there are significant climate threats. The two climate parameters that significantly affect road design on the HH are extreme rainfall of a short duration and prolonged rainfall. There is much evidence of the past impacts of these two climate parameters at many points along the HH. These challenges are most likely to be exacerbated by climate change.

24. The Highlands Highway is at risk to climate threats, particularly to extreme rainfall events, and it is vulnerable to climate change.

25. The overall approach of the SHHIP to climate resilience is sensible and appropriate, based on best available knowledge. This notably includes the focus on repair and upgrading, the focus on maintenance and emergency response, and the inclusion of some activities uniquely to address climate threats. Further, the SHHIP’s multi-tranche, long-term nature enables the development of climate resilience measures. Notably, innovative measures can be developed and/or piloted in Tranche 1, and, if successful, support can be mobilized to their broad replication in later tranches.

26. The approach of SHHIP to individual activities is also sensible and appropriate, based on best available knowledge. The PPTA design team has assessed climate risks to the SHHIP by observing the past impacts of climate, using best available data and knowledge and extrapolating. This is appropriate. In response to the risks identified, SHHIP has integrated climate resilience into activities as necessary. However, possibly, more emphasis could have been placed on ecosystem-based adaptation approaches.

27. There will be residual climate risks. Inherent to the SHHIP approach is that there will be residual climate threats and damage. The proposed maintenance and emergency response measures in SHHIP will provide some protection and mitigation against these residual threats. Notwithstanding, some threats will remain.

28. The capacity of the Department of Works to address climate change appears very limited. Currently, DoW has little capacity to specifically addressing climate change. Until now, this has not been a priority, it has been more important for DoW to focus on ensuring best practices.

K. Counting the Climate Finance

29. For the overall ten-year Investment Program, the estimated cost of the SHHIP measures and activities that qualify as climate change adaptation finance is $226.7 million or 23% of the overall budget. For Tranche 1, the estimated cost of measures and activities that qualify as climate change adaptation finance is $69.8 million or 20% of Tranche 1's budget.

L. Recommendations

30. Section 7 of the main report provides detailed recommendations. These are in response to the conclusions and relate mostly to improving understanding and capacity so that future tranches and future road transport projects in PNG are better in adapting to climate change. These are summarized as:

31. Support activities to increase knowledge and understanding. This includes:

- Establish a systematic climate surveillance, including a proper climate database;
- Determine credible estimates of the economic costs and benefits of the project with and without climate change, and with and without adaptation measures;
- Undertake specific studies of the costs and benefits of the improved maintenance and emergency response measures.

32. Explore and develop innovative approaches to adaptation, including:

- Pilot ecosystem based approaches to adaptation such as (i) bio-engineering to increase adjacent slope stability and (ii) watershed management in micro-catchments to better regulate the hydrological cycle;
- Pilot early warning systems;
- Explore the insurance of road assets as a climate adaptation measure.

33. Build DoW capacity to address climate change. The capacity can be developed during Tranche 1 of SHHIP and subsequently applied to the design and support of SHHIP Tranches 2 and 3. This possibly includes:

- Raise awareness across all DoW units;
- Establish a small, specialist climate change capacity in DoW;
- Develop collaboration between DoW and other agencies working on climate change; Develop necessary capacity in DoW to access international climate finance; and Prepare a set of practical guidelines or a manual for climate proofing.

I. INTRODUCTION

A. Purpose, Scope, Structure, Methodology and Limits to this Assessment

1. The proposed Sustainable Highlands Highway Infrastructure Program (SHHIP) is a ten-year, multi-partner, multi-tranche financing facility aiming to restore and upgrade the existing Highlands Highway in Papua New Guinea (PNG). The initial climate screening of SHHIP using the on-line tool AWARE determined the Program to be at *medium risk* to climate and climate change. As a result, ADB procedures require that a climate risk and vulnerability assessment (CRVA) be undertaken during the design stage. This report presents the findings of the CRVA.

2. Climate change is a central development challenge across the Pacific. Several studies indicate that road transport is amongst the sectors that are most vulnerable to climate change. In response, the ADB has committed to assisting its Pacific development member countries (DMCs) to climate proof projects and to ensure that the outcomes of projects are not compromised by climate change. This is relevant in PNG with its challenging geography and climate.

3. The purpose of this CRVA is to assess the climate and climate change threats to the SHHIP, to assess the adaptation measures that are proposed in the SHHIP design, to determine to what extent the performance and design of SHHIP is vulnerable to climate change, and to recommend measures that will improve the climate resilience of SHHIP.

B. Scope

4. The CRVA covers all aspects of the SHHIP program. The SHHIP focuses on a 430 km stretch of the Highlands Highway (HH). The principal focus of the SHHIP is to ensure that the road is operational at all times. In addition, the SHHIP includes several smaller investments linked to road transport, developing economic opportunities and providing necessary support to capacity development, technical assistance and institutional strengthening. The CRVA covers all SHHIP components as necessary. The CRVA assumes a design life for SHHIP of 25-30 years, and hence, typically uses climate projections through 2055.

5. The original Terms of Reference for this CRVA are provided in Annex 1. As can be seen from Annex 1, the initial plan was for the Climate Change Specialist to prepare a CRVA for both the overall SHHIP and for Tranche 1 of the SHHIP. This report provides the CRVA for the overall SHHIP and provides sufficient coverage for Tranche 1. As more data become available, it will be necessary to prepare assessments for Tranches 2 and 3.

C. Report Structure

6. This introductory section sets out the aims and approach of the CRVA. It also briefly reviews the approach taken to climate assessments by similar projects in order to learn lessons. Next, Section 2 introduces the existing HH: its purpose, history and current status. Subsequently, Section 3 sets out the information available on the climate parameters most pertinent to the operations of the Highlands Highway. Section 3 also introduces how projected global climate change would affect these parameters. Section 4 introduces and describes in some detail the proposed SHHIP to be supported by ADB. Section 4 also assesses SHHIP's overall approach to climate resilience.

7. Section 5 provides the essence of the CRVA of the SHHIP. Section 5 looks at each component of the SHHIP and assesses the associated climate and climate change risks. It then assesses the steps taken by SHHIP to manage these risks. As the principal element of

SHHIP is an investment in physical infrastructure, the CRVA focus is the risks faced by these infrastructure components and their performance through projected climate change. In addition, Section 5 provides an estimate of the costs of SHHIP activities which qualify as climate finance – in line with ADB commitments to track and report on climate finance.

8. Subsequently, Section 6 provides the conclusions of the CRVA and Section 7 provides recommendations.

D. Methodology to Preparing the CRVA

9. The CRVA was prepared as an integral part of the SHHIP preparation and design process – the Project Preparatory Technical Assistance (PPTA). The CRVA included efforts to fully understand the challenges being addressed by the SHHIP, the details of the SHHIP approach and the limitations on the SHHIP approach. The CRVA is therefore fully adapted to the SHHIP and constructed around it. Specifically, the approach to preparing this CRVA involved the following logic steps:

- Understand the problem being addressed by the baseline project (the SHHIP) including the climate-related challenges;
- Understand the SHHIP. This includes understanding the evolving nature of SHHIP as it evolves to meet challenges and opportunities. This also includes understanding the SHHIP's approach to climate risks;
- Determine how climate change may influence the SHHIP; and,
- Identify gaps, if any, in the SHHIP approach to climate risks and make recommendations.

10. When determining how climate change may influence a project, a standard approach is to determine current climate parameters, to determine how they will change through global climate change, to determine how this should affect project design or how it may impact the project assets, and then determine how to adapt the project specifications. This CRVA implements this standard approach to the extent possible. However, incomplete data made this approach problematic. Hence, a complementary approach was adopted. In this complementary approach, it is not necessary to have a detailed and highly resolved understanding of the past climate – it is necessary simply to know how the climate has previously impacted infrastructure and how the climate will change in coming decades. This involves the following:

- Observe how climate parameters have impacted the highway's assets over previous decades;
- Determine how global climate change will affect the climate parameters; and
- Extrapolate into the future to determine how climate parameters will impact the highway through climate change.

11. The specific activities taken to undertake this CRVA included:

- Interviews with key informants. See Annex 2 for list of persons consulted.
- Literature review. This covered: documentation on climate and climate change related to PNG; geographical documentation related to PNG Highlands and to the Highlands Highway; previous technical reports and design documents related to the SHHIP; and documentation on climate assessments for similar projects in similar geographical zones. See Annex 3 for the list of reference documentation.
- Site visit to assess the status of the highlands highway and observe the impacts of previous climate events.

- Analysis of rainfall data and NASA climate change projections for pertinent sites in the Highlands (see Annex 6).
- A series of intensive interactions and brainstorming with the SHHIP PPTA Team Leader and other team members, in order to fully understand the problems to be addressed by the SHHIP, the approach to be taken, and the proposed approach to climate resilience.
- Report drafting and review, in consultation with team members, ADB climate specialists, and ADB road sector specialists.

12. Finally, specific methodologies were developed for two steps in this CRVA: (i) assessing and prioritizing the climate risks facing components of the SHHIP and (ii) counting the costs of SHHIP activities that qualify as climate finance. More details of these specific methodologies are provided in Section 5 and the relevant annexes.

E. Limits to the Assessment

13. Two important constraining factors are the incompleteness of data and the incomplete nature of climate change models. With regards to the former, this notably includes detailed data on past climate at sites along and near the HH. It also includes basic geographical and geological parameters such as land cover, soil types, etc. In essence, the previous weather is not known in sufficient detail, and thus there is not a full understanding of how previous weather affected the terrain, waterways and vegetation in the Highlands.

14. With regards to climate change models, these are not sufficiently accurate to provide precise projections at the level of sub-catchments in the Highlands.

15. Finally, at the time of preparing this report, the detailed data for the design of Tranche 1 was not available.

16. These constraints have greatly limited the ability to undertake economic analysis of the impacts of climate change and of adaptation measures.[1]

F. Lessons Learnt from Similar Climate Risk Assessments

17. The requirement for ADB projects and programs to undertake a CRVA is relatively new. As of yet there is no formal template nor fixed set of contents for a CRVA, nor is there an established methodology. Hence, in order to ensure that this CRVA builds on best practices and knowledge, the following were undertaken: (i) a rapid review of CRVA findings from a small number of ADB projects in other countries and (ii) a rapid review of the approach to climate risk assessment for similar projects in PNG.

18. The rapid review of CRVAs from ADB projects in other countries revealed that they vary in approach, methodology, scope and depth of detail. The reasons for this diversity are presumably the diverse types of project, the different timing of the CRVA with respect to the project cycle, and the diverse availability of resources and data.

19. In most cases, the starting point is to develop climate scenarios for the project site. Then, after establishing any assumptions, a next step is to establish project *scenarios:* with and without climate change, and: with and without adaption measures being implemented. This permits economic assessments and provides the basis for recommendations. These scenarios and the economic assessments demonstrate the general importance of undertaking climate change adaptation measures and indicate the type of measures that

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[1] As a result, one recommendation in Section 7 is to undertake probability based economic assessments of climate hazards and adaptation measures.

would be useful to adopt. In general, these CRVAs lead to a series of good but general recommendations. It is worth noting that in many cases, the recommendations are for what would be considered good practices and may also apply without climate change. This reconfirms that, in general, what is good for adapting to climate change is good for project design. These recommendations provide additional rationale for the inclusion of certain good practices in the Project design. However, due to the significant assumptions made and the simplifications in models, it is not usually possible to use these studies in order to make specific recommendations to the project design team. These CRVAs were rarely, if ever, used by the project engineer or project economist to select or design measures specific for adapting to climate change.

20. The review of the approach taken to climate risk assessment for similar projects in PNG determined the following:

- Bridges Replacement Program (BRIRAP), supported by ADB. A full CRVA was undertaken during the preparatory stage but was not finalized until several years later for contractual reasons. Following the elaboration of climate scenarios and the projected impacts on discharges in the watershed, the draft CRVA report identified that the bridges face many climate change related threats. It ranked the bridges in terms of the level of risk faced. It notably found that bridges on the New Britain highway are the most vulnerable to climate. It made a series of recommendations related to the design and construction of bridges. These recommendations were appropriate and pertinent, yet, they were general in nature and were not sufficiently specific to be used directly by design teams. In most cases, these recommendations were for best practices that may make sense with or without climate change. It is not clear to what extent the preparatory and design teams were able to make best use of these findings and recommendations. At a later date, updated IIE were prepared for each component of BRIRAP. The updated IEE reported that all climate considerations had been considered in the final designs and that there was no need for additional funds to accommodate for climate change adaptations. During implementation, the lack of data on rainfall and land coverage present an important challenge to forecasting maximum water discharges when designing bridges.[2]
- Transport Sector Support Program (TSSP) supported by the Government of Australia (DFAT). TSSP started operations in 2007 and Phase 1 is now complete. Phase 2 is now starting up. TSSP has provided significant support to small scale repair and maintenance on highways and roads in PNG. The TSSP project team reported that addressing climate threats is an integral part of all work in the transport sector in PNG, including in TSSP, and accordingly the work supported by TSSP certainly contributes to climate resilience. However, for Phase 1, given incomplete data on climate and climate change, it had not been possible to separate out climate and climate change risks in the design work.
- The Road Maintenance and Rehabilitation Project (RRMP) supported by the World Bank. RRMP has been supported through several stages. It includes a TA titled ‘Building a More Disaster and Climate Resilient Transport Sector Project’. Overall, the design and implementation of RRMP recognize that addressing climate threats is an integral part of all work in the transport sector in PNG. Until now, there have been no dedicated assessments of climate change and no determination of the specific implications on project design. However, the TA used probabilistic methods to model the costs of climate hazards on transport assets in PNG and prepared a draft manual for addressing climate risks in road transport projects.

21. In summary, the CRVAs and the climate risk assessments of transport projects in PNG have: (i) established that the current climate risks are critical and must be addressed in

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[2] Personal communication from the Design and Supervision Consultants

project design and performance; (ii) demonstrated, or assumed, that climate change will exacerbate the risks; and in most cases (iii) provided general understanding of the additional needs related to climate change and provided general recommendations. In most cases, the recommendations are best practices that would make sense with or without climate change. There are very few, if any, examples of specific studies of climate change leading to specific recommendations pertaining to the design or operations. This may ultimately be due to challenges in obtaining climate and other data and to the limited precision of climate change projections.

22. Finally, as reported by several road design consultants with experience in the Highlands of PNG, current approaches to designing rural roads in the PNG Highlands cannot be fully reliant on rainfall data or hydrological models. Trial and error plays an important role in drainage design. Further, experts often use anecdotal evidence provided by elderly community members to determine peak river discharges.

II. THE HIGHLANDS HIGHWAY

A. Location and General Overview of the Highway

23. The Highlands of Papua New Guinea (PNG) is a chain of mountains and high valleys stretching in a generally west to east direction from the border with Indonesia in the center of the island to the eastern coast. The valleys are typically 1,500 m above sea level and are surrounded by peaks up to 4,000 m. The Highlands have been inhabited for many thousands of years and are known to be one of the first places to develop agriculture. The mountain valleys of the Highlands have been relatively densely populated for a long time and remain so to this day; estimates suggest that some 40% of the PNG population lives in the Highlands.

24. The Highlands have many defining geographical characteristics some of which are particularly pertinent to this study. First is the prevalence of sharp relief. There is very little flat land in the highlands and a large proportion of the land is steep to very steep. Second is the highly fragmented nature of the watersheds. Much of the Highlands are made up of small and micro-catchments (see Photo 1 in the Appendix). Third, there are large areas with loose soil and large areas with clay-based soil and large areas where the water table is very high. This latter has resulted in many damp or swampy areas. These geographical characteristics contributed to historical impenetrability of the Highlands; until the middle of the 20th century the Highlands were almost entirely isolated from the rest of the country and the world.

25. The HH stretches from Lae in Morobe Province on the eastern coast for over 600 km to Mendi in Southern Highlands Province (see map in Figure 1). The HH passes through the following provinces: Eastern Highlands, Shimbu, Jiwaka and Western Highlands. It is a two-lane highway. Although construction started in the 1950s, it was only in the late 1970s that construction commenced on a modern, sealed highway. Till this day, it is the only terrestrial means of communication between the large Highlands population and the rest of PNG and the world. Hence, it provides a lifeline for the economy, as well as for all social, educational and other services.

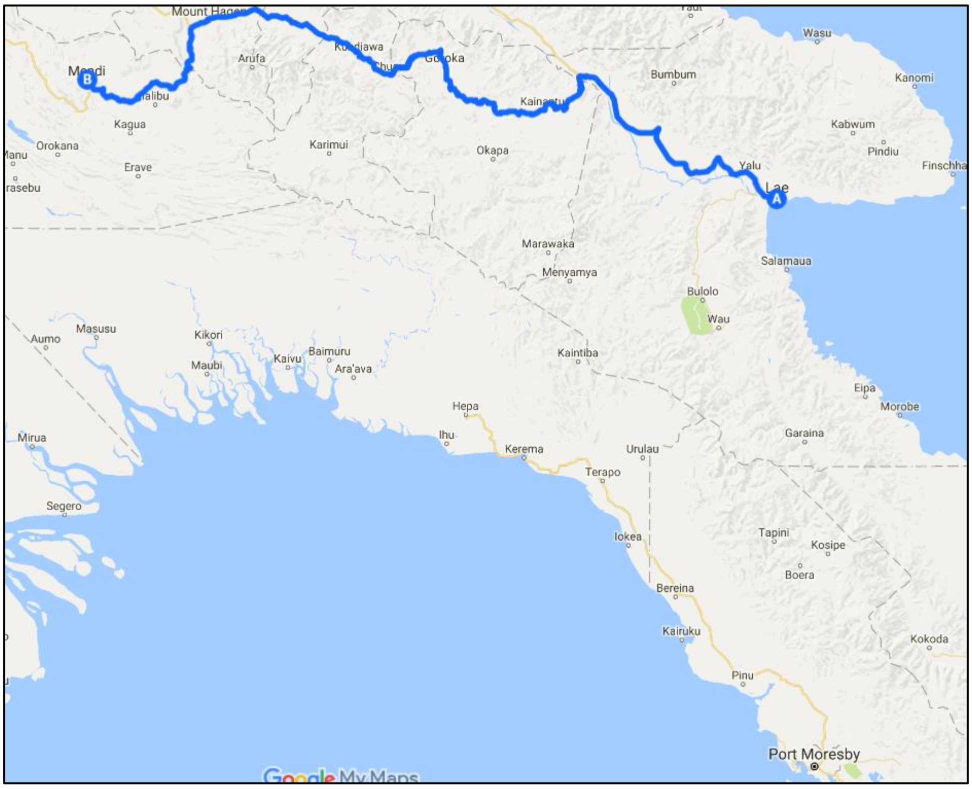

Figure 1: Map showing Highlands Highway with respect to capital at Port Moresby

26. The HH leaves Lae city and for approximately 160 km it crosses the lower reaches of the Markham valley traveling in a generally west-northwest direction and rising very slowly in altitude. In this area the Markham valley is broad, close to sea level and contains significant alluvial deposits, which are constantly being replenished and shifting continuously. The result is an undulating, dynamic plain. The river is very broad and braided. The main branch and smaller braids are subject to regular shifting and to localized flooding. The HH is not straight and from time to time it touches the northern edge of the valley where it crosses highly seasonal streams coming down from the hills to the North.

27. The HH leaves the Markham valley at Madang junction (450 m asl), turning southwards and rising quickly to approximately 1,400 m asl over a 15 km stretch. The HH then enters the Highlands at Kassam Summit. The remaining 425km of HH lie at approximately 1,500m. It travels in a general west northwest direction to Mount Hagen before turning south towards Mendi. The HH is typically narrow, winding, with many hairpin bends and steep gradients. The population is evenly spread along the highway, although there are some larger settlements such as Goroka and Mount Hagen.

28. For the most part, the HH is surrounded by small-scale agriculture and associated dwellings. There are also some small coffee plantations. As a result, the land to either side of the Highway is mostly covered with vegetation, and this is often quite thick, even when the relief is steep. However, at some points, agricultural practices have left much land uncovered and exposed to erosion. Finally, there are some stretches of grassland, some of which is almost barren, and some of these stretches are adjacent to the HH. See photos 1 – 5 in the Appendix.

29. The HH is a major element in PNG's national road network. The PNG national road network consists of approximately 28,000 km of road, of which 8,738 km are national roads, of which only 40% is sealed and approximately 30% is in the Highlands. The HH is one of only a very small number of roads that links and crosses provinces in PNG. Currently, the HH is the only road in the Highlands that crosses a provincial boundary.

B. Condition of the Highlands Highway and Past Climate Resilience

30. This section describes the HH over the 430 km stretch between the turn offs for Lae Airport (at Nadzab, 40 km outside Lae) and Mount Hagen airport (at Kagamuga, 20 km before Mount Hagen). This section describes to what extent the original HH design and construction have resisted climate risks and it informs how climatic parameters have affected road design and performance in the past. This understanding will be used as an input into the climate and climate change risk assessment in later sections.

31. For the purpose of this analysis, this 430 km stretch is divided into five zones based primarily on the current condition of the HH. It is noted that the current condition of the HH is mostly determined by geographical and soil characteristics, hence, the zones reflect the changing geography.

Figure 2: Map showing the five zones along the Highway, between Nadzab airport and Kagamuga turn-off

32. The analysis in this section was based on the following:

- Detailed reports provided by the PPTA Team Leader;
- Visual observations by the Climate Change Specialist;
- A rapid review of previous assessments of the HH and of the geographical conditions in the Highlands region undertaken in recent years. In particular a thorough survey was undertaken in 2002.[3]

33. The photos in the Appendix, notably photos 6-16, provide illustration of the issues raised.

34. **Zone 1** is from Nadzab airport to Umi Bridge, a total of 101 km. The HH includes 12 bridges, all two-lane. The road is mostly flat, undulating between 150 m and 450 m above sea level. It runs close to and crosses the Markham river and/or tributaries at several points. Several tributaries pass through large culverts under the HH. The sedimentation loads in the rivers are high, and so the rivers are braided and are prone to shifting course. At several

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[3] See SMEC, 2002. *Highlands Highway Rehabilitation Project (53672).*

points, the HH passes over land that appears swampy, and several areas appear at risk from flooding. There is almost no danger of landslides in Zone 1. There are reports that recent upstream shifts in stream courses have led to sub-branches finding a best path along the road pavement for several km.

35. The road pavement in Zone 1 is generally in fair condition. There are many small potholes distributed irregularly. The shoulder edges are damaged at many points. There are some severe depressions in the pavement. The bridges appear largely in good condition, although in some cases the abutments may be undermined by siltation shifts in the river bed.[4] Side drains are present in many places although are not complete. There are signs of damaged or missing cross-drains (culverts). However, the entire road is passable, and the sub-base, base and surface layers are almost entirely intact.

36. Without undertaking a thorough analysis at each site, it would appear that localized flooding has contributed to the depressions and in some cases it has weakened the pavement edges and facilitated formation of potholes. It appears likely that a high water table at many points has contributed to pothole formation and to weakening the road edge. At times of high water discharge in the main rivers, these high discharges may have contributed to weakening bridge abutments, and potentially other minor damage to bridges. Peak water discharges in cross streams has likely caused damages to some side drains and culverts.

37. **Zone 2** is from Umi Bridge to Magiro Bridge at the border between Eastern Highlands and Chimbu Provinces, a total of 208 km. It includes 21 two-lane bridges and 19 single-lane bridges. In addition, the road crosses many small streams running under the road through culverts. The crossing streams are narrow with fast running water and highly variable discharges.

38. Umi Bridge lies 450 m asl. The road climbs, slowly at first, and then rapidly to over 1,500m asl at the Kassam summit - approximately 33 km from Umi Bridge. In general, the land lying next to the road has a low-medium incline towards the road, although some stretches of the road in this Zone lie next to very steep inclines with a high danger of rock or land-slides. Recently a severe landslide occurred recently close to Kassam Summit creating a very dangerous and unstable situation. The water table appears high and close to the surface at many points. Side drains are largely absent or ineffective.

39. The road pavement is generally in fair-poor condition. There are many irregular potholes. In some cases these have connected up. In some cases these are compounded by subsidence. There is evidence of recent land-slides at many points; these block the road and may cause damage to the pavement, but do not threaten to remove parts of the HH. There are several examples of regressive erosion,[5] where large sections of the pavement are in danger of caving away, or have caved away already. There are several examples of deformation, sometimes severe, sometimes over several tens of meters. There are several areas where the pavement is affected by subsidence. At several points, these factors have combined and the entire pavement surface layer is missing for tens or even hundreds of meters. Although a more detailed study is necessary, it appears possible that some of the bridges may have been slightly weakened or damaged due to peak water discharges, to shifting sedimentation or to land-slides. However, the entire road is passable, the sub-base and base layers are almost entirely intact, and the vast majority of the surface layer remains intact.

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[4] A more thorough investigation of each bridge is necessary.

[5] Typically where the land under the road, on one side, has been scoured by the action of water. This is either water that has crossed under the road in a culvert and then regressed into the road base, or water in fast streams that run parallel to the road and which, at peak discharges, have cut into the road base.

40. Most damage to the pavement originates from rainwater falling on the surrounding catchments through the following mechanisms:

- This raises the water table so that it reaches the pavement foundation layers or even the surface. This weakens the foundations and contributes to subsidence, deformation and pothole formation;
- During the short-term, intensive rain events, ineffective or absent side drains mean high energy rainwater flows down the road crown and/or the road edge. This weakens the foundations and exacerbates any existing failures.
- During short-term, intensive rain events, rainwater overflows the cross-culverts and crosses the road surface. In addition to damaging the surface, this can erode road foundations near the culvert outlet.
- Accumulated rain, from both short-term, intensive events and prolonged rain spells, saturates the soil and contributes to rock and land instability.

41. It is noted that the land cover and agricultural practices affect the hydrological cycle in land near the road and this may affect the road condition (see Box 1).

Relationship between land cover and damage to road assets

Visual evidence from the site suggests that, as in other parts of the world, the land cover may interact with rainfall to affect the road. This can be through several mechanisms, although the extent and relative contribution is unknown. These include:

- Reduced vegetation cover can reduce the stability of soil and so facilitate land and rock-slides;
- Dominance of vegetation species that do not promote slope stability on slopes adjacent to the road. This can reduce the stability of soil and so facilitate land and rock-slides;
- Reduced or inappropriate vegetation cover on slopes adjacent to the road affects the hydrological cycle – possibly leading to a rising water table and to increases in peak discharges;
- Reduced or inappropriate vegetation cover on slopes in the catchment in areas more distant from the road. This can affect the hydrological cycle and lead to increases in the peak discharge in the larger streams crossing the road.

Box 1: Relationship between land cover and the road condition

42. **Zone 3** covers all the HH in Chimbu Province, from Magiro bridge to Miunde bridge, a total of 57 km. It includes 4 two-lane and 2 single-lane bridges, and many large culverts. The crossing streams are narrow with fast running water and highly variable discharges.

43. Although much of the land adjacent to the road has a low-medium incline towards the road, there are many stretches with steep to very steep inclines to the road. These stretches face a risk of rock or land-slides. This risk is compounded by the nature of the soil in Chimbu which is known to facilitate instability. The water table appears high and water can be observed exfiltrating from the soil at many points. Side drains are largely absent or ineffective.

44. The road pavement is generally in poor condition. Large stretches of the road have no surface and at many points the base layer is also damaged. All parts of the road have a large number of irregular potholes, some compounded by subsidence. There is evidence of many recent land-slides. There are many examples of regressive erosion causing damage to the pavement. There are many examples of deformation and several deep holes in the pavement. Although a more detailed study is necessary, it appears possible that some of the

bridges may have been slightly weakened or damaged due to peak water discharges. Although the entire road is passable there are considerable delays, there is a significant risk of chronic damage to vehicles, and comfort is badly affected. The sub-base layer is almost entirely intact, and the vast majority of the base layer remains intact.

45. As with other zones, most damage to the pavement originates entirely from rain falling in the surrounding catchments. During intensive rain events, side drains have been ineffective or absent, meaning the rainwater flows down the road crown and edge. This exacerbates existing failures and weakens the foundations. Also, during intensive rain events, cross-drains have been inadequate. The rainwater has notably eroded the road foundations near the culvert outlet. The high water table weakens foundations and contributes to flooding, contributing to subsidence, deformation and surface damage. Finally, inappropriate and/or inadequate land cover both adjacent to the road and in higher catchments may facilitate land-slides and increases in peak discharges in small and larger streams.

46. **Zone 4** starts at Miunde Bridge at the border between Chimbu and Jiwaka Provinces and travels to Ambeke Bridge, a total of 20 km. It includes 5 single-lane bridges. In addition, the road crosses some small streams running through culverts, and the streams are fast running and narrow, with variable discharges. In general, the land adjacent to the road has a low-medium incline to the road, although some stretches in this Zone lie next to very steep inclines with a high danger of rock or land-slides. The water table appears high and close to the surface at many points. Side drains are largely absent or ineffective.

47. The road pavement is generally in fair-poor condition. There are many irregular potholes, some connected up, and some compounded by subsidence. There is one site with regressive erosion where a section of the pavement has caved away. There is at least one deformation caused by subsidence. In some places these factors have combined and the pavement surface layer is missing. Although a more detailed study is necessary, it appears possible that some of the bridges may have been slightly weakened or damaged due to peak water discharges and/or shifting sedimentation. However, the entire road is passable, the sub-base and base layers are almost entirely intact, and the vast majority of the surface layer remains intact. As with the previously described zones, most damage to the pavement originates entirely from rainwater in the catchment slopes. This is mostly through the high water table and inadequate drainage. There appears to be less danger of land-slides than Zone 3.

48. **Zone 5** is from Ambeke Bridge to the Kagamuga airport turn-off, a total of 42 km, mostly in Jiwaka province and only the final 3km lying in Western Highlands Province. It includes 4 two-lane bridges and 3 single-lane bridges. It also crosses some small streams running through culverts. In general, the land directly next to the road is low-medium inclined to the road and there appears little danger of rock or land-slides. Side drains are absent or ineffective at some points. The water table appears close to the surface at some points.

49. The road pavement in Zone 5 is generally in fair condition. There are irregular potholes and significant damage to road edges over small stretches. There is some evidence of deformation or subsidence. In some places these factors have combined and the pavement surface layer is missing – the road is notably not sealed for a 1km stretch. Although a more detailed study is necessary, it appears possible that some of the bridges may have been slightly weakened or damaged. However, the entire road is passable, the sub-base and base layers are almost entirely intact, and the vast majority of the surface layer remains intact. As with the previously described zones, most damage to the pavement originates entirely from rainwater in surrounding catchments. This is mostly through the high water table and inadequate drainage. There is little danger of land-slides.

50. Annex 4 provides details on the location, type and scope of damage and failures along all five zones.

51. In summary, the road is passable at all points, which, given the challenging climate and terrain, is a testament to the quality of the original design and construction over 30 years ago. However, the pavement is damaged at many points. There is damage to the edges, the surface, the base layers, the culverts and the side drains. There may also be damage to the bridges –more studies are needed to determine and quantify this. Worryingly, there is evidence that the pace of deterioration is increasing[6]. This may lead to more frequent blockages or to passability being severely reduced in the near future. Table 1 summarizes the mechanisms by which the main climate hazards contribute to the deterioration of road assets and of highway performance.

Climate Hazard	Mechanism of deterioration	Main impacts on road asset or performance	Concerned Zone
Extreme or intensive rain events over small catchments	Although these only last a short time, these lead to peak water discharges in the small catchments and peak levels in the streams across the catchment	This can damage side and cross-drains	In the following order: 3, 2, 4, 5
		This may directly damage the pavement	In the following order: 3, 2, 4, 5
		This undermine the slopes above and beneath the road	In the following order: 3, 2, 4, 5
		The high waters in streams/rivers parallel to road may erode or scour beneath the road	In the following order: 3, 2, 4, 5
Prolonged periods of rainfall over small catchments	The accumulation leads to increases in the moisture level in the soil, and to a rising of the water table. This can be exacerbated by intensive short-term events	This may lead to slope failure in slopes next to pavement. This, in turn, may lead to: (i) pavement damage, and (ii) road blocks	Mostly 3
		High water table under or next to road facilitates pavement failure	In the following order: 3, 2, 4,
Prolonged periods of rainfall accompanied by intensive rain events over medium sized catchments	This leads to peak water discharges and peak water levels over the catchment and in the larger streams and rivers.	This may lead to bridge damage in particular to abutments (the damage may take many forms)	Mostly 2 (which has many bridges)
Prolonged periods of rainfall accompanied by intensive rain events over the entire catchments	This leads to peak water discharges and peak water levels in the Markham River in Morobe Province	This may lead to damage to bridges	1
		This may lead to regular flooding of road, leading to: (i) sections of the road cut off for lengthy periods, and (ii) diverse forms of damage to pavement	1

Table 1: Summarizing how climate hazards have damaged road assets along the existing Highway

52. Generally, the damage to the pavement and other road features is initiated either by rainwater flows (most cases) or land-slides. If this damage is not repaired, the traffic passing over it exacerbates the damage and subsequent water flows and landslides also exacerbate

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[6] As explained in many road engineering manuals, pavement deterioration follows an exponential law.

the damage. For example, when a pothole is not repaired, water enters into it and widens it, and it enters the underlying pavement layers, weakening them. Regular traffic causes further damage, accelerating the downward cycle. A second example is when a peak discharge overflows a culvert and crosses the pavement, initiating damage to the culvert and to the surface. Initially, the damaged culvert leads to more water flowing over the surface and more surface damage. It was observed that in many such cases, the culvert has been repaired but not the road surface. The road surface in some cases has become severely damaged by the traffic, even though the culvert (the principal cause of the initial problem) is now performing well.

53. These examples illustrate the importance of effective maintenance to quickly repair damage. Generally, it is held that maintenance along the Highlands Highway was effective in the 1990s and early 2000s, but has since become much less effective. Notably, good maintenance means that the drains continue to function and rainwater is kept away from the pavement and is channeled away from culvert outlets – reducing erosion. Effective maintenance also means that small failures (to edges and to potholes) are repaired *before* significant amounts of water enter and damage the base and sub-base layers, and so before the surface failures expand and link-up. Finally, maintenance of bridges means they retain the capacity to handle peak discharges and avoid damage.

III. CLIMATE, CLIMATE RISKS AND CLIMATE CHANGE PERTINENT TO THE HIGHLANDS HIGHWAY

A. Overview of PNG’s Climate

54. PNG is a tropical country lying roughly between latitudes 2° S and 12° S. The main climate drivers are the El Niño Southern Oscillation (ENSO) and, to a lesser extent, the position of the South Pacific Convergence Zone. ENSO is considered to have a weaker influence on the northern part of the country. There is little variation over the year in terms of maximum and minimum temperatures. The temperature in Port Moresby rarely rises above 32°c. The wet season is from November to April and the dry season from May to October, although, the seasonality of rainfall is considered rather weak except for the region around Port Moresby.[7]

55. Rainfall across PNG exhibits high spatial and temporal variability. For example, annual average rainfall in the capital Port Moresby is 1190mm, whereas at Kavieng (on New Ireland Island) it is 3150 mm.[8] Year-to-year variability is mostly driven by the El Niño Southern Oscillation which has two extreme phases (El Niño and La Niña) and a neutral phase. Generally, El Niño years are drier, and the La Niña are wetter and lead to more flooding and landslides. El Niño is also associated with a late start to the monsoon. Finally, only southern PNG is affected by tropical cyclones and these are not considered to significantly affect rainfall in the Highlands.

B. The Climate along the Highlands Highway

56. Annex 5 assesses the level of risk to road assets on the HH from various climate hazards. It determines that the main climate parameter affecting the design and performance of the HH is rainfall and, in particular, intensive rainfall of short duration. This was also evidenced in Section 2 above. Accordingly, this section focuses mostly on this parameter.

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[7] GoPNG, 2014. *Papua New Guinea Second National Communication to the United Nations Framework Convention on Climate Change*

[8] Source: Australian Bureau of Meteorology (BoM) and Commonwealth Scientific and Industrial Research Organisation (CSIRO), 2015 (under PACSAP). *Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports, 2014*. Period covered is 1945 – 2011.

57. Generally speaking, the HH passes through two climatic regions: the Highlands and the Markham Valley. The Highlands lie in a region classified as warm and wet with no marked dry season; the Markham Valley lies in a region classified as hot with a marked dry season. The main threats posed to the Highway in the Markham valley from rainfall originates from intensive rainfall in the surrounding catchments – not from the rain in the valley itself.

Rainfall

58. The data available on rainfall in the Highlands is dispersed and incomplete. Data from various sources was collected in order to construct the most accurate and most complete picture of rainfall, however, this remains far from complete. Fifty years of annual rainfall was obtained for one site. With regards to daily rainfall, a total of 11 years data spread over 7 points in the Highlands was obtained. Annex 6 assesses additional data available.

59. The main findings for the Highlands are (see location of sites mentioned in the map in Figure 3):

- Annual rainfall in the Highlands is highly variable temporarily. For example, at Mendi, during a 52-year period from 1951, the annual rainfall ranged from 1,570 mm to 4,015 mm.
- There is some evidence that annual rainfall in the highlands is also variable spatially – i.e. different sites along the highway have different average annual rainfalls and different maximum annual rainfalls. For example, annual rainfall, at four highlands cities[9], over the three year period 1998 – 2000, ranged from 1,282 mm (at Kainantu) to 3,026 mm (Mt. Hagen).The region is subject to intensive rainfall events. Although the data is very limited, the highest recorded rainfall within a 24-hour period was 110 mm (recorded at the 20 km marker along the Mendi-Kandep highway).
- The intensive rainfall events appear to cover a small geographical area. That is, an intensive rainfall event may strongly impact one catchment but not touch a neighboring catchment. For example, on the day that 110 mm of rain was recorded at the 20 km marker along the Mendi-Kandep highway, the rainfall at Mendi and Kandep, both considerably less than 40 km distant[10], was only 5.7 and 5.5 mm, respectively.
- There is some evidence of spatial variability in the maximum intensity of short-term rainfall – i.e. the maximum rainfall in a given time (2 or 24 hours) with a given return period (say 2 years) at one site may be quite different from that at a nearby site. For example, for Goroka, the highest recorded daily rainfall over the five years for which data is available is 65.6 mm; however, at the 20 km marker along the Mendi-Kandep highway, more than 80 mm was recorded six times during a six-month period in 2013.
- There is no data available for rainfall in time lapses shorter than 24 hours.
- There is insufficient data to understand any *trends* in annual rainfall in the Highlands. However, the limited data from Mendi is consistent with general findings for the Pacific that annual rainfall may be increasing slightly and that inter-annual variability may be increasing slightly.

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[9] Mendi, Mount Hagen, Goroka and Kainantu.

[10] When considered in a straight line, see map.

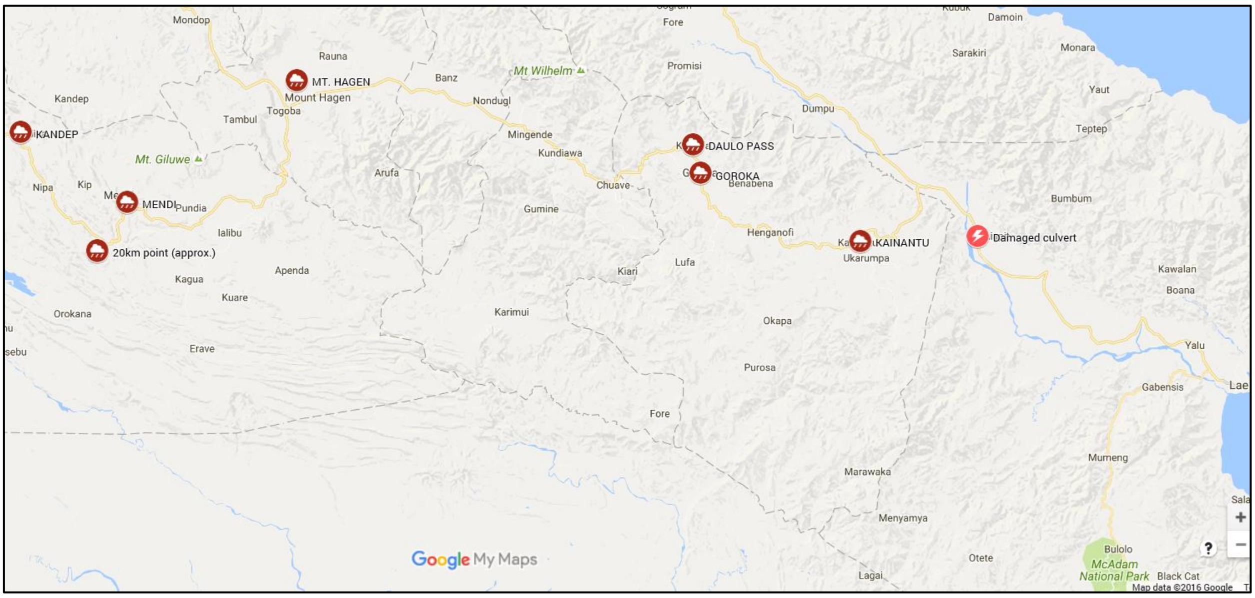

Figure 3: Map showing sites with rainfall data

60. When constructing roads in areas subject to flooding and other rain-related damages, a key design parameter is the maximum rainfall during an intensive event within a given return period. Notably, in ideal circumstances, this parameter, along with other geographical data on the catchment, is used to determine the size, type and location of all drains.

61. However, the **findings above suggest that there is insufficient data to accurately determine this parameter for all sites along the HH. The implication is that, if possible, when designing the drains for the HH, a complementary method must be used to determine appropriate drain sizes.** This will be discussed later in this document.

Temperature

62. Temperatures differ between the lower Markham valley and the Highlands. SMEC (2002) reported that temperature data for the highlands is not available from the National Weather Service. SMEC (2002) using various sources reported a mean annual maximum temperature of 23.7°c and mean annual minimum temperature of 13.0°c (both for Mount Hagen area). It reported that similar temperatures can be expected along the length of the highway within the highlands. However, it reported that temperatures in the lowlands are consistently hotter, falling between 25°c and 35°c and rarely falling below 20°c.

63. There is no evidence for sustained hot periods which could cause damage to construction materials used in road pavements.

C. Climate Change in the PNG Highlands

64. This study takes the existing best available climate change projections for PNG and uses these to determine how rainfall in the Highlands (and other parameters) may evolve in coming decades.

PACCSAP Findings

65. The most comprehensive and recent studies available on climate change in the Pacific were completed with the support of the Australian Government under the Pacific-

Australia Climate Change Science and Adaptation Planning (PACCSAP) Program in 2014.[11] This work was undertaken through partnerships between BoM, CSIRO and Meteorological Departments in the Pacific island countries. The summary findings for Papua New Guinea are presented below. It is important to note that the models and knowledge are not sufficiently resolved to focus on the PNG Highlands. The information and understanding, to the extent that it does exist, exists at the level of PNG as a whole.

- El Niño and La Niña. These events are projected to continue, but there is little consensus as to whether these will be more or less frequent, or whether they will be more or less intensive;
- Temperature. Annual mean temperatures are projected to continue to rise across PNG. Relative to 1995, they are projected to rise by 1.1°C by 2030, and, by 2090, a further rise of 0.4 – 4.2°C is projected, depending on scenarios and models used;
- Extreme temperatures are also projected to continue to rise, by approximately the same amount as the annual mean temperatures. Further, the frequency of extremely hot days is projected to increase;
- Annual rainfall. The long term average rainfall is projected to increase in most areas of PNG. By 2050, annual rainfall is projected to increase by 6% to 8 % depending on the scenario (the entire range of possible increases, using all models, is from -3 to +14%). In addition, rainfall is projected to be more concentrated into the rainy seasons. Based on this, to avoid risk, it may be appropriate to **assume that the average annual rainfall will increase by at most 14% by 2050.** This figure will be used where pertinent through the remainder of this report;
- Extreme rainfall. The maximum intensity of rainfall is also projected to increase, although this projection is subject to a lower level of confidence than for annual average rainfall. The PACCSAP report states that, by 2030, the current 1-in-20 year daily rainfall amount is projected to increase by 12-14 mm; and by 2090, it is projected to increase by 21-55 mm. By 2090, the current 1-in-20 year daily rainfall event will become, on average, a 1-in-7 year or even a 1-in-4 year event.

Projecting Changes in Extreme Rainfall

66. PACCSAP projects an increase of 12-14 mm by 2030 or 21-55 mm by 2090 in the daily rainfall amount with a 20-year return period. However, given the likely spatial variability in maximum daily rainfall amounts, it is not clear how this figure can be converted into a percentage increase of use in SHHIP design:

- Five years of daily rainfall data is available for Goroka airport. During that period, the highest recorded daily rainfall was 65.5 mm. If we were to assume that this is equivalent to the daily rainfall amount with a 20 year return period, in percentage terms the increases projected by PACCSAP would be 18–21% by 2030 and 32-84% by 2090.
- Collectively, 11 years of data was available for daily rainfall spread over 7 separate points in the Highlands. The highest daily recorded figure was 110 mm. If we were to assume that this is equivalent to the daily rainfall amount with a 20-year return period, in percentage terms the increases projected by PACCSAP would be 11-13% by 2030, and 19–50 % by 2090.
- Based on the above assumptions, and using the PACCSAP projections, maximum daily rainfall with a 20-year return period may increase by 11–21 % by 2030 and 19–84% by 2090. Based on these figures, it seems reasonable to project that by 2055 maximum daily rainfall with a 20-year return period could increase by 20-25%.

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[11] See Australian Bureau of Meteorology (BoM) and Commonwealth Scientific and Industrial Research Organisation (CSIRO), 2015 (under PACSAP). *Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports, 2014*

67. Additional analysis of the projected increases in intensive rainfall was supported by ADB and undertaken during 2013 (unpublished). This was partly based on work done under PACCSAP. This attempted to project the percentage increases in daily rainfall for the 1-in-2 year event on PNG.[12] By 2055, the 1-in-2 year daily rainfall event was projected to increase by 11.5-20%.

68. Further, for rainfall intensity, assessments based on the slope of the saturation-vapour pressure curve provide a "rule of thumb" projection that rainfall intensity should increase by 6% - 7% per degree (Celsius) of warming. Thus, a 2.0°C rise by 2050 suggests increases in intensity for an event of any given likelihood of around 12% to 14%.[13] Finally, in Annex 6, projections to 2050, based on climate model results available from NASA, provide a range of estimates for increases in maximum daily rainfall, centred on approximately 15%.

69. Several different approaches to estimating the increase in maximum rain intensity were presented in the previous paragraphs. Each approach draws on several assumptions and none claim full accuracy. There is, however, a level of agreement across the results: they all project a positive increase in the daily rainfall with a given return period, and they are mostly in the range of 11.5-25% increase by 2055. Hence, in order to be conservative, for this CRVA, where relevant, a projected increase in the maximum daily rainfall (with any given return period) by 2055 of 30% will be used.

Summary of assumptions to be used in the report

70. Tropical cyclones. Until present, the Highlands region is not affected by tropical cyclones. Climate change models do not project a change in this situation.

71. Temperature Extreme temperature increases of up to 4°C, as projected by PACCSAP, will not lead to temperatures that affect the road construction or road surface.

72. Rainfall As mentioned previously, the two climate parameters of concern to this study are the maximum intensity of short-term rainfalls and the average annual rainfall. **Hence, the two pertinent assumptions used through this report are:**

- **average annual rainfall will increase by, at most, 14% by 2050; and**
- **the maximum daily rainfall for any given return period may increase by 30% by 2055.**

IV. THE PROPOSED INVESTMENT: THE SUSTAINABLE HIGHLANDS HIGHWAY INVESTMENT PROGRAM (SHHIP)

A. Introduction and Goals of the SHHIP

73. The Sustainable Highlands Highway Investment Program is a multi-partner financing facility (MFF) to be implemented in three tranches over a ten-year period. SHHIP's expected impact is aligned with national strategies to improve access to health, education and standard of living of the people of PNG, increase opportunities for equality and prosperity in rural areas and provide well integrated, safe, affordable, financially and environmentally sustainable transport systems.[14] SHHIP's expected outcome is the efficient and safe

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[12] ADB, 2013 (unapproved draft, not for circulation). *Papua New Guinea Bridges Replacement Program: Climate Change Vulnerability Assessment.* This is based on work undertaken by Sinclair Knight Merz and CSIRO.

[13] See, for example, "The Changing Character of Precipitation", Kevin E. Trenberth et al (2003) article in the Journal of the American Meteorological Society.IPCC Report.

[14] As set out in the Development Strategic Plan (2010), the National Strategy for Responsible Sustainable Development for Papua New Guinea (2014) and the National Transport Strategy (2014).

movement of people, goods and services between the Highlands region and domestic and international markets.

74. SHHIP, as currently envisaged, has four Outputs, i.e.:

i) Highlands Highway from Lae Nadzab airport to Kagamuga airport at Mt. Hagen, is restored, effectively maintained, and upgraded as required to be safe, climate and disaster resilient for all users. This covers the 430 km over the five zones;
ii) Road safety increased and sustained for pedestrians and vehicle passengers on the Highlands Highway;
iii) Transport logistics and services improved in the Highlands region to strengthen value chain for domestic and international trade; and
iv) Program management and institutional capacity improved to deliver the program and sustain its benefits.

75. The first Output is the main investment and is the main focus of subsequent sections.

B. Options for Achieving the Goals

76. Two options were considered to deliver the Outputs and achieve the Goals:

77. Option 1: Fully rehabilitate and substantially upgrade selected sections of the highway. This would involve complete reconstruction of sections of the highway. The sections to be reconstructed would presumably be those most requiring upgrading or those with the highest economic or political value. The high costs of fully rehabilitating these sections would reduce the budget available for maintenance activities on other sections – maintenance would be limited to emergency interventions to restore traffic after major distress or road collapse.

78. Option 2: Two sets of activities run in parallel from the outset: (a) rapidly act to ensure that the entire HH is smooth and passable by undertaking the necessary immediate[15] repairs, notably to small potholes and damaged edges, and by leveling stretches that currently are without a surface layer; (b) systematically repair/upgrade all sections of the Highway as necessary, bringing them to an acceptable condition and specification. In general, this would typically mean either resurfacing, or using the existing base layer as a sub-base, and so adding a new base layer and then resurfacing. This systematic repair/upgrade would occur over the ten-year period.

79. With Option 2, some sections may have to wait several years before being fully repaired/upgraded, and during that period they may require immediate repair several times, i.e. actions under “(a)” can occur more than once at a site. However, as the upgrading/repair process gradually proceeds along the entire highway through “(b)”, there will be less and less need for “(a)”. Once “(b)” has been applied to the entire HH, there will be no need for “(a)”. At this point, it will simply be necessary to continue routine and periodic maintenance across the entire highway.

80. Option 1 is expensive and leaves a high risk of road closures and worsening driving conditions on the sections not benefitting from the upgrading works. Also, the approach leaves little budget for maintenance and repairs, this would lead to reduced flexibility, which is likely to lead to less ability to respond to climate risks and so, overall, to less climate resilience.

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[15] i.e. Quickly making the road usable, but unlikely to provide a long-term solution.

81. Option 2 was selected. It ensures the entire road is passable at all times, meaning the communities are always connected. And it ultimately leads to an entire road that meets required specifications.

82. Option 2 notably includes the following core activities:

- Comprehensive and sustained maintenance: The entire section will be put under specific (repairs) routine and periodic (resurfacing) maintenance (see Table 4 for description of these terms) from day one to keep the road open to traffic at all time. This will gradually improve the ride comfort and allow salvage of sections in fair condition. Maintenance will remove the vegetation encroachment, restore drainage efficacy, and unearth currently suppressed paved shoulders. Also, a quick-response mechanism to address emergency situations will be established.
- Undertaking appropriate upgrading: Over the Investment Program period, the entire section will progressively be resurfaced or strengthened[16]. At the same time, the drainage capacity will be increased and protections against slope instability will be multiplied, in line with recommendations for adaptation to climate change. A series of other measures will be taken to improve traffic safety; build a bypass to divert traffic around Goroka;[17] build truck climbing lanes in the steep slopes of the Kassam and Daulo Passes; build two truck weigh stations; and build two logistics platform for the trade of fresh produce.
- Bridges Improvement: Widen all 29 single lane bridges to 2 lanes; repair, reinforce and reconstruct as appropriate all 40 2-lane bridges; integrate climate change adaptation recommendation in the design and complete all the due diligence for social and environment safeguards. Because of their size and duration, only the preparatory activities will be undertaken during the first tranche of the program while the works will be executed over the second and third tranches.

C. Climate Resilience of SHHIP - General Considerations

83. The selected approach to SHHIP has many positive characteristics in terms of increasing climate resilience. Firstly, the multi-tranche approach facilitates the integration of climate change measures. It allows time and space to collect climate related data, to develop innovative approaches and to convince all decision-makers of the feasibility and necessity of adapting. Also, whilst assuring the immediate execution of urgent and ‘ready-to-go’ investments, it allows for detailed preparatory work for the more complex investments – which should allow the inclusion of innovative measures to adapt to climate change.

84. Secondly, compared to Option 1, Option 2 allows more flexibility, and therefore it allows adaptive responses to climate change to be developed when needed and when available. It also provides for more maintenance and emergency response – thereby both preventing climate impacts and creating the capacity to respond to climate impacts after they happen. Studies show that maintenance and emergency response are often the most effective climate adaptation measures in road transport.[18] Further, unlike Option 1, under Option 2 it is intended to keep all the road open and passable at all times: during the construction period climate hazards will not reduce economic activity nor lead to the temporary isolation of marginal populations.

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[16] Including grade rising on a few flood prone sections in the Morobe Province.

[17] Current investigations point to an alignment of about 24 km long

[18] See for example, *Climate Proofing: A Risk-based Approach to Adaptation* (ADB, 2005) and *Climate and Disaster Resilience* (from the World Bank Group Pacific Possible series, 2016 draft).

85. Finally, as the Highway is progressively upgraded under Option 2, measures will be taken to increase drainage capacity and slope stability – these are important engineering measures to increase climate resilience.

V. CLIMATE RISK AND VULNERABILITY ASSESSMENT OF THE SHHIP

86. This Section undertakes the detailed assessment of all components of SHHIP. Where appropriate, the methodology is described.

A. Output 1

87. Output 1 is "*Highlands Highway from Lae Nadzab airport to Kagamuga airport at Mt. Hagen, is restored, effectively maintained, and upgraded as required to be safe, climate- and disaster resilient for all users*". Output 1 constitutes the majority of the investments under the SHHIP and is the main focus of this CRVA.

88. The steps to determining the climate risks and vulnerability of the first Output are illustrated in *Figure 4* and described in detail in the sections 5.1.1 through 5.1.4.

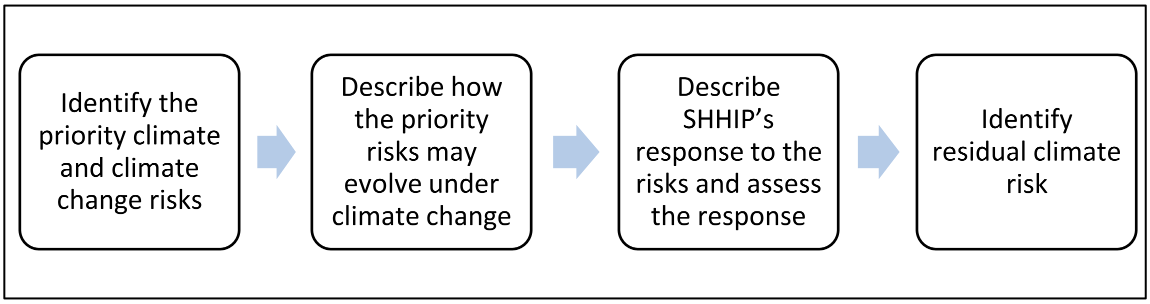

Figure 4: Steps to assessing climate risks and vulnerability

A. 1. Identifying the Priority Risks

89. As mentioned previously, the standard approach to identifying the risks associated with climate change is to determine current climate parameters, to determine how the parameters will change through global climate change, and then to determine how this should affect project design or how it may impact the project assets. For two reasons that approach is not sufficient nor most appropriate in this case. First, the data on the current climate (rainfall), as well as other critical geographical (notably on watersheds) data, is insufficient. Second, since the road has existed for over thirty years, it is possible, by observing the current road conditions, to determine which climate risks affect which sections of the road and to what extent. Using this information and projected climate change, it is possible to extrapolate how and where climate change will affect the road in the future.

90. This process is followed in Annex 5. Annex 5 reviews and assesses the level of risk from each climate hazard to road assets for each zone of the highway. The climate hazards

considered in Annex 5 account for both current climate conditions and projected climate change. In Annex 5, risk is considered as a function of the following three parameters: hazard, exposure and vulnerability:

- The *scale of the hazard* refers to the scale of the projected climate events and extremes in the zone. Given the absence of detailed past climate data and of accurate climate change projections, this is determined based on (i) available knowledge of past weather conditions in the concerned zone; (ii) best available climate change projections for the area; and (iii) evidence of climate events along the highway.
- The *scale of exposure.* This reflects the extent that the road assets will be exposed to the climate events/extremes. This is notably a function of the surrounding geography (relief, hydrology, soil structure, etc.) and the position of the road in that landscape. Given the absence of detailed GIS and other geographical data, this is determined based on (i) evidence of previous climate-induced damage along the highway and (ii) the impacts that climate change is projected to have on hydrology and hydraulics in the zone (as these are the mechanisms through which the risk is manifested).
- The *scale of vulnerability*. This reflects to what extent the road could be negatively affected by exposure to the climate threat. In addition to previous factors (notably evidence of past damage), this is partly determined by the presence of any factors in the zone that tend to either mitigate or exacerbate the concerned risk. In this case, this also covers *economic vulnerability* by accounting for the critical nature of the asset with respect to mobility and transport.

91. Annex 5 determines the level of risk from climate hazards to road assets in each zone – in both current and climate changed conditions. The findings are summarized in Table 2.

Zone	**Climate Hazard**			
	Extreme rainfall	**Temperature**	**Accumulated rainfall**	**Winds**
1	High risk	Low risk	Medium risk	Low risk
2	High risk	Low risk	Medium risk	Low risk
3	Very high risk	Low risk	Medium risk	Low risk
4	High risk	Low risk	Medium risk	Low risk
5	High risk	Low risk	Medium risk	Low risk

Table 2: The level of risk from climate hazards to road assets in each zone – in current and climate changed conditions

92. Hence, the greatest risks are related to extreme rainfall. Next, accumulated rainfall – over the medium and/or long-term - present a medium risk. The risks associated with temperature and winds are not significant. Further, assets in Zone 3 face the highest overall risk, and assets in the other zones all face a similar degree of risk.

A.2. Determining How the Priority Risks May Evolve with Climate Change

93. Table 1 in Section 2.2 summarized the four main mechanisms by which climate hazards cause damage to road assets, as follows:

- Extreme or intensive rain events over small catchments, these lead to peak water discharges in the small catchments and peak levels in the streams across the catchment.
- Prolonged periods of rainfall over small catchments. The accumulated rainfall leads to increases in the moisture level in the soil and to a rising of the water table. This can be exacerbated by intensive short-term events.

- Prolonged periods of rainfall accompanied by intensive rain events over medium sized catchments that lead to peak water discharges and peak water levels over the catchment and in the larger streams and rivers.
- Prolonged periods of rainfall accompanied by intensive rain events over the entire catchments, this leads to peak water discharges and peak water levels in the Markham River in Morobe Province.

94. Section 3.2 determined that the following assumptions should be used with regards to the pertinent climate parameters during climate change:

- average annual rainfall will increase by, at most, 14% by 2050;
- the maximum daily rainfall for a given return period may increase by 30% by 2055.

95. This Section determines how these changes in the climate will affect the peak water discharges, the peak water levels and the soil moisture levels, and in turn how this will affect road assets.

<u>Peak water discharges and peak water levels in small catchments</u>

96. The discharge of water from a small catchment into a stream is affected by several factors including the surface area, the land cover, the slope, the intensity of the rainfall and the duration of the rainfall. For the Highlands, there is insufficient data to establish exact models linking these factors.

97. Further, once in the stream, the level of the water at a given point is affected by several factors, notably the cross-section of the stream, the slope, the stream shape, the composition of the bed-?, the presence of obstacles and the discharge rate. For the Highlands, there is insufficient data to establish exact models linking these factors. Hence, even if data on discharges was available, it would not be possible to precisely determine water levels.

98. In order to estimate water discharge and water levels in the absence of full data, the Government of PNG, with technical support from SMEC, prepared '*Flood Estimation Guidelines'* (in 1990). These *Guidelines* provide standard and simplified methods for estimating flood levels for use in small and medium-sized engineering works in PNG, notably for bridges, culverts and drainage. The *Guidelines* set out a two-step process that is followed in the following paragraphs. The first step is to estimate the peak discharge. The second step is to estimate the peak water level - using the estimated peak discharge from the first step.

99. Step 1 – estimating the peak discharge. The Guidelines provide seven methods for doing this: the method to be used depends on the data available and the area of the catchment. Of the seven methods, the '*Regional Flood Frequency'* method is the only one applicable to this case. This method is applicable to rural catchments larger than 4 km^2. It is stated that: "*This method is derived from an analysis of 66 catchments across Papua New Guinea, ranging in size from 5 km^2 to 40,900 km^2. While this flood estimation method is able to be applied across Papua New Guinea, some caution should be used to ensure that the catchment of interest is characteristic of the data used to create the method*."

100. This method looks at the relationship between peak rainfall amounts (P, measured in mm) and peak discharges from the catchment (Q, measured in mm^3). It can be approximated that, if all other factors are kept constant, the relationship between P_2 (the maximum daily rainfall with a two year return period) and Q_2 (the peak discharge with a two year return period) is as follows: $Q_2 \propto P_2^{1.12}$ (1). It therefore follows that an increase in daily

rainfall of 30% will lead to an increase of peak discharge of 34%. I.e., the discharge associated with rainfall with a two-year return period will increase by 34% in 2055 due to climate change.

101. The key assumptions made in Step 1 are: (i) the relationship between P and Q applies constantly to all the catchments along the Highway, (ii) the relationship between P and Q applies to all return periods and (iii) daily rainfall – rather than two-hourly rainfall - is sufficiently intensive[19] for the relationship to hold.

102. Step 2 - estimating the peak water level. The *Guidelines* suggest the use of the Manning Equation to calculate peak water levels. In the Manning Equation, if one assumes uniform flow and a rectangular cross-section, and all other factors are kept constant, the relationship between flow height at a given location in a stream (R, in mm) and discharge in the stream Q (in mm^3) is as follows: $R \propto Q^{1.5}$ (2). It therefore follows an increase in daily rainfall of 30%, that leads to an increase of peak discharge of 34%, which will lead in turn to an increase in flow height of 55%, i.e., the peak water level associated with rainfall with a two-year return period will increase by 55% in 2055 due to climate change.

103. Note that combining (1) and (2), it follows that the relationship between R, the water level, and P, the rainfall intensity, may be $R \propto P^{1.68}$. I.e., the peak flow height rises much more quickly than the peak rainfall. It has to be stated that there are many assumptions and approximations in these estimations.

104. In summary, from the above, it is estimated that, by 2050, **due to climate change:**

- **(i) the peak discharge from a small catchment, for any given return period, may increase by 34%. This should notably guide the design size of drains; and**
- **(ii) the peak water levels in streams and rivers in small catchments, for any given return period, may rise by 55%. This should notably guide the height and design of bridges.**

Peak water discharges and peak water levels in large catchments

105. Discharges from several small catchments join together to form the stream or river for the overall catchment. However the conversion of peak discharge over several small catchments to a peak discharge in the large catchment is not straightforward. Further, the conversion of the *changes* to peak discharges in small catchments due to climate change to *changes* to the peak discharge in the large catchment due to climate change is even less straightforward.

106. The limited data available suggests that storms are small in scale (compared to the overall catchment). Hence, a peak discharge from one small catchment is unlikely to coincide with a peak discharge in other small catchments. Therefore, the peak discharges do not necessarily accumulate. However, if true, this has always been the case in the PNG Highlands, and the observed peak discharges in the large catchment already account for this.

107. The peak discharge in the large catchment are affected by two factors:

- the scale of the peak discharges in all the constituent small catchments. We saw in the previous section that, due to climate change, **the peak discharge from a small catchment, for any given return period, may increase by 34%; and**

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[19] Typically, intensive rainfall will refer to 1 or 2 hourly amounts.

- the degree to which peak discharges in neighboring small catchments coincide. Due to climate change, this could increase if the geographical scale of extreme storms increases, and this should decrease if the geographical scale of extreme storms decreases. The existing climate change models do not provide guidance on this matter.

108. **For larger catchments, it may be postulated, for any given return period: (i) the peak discharge will rise, but probably by less than 34% and (ii) the peak water level will rise, but probably by less than 55**%.

Soil moisture content and height of water table

109. It is generally agreed that there is a relationship between rainfall – both extreme and accumulated over a prolonged period – and soil moisture levels. This has also been established in the PNG Highlands (see, for example, Braybrooke (1969) and Jacobson and Harris (1970)). Further, it is agreed that there is, in turn, a relationship between soil moisture levels on the one hand, and slope stability and the strength of a road's lower layers on the other hand. These relationships are illustrated in Figure 5.

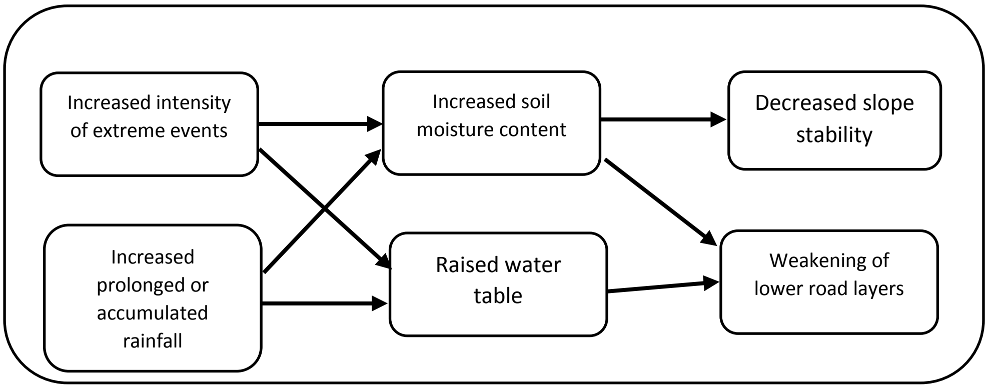

Figure 5: Illustrating simplified description of relationship between rainfall and threats to road structure

110. However, the nature of the relationship between these factors is highly complex. In addition to extreme and prolonged rainfall, many other factors affect soil moisture and water table height. Further, in addition to soil moisture and water table height, many other factors affect slope stability[20] and the strength of the lower road layers. As a result, it is difficult to ascertain the quantitative relationship between rainfall and slope stability/strength of road layers that can be applied to the conditions in the Highlands. **It is reasonable to assume that as climate change leads to increases in extreme rainfall and prolonged medium term rainfall this will, most likely, lead to some decreased slope stability and some weakening of the lower road layers.**

Summary Description of Priority Risks Through Climate Change

111. Table 3 summarizes how climate change will lead to increased climate hazards and therefore an increased risk of negative impacts on road assets and/or performance on the Highlands Highway.

Climate Hazard	**Impact on hydrology**	**Potential Climate Change Impacts**	**Main impact on road asset or performance**	**Concerned Zone**
Extreme or	This leads to peak	34% increase in peak	Drains/cross-	In the

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[20] These factors include soil type, land-use, drainage, slope, presence of construction.

Climate Hazard	Impact on hydrology	Potential Climate Change Impacts	Main impact on road asset or performance	Concerned Zone
intensive rain events over small catchments	water discharges in the small catchment and peak levels in the streams across the catchment	discharge and 55% increase in peak water level will exacerbate the impacts on road assets and on road performance.	drains may be damaged	following order: 3, 2, 4, 5
			Water may damage pavement	In the following order: 3, 2, 4, 5
			Water flowing down slope may damage cut or fill	In the following order: 3, 2, 4, 5
			Water in nearby rivers may erode or scour fill beneath the road	In the following order: 3, 2, 4, 5
Prolonged periods of rainfall over small catchments	The accumulation leads to increases in the moisture level in the soil, and to a rising of the water table. This can be exacerbated by intensive short-term events	Increases in extreme and prolonged rainfall will likely to lead to even more moisture in the soil and further rising of the water table. However, the relationships are complicated	Moisture leads to slope failure that may lead to (i) pavement damage (ii) road blocks	Mostly 3
			High water table exacerbates pavement failure.	In the following order: 3, 2, 4
Prolonged periods of rainfall accompanied by intensive rain events over medium sized catchments	This leads to peak water discharges and peak water levels over the catchment and in the larger streams and rivers	Increases in extreme rainfall will lead to higher peak discharges and water levels. However, the increase is likely to be less than the 34% (discharge) and 55% (level) associated with small catchments	Bridges may be damaged (damage may take many forms)	Mostly 2 (which has many bridges)
Prolonged periods of rainfall accompanied by intensive rain events over the entire catchments	This leads to peak water discharges and peak water levels in the Markham River in Morobe Province	Increases in extreme rainfall will lead to higher peak discharges and water levels. However, the increase may be less, possibly significantly less, than the 34% (discharge) and 55% (level) associated with small catchments	Damage to bridges	1
			Regular flooding of road	1
			Flood damage to pavement	1

Table 3: Expected impacts of climate change on certain road assets and performance aspects

A.3 SHHIP Response to the Climate and Climate Change Risks, and Assessment of the Response

112. Table 3 lists the projected main impacts of climate change on road assets or performance. This section assesses how the current SHHIP design addresses these projected impacts.

113. As described above, the approach adopted by SHHIP is to run two sets of activities: (a) maintenance – to act rapidly to salvage the sections that are still in fair condition and ensure that the entire Highway is smooth and passable by providing the necessary maintenance and immediate repairs; (b) investment – to systematically upgrade all sections of the Highway where necessary, bringing them to an acceptable condition and specification. For those sections subject to “(b)”, after the investment takes place, it will be necessary to provide routine maintenance through “(a)”.

114. For planning reasons, SHHIP activities in Output 1 are categorized as follows:

- Maintenance: routine maintenance, specific maintenance, milling levelling & compacting, and bridge maintenance;
- Investment: road strengthening, road resurfacing, grade raising, drainage improvement, landslide protection, emergency works, goroka bypass, truck climbing lanes, and;
- Bridges investment program: bridge widening from one to two lanes, bridge reinforcement, bridge reconstruction, and bridge repair.

115. In all there are 17 types of activity. Table 4 describes each activity type, assesses if and how it may be at risk from the climate change factors identified in Table 3, and then assesses whether the proposed SHHIP approach is adapted to climate change or if it provides sufficient climate proofing.

	Activity Description	Likely Impact of Climate Change	Planned Measure by SHHIP	Assessment of Effectiveness of SHHIP Response to Climate Risks and Climate Change
Maintenance	**Routine Maintenance** This includes inspection, road side vegetation clearing (many times a year), occasional light repairs to pavement, cleaning of side and cross drains and discharge, and inspection and occasional light repair to uphill slope protection, and to road accessories like signing and crash barriers. This takes place primarily on roads in good condition, including after roads have been restored/upgraded. It is still necessary after strengthening/resurfacing	Projected increases in short term rainfall intensity lead to increased stress on drains and pavement. Climate change is likely to lead to less predictability and more small-scale damage	SHHIP has planned and will implement improved maintenance, notably of drains and culverts	Maintenance is considered a key tool to adapt to climate change. This is a good response that will considerably increase climate proofing However, given uncertainties associated with climate change, it is not possible to assess if this response will be fully adequate in all circumstances
	Specific Maintenance Heavy Repair Applies to roads classified in the lower half of fair condition before they become poor. This includes repairs to potholes/edges, cross and side drainage, and uphill protection slopes when these are very frequent. It also includes activities in routine maintenance. This notably includes activities that will prevent more severe damage from occurring This will need to be repeated every year until resurfacing (through 'investment', see below), after which it will no longer be necessary	The 'heavy repair' is a temporary measure to keep the road passable until the necessary upgrading investment can take place. The upgrading investment is listed lower in this table in the rows marked 'investment'. The upgrading investment will take place within 2-5 years of the heavy repair – and climate change will be fully accounted for during the upgrading investment Also, as the 'design life' of the heavy repair is only 2-5 years, the climate will not change considerably during this period For above reasons climate change considerations do not need to be specifically addressed in the heavy repair activities	Not applicable	Not applicable
	Specific Maintenance Light Repair Applies to roads classified in the upper half of fair condition when they start deterioration from good condition. Activities are identical to 'specific maintenance heavy repair' but are less frequent This will need to be repeated every year until strengthening/resurfacing (through 'investment', see below), after which it will no longer be necessary	The 'light repair' is a temporary measure to keep the road passable until the necessary upgrading investment can take place. The upgrading investment is listed lower in this table in the rows marked 'investment'. The upgrading investment will take place within 2-5 years of the light repair – and climate change will be fully accounted for during the upgrading investment Also, as the 'design life' of the light repair is only 2-5 years, the climate will not change considerably during this period For above reasons climate change	Not applicable	Not applicable

	Activity Description	Likely Impact of Climate Change	Planned Measure by SHHIP	Assessment of Effectiveness of SHHIP Response to Climate Risks and Climate Change
		considerations do not need to be specifically addressed in the light repair activities		
	Milling Levelling & compacting This is a temporary measure to make badly damaged sections (i.e. those with little or no remaining surface pavement) passable. The existing rough surface is milled, levelled, and compacted to improve the ride comfort. Such interventions are temporary and followed by strengthening as soon as possible	As above with specific maintenance, there are no impacts of climate change to be considered here	Not applicable	Not applicable
	Bridge Maintenance This notably includes inspection of bridge structure and abutments, and undertaking necessary small repairs	Projected increases in flood heights and sedimentation flows lead to damage to bridge infrastructure, and potentially undermine bridge stability	SHHIP has planned and will implement improved maintenance, notably to adequately cover abutments	Maintenance is considered a key tool to adapt to climate change. This is a good response that will considerably increase climate proofing However, given uncertainties associated with climate change, it is not possible to assess if this response will be fully adequate in all circumstances
Investment	**Road Strengthening** This is a key part of the upgrading process. This is applied where an existing pavement structure is found too weak to meet traffic requirements and happens primarily where the road underwent specific maintenance heavy repair or milling/levelling/compacting interventions. It consists of overlaying a crushed base course topped by a bituminous surface course on the existing surface	Increased rain, water flows and potentially rising water table may lead to more damage to base course layer	SHHIP will utilize stronger, better graded (and so more resilient) materials in the base course, including stabilizers	This is an appropriate response and will increase resilience considerably However, given uncertainties associated with climate change, it cannot be sure that this will entirely remove the climate threat, damp courses and rising water tables may continue to undermine road structure
	Road Resurfacing This is a key part of the restoration and upgrading processes. This is applied to all sections that underwent specific maintenance light repair. It consists of applying a new bituminous surface layer	Increased rain and localized flooding, from overloaded drains, may cause more damage to road surface	SHHIP will utilize improved surfacing materials that are more resilient to water and therefore to climate change	This is an appropriate response and will increase resilience considerably However, given uncertainties associated with climate change, the new surface cannot be sure to be fully resilient to all climate hazards in coming decades
	Grade Raising This is in areas that are prone to flooding - it involves raising the pavement to avoid the flooding	Projected increases in flooding and sedimentation flows downstream may lead to deeper and more widespread flooding	The activity is entirely a response to the climate threat. SHHIP will design and construct a raised pavement at vulnerable	As the activity is entirely a response to climate threats, this is an appropriate response and will increase resilience considerably

	Activity Description	Likely Impact of Climate Change	Planned Measure by SHHIP	Assessment of Effectiveness of SHHIP Response to Climate Risks and Climate Change
			points	However, given uncertainties associated with climate change, we cannot be sure of the extent of future flooding, and cannot be sure that sufficient sections will be raised
	Drainage Improvement This is the installation of lined side drains and larger cross drains on all sections of the road	Projected increases in intensive rainfalls will lead to drain overloading and infrastructure damage	The activity is entirely a response to the climate threat. SHHIP is designing and will construct effective side drains and cross-drains. These will be 50% larger than previous drains (where previous drains existed)	As the activity is entirely a response to climate threats, this is an appropriate response and will increase resilience considerably. However, given uncertainties associated with climate change, we cannot be sure of future peak discharges, and the bigger drains may not be sufficient at all points
	Landslide Protection In parts of the road surrounded by unstable and/or steeply inclined slopes, this involves measures to stop land and rock slides. The measures are: horizontal drainage in slopes; drainage under the road structure; physical roadside protection (e.g. gabion walls)	Projected increases in rainfall intensity will lead to more land slides, blocking roads and damaging infrastructure	The activity is entirely a response to the climate threat. SHHIP is designing and will construct: (i) drainage in slopes and under pavement; (ii) slope stabilization measures	As the activity is entirely a response to climate threats, this is an appropriate response and will increase resilience considerably. However, given uncertainties associated with climate change, we cannot be sure of future risks, and instability will persist at some points. Further, best climate adaptation practices recommend the use of bio-engineering and catchment management where feasible
	Emergency Works This is a facility to rapidly respond to road failures (e.g. landslides, flooding damage) after they occur, and so ensure the road is out of operations for a very short time	After all the measures taken, there will be a residual climate threat, and that will lead to damage to drains and pavement, to blocked roads and to degradation. Climate change exacerbates this	The activity is entirely a response to the climate threat. SHHIP plans and will implement rapid activities to immediately repair damage	As the activity is entirely a response to climate threats, this is an appropriate response and will increase resilience considerably. However, given uncertainties associated with climate change, we cannot be sure of how often the emergency works will be needed, and so cannot asses if the facility established will be fully adequate
	Goroka Bypass This is essentially a new road to avoid busy, built up areas in Goroka town centre. The new section of road will likely	Climate change and variability will threaten the design and performance of the bypass	SHHIP is designing and will construct a bypass that meets all requirements and	This is an appropriate response and will increase resilience considerably

	Activity Description	Likely Impact of Climate Change	Planned Measure by SHHIP	Assessment of Effectiveness of SHHIP Response to Climate Risks and Climate Change
	be 20 to 25 km in length		is climate resilient	However, given uncertainties associated with climate change, we cannot be sure of the future climate threat, and so cannot be sure the design will be adequate
	Truck Climbing Lanes On the climb to the Kassam and Daulo Passes, where the slopes are higher than 10%, an additional lane will be constructed for slow moving trucks	Climate change and variability will threaten the design and performance of the lanes	The measures taken through other SHHIP activities (i.e. road resurfacing, drainage improvement, landslide protection) will provide climate protection	Not applicable
Bridges	**Bridge Widening from 1 to 2 lanes** All 29 one-lane bridges along the highway will be widened. This will involve the reconstruction of abutments and possibly some slight road realignment and some reconstruction of decks, etc	Increased flooding and shifting sedimentation loads threaten the bridge structure, stability and abutments	SHHIP, as part of widening process, will design and construct more resilient bridge structures and abutments	This is an appropriate response and will increase resilience considerably However, given uncertainties associated with climate change, it is not possible to assess if this response will be fully adequate in all circumstances
	Bridge Reinforcement This is reinforcing healthy bridges whose bearing capacity no longer meets traffic requirements	Increased risks from flooding and shifting sedimentation may threaten these bridges	SHHIP will strengthen the bridge structure and, if necessary, the abutment	This is an appropriate response and will increase resilience considerably However, given uncertainties associated with climate change, it is not possible to assess if this response will be fully adequate in all circumstances
	Bridge Reconstruction This applies to bridges that have suffered severe damage or no longer meet traffic requirements and the bridge requires reconstruction	In these cases, the concerned bridges may have already suffered structural damage, probably due to climate factors. In future, due to Increased flooding and shifting sedimentation loads, the threats to the bridge will be even higher	SHHIP will design and reconstruct higher, stronger, more stable bridges	This is an appropriate response and will increase resilience considerably However, given uncertainties associated with climate change, it is not possible to assess if this response will be fully adequate in all circumstances
	Bridge Repair This applies to bridges that have suffered little damage and so have demonstrated climate resilience	Past experience suggests these bridges are not vulnerable to climate hazards	Not applicable	Not applicable

Table 4: Assessing how the proposed SHHIP design addresses climate change risks

116. In summary, from Table 4 (see notably the final column) we can conclude that under Output 1:

- Four of the 17 types of activity to be implemented by SHHIP are purely in response to the climate threat. Based on best available knowledge and understanding, these appear reasonable and adequate.
- Eight of the 17 types of activity to be implemented by SHHIP have been adapted to increase the resilience to climate change. Based on best available knowledge and understanding, these appear reasonable and adequate.
- Five of the 17 types of activity are not threatened by climate or climate change. There is no significant climate change risk.
- Although, in each case, the measures taken by SHHIP to climate proof are adequate and appropriate, the uncertainties associated with climate change mean the measures taken by SHHIP are not guaranteed to provide full climate resilience in all circumstances.
- The uncertainties associated with climate change mean it is impossible to quantify the climate threat, nor to predict exactly where it will occur. One possibility would be to construct the entire highway to a specification that would be resilient to every threat imaginable. This is not feasible. The alternative approach, taken by SHHIP, is to increase appropriately the resilience and build an appropriate degree of flexibility and adaptive response measures. SHHIP does this latter through effective maintenance systems and emergency response mechanisms.
- SHHIP could explore the utilization of more ecosystem based approaches to adaptation, such as bioengineering and catchment management, in order to reduce peak water discharges and increase slope stability.

A.4. Residual Climate Change Risks

117. The PNG Highlands have a challenging, unpredictable and variable climate. Further, the details of the extreme climate are unknown even in current conditions. It is therefore impossible to forecast the scale, timing and content of peak extreme rainfalls in the current climate. Looking to the future, there is even greater uncertainty regarding climate change conditions. Hence, SHHIP was faced with two design alternatives to address climate change:

- Utilize design specifications that cover every possible extreme in terms of climate. However, this would this lead to an extremely high budget. Also, it would almost certainly mean that the Highway is ‘over-designed’, and this would therefore be a very inefficient use of funds.
- Based on observations of previous climate and climate impacts, design the Highway to specifications somewhat greater than would have been necessary in the past, within reasonable costs. Using this approach, it is accepted that there will be residual climate risks.

118. The latter approach was adopted. To address residual climate risks, two additional measures have been adopted: (i) enhanced maintenance, to ensure that climate related damage is minimized, and that it can be monitored, even predicted; and (ii) establish an emergency response mechanism to intervene rapidly and effectively after the inevitable damage.

119. Hence, the SHHIP approach accepts that there will be ‘residual climate change risks’ and sets out to manage these.

120. A good example of residual climate risk is provided by recent work through the Australian supported TSSP project. The TSSP project has been responsible for providing maintenance and light repair work to sections of the HH. Within that framework, the project supported the design and reconstruction of several culverts for streams crossing the Highway in

Zone 1. To do this, TSSP undertook a thorough approach to scoping, designing and constructing culverts in line with international best practices.

121. One such culvert was constructed between Leron Bridge and Clearwater Bridge at the 98 km point (see location in map in Figure 6). The culvert services a small stream from a small catchment with little vegetation cover. The stream is often dry or almost. In the 12 months after construction, the stream experienced three events that, based on previously available data, appeared to correspond to the 1-in-100 year event.[21] The result was serious damage to the culvert outlet, requiring major repairs (see photos 17 and 18 in Appendix).

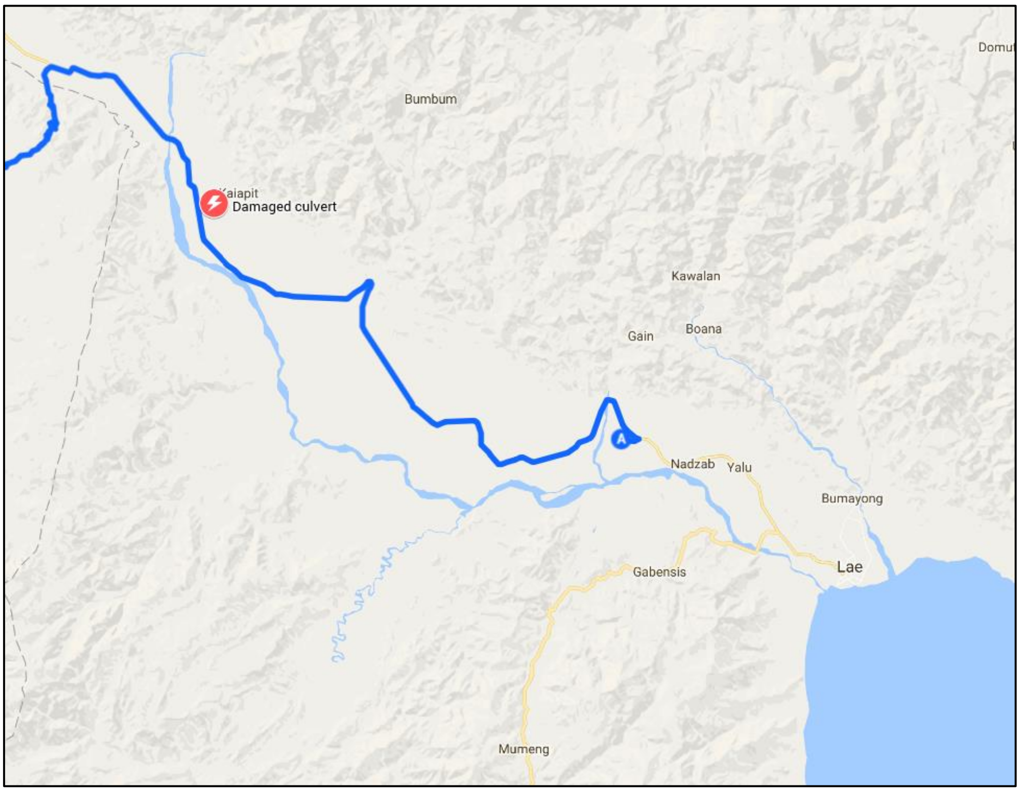

Figure 6: Map showing approximate location of damaged TSSP culvert

122. Analysis of the event has not yet fully clarified why the damage was caused. However, this illustrates that sections of the highway will always be vulnerable to climate induced damage. The approach of SHHIP, to accept this, to manage it, and to have flexible response mechanisms, is considered the best approach.

B. Output 2

123. Output 2 is "*Road safety increased and sustained for pedestrians and vehicle passengers on the Highlands Highway*".

124. Output 2 will constitute a series of measures to increase road safety, notably:

- Awareness campaigns for local communities;
- Training for DoW staff;
- Creation of footpaths and other measures for the safety of pedestrians;
- Incorporation of engineering safety measures within the design of the rehabilitated and upgraded sections to reduce risks of road accidents (This may include signage, barriers or other control measures); and
- Regular monitoring of road safety.

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[21] Personal communication, TSSP Senior Road Engineer Adviser

125. Output 2 does not include the construction of infrastructure that is at risk to climate hazards or vulnerable to climate change.[22] Output 2 does not include entry points through which adaptation measures can be introduced. No additional measures are required in Output 2 with regards to climate change.

C. Output 3

126. Output 3 is "*Highlands Transport logistics and services improved in the Highlands region to strengthen value chain for domestic and international trade".*

127. Output 3 is principally the construction of two freight logistics platforms. These will facilitate the integration of small-scale farmers and local entrepreneurs into the local and national economies. This will include open information systems, clean and cold storage facilities, wholesale marketing facilities and loading equipment.

128. Output 3 does not include the construction of infrastructure that is at risk to climate hazards or vulnerable to climate change. Output 3 does not include entry points through which adaptation measures can be introduced. No additional measures are required in Output 3 with regards to climate change.

D. Output 4

129. Output 4 is "*Program management and institutional capacity improved to deliver the program and sustain its benefits".*

130. Output 4 includes a series of support measures to the governance of the SHHIP, the day to day management of the SHHIP, and to ensure that the SHHIP benefits from best available technical support and capacity development. Output 4 notably includes support to a high level Steering Committee, to a project management unit, to design and supervision consultants, to DoW's capacity development, and to implementation of a gender action plan.

131. With regards to DoW capacity, a very rapid observation of DoW capacity to address climate change was undertaken whilst preparing this report. The observations suggest that current capacity is minimal: there was little evidence of understanding of basic climate change concepts; there was no evidence of in-depth knowledge of climate change; there is no focal point or responsible person for climate change; there are no guidance documents, manuals or guidelines currently being used.

132. Output 4 provides an entry point to develop the required capacity in DoW with regards to climate change. Further, Output 4 provides an entry point to improve available data and knowledge and to pilot innovative approaches. All this can be undertaken during Tranche 1 – creating the basis for a more thorough and integrated approach to climate change adaptation in Tranches 2 and 3.

133. Specifically under Output 4 during Tranche 1, technical support and capacity development may be utilized to:

- Improve knowledge and understanding of the linkages between road construction and climate and climate change;
- Test innovative adaptation measures;
- Raise overall DoW capacity to understand and address climate change. This capacity can be applied to later tranches of SHHIP and to other infrastructure projects in PNG.

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[22] With the possible exception of the footpaths. However, (i) the footpaths are not subject to the same deteriorating forces as the main pavement and so are not expected to deteriorate and (ii) should footpaths be damaged, they can be easily repaired or reconstructed. Hence the footpath design/construction does not require measures for increasing climate resilience.

134. Finally, Output 4 also includes two weighbridges located at strategic points on the Highway, whose principal function will be to ensure that trucks traveling on the HH respect the maximum load requirements. These are unlikely to be at risk to climate hazards or vulnerable to climate change.

E. Counting the Costs of SHHIP Measures that Contribute to Climate Change

135. Annex 7 estimates the costs of the SHHIP measures and activities that contribute to climate change adaptation. The methodology is provided in Annex 7. The costs are estimated for the ten-year, multi-tranche Investment Program and for Tranche 1.

136. A two-step process to estimate the costs of climate change finance was followed. The first step was to determine all the activities that lead to an upgrade that increases climate resilience. Hence, activities that simply restore the highway to previous specifications or that do not increase climate resilience are precluded through this first step.

137. The second step was to determine, for each activity, the increment of the cost of the activity that can be counted as climate change finance. The parameters used to determine the increment were: (i) the length of road affected by the concerned climate risks and/or (ii) the level of effort required to ensure the activity is climate proofed.

138. The overall findings are (see details and methodology in Annex 7):

- For the entire SHHIP program, $226.7 million or 23% of the overall SHHIP budget qualifies as climate finance; and
- For Tranche 1, $69.8 million or 20% of the Tranche 1 budget qualifies as climate finance.

139. As described earlier, the Investment Program includes significant specific maintenance in the early years. This is prior to road strengthening and resurfacing. This does not contribute to climate change adaptation. Hence, in the early years (i.e. Tranche 1) the percentage of SHHIP costs contributing to climate change remains *lower* than for the overall program. In later years, (Tranches 2 and 3), there will be proportionally less specific maintenance, hence, the percentage of SHHIP costs contributing to climate change will rise.

VI. CONCLUSIONS

140. Limited data, knowledge, models and understanding mean a classical approach to designing adaptation measures is not possible. By classical approach it is meant: determining current parameters, projecting future climate change, determining impacts on the project of climate change, and recommending specific adaption approaches and measures. The limited data, knowledge, models and understanding are major constraints to doing this. This is compounded by the great variability of rainfall. This, and uncertainty associated with projections for climate change over the coming decades, make it impossible to precisely project the future climate and how it may affect road infrastructure.

141. Extrapolation from past climate impacts to the road provides an appropriate complementary approach to identifying needs and designing adaptation measures. As the road has existed for several decades, the impacts of previous climate hazards can be easily observed. By extrapolating from these, and using available climate change projections, it is possible to project the climate risks facing each section of the highway in the future.

142. The climate in the PNG Highlands is challenging and there are significant climate threats. The two climate parameters that significantly affect road design on the Highlands Highway are extreme rainfall of a short duration and prolonged rainfall. There is much evidence of the past impacts of these two climate parameters at many points along the Highway. These challenges are most likely to be exacerbated by climate change.

143. The Highlands Highway is at risk to climate threats, particularly to extreme rainfall events, and is also vulnerable to climate change.

144. The overall approach of the SHHIP to climate resilience is sensible and appropriate, based on best available knowledge. This notably includes the focus on repair and upgrading, the focus on maintenance and emergency response, and the inclusion of some activities uniquely to address climate threats. Further, the SHHIP's multi-tranche, long-term nature enables the development of climate resilience measures. Notably, innovative measures can be developed and/or piloted in the first Tranche, and, if successful, support can be mobilized to their broad replication in later tranches.

145. The approach of SHHIP to individual activities is also sensible and appropriate, based on best available knowledge. The PPTA design team has assessed climate risks to the SHHIP by observing the past impacts of climate, using best available data and knowledge and extrapolating. This is appropriate. In response to the risks identified, SHHIP has integrated climate resilience into activities as necessary. Allowance has been made for climate proofing to a reasonable degree. However, possibly, more emphasis could have been placed on ecosystem based adaptation approaches.

146. There will be residual climate risks. Inherent to the SHHIP approach is that there will be residual climate threats and damage. The proposed maintenance and emergency response measures in SHHIP will provide some protection and mitigation against these residual threats. Notwithstanding, some threats will remain.

147. The capacity of the Department of Works to address climate change appears very limited. Currently, DoW has little capacity to specifically addressing climate change. Until now, this has not been a priority, it has been more important for DoW to focus on ensuring best practices.

148. SHHIP's climate change adaptation finance has been estimated. The estimated cost of the SHHIP measures and activities that qualify as climate change adaptation finance is $226.7 million or 23% of the overall budget. For Tranche 1, the estimated cost of measures and activities that qualify as climate change adaptation finance is $69.8 million or 20% of Tranche 1's budget.

VII. RECOMMENDATIONS

149. The Recommendations respond to three of the conclusions above, notably:

- Limited data, knowledge, models and understanding mean a classical approach to designing adaptation measures is not possible;
- SHHIP's multi-tranche, long-term nature enables the development of climate resilience measures; and
- The capacity of the DoW to address climate change appears very limited.

150. The following sections present general recommendations. More assessment, consultation and prioritization would be necessary to develop the details of a climate change technical assistance support program.

A. Increased Knowledge and Understanding

151. Improved understanding and better documenting of the linkages between the climate and the Highway's assets and performance will feed into future highway planning and design (including later SHHIP tranches). To achieve this, a program of **systematic climate surveillance** is recommended, possibly including the following:

- Creating a database – this includes collecting existing data on rainfall from the many sources;

- Systematic and accurate recording of rainfall and river discharges;
- Monitoring and recording the occurrence of climate events and the impacts of climate events on highway assets and performance, including the details of damages, costs and the repairs required;
- Develop a tool for predicting road damage as a function of position in the landscape, condition of assets, nature and intensity of climatic events and other variables (this could be a basis for targeting subsequent interventions to the highest-risk road sections);
- Recording all measures taken to climate proof or adapt to climate change;
- Assessing and recording the costs and benefits of climate proofing and adaptation measures; and
- Analyze all above data and prepare recommendations for road transport planners and engineers.

152. An improved better understanding and more credible knowledge of the **economic costs** of climate threats, climate change and climate change adaptation is useful to guide road transport planners and to convince decision-makers of the importance of adapting to climate change. To achieve this, the following technical assistance is recommended:

- Using a probabilistic approach, forecast the economic losses due to climate hazards on the road assets over the coming years, without accounting for climate change. The steps may be:

    - determine the value of all HH related assets;
    - determine the probability of an hazard ‘occurrence’;
    - determine average cost of an hazard ‘occurrence’ (including reconstruction costs and performance losses); and
    - model the total estimated losses across the HH in a given period.

- Using a similar approach, but accounting for climate change, forecast losses due to climate hazards over the coming years, and
- Propose a basic set of adaptation measures. Then, using a similar approach to the above, estimate the costs and benefits of implementing the adaptation measures.

153. **Study the costs and benefits of improved maintenance and emergency response**. Previous studies, both in PNG and elsewhere, suggest that improved maintenance and improved emergency response are priority measures to adapt to climate change. It is recommended to analyze and record how this applies to HH, including an estimation of the economic costs and benefits. This knowledge will be a useful tool to present to planners and decision-makers and further strengthen the case for increased maintenance and improved emergency response.

B. Piloting and Innovating

154. As a ten-year program, SHHIP provides an opportunity for exploring and piloting innovative approaches to climate proofing, documenting the impacts, learning from the experience and replicating/upscaling as appropriate. Based on the findings of this report, the following are recommended for piloting:

155. **Ecosystem based approaches (EBA) to adaptation**. EBA use biodiversity and ecosystem services as part of an overall adaptation strategy to help people, communities and economies adapt to the negative effects of climate change. EBA are characterised as generally having co-benefits, such as the production of natural resources of use to local communities. The UNFCCC Convention and other international partners are giving increasing attention to EBA.

156. The land surrounding the Highlands is mostly covered with thick vegetation, even when very steep slopes go to the edge of the HH. However, at some points, the vegetation is thin or

almost non-existent. This can increase road exposure to climate events. In response, two types of EBA may provide adaptation and other benefits: (i) bio-engineering on slopes adjacent to the Highway to increase slope stability and (ii) watershed management in micro-catchment near the Highway to help manage the hydrological cycle and reduce peak water discharges. It is recommended to pilot each of these at 2-3 sites along the HH, as follows:

157. **Bio-engineering to increase adjacent slope stability**. This consists of ensuring the slopes are covered with species that stabilize the soil, notably through their root system. This can be undertaken in lieu or jointly with structural or classical engineering measures. The choice of appropriate species can generate other benefits for example through the production of wood, roots, nuts, berries or traditional medicine. The steps would be:

- Identify slopes where bio-engineering measures appears suitable;
- Select appropriate bio-engineering techniques - in collaboration with local communities;
- Pilot the techniques, initially in combination with classical engineering measures; and
- Systematically monitor all the above steps, including the determination of the costs/benefits of the measures and prepare recommendations for measures to be upscaled or expanded if appropriate.

158. **Watershed management in micro-catchments**. In particular in catchments with little vegetation cover, measures to cover the watershed with vegetation may have a positive impact on the hydrological cycle as well as lead to the production of natural resources of use to local communities (timber, fuel, roots, nuts, berries or traditional medicine). The steps would be:

- Identify micro-catchments where the approach may be suitable. Notably this would have to include the active participation of a community who are able to benefit from the watershed management in some way;
- Select, in a participatory manner, appropriate catchment management measures;
- Pilot the catchment management measures; and
- Systematically monitor all the above steps, including the determination of the costs/benefits of the measures and prepare recommendations for measures to be upscaled or expanded if appropriate.

159. **Early warning systems (EWS)**. EWS are technologies and associated policies and procedures designed to predict the impact of disasters and other undesirable events. EWS have already been utilised in many sectors, notably agriculture, to predict climate hazards. This helps plan measures to mitigate the negative impacts and helps communities and economies adapt. During the preparation of this report, the National Weather Service (NWS) expressed its intent to pilot the use of EWS as a tool for climate change adaptation in an infrastructure sub-sector.

160. Piloting EWS is recommended for the road transport sector, along the Highlands Highway. Specifically, the aim would be to provide more accurate and more updated climate information to road transport managers and thereby help them to more efficiently meet their objectives, including preventing damage, repairing damage, and keeping the road passable. This may involve:

- The systematic and automatic collection of weather data at key points on the HH;
- The preparation of short, medium and long-term weather forecasts for sites along the Highway;
- The application of weather forecasts to physical conditions along the HH, in order to forecast, over the medium term, the probability and location of: (i) localized floods; (ii) land-slides and; (iii) large scale floods;
- The use, by DoW, of these forecasts, in order to modify maintenance and emergency response measures, in order to more effectively and more efficiently both prevent climate impacts and rapidly restore after climate damage; and

- The systematic observing and monitoring of all the above, including the determination of the costs/benefits of the EWS, and recommendations, if appropriate, for it to be upscaled or expanded.

161. **Exploring insurance of road assets as a climate adaptation measure**. Insurance has already been utilized in many countries across many sectors to mitigate negative climate impacts. In addition, if well designed, insurance products can provide an incentive for good asset management, including maintenance. However, there are many forms of insurance and there are many potential barriers to insuring the HH. The first step would be to assess if there are insurance products that could potentially provide insurance against climate damage to the highway and its operations. If affirmative, the next step would be to develop, in a participatory manner, a proposal to pilot the products. Specifically:

- Review all potential insurance products;
- Contact potential insurers in order to determine the prevailing insurance market conditions;
- Review rules and practices in PNG regarding insuring public assets; and
- Prepare a roadmap for piloting the insurance of a section of the HH.

C. Building DoW Capacity to Address Climate Change

162. The current capacity of DoW to manage climate change and exploit the opportunities that climate change presents is very limited. This capacity can be developed efficiently. The following are recommended:

- **Awareness raising**. A short but broad campaign to ensure all professionals in DoW understand: (i) the basics of the causes of climate change; (ii) the basics of the impacts of climate change in PNG; (iii) the basics of the linkages between climate change and road transport infrastructure; and (iv) the role of DoW in managing climate change. Once acquired, this awareness would be directly applicable by DoW staff in their work program.
- Further, a small group (2-3 persons) should develop **specialist climate change capacity**. First, a climate change focal point should be established in DoW. Then, staff should receive in-depth training on: (i) impacts of climate change in PNG; (ii) the linkages between climate change and road transport infrastructure; (iii) climate finance (see below). This knowledge would enable the staff to integrate climate change concerns into DoW plans and projects, and would enable DoW to engage with other departments and international partners on climate change.
- DoW is not a climate change agency. To achieve its climate change related objectives it should develop the capacity to **collaborate with other agencies** on climate change issues. Notably, joint activities should be undertaken with the Office for Climate Change Development (OCCD) and the National Weather Service (NWS). Specific proposals are proposed in Section 7.2 above and the next point.
- DoW is eligible to access global climate finance for climate proofing road transport infrastructure. To achieve this, DoW should develop the necessary **capacity to access climate finance –** most likely working together with OCCD. There is considerable international finance available for climate proofing and climate change adaptation and accessing it requires following diverse procedures and allocation cycles. It is not necessary for DoW to have the full capacity to access climate finance, but it is essential that staff in DoW: (i) understand the basics of climate finance; (ii) are able to identify potential finance and initiate the application process, and; (iii) are able to support an ongoing process to obtain climate finance until successful completion.
- Ultimately, DoW could benefit from a set of practical **guidelines or a manual for climate proofing** road transport infrastructure or for climate change adaption. Such a manual would bridge the gap between science and engineering. It would present information and choices in the form of a decision-support tool for DoW design teams and/or planners.

163. The above capacity development can be completed within Tranche 1 of SHHIP. Subsequently, the capacity developed can be directly applied to the design and support of SHHIP Tranches 2 and 3, including potentially the mobilization of climate finance.

Terms of Reference for the Climate Specialist (Original)

Climate Change Adaptation Specialist (international, 2.5 person-months, intermittent).

1. The **Climate Change Adaptation Specialist** will assess climate change risks and vulnerability and propose options for managing the climate risks in consultation with the key members of the PPTA team. The work will be in two steps covering initially the entire program and later the detailed design of Project 1. Tasks will include: (i) identify project areas and components that are sensitive to climate and disaster risks; (ii) develop a detailed work plan to produce a climate risk assessment and management study, consistent with TA milestones for investment project preparation; (iii) Produce the climate risk and vulnerability assessment and management study, which will include climate scenarios, a risk assessment of the program to projected climate change, adaptive options to manage the risks, and an initial comparison of the options (including basic economic analysis); (iv) prioritize adaptation measures, and prepare initial cost estimates for the incremental costs of adaptation measures; (v) with regards to Project 1, guide the project design team to prioritize adaptation measures, to design the adaptation measures and to prepare estimates of the additional costs of the adaptation measures; (vi) Prepare a technical report, which will include the overall methodology, data used, assumptions made, limitations, key findings, and implications for the investment project; (vii) contribute to the preparation of the proposal to the GCF. The Climate Change Specialist will have at least 10 years of experience working in the fields of climate change scenario analysis, climate change impact, vulnerability and adaptation. The specialist will also be experienced in working within a multi-disciplinary team and communicating climate science to a wide range of audiences.

List of Persons Consulted

Government of Papua New Guinea

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Focus Group/Consultation Meetings

Western Highlands Province Stakeholders (approx. 15 participants), Mount Hagen, 31/October morning

Jawaka Province Stakeholders (approx. 25 participants), Jawaka, 1/November morning

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Risk Assessment Report- Central Province, PNG (prepared for PNG Department of Works by RMSI).
Risk Assessment Report- Gulf Province, PNG (prepared for PNG Department of Works by RMSI).
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Various.

Annex 4

Chainage of Highlands Highway with Information on Deterioration and Failures

1. This table indicates the main damage to the highway and its location (with respect to the Zone, the Province, the distances from Kagamuga and Goroka and Lae). It also lists the main features and failures along on the highway.

Province	Bridge or Other Feature	Zone	Km from Kagamuga	Km to/from Goroka	Km from Lae		Road Condition/Cause of Damage
	Kagamuga TO	Zone 5 - Sp Maint LR 42 km	0	169	467		
			1	168	466		shoulder edges
WHP	**Wahgi Br**		2.96	166.04	464		
Jiwaka P	**Komun Br**		4.87	164.13	462		shoulder edges
			8	161	459		shoulder edges
	Avi Market		10	159	457		
	Pehn Br		11.4	157.6	455.6		
			12	157	455		shoulder edges
			15	154	452		shoulder edges
			17	152	450		shoulder edges
	Tuman Br		17.6	151.4	449.4		
			22	147	445		no drain left side to Hagen
	Fruit Market 2		22.4	146.6	444.6		shoulder edges
	Fruit Market		22.7	146.3	444.3		unsealed 1km
			26.5	142.5	440.5		narrow cross section
			27	142	440		shoulder edges
			30	139	437		narrow cross section
			31	138	436		narrow cross section
			32	137	435		deformation
			33	136	434		damp - check water table and underneath/upslope drainage
			33.5	135.5	433.5		narrow cross section
	Kudjip Junction		34.3	134.7	432.7		shoulder edges
	Kudjip Br		34.6	134.4	432.4		
			35.9	133.1	431.1		ongoing works on cross drainage
	Kurumula Br		39.1	129.9	427.9		
	Jiwaka Govt Build		40.4	128.6	426.6		
	Kurumula Br 2		41.4	127.6	425.6		
	Ambeke Br	Zone 4 - Sp Maint HR 20 km	42.2	126.8	424.8		
			42.5	126.5	424.5		surface water - check water table and underneath/upslope drainage
	Damne Br		43.5	125.5	423.5		
	Kupka Br		44.4	124.6	422.6		
	Minj		47.4	121.6	419.6		

Province	Bridge or Other Feature	Zone	Km from Kagamuga	Km to/from Goroka	Km from Lae		Road Condition/Cause of Damage
	Wahgi Br 2		52	117	415		
	Ahl Br		52.8	116.2	414.2		
			54	115	413		deformation
			57	112	410		regressive erosion
			59	110	408		damp - check water table and underneath/upslope drainage
			60	109	407		surface water - check water table and underneath/upslope drainage
Jiwaka P			61	108	406		narrow cross section
Simbu P	**Miunde Br**	Zone 3 - Strengthening 57 km	62.2	106.8	404.8		
			63	106	404		deformation
	Garniger Br		65.3	103.7	401.7		
	Large Culvert		68.3	100	398		
			69.1	99.9	397.9		narrow cross section
	Koronige Br		69.5	99.3	397.3		
	Mingende		75.1	93.6	391.6		slow overall earth movement over 2 km for many years
			78	91	389		surface water - check water table and underneath/upslope drainage
			80	89	387		damp - check water table and underneath/upslope drainage
			81	88	386		severe regressive erosion
			81.2	87.8	385.8		potential landslide lots of surface water
			82.4	86.6	384.6		regressive erosion
			85.2	83.8	381.8		deep hole in the roadway
			85.1				regressive erosion
			85.5	83.5	381.5		potential landslide
			86.4	82.4	380.4		**severe regressive erosion**
	Kundiawa		87.8	81	379		
	Wara Simbu B		90.3	78.7	376.7		
			95.9	73.1	371.1		potential landslide
			97.4	71.6	369.6		damp - check water table and underneath/upslope drainage
			97.6	71.4	369.4		damp - check water table and underneath/upslope drainage
			98.2	70.8	368.8		surface water - check water table and underneath/upslope drainage
			98.6	70.4	368.4	🟥	surface water - check water table and underneath/upslope drainage
			99	70	368	🟥	regressive erosion
			99.3	69.7	367.7	🟥	potential landslide
			100.6	68.4	366.4		surface water - check water table and underneath/upslope drainage
			101.6	67.4	365.4		run off water check lateral and

Province	Bridge or Other Feature	Zone	Km from Kagamuga	Km to/from Goroka	Km from Lae		Road Condition/Cause of Damage
							upslope drainage
			102.2	66.8	364.8		potential landslide
			102.8	66.2	364.2		recent landslide
			103.1	65.9	363.9		run off water - low point - check road and upslope drainage
			103.2	65.8	363.8		regressive erosion
			105.4	63.6	361.6		run off water check lateral and upslope drainage
			107.7	61.3	359.3		potential landslide
			109.3	59.7	357.7		potential landslide
			112.1	56.9	354.9		run off water - low point - check road and upslope drainage
			112.9	56.1	354.1		slight deformation
Simbu P	**Magiro Bridge**		118.6	50.4	348.4		
EHP		Zone 2 - Sp Maint HR 208 km	118.9	50.1	348.1		deformation
			119.3	49.7	347.7		recent landslide
			120.4	48.6	346.6		run off water check lateral and upslope drainage
	Kenangi Br		121.7	47.3	345.3		
	Nurape Br		124	45	343		
			126.9	42.1	340.1		potential landslide
			129.8	39.2	337.2		severe deformation
			129.9	39.1	337.1		subsidence
			130.2	38.8	336.8		severe subsidence
			130.6	38.4	336.4		recent landslide
			130.4	38.6	336.6		recent landslide
	Feonoku Br		131.5	37.5	335.5		
			132.3	36.7	334.7		regressive erosion
			133.7	35.3	333.3		recent landslide
			134.7	34.3	332.3		regressive erosion
			135.1	33.9	331.9		deformation
			135.6	33.4	331.4		deformation
			135.9	33.1	331.1		recent landslide
			137.4	31.6	329.6		narrow cross section
	Daulo Summit		137.9	31.1	329.1		
			138.1	30.9	328.9		narrow cross section
			139.4	29.6	327.6		deformation
			139.5	29.5	327.5		narrow cross section
			142.3	26.7	324.7		**severe regressive erosion**
			142.9	26.1	324.1		deformation
			143.5	25.5	323.5		recent landslide
			143.7	25.3	323.3		recent landslide
			144.4	24.6	322.6		deformation
			145.9	23.1	321.1		regressive erosion

Province	Bridge or Other Feature	Zone	Km from Kagamuga	Km to/from Goroka	Km from Lae		Road Condition/Cause of Damage
			148.5	20.5	318.5		TO to first possible bypass of Goroka in Mando
	Asaro Br		151.9	17.1	315.1		
	Asaro Br 2		152.5	16.5	314.5		
	Mapemo Br		156.1	12.9	310.9		
			159.6	9.4	307.4		drainage
			165	4	302		TO to second possible bypass of Goroka
	Kafamo Br		165.2	3.8	301.8		
			166.1	2.9	300.9		shoulder edges
	Jogi Br		168.1	0.9	298.9		
	GOROKA		169	0	298		
				7	291		deformation
				8	290		deformation
	Covec Crusher			8.6	289.4		deformation
	Rothcliff Crusher			9.5	288.5		shoulder edges
	Kanali Pi Br			9.8	288.2		
	Taraboro Br			12.4	285.6		
	NewTribes Mission			13.3	284.7		
				14	284		half road collapse 1 m down over 50 m
				14.6	283.4		deformation
				16	282		deformation
	Bena Bena Br			17.3	280.7		
				18	280		regressive erosion
				20	278		deformation
	Finito Br 2			25.3	272.7		deformation
	Finito Br			26.2	271.8		
				29	269		deformation
	Bridge 40			31.7	266.3		
	Dirty Wara Br			40	258		old truss bridge
	Bridge 38			47.3	250.7		
	Henganofi Br 2			48.6	249.4		
	Henganofi Br			48.7	249.3		
	Kemunde Br			57.7	240.3		
	Bridge 34			60.5	237.5		
				61	237		deformation
	Avani			62.4	235.6		**severe regressive erosion**
	Bridge 33			63.2	234.8		
				70	228		regressive erosion
	Bridge 32			73.4	224.6		(mile post 230 km to Lae)
	Bridge 31			74.2	223.8		

Province	Bridge or Other Feature	Zone	Km from Kagamuga	Km to/from Goroka	Km from Lae		Road Condition/Cause of Damage
	Bridge 30			74.6	223.4		
				76	222		deformation
	Bridge 29			76.5	221.5		
	Bridge 28			76.8	221.2		
				77.5	220.5		deformation
				78	220		deformation
	Junction Okapa			78.3	219.7		
				81	217		deformation
	Bridge 27			82.3	215.7		
	Kainantu			86.3	211.7		
	Kainantu Br			87.1	210.9		
				88	210		deformation
				89	209		regressive erosion
	Bridge 25			91.9	206.1		
				97	201		deformation
	Bridge 24			97.4	200.6		
	Bridge 23			99	199		
				100	198		deformation
				102	196		large deep hole in the roadway
	Kolwara			103	195		**severe regressive erosion**
	Yonki Dam			112	186		
				113	185		deformation
				113.5	184.5		deformation
				115	183		subsidence
	Bridge 21			118	180		
	Bridge 20			120	178		
	Kassam Summit			121	177		
				123	175		**massive landslide**
EHP	**Yung Creek Br**			131	167		
Morobe P	**Bridge 18**			133	165		
	Bridge 17			137	161		
	Madang Junction			138	160		
	Bridge 16			140.5	157.5		
	Bridge 15			141	157		
				144	154		**possibly flood prone - drainage works ongoing**
	Bridge 14			145	153		shoulder edges
	Bridge 13			147	151		
	Umi Br	Zone 1 - Sp Maint LR 101 km		158	140		
				160	138		shoulder edges
	Bridge 11			161	137		
	Zumin Br			165	133		

Province	Bridge or Other Feature	Zone	Km from Kagamuga	Km to/from Goroka	Km from Lae		Road Condition/Cause of Damage
		🟨		166	132		**flood prone area**
				168	130		**flood prone area**
				169	129		severe depression in the roadway
				170	128		severe depression in the roadway
	Mutsing Br			176	122		
				177.4	120.6		no cross drainage
				177.5	120.5		**flood prone area**
	Bridge 8			178	120		
	Bridge 7			182	116		
	GoramBamPam Br			185	113		**flood prone area**
	Leron Br			198	100		lots of alluvions and silt
				200	98		Replaced culvert (overspill in 2016)
				215.1	82.9		**flood prone area**
				215.6	82.4		**flood prone area**
	Clear Water Br			220.6	77.4		
				229.2	68.8		**flood prone area**
				231	67		
				232	66		
	Rumu Br			233.8	64.2		
				234	64		shoulder edges
				234.3	63.7		narrow cross section
	Maralumi Br			242.7	55.3		
	Erap Br			251.9	46.1		
	Nadzab TO			259	39		
	One-Lane Bridge						
	Two-Lane Bridge						

Assessing the Level of Risk from Climate Hazards to Road Assets on the Highlands Highway

1. This annex reviews and assesses the level of risk from each climate hazard to road assets for each zone of the highway. A classic approach is applied whereby risk is considered a function of the following three parameters: hazard, exposure and vulnerability. Noting:

- The *scale of the hazard* refers to the scale of the projected climate events and extremes in the zone. Given the absence of detailed past climate data and of accurate climate change projections, this is determined based on (i) available knowledge of past weather conditions in the concerned zone; (ii) best available climate change projections for the area; and (iii) evidence of climate events along the highway;
- The *scale of exposure* reflects the extent that the road assets will be exposed to the climate events/extremes. This is notably a function of the surrounding geography (relief, hydrology, soil structure, etc.) and the position of the road in that landscape. Given the absence of detailed GIS and other geographical data, this is determined based on (i) evidence of previous climate-induced damage along the highway and (ii) the impacts that climate change is projected to have on hydrology and hydraulics in the zone (as these are the mechanisms through which the risk is manifested);
- The *scale of vulnerability*. This reflects to what extent the road could be negatively affected by exposure to the climate threat. In addition to previous factors (notably evidence of past damage), this is partly determined by the presence of any factors in the zone that tend to either mitigate or exacerbate the concerned risk. In this case, this also covers *economic vulnerability* by accounting for the critical nature of the asset with respect to mobility and transport.

2. Based on the above qualitative considerations, a score of 1 to 3 is attached to each of these three parameters in each zone for each hazard. The scores are given equal weighting and then multiplied. The resulting product gives the ranking:

- < 8 low risk (LR)
- 9 – 16 medium risk (MR)
- 17 -24 high risk (HR)
- > 24 very high risk (VHR).

3. See Tables 1 – 4.

4. Finally, Table 5 presents the aggregate risk across all hazards for each zone.

Table 1: Climate hazard: Intensive short term rainfall

Zone	Hazard Level	Asset Exposure Level	Vulnerability Level of Asset	Total	Ranking
1	3 - Short term rainfall over catchments next to Zone 1 are common, and can be very intensive, leading to localized flooding and shifting/deposing sediments. All rains accumulate in this downstream section Climate change will exacerbate this	3 - although this area is flat, culverts side drains and bridges have been badly affected in the past	2 - medium scale damage and disruption may be caused	18	HR
2	3 – highly intensive short term rainfall is observed at many points in Zone 2. Climate change will	3 – at many points, as in the past, this will damage infrastructure and cause disruptions	2 – at some points steep slopes and low land cover increase	18	HR

	exacerbate this		vulnerability		
3	3 – highly intensive short term rainfall is observed at many points in Zone 3. Climate change will exacerbate this	3 – at many points, as in the past, this will damage infrastructure and cause disruption.	3. Vulnerability is exacerbated by: large number of very steep slopes; unstable soils; and land conflicts	27	VHR
4	3 – highly intensive short term rainfall is observed at many points in Zone 4. Climate change will exacerbate this	3 – at many points, as in the past, this will damage infrastructure and cause disruptions	2 – at some points steep slopes and low land cover increase vulnerability	18	HR
5	3– highly intensive short term rainfall is observed at many points in Zone 5. Climate change will exacerbate this	3 – at some points, as in the past, this will damage infrastructure and cause disruptions	2 – at some points steep slopes and low land cover increase vulnerability	18	HR

The aggregate risk associated with short-term rainfall is 93

Table 2: Climate hazard: Temperature Rise

Zone	Hazard level	Asset exposure level	Vulnerability level of asset	Total	Ranking
1	2 – the average and maximum temperatures are expected to rise significantly, as will the number of hot days/hot nights	1 – the temperatures experienced will not rise sufficiently to threaten the roads, pavements or bridges Notably the pavements will be asphalt (double bituminous surface treatment or DBST) This does not liquefy due to high sand/gravel content. At worst it softens but only after high temperatures (>40C) for a long period of time. These are not experienced in PNG, especially not in the highlands	1 – there are no exacerbating factors and the assets are not considered vulnerable to this hazard.	2	LR
2	2 – the average and maximum temperatures are expected to rise significantly, as will the number of hot days/hot nights	1 – the temperatures experienced will not rise sufficiently to threaten the roads, pavements or bridges	1 – there are no exacerbating factors and the assets are not considered vulnerable to this hazard	2	LR
3	2 – the average and maximum temperatures are expected to rise significantly, as will the number of hot days/hot nights	1 – the temperatures experienced will not rise sufficiently to threaten the roads, pavements or bridges	1 – there are no exacerbating factors and the assets are not considered vulnerable to this hazard	2	LR
4	2 – the average and maximum temperatures are expected to rise significantly, as will the number of hot days/hot nights	1 – – the temperatures experienced will not rise sufficiently to threaten the roads, pavements or bridges	1 – there are no exacerbating factors and the assets are not considered vulnerable to this hazard	2	LR
5	2 – the average and maximum temperatures are expected to rise significantly, as will the	1 – the temperatures experienced will not rise sufficiently to threaten the roads, pavements or	1 – there are no exacerbating factors and the assets are not considered	2	LR

	number of hot days/hot nights	bridges	vulnerable to this hazard		

The aggregate risk associated with temperature is 8.

Table 3: Climate hazard: Medium and Long term rainfall

Zone	Hazard level	Asset exposure level	Vulnerability level of asset	Total	Ranking
1	2 – Medium and long-term rainfall can be very high in this region, and this will increase with climate change	2 – damage is caused by the high water table at several points	2 – previous evidence suggest bridges, abutments and some section of road are vulnerable	8	MR
2	2 – Medium and long-term rainfall can be very high in this region, and this will increase with climate change	2 – damage is caused by the high water table at some points and potential landslides at some points	2 – previous evidence suggest pavement and side slopes are vulnerable	8	MR
3	2 – Medium and long-term rainfall can be very high in this region, and this will increase with climate change	3 – damage is caused by the high water table at many points and to potential landslides at many points	2 – previous evidence suggest pavement and side slopes are vulnerable	12	MR
4	2 – Medium and long-term rainfall can be very high in this region, and this will increase with climate change	2 – damage is caused by the high water table at some points and potential landslides at some points	2 – previous evidence suggest pavement and side slopes are vulnerable	8	MR
5	2 – Medium and long-term rainfall can be very high in this region, and this will increase with climate change	2 – damage is caused by the high water table at some points and potential landslides at some points	2 – previous evidence suggest pavement and side slopes are vulnerable	8	MR

The aggregate risk associated with long and medium-term rainfall is 44

Table 4: Climate hazard: Increases winds

Zone	Hazard level	Asset exposure level	Vulnerability level of asset	Total	Ranking
1	2 – storms are frequent and can be violent, and this can be exacerbated by climate change	1 – there is no evidence that this has previously damaged assets	1 – there are no exacerbating factors and the assets are not considered vulnerable to this hazard	2	LR
2	2 – storms are frequent and can be violent, and this can be exacerbated by climate change	1 – there is no evidence that this has previously damaged assets	1 – there are no exacerbating factors and the assets are not considered vulnerable to this hazard	2	LR
3	2 – storms are frequent and can be violent, and this can be exacerbated by climate change	1 – there is no evidence that this has previously damaged assets	1 – there are no exacerbating factors and the assets are not considered vulnerable to this hazard	2	LR
4	2 – storms are frequent and can be violent, and this can be exacerbated by climate change	1 – there is no evidence that this has previously damaged assets	1 – there are no exacerbating factors and the assets are not considered vulnerable to this hazard	2	LR
5	2 – storms are frequent and can be violent, and this can be exacerbated by climate change	1 – there is no evidence that this has previously damaged assets	1 – there are no exacerbating factors and the assets are not considered vulnerable to this hazard	2	LR

The aggregate risk associated with winds is 8.

Table 5: Summary of Hazard Risk for Each Zone

Zone	Short term rainfall	Temperature	Medium-long term rainfall	Wind	Aggregate climate risk
1	18	2	8	2	30
2	18	2	8	2	30
3	27	2	12	2	43
4	18	2	8	2	30
5	18	2	8	2	30

Assessment of Rainfall Data and Related Calculations

A. Introduction

1. As stated in the main text of the Climate Risk and Vulnerability Assessment (CRVA) for the SHHIP: "A key design parameter when designing roads is the maximum intensity of short-term rainfall, i.e. the maximum amount of rain to fall in a short period, say 2, 12 or 24 hours. The short term intensive rainfall leads to peak flows in rivers and streams, and so in side drains and cross-drains. Roads must be designed to meet the highest expected values for short-term rainfall. Typically, when designing road infrastructure, design engineers require several years of data for *hourly* rainfall in order to understand expected peaks. However, for the Highlands, there is only limited data available and for *daily* rainfall; no data was found on hourly rainfall."

2. The methods and conclusions of this technical Annex are intended to address the need for credible estimates of the likely impacts of climate change in the PNG Highlands on maximum daily precipitation values in order to provide a basis for any recommended changes in the design of project components. Since very little systematic, historical time series data on daily rainfall is available for the project area (PNG Highlands), this annex does not contain explicit guidance on the rainfall design events themselves to be used in project design; it provides estimates and recommendations concerning how climate change might impact the magnitude of such events; and how they can be adjusted to address these risks.

B. Climate Change and Changes in Rainfall Intensity

3. Many of the adaptation strategies proposed for PNG highlands roads involve modification of design capacity to reflect anticipated changes in rainfall frequency and/or intensity. Design rainfall events are typically expressed in terms of precipitation of a specific intensity and duration, and possibly areal extent, having a specified probability of occurrence in a given location on an annual basis. Thus the 20-year 4-hour precipitation event is the 4-hour precipitation accumulation equalled or exceeded once every twenty years on long-term average, equivalent to an annual exceedance probability of 5%. The use of precipitation design events (quantiles) as the basis of the design of hydrologic and hydraulic structures such as side drains, cross drains, culverts and bridge cross sections is long established practice in water engineering.

4. In the context of the PNG highlands road project, the use of precipitation design events is complicated by two factors. The first is that the time series of observed rainfall at daily or finer time resolution, of reasonably high quality and for long enough periods to support robust statistical estimates are in general not available in the PNG Highlands. The second concern is that the assumptions underlying the statistical estimation of rainfall quantiles – that the observed sequence of annual peak rainfall events represents independent observations drawn from a common and stationary population of such events, which in turn assumes a stationary regional climate – are violated as a consequence of climate change.

5. There are several reasons to anticipate changes in the frequency and magnitude of extreme rainfall events as consequences of climate change. Among the most important is the relationship between air temperature and moisture holding capacity (saturation vapor pressure). This relationship, expressed in the Clausius–Clapeyron equation, indicates that the moisture holding capacity of the atmosphere increases by roughly 7% per degree K (C) of temperature increase globally.

6. Although changes in actual humidity (air moisture content) are influenced by many factors, including availability of water and energy required for evaporation, both empirical evidence and model simulation indicate that changes in *relative* humidity associated with temperature increase are small; and that total (global) rainfall increases at around 1% to 2% per degree (K) of air temperature increase (Trenberth et al., 2003). However, due to low level convergence during storms and other local dynamic factors, event rainfall, or more specifically

the rainfall intensity having a given probability of occurrence, is likely to increase by more than 1% to 2% per degree K increase, although not necessarily in direct proportion to the increase in saturation vapor pressure (7% per degree K). To summarize, while consideration of basic physical relationships indicates that the intensity of extreme rainfall events should increase as a consequence of temperature increase, it cannot be assumed that any increases will scale directly to the increase in temperature.

7. General circulation (global climate) models (GCM) are among the only tools available for estimating the likely changes in precipitation intensity resulting from the regional manifestations of global climate change, particularly if the changes in question are outside of historical experience. Since GCM typically are specified with horizontal resolution of 100 km – 200 km, GCM outputs are typically down-scaled (typically to 10 km - 50 km horizontal resolution) in order to introduce such factors as topographic and coastal influences on precipitation that are not well represented in GCM simulations. Topographic influence is of particular importance in the PNG Highlands, where elevations can reach 4000 masl.

8. Simulated rates of precipitation increase associated with global warming show particularly wide inter-model variation in the tropics, reflecting among other factors the sensitivity of model simulations to differences in model parameterization of such processes as moist convection, which are currently poorly understood. In the tropics, simulated changes in precipitation extremes (normalized to the increase in surface air temperature) were found to range from 1.3% K^{-1} to 30% K^{-1} (O’Gorman and Schneider, 2009).

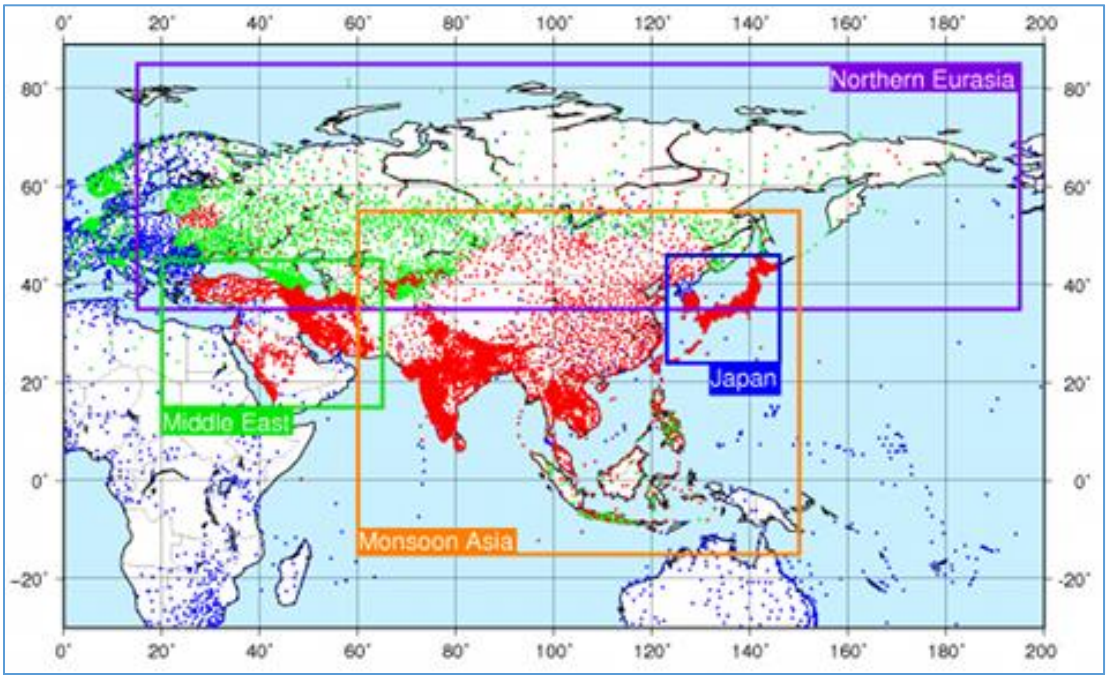
9. In regions such as the PNG Highlands, where there are relatively few long, reliable precipitation records available, it is furthermore difficult to validate model outputs. And, in general, GCMs are known to under-estimate precipitation extremes relative to observations (e.g., Dai, 2006), although in the absence of observational data it is difficult to evaluate model biases. These points are raised so that it is clear that the specific results of model simulations should not be over-interpreted or taken as forecasts of future conditions, but rather as indicative of what may occur contingent on degree of success in mitigating GHG emissions.

Rainfall in Papua New Guinea

10. PNG is in general characterized as having annual rainfall accumulations among the highest in the world, with most regions receiving between 2,000 and 4,000 mm yr^{-1}. Many of the zones of highest accumulation are found in the Highlands. There is no dry season as such (e.g., less than 100 mm mo^{-1}); all months receive significant rainfall in most years (McAlpine et al., 1983).

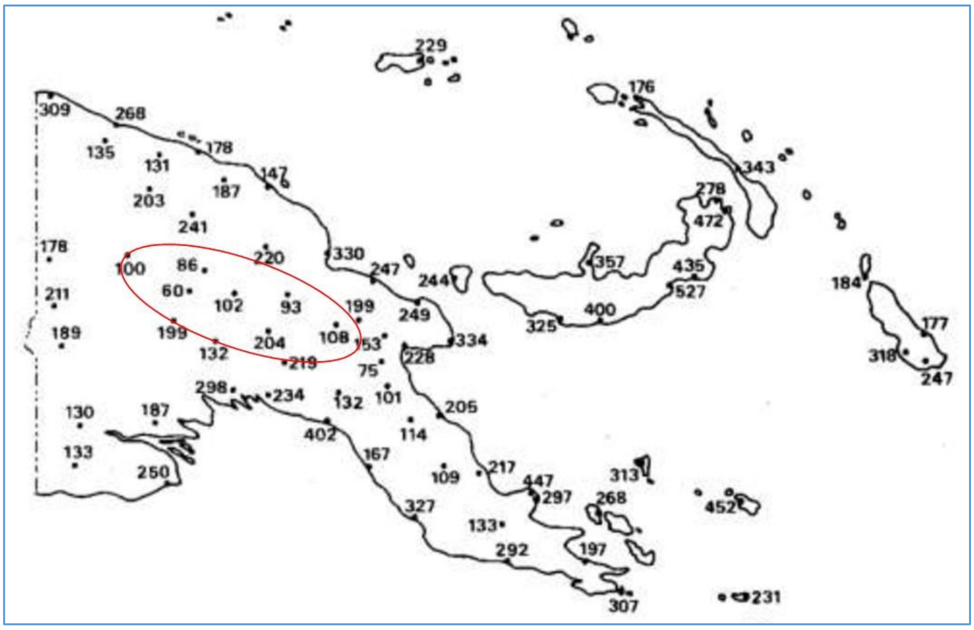
11. While annual and seasonal rainfall totals are important in many contexts such as agriculture and hydropower, the focus of this study is on high-intensity rainfall events which have implications for the design of hydraulic structures and materials. Attempts were made to identify and obtain historical records of daily rainfall occurrence, they were in general unsuccessful. To illustrate, an attempt was made to retrieve rainfall data from the APHRODITE (Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation) gridded dataset, which provides daily data at 0.25 and 0.5 arc degree resolution from 1950 through 2007 over most of Asia (UCAR, 2017). Since daily rainfall is gridded on the basis of point (rain gauge) records, its accuracy depends entirely on the availability and accuracy of such gauge records. In Figure 1, it is seen that APHRODITE gridded estimates are supported by no underlying gauge data, hence unusable in the desired context. Other sources, such as the Pacific Climate Change Data Portal (AU Bureau of Meteorology) have daily data for only three sites in PNG, none of which are in the Highlands.

Figure 1: APHRODITE Station Distribution (source: UCAR 2017)



12. Some information on maximum daily rainfall occurrence in the PNG Highlands is found in McAlpine et al (1983), reproduced in Figure 2. Although these data are not current (most data series end in the 1970's) they can be taken as indicative of daily maxima in that region, although the annual probability of occurrence cannot be known. The approximate region of interest is highlighted in red. Daily rainfall maxima for unknown periods of record range from around 60 mm/day to 200 mm/day in project region, with values around 100 mm/day most common.

Figure 2: Maximum Recorded Daily Rainfalls in PNG (McAlpine et al., 1983 Fig. 19)



C. Estimating Change in Daily Rainfall Intensity Using Down-scaled GCM Projections

13. Due to the absence of long-term and reliable gauge records of daily precipitation for the project area, quantitative estimates of rainfall design events were not made. However, *changes* in daily rainfall at specified probabilities of occurrence were made on the basis of GCM outputs

down-scaled to a suitable spatial resolution using the delta method. The delta method estimates changes in climatic variables by comparing modeled historical conditions with modeled future conditions, and applying the estimates changes (or rates of change) to observed data. In this way, any model biases relative to observed climatic conditions do not contribute to projection error as long as the biases themselves do not change significantly over the modeling time horizon.

14. In June 2015 the U.S. National Aeronautics and Space Administration (NASA) released the NASA Earth Exchange (NEX) Global Daily Downscaled Projections (GDDP) dataset. The dataset was produced in support of the IPCC AR5, and consists of daily projected values of three primary climatic variables – maximum and minimum temperature and precipitation – at 0.25 degree horizontal resolution (equivalent to approximately 25 km) for the entire globe. Projections are available for the historical period (1950-2005) and for 2006–2100 under two representative concentration pathways (RCP; corresponding to emissions scenarios): RCP4.5 and RCP8.5. The first is consistent with a relatively optimistic vision of progress in GHG mitigation[23], and the second (RCP8.5) is equivalent to a “business as usual” scenario and consistent with current global GHG emissions patterns.

15. Down-scaled projections are obtained using a statistical approach. The bias-correction spatial disaggregation (BCSD) approach (Maurer and Hidalgo., 2008) was applied to 21 of the CMIP5 models for which daily projections were made available by the global modeling centers.[24] The stated purpose of the GDDP is “… to provide a set of global, high resolution, bias-corrected climate change projections that can be used to evaluate climate change impacts on processes that are sensitive to finer-scale climate gradients and the effects of local topography on climate conditions” (Thrasher and Nemani, 2015).

16. GDDP projections at daily timestep were downloaded from the NASA NEX server for a transect of 13 0.25 °C x 0.25 °C rasters corresponding to the project locations within the PNG Highlands. Table 1 indicates the centroidal locations of each raster. Data from all 21 GCMs was down-loaded, but preliminary analysis determined that projected values produced by one of these models (ACCESS1-0) were implausible, and were excluded. Estimates presented in this study therefore represent 20 GCMs, as indicated in Tables 2 and 3. It should be further noted that many of these models share specification (e.g., MIROC-ESM and MIROC-ESM-CHEM) or represent two different resolutions (e.g., IPSL-CM5A-LR and IPSL-CM5A-MR).

17. Two time periods were defined for the purposes of applying the delta method. The historical period is defined as January 1971-December 2000, and the projection period as January 2036-December 2065 (both 30 years). The results of the CMIP5 historical simulations are used in bias-correction. For the projection period, RCP8.5 projections were used. RCP8.5 represents a future with more extreme climate change than RCP4.5, but was selected for this analysis consistent with a precautionary approach, since it is not possible to assign probabilities to the respective likelihoods of each of the RCPs.

Table 1: Centroid Locations of GDDP Rasters Used in the Study

Raster	Longitude	Latitude
ppt_01	146.375	-6.375
ppt_02	146.125	-6.375
ppt_03	146.125	-6.125
ppt_04	145.625	-6.125
ppt_05	145.625	-6.375
ppt_06	145.375	-6.125

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[23] Although relatively optimistic, RCP4.5 is nevertheless inconsistent with global temperature increases limited to 2.0 °C or less as targeted by the Paris Agreement (2015). Only RCP2.6, which includes removal of CO_2 from the atmosphere, is fully consistent with the Paris outcome.

[24] Although all GCMs run at 3-hour or equivalent timesteps, not all centers make daily outputs publicly available.

ppt_07	145.125	-6.125
ppt_08	144.875	-5.875
ppt_09	144.875	-6.125
ppt_10	144.625	-5.875
ppt_11	144.375	-5.625
ppt_12	144.375	-5.875
ppt_13	144.125	-5.875

18. Projections for each GCM and raster are necessarily correlated, since they are extracted from a contemporaneous simulation field. However, projections from different GCMs on a single raster are relatively independent for any given year, either historical or projected. Due to constraints on time and effort, only two rasters were selected for subsequent analysis. Raster 13 (144.125 E Lon; -5.875 S Lat) was chosen since it corresponds spatially to Mt. Hagen, location of one of the few daily rainfall records available in the Highlands. The second is raster 7 (145.125 E Lon; -6.125 S Lat), chosen as it corresponds to the road right-of-way in Chimbu Province, where roads are generally in poor condition. Raster 7 is directly west of Goroka, where historical climate records also exist. Figure 3 provides a comparison between historical and modelled monthly precipitation (mean of 20 GCMs) at Mt. Hagen, and Figure 4 for Raster 7 and Goroka.

Figure 3: Comparison of Monthly Precipitation, 20 GDDP Simulations (1971-2000) and Historical Observation, Mt. Hagen (Raster 13)

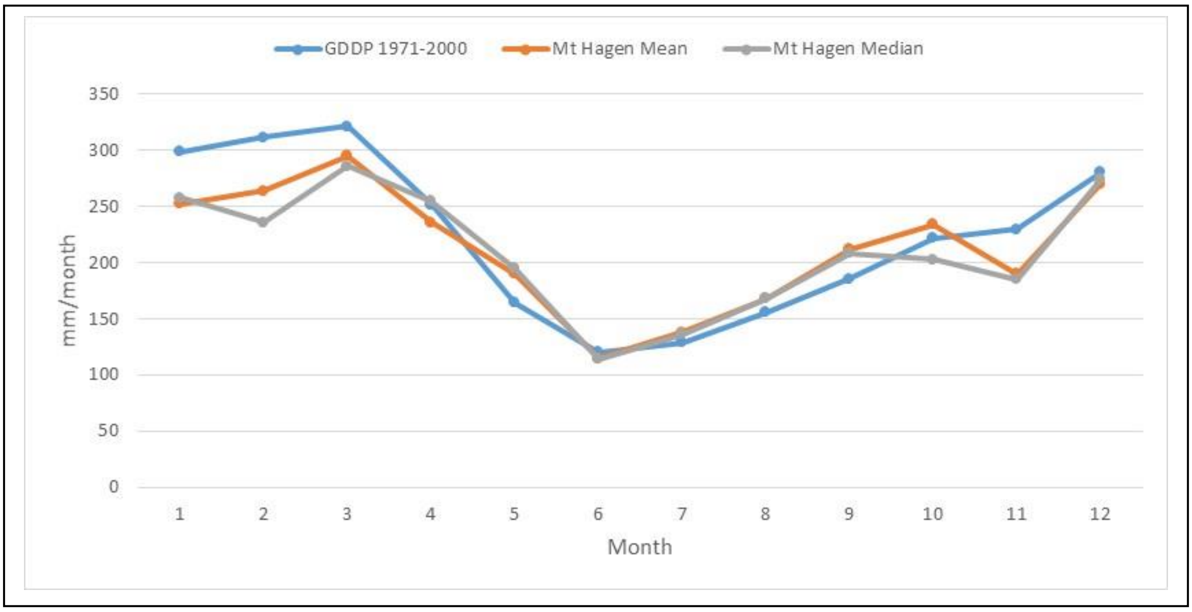
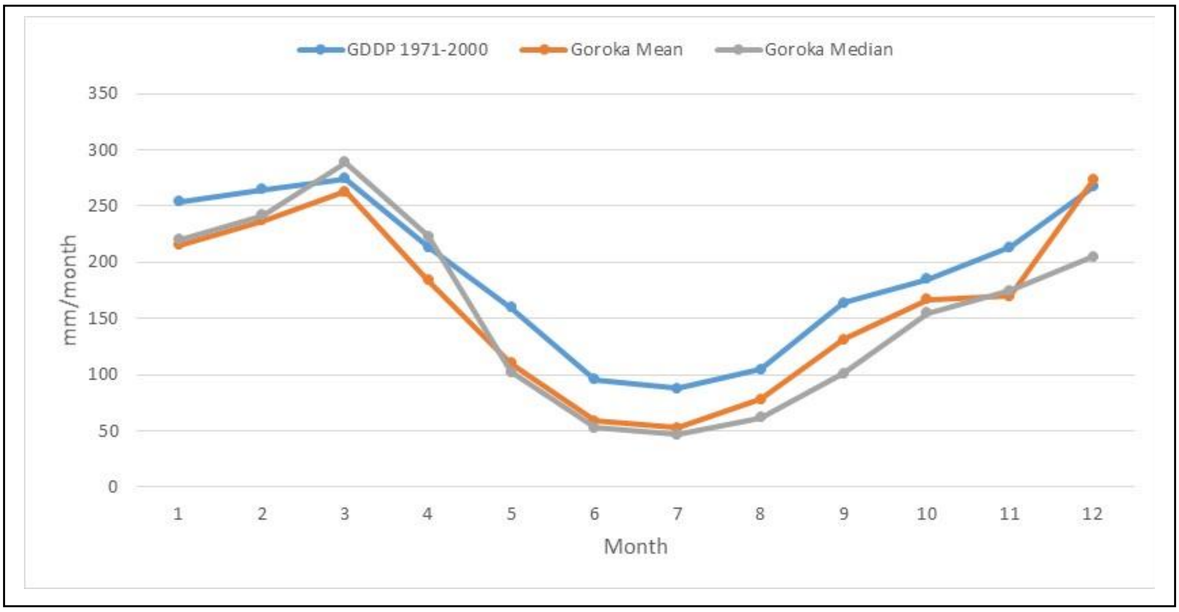


Figure 4: Comparison of Monthly Precipitation, 20 GDDP Simulations (1971-2000) and Historical Observation, Goroka and Raster 7



19. It is observed that the model-simulated monthly rainfall at Mt. Hagen closely approximates historically observed averages, although they implicitly refer to different historical time periods (pre-1970s for Mt. Hagen observed vs. 1971-2000 for GDDP simulated historical). Simulated monthly precipitation in Raster 7 is slightly above observed rainfall at Goroka, although Raster 7 lies roughly 0.25 arc degrees west of Goroka along a precipitation gradient, and also corresponds to a later period. In both cases the historical seasonal pattern is well simulated. This is likely due largely to the bias correction algorithm used in the GDDP as a component of statistical down-scaling.

20. For each 30-year record of simulated daily data, the largest daily precipitation value for each year was extracted, yielding 30-year extreme value records for both historical and projection periods and for 20 down-scaled GCMs at each raster. Daily precipitation quantiles were estimated for each series assuming the generalized extreme value distribution (GEV) estimated using the method of L-moments (Hosking and Wallis, 2005). Results for both 10-year recurrence (p=0.10) and 25-year recurrence (p=0.04) and percentage changes (projected relative to historical) appear in Table 2 for Raster 7 (near Goroka) and in Table 3 for Raster 13 at Mt. Hagen. Comparisons for 25-year daily quantiles are also presented graphically in Figures 5 (Raster 7) and 6 (Raster 13/Mt. Hagen).

21. For Raster 7 (Goroka), 10-year daily quantiles average around 59 mm/day for the (simulated) historical period, and around 67 mm/day for the projection period. The percentage increase (average of individual model increases) is around 14% for the 10-year events. Corresponding figures are 69 mm/day historical and 78 mm/day projected for the 25-year event, with a model-average increase of 14%

For raster 13 (Mt. Hagen) the corresponding figures are 63 mm/day historical and 73 mm/day projected for the 10-year event, an increase of over 16%, and 71 mm/day historical and 82 mm/day projected for the 25-year event, a model average increase of 15.6%.

Table 2: Changes in 10-Year and 25-Year Daily Rainfall, Pixel 7 West of Goroka

Model	Q10	Q10	% change	Q25	Q25	% change
	1971-2000	2036-2065		1971-2000	2036-2065	
CCSM4	84.0	90.4	7.7%	104.4	110.1	5.5%
CSIROmk3_6	62.5	64.0	2.3%	72.0	70.3	-2.4%
BNU_ESM	53.2	45.3	-14.9%	66.1	47.0	-28.9%
CESM1(BGC)	75.8	99.6	31.3%	93.7	120.0	28.1%
CNRM_CM5	75.6	91.3	20.8%	93.0	107.0	15.0%
CanESM2	40.1	46.9	16.9%	43.7	51.6	18.1%
GFDL_CM3	50.1	61.4	22.6%	57.1	72.5	26.9%
GFDL_ESM2G	48.5	73.7	52.0%	53.8	88.4	64.2%
GFDL_ESM2M	47.5	58.0	22.0%	49.8	65.7	32.0%
IPSL_CM5A_LR	45.4	56.9	25.4%	51.5	69.7	35.5%
IPSL_CM5A_MR	74.7	77.3	3.5%	90.8	92.1	1.4%
MIROC_ESM	47.4	42.9	-9.4%	53.8	49.8	-7.5%
MIROC_ESM_CHEM	43.6	40.6	-6.9%	47.0	47.1	0.4%
MIROC5	62.6	73.1	16.7%	71.6	82.0	14.6%
MPI_ESM_LR	61.8	61.8	0.0%	70.5	70.0	-0.7%
MPI_ESM_MR	62.5	65.0	4.1%	70.5	71.3	1.1%
MRI_CGCM3	73.6	106.8	45.0%	83.3	127.9	53.6%
NorESM1_M	61.0	72.3	18.6%	72.3	77.2	6.9%
BCC_CSM1_1	49.0	59.3	20.9%	58.2	69.8	20.0%
INMCM4	59.0	56.6	-4.0%	67.5	63.2	-6.4%
Mean	58.9	67.2	13.7%	68.5	77.6	13.9%

Figure 5: Changes in the 25-Year Maximum 1-Day Precipitation, Raster 7 (Goroka)

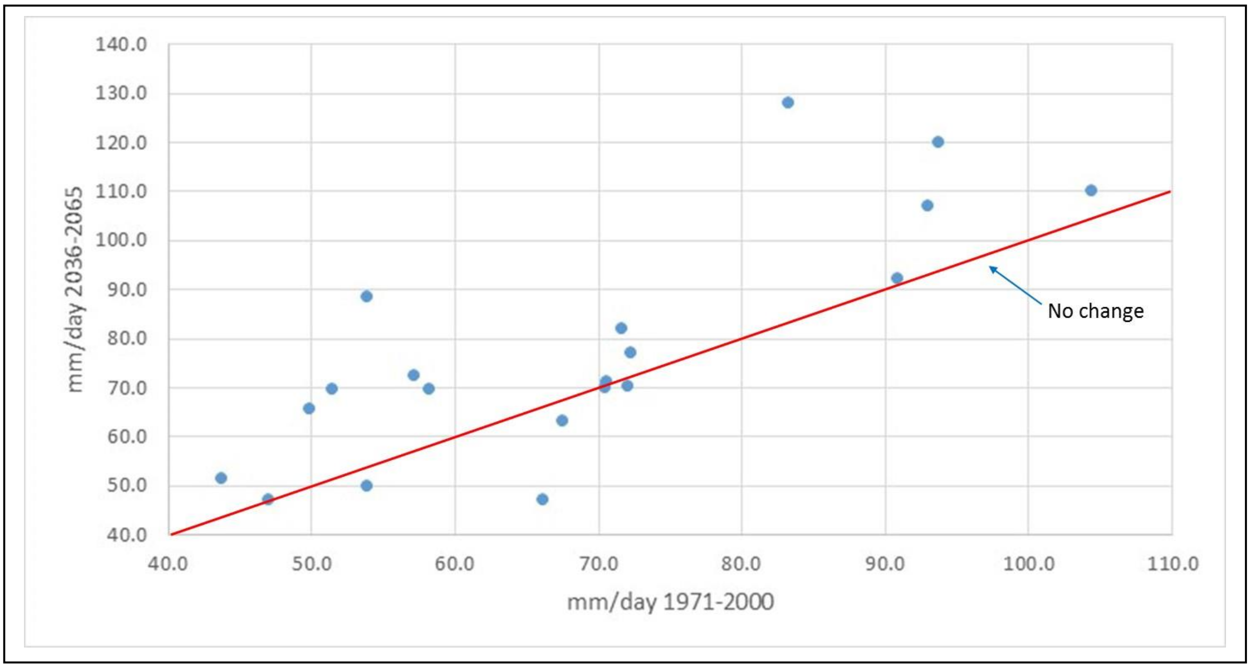
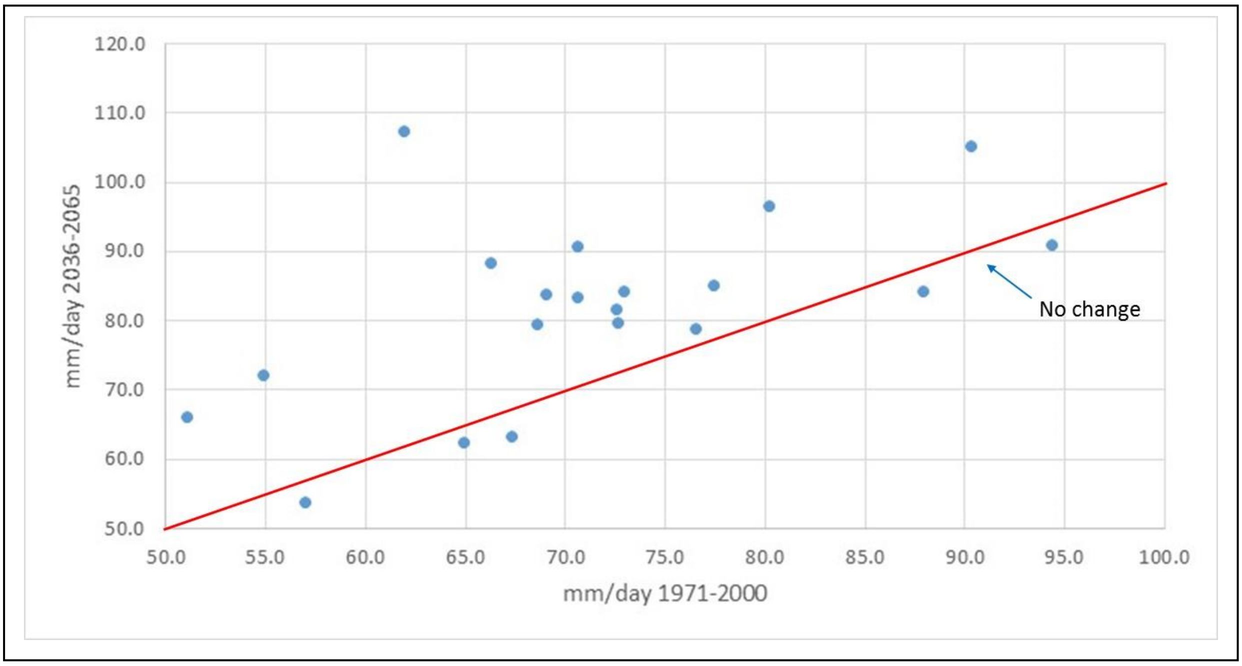


Table 3: Changes in 10-Year and 25-Year Daily Rainfall, Pixel 13 at Mt. Hagen

Model	Q10	Q10	% change	Q25	Q25	% change
	1971-2000	2036-2065		1971-2000	2036-2065	
CCSM4	79.2	94.7	19.6%	90.3	105.1	16.4%
CSIROmk3_6	66.5	77.7	16.8%	77.5	85.1	9.9%
BNU_ESM	57.4	56.8	-1.1%	67.4	63.1	-6.3%
CESM1(BGC)	72.1	87.6	21.4%	80.3	96.6	20.3%
CNRM_CM5	80.5	82.1	2.0%	94.4	90.9	-3.7%
CanESM2	48.6	62.0	27.4%	54.9	72.1	31.2%
GFDL_CM3	62.8	72.3	15.1%	73.0	84.1	15.2%
GFDL_ESM2G	56.6	94.0	65.9%	62.0	107.2	72.9%
GFDL_ESM2M	59.5	76.0	27.8%	66.3	88.3	33.2%
IPSL_CM5A_LR	46.5	57.7	24.1%	51.1	66.0	29.3%
IPSL_CM5A_MR	62.2	68.3	9.8%	72.7	79.6	9.5%
MIROC_ESM	58.3	52.9	-9.3%	65.0	62.2	-4.3%
MIROC_ESM_CHEM	50.4	49.5	-1.9%	57.0	53.8	-5.7%
MIROC5	64.0	74.1	15.7%	72.6	81.5	12.4%
MPI_ESM_LR	66.9	72.7	8.6%	76.6	78.6	2.7%
MPI_ESM_MR	76.2	79.1	3.7%	88.0	84.1	-4.4%
MRI_CGCM3	62.8	78.5	25.1%	70.6	83.3	17.9%
NorESM1_M	62.6	79.1	26.3%	70.7	90.7	28.4%
BCC_CSM1_1	58.8	71.4	21.6%	69.1	83.6	21.1%
INMCM4	63.3	68.9	9.0%	68.6	79.5	15.8%
Mean	62.8	72.8	16.4%	71.4	81.8	15.6%

Figure 6: Changes in the 25-Year Maximum 1-Day Precipitation, Raster 13 (Mt. Hagen)



22. It is observed in Tables 2 and 3 and Figures 5 and 6 that there is considerable variation in both estimated quantiles; and in changes between the two periods. Both positive and negative changes are simulated for each location and recurrence interval, although simulated increases greatly out-number simulated decreases (15 of 20 are positive for Rasters 7 and 13) and averages over all models are positive. It is also seen that while most simulated decreases in the 10-year and 25-year quantiles are small (only 1 exceeds -10%), many of the simulated increases are much larger than the ensemble average. An additional point is that the range of simulated 25-year historical quantiles -- from 44 to 104 mm/day in Raster 7 and from 51 to 94 mm/day in Raster 13 – is consistent with the recorded maxima at gauging stations within the same region (refer to Figure 2).

23. Numerous studies have found both that climate models tend to underestimate precipitation extremes relative to observations, and that they often do not correctly reproduce the interannual variability of precipitation extremes in the tropics (O'Gorman and Schneider, 2009). This can lead to a compression in the range of simulated annual daily maximum values over the 30-year record relative to observation. This will in turn lead to systematic under-estimation of quantiles, increasing with recurrence interval. However, this is not a major concern when using the delta method, since only relative change is being estimated.

D. Recommendations

24. The advantage of evaluating large ensembles of projected climate is that the uncertainty in future climate related to model specification, initial conditions and other factors is made visible. What is evident from this study is that there is considerable uncertainty around the extent to which extreme daily rainfall will change I the PNG Highlands as a consequence of climate change. It is also evident, both from these simulated future climates and from established physical theory, that the intensity of daily events of a given recurrence interval (quantiles) are likely to increase. Time frame is important in considering the extent of increase.

25. In this study, a 30-year future time slice centered on 2050 has been used. For this endpoint, it is reasonable to assume that daily rainfall quantiles commonly used in hydrologic design of drainage structures (10- or 20-year events) might increase by around 15% (the rough mean of increases at both sites as projected by 20 GCMs).

26. The recommendation of this study is to take a precautionary approach and assume that annual maximum daily rainfall events used in drainage design and related applications will increase by 20% by 2050. For intermediate time frames, the increase would be in linear proportion to time. As an example, if the design decision relates to 2030, then one would assume an increase of around 13% to 14%, since 2030 is roughly 70% of the distance between 1985 (the midpoint of the historical baseline used I this study) and 2050, the midpoint of the projection period; and 13% - 14% is 70% of a 20% increase.

27. To provide ongoing support to and improvement of PNG's road asset management under climate change, it is also strongly recommended that daily meteorological data be collected systematically at several points within the project area, building wherever possible on existing records, so that the capacity to identify and analyze any developing trends in measured rainfall intensity can be increased progressively.

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Counting the Costs of SHHIP Measures that Contribute to Climate Change

1. In general, the methodology for establishing that a project/activity qualifies as climate finance (adaptation) is as follows:

i) set out the climate vulnerability context of the project/activity;
ii) state, explicitly, the intent to address climate vulnerability as part of the project/activity;
iii) articulate a clear and direct link between the climate vulnerability context and the specific activity.

If this can be done, the project/activity can be considered to qualify as climate finance (adaptation).

2. Noting:

- Over 2011 – 2016, for the Pacific, for approved ADB transport projects, on average 9% of the project costs counted as climate finance – in all cases climate change adaptation;
- The report ‘Pacific Possible’ (World Bank, 2016), estimates that, across Pacific countries, the range of costs for pre-emptive adaptation measures in the ‘roads’ sector is 14.8% – 43.8% of the project costs;
- The SHHIP takes place in an area with very high climate variability and high climate vulnerability;
- In PNG, for the ‘*Highlands Region Road Improvement Investment Program (Project 2*)’, 13% of the project budget qualified as climate finance (adaptation);
- In TIM, for the ‘Road Network Upgrading Project (Additional Financing)’, 41% of the project budget qualified as climate finance (adaptation).

3) Specifics of methodology in the SHHIP Program:

- The first step is to determine which activities qualify for consideration as climate finance, i.e. determine the qualified project activities (QPA);
- It is assumed that wherever a Project activity leads to ‘upgrading’, and wherever this upgrading leads to increased climate resilience, the activity is a QPA and qualifies for consideration as climate finance;
- However, for Project activities that ‘restore’ the highway to original specifications, or for Project activities that upgrade but do not lead to increased resilience, the concerned activity does *not qualify* as climate finance;[25]
- The second step involves taking a closer look at all the QPA and estimating the ***increment*** of these activities that qualifies as climate change adaptation finance.
- For several QPA the principal aim of the activity is adaptation or climate proofing. Such activities are considered 100% incremental;
- However, for several other activities, although they are QPA, the activities are being supported by the SHHIP as a good practice. Although they do increase climate resilience that is not the primary benefit nor the primary objective of the activity. It is therefore not reasonable to consider *all* the budget of these activities as climate finance;
- The percentage ***increment*** of these activities was therefore estimated. The parameters to determine the increment were: (i) the length of road affected by the

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[25] This approach is consistent with the most appropriate guidance obtained (see *Climate Finance Tracking Guidance Manual –Transport Sector,* African Development Bank, 2013);

concerned climate risks and/or (ii) the level of effort required to ensure the activity is climate proofed (as a proportion of the overall activity). The percentage figures were determined based on guidance from the PPTA Team Leader and experience with similar projects.

Findings

See tables below for complete information.

Following Step 1, it was determined that:

- The budget allocated to QPA over the entire SHHIP MFF is $657.1 million or 67% of the overall SHHIP budget;
- The budget allocated to QPA in Tranche 1 of SHHIP is $204.9 million or 60% of the Tranche 1 budget.

Following Step 2 it was determined:

- Several QPA are considered 100% incremental – i.e. 100% of the activity costs counts as climate finance;
- All other QPA were 25-30% incremental - i.e. 25-30% of the activity costs counts as climate finance.

As a result

- For the entire SHHIP program, $226.7 million or 23% of the overall SHHIP budget qualifies as climate finance;
- For Tranche 1, $69.8 million or 20% of the Tranche 1 budget qualifies as climate finance.

Overall SHHIP Programme

	Activity	Vulnerability	Intent	Linkage	Step 1: QPA?	Step 2: CC adaptation increment	Total SHHIP cost ($ mn)	Total QPA cost ($ mn)	CC increment cost ($ mn)
maintenance	Routine Maintenance (drains and pavement)	Projected increases in rainfall intensity lead to drain overloading and infrastructure damage through various mechanisms. Climate change is likely to lead to less predictability and more small-scale damage	Plan and implement improved maintenance, notably of culverts.	Improved maintenance keeps drains clear, this significantly reduces risk of climate induced damage. Also, improved maintenance ensures timely repairs to pavement and so protects the pavement from climate risks	Yes: the improved maintenance activity significantly lowers the climate risk	30%: this is an approximation of the additional effort in maintenance to reduce climate risk	43.8	43.8	13.14
	Specific Maintenance Heavy Repair	None – it is restoring to original specification – prior to road strengthening and resurfacing			No	0	54.4	0	0
	Specific Maintenance Light Repair	None – it is restoring to original specification – prior to road resurfacing			No	0	58.5	0	0
	Milling Levelling & compacting	None – it is restoring to original specification – prior to road strengthening and resurfacing			No	0	36.2	0	0
	Bridge Maintenance	Projected increases in flood heights and sedimentation flows lead to damage to bridge infrastructure, and potentially undermine bridge stability	Plan and implement improved maintenance, notably to adequately cover abutments	Improved bridge maintenance protects abutments from climate damage, and lessens instability due to siltation	Yes, the improved maintenance activity significantly lowers the climate risk	30%: this is an approximation of the additional effort in maintenance to reduce climate risk	17.8	17.8	0.534
investment	Road Strengthening	Increased rain, water flows and potentially rising water table may lead to more damage to base course layer	Utilize stronger, better graded (and so more resilient) materials in the base course, including stabilizers	Stronger, more stable base will resist the action of water in the water table and from flooding	Yes, the upgraded base course will be more resilient to climate change	30%: this is an approximation of the length of the road which is vulnerable to water table damage.	92.9	92.9	27.9
	Road Resurfacing	Increased rain and localized flooding, from overloaded drains,	Utilize improve surfacing material that is more	The improved surface resists climate change and is less prone to failure, and so lasts longer	Yes, the upgraded surface will	30%: this is an approximation	100.5	100.5	30.1

	Activity	Vulnerability	Intent	Linkage	Step 1: QPA?	Step 2: CC adaptation increment	Total SHHIP cost ($ mn)	Total QPA cost ($ mn)	CC increment cost ($ mn)
		damages road surface	resilient to water and to climate change		be more resilient to climate change	of the length of the road surface which is vulnerable to climate			
	Grade Raising	Projected increases in flooding and sedimentation flows downstream cause damage to the pavement	Design and construct a raised pavement at vulnerable points	Pavement raising will lessen the risk of flood and associated damage	Yes	100%: all the activity, it is upgrading to address the flooding risk	43.6	43.6	43.6
	Drainage Improvement	Projected increases in rainfall intensity lead to drain overloading and infrastructure damage	Design and construct effective side drains and cross-drains to increased specifications	Effective drains carry water away from pavement, reducing damage	Yes, the drains, side and cross-drains, are an upgrading and so increase resilience	25%: this is a first order assessment of the additional costs required to meet higher flows	111.9	111.9	28
	Landslide Protection	Projected increases in rainfall intensity lead to more land slides, blocking roads and damaging infrastructure	Design and construct: (i) drainage in slopes and under pavement; (ii) other slope stabilization measures	Improved slope stabilization will lead to fewer landslides and related damage	Yes	100%: the activity is an upgrade to address the risk	8.9	8.9	8.9
	Emergency Works	After all measures taken, there will be a residual climate threat, and that will lead to damage to drains and pavement, to blocked roads and to degradation. Climate change exacerbates this	Plan and implement rapid activities to immediately repair damage	Rapid responses will ensure roads remain passable and will protect the pavement from future damage	Yes, the activity is an upgrade to address the risk.	30%: this is an approximation of the length of the road which is vulnerable to climate change	72.7	72.7	21.8
	Road Safety Improvement	None – not applicable			No		72.7	0	0

	Activity	Vulnerability	Intent	Linkage	Step 1: QPA?	Step 2: CC adaptation increment	Total SHHIP cost ($ mn)	Total QPA cost ($ mn)	CC increment cost ($ mn)
	Goroka Bypass	This will be a major upgrading – effectively a new road. Climate change and variability will threaten the design and performance of bypass	Design and construct a bypass that meets all requirements and is climate resilient.	Goroka bypass will reach the same level of climate resilience as all other parts of road .	Yes	The same proportion as the overall programme will count as climate finance	104.6	70.6	24.38
	Truck Climbing Lanes	The measures taken through other SHHIP activities (i.e. road resurfacing, drainage improvement, landslide protection) will provide climate protection.			No		26.2	0	0
Bridges	Bridge Widening 1L to 2L	Increased flooding and shifting sedimentation loads threaten the bridge structure and abutment	As part of widening process, design and construct more resilient bridge structures and abutments.	The stronger, better protected bridge will be more resilient to climate threats	Yes, the bridges will be more resilient so the activity qualifies as climate finance	30%: this is an approximation of the additional effort in maintenance to reduce climate risk	69.5	69.5	20.85
	Bridge Reinforcement	This is reinforcing healthy bridges whose bearing capacity no longer meets traffic requirements. In future, due to Increased flooding and shifting sedimentation loads, the threats to the bridge will come even higher	Strengthen the bridge structure and possibly the abutment.	As part of the process to strengthen the bridge structure and possibly the abutment, it will all become more resilient.	An estimated half of the bridges will be more resilient - so 50% of the activity qualifies as climate finance	30%: this is an approximation of the additional effort in maintenance to reduce climate risk	27.9	13.95	4.2
	Bridge Reconstruction	In these cases, the concerned bridges that have suffered severe damage (typically due to climate impacts) or no longer meet traffic requirements and the bridge requires reconstruction	Design and reconstruct higher, stronger, more stable bridges.	Bridges will be more stable and more resilient to water and sedimentation flows.	Yes, the bridges will be more resilient so the activity qualifies as climate finance	30%: this is an approximation of the additional effort in maintenance to reduce climate risk	10.9	10.9	3.3
	Bridge Repair	This applies to bridges that have suffered little damage and so have demonstrated climate resilience. Past experience suggests these bridges are not vulnerable to climate hazards			No		5.2	0	0

	Activity	**Vulnerability**	**Intent**	**Linkage**	**Step 1: QPA?**	**Step 2: CC adaptation increment**	**Total SHHIP cost ($ mn)**	**Total QPA cost ($ mn)**	**CC increment cost ($ mn)**
Other	Trade and Logistics Platform	Not considered vulnerable to climate change			No		8.70	0	0
	Weigh bridges	Not considered vulnerable to climate change			No		5.8	0	0
TOTALS							972.7	657.11 Or 67%	226.7 0r 23%

Tranche 1 SHHIP Activities

	Activity	Vulnerability	Intent	Linkage	Step 1: QPA?	Step 2: CC adaptation increment	Total Tranche 1 cost ($ mn)	Total QPA cost ($ mn)	CC increment cost ($ mn)
maintenance	Routine Maintenance (drains and pavement)	Projected increases in rainfall intensity lead to drain overloading and infrastructure damage through various mechanisms. Climate change is likely to lead to less predictability and more small-scale damage	Plan and implement improved maintenance, notably of culverts	Improved maintenance keeps drains clear, this significantly reduces risk of climate induced damage. Also, improved maintenance ensures timely repairs to pavement and so protects the pavement from climate risks	Yes: the improved maintenance activity significantly lowers the climate risk	30%: this is an approximation of the additional effort in maintenance to reduce climate risk	4.3	4.3	1.29
	Specific Maintenance Heavy Repair	None – it is restoring to original specification – prior to road strengthening and resurfacing			No	0	45.8	0	0
	Specific Maintenance Light Repair	None – it is restoring to original specification – prior to road resurfacing			No	0	38.1	0	0
	Milling Levelling & compacting	None – it is restoring to original specification – prior to road strengthening and resurfacing			No	0	25.7	0	0
	Bridge Maintenance	Projected increases in flood heights and sedimentation flows lead to damage to bridge infrastructure, and potentially undermine bridge stability	Plan and implement improved maintenance, notably to adequately cover abutments	Improved bridge maintenance protects abutments from climate damage, and lessens instability due to siltation	Yes, the improved maintenance activity significantly lowers the climate risk	30%: this is an approximation of the additional effort in maintenance to reduce climate risk	7.5	7.5	2.25
investment	Road Strengthening	Increased rain, water discharges and potentially rising water table may lead to more damage to base course layer	Utilize stronger, better graded (and so more resilient) materials in the base course, including stabilizers	Stronger, more stable base will resist the action of water in the water table and from flooding	Yes, the upgraded base course will be more resilient to climate change	30%: this is an approximation of the length of the road which is vulnerable to water table damage	56.9	56.9	17.1
	Road Resurfacing	Increased rain and localized flooding, from overloaded drains,	Utilize improve surfacing material that is more	The improved surface resists climate change and is less prone to failure, and so lasts longer	Yes, the upgraded surface will	30%: this is an approximation	36.1	36.1	10.83

	Activity	Vulnerability	Intent	Linkage	Step 1: QPA?	Step 2: CC adaptation increment	Total Tranche 1 cost ($ mn)	Total QPA cost ($ mn)	CC increment cost ($ mn)
		damages road surface	resilient to water and to climate change		be more resilient to climate change	of the length of the road surface which is vulnerable to climate			
	Grade Raising	Projected increases in flooding and sedimentation flows downstream cause damage to the pavement	Design and construct a raised pavement at vulnerable points	Pavement raising will lessen the risk of flood and associated damage	Yes	100%: all the activity, it is upgrading to address the flooding risk	7.3	7.3	7.3
	Drainage Improvement	Projected increases in rainfall intensity lead to drain overloading and infrastructure damage	Design and construct effective side drains and cross-drains to increased specifications	Effective drains carry water away from pavement, reducing damage	Yes, the drains, side and cross-drains, are an upgrading and so increase resilience	25%: this is a first order assessment of the additional costs required to meet higher discharges	55.2	55.2	13.8
	Landslide Protection	Projected increases in rainfall intensity lead to more land slides, blocking roads and damaging infrastructure	Design and construct: (i) drainage in slopes and under pavement; (ii) other slope stabilization measures	Improved slope stabilization will lead to fewer landslides and related damage	Yes	100%: the activity is an upgrade to address the risk	8.5	8.5	8.5
	Emergency Works	After all measures taken, there will be a residual climate threat, and that will lead to damage to drains and pavement, to blocked roads and to degradation. Climate change exacerbates this	Plan and implement rapid activities to immediately repair damage	Rapid responses will ensure roads remain passable and will protect the pavement from future damage	Yes, the activity is an upgrade to address the risk	30%: this is an approximation of the length of the road which is vulnerable to climate change	29.1	29.1	8.73
	Road Safety Improvement	None – not applicable			No		29.1	0	0

	Activity	Vulnerability	Intent	Linkage	Step 1: QPA?	Step 2: CC adaptation increment	Total Tranche 1 cost ($ mn)	Total QPA cost ($ mn)	CC increment cost ($ mn)
	Goroka Bypass	Not in Tranche 1			-		0	0	0
	Truck Climbing Lanes	Not in Tranche 1			-		0	0	0
Bridges	Bridge Widening 1L to 2L	Not in Tranche 1			-		0	0	0
	Bridge Reinforcement	Not in Tranche 1			-		0	0	0
	Bridge Reconstruction	Not in Tranche 1			-		0	0	0
	Bridge Repair	Not in Tranche 1			-		0	0	0
Other	Trade and Logistics Platform	Not in Tranche 1			-		0	0	0
	Weigh bridges	Not in Tranche 1			-		0	0	0
TOTALS							343.6	204.9 or 59.6%	69.8 or 20%

APPENDIX: PHOTOGRAPHS

Photo 1 illustrating the fragmented nature of the catchments and the steep relief in the Highlands

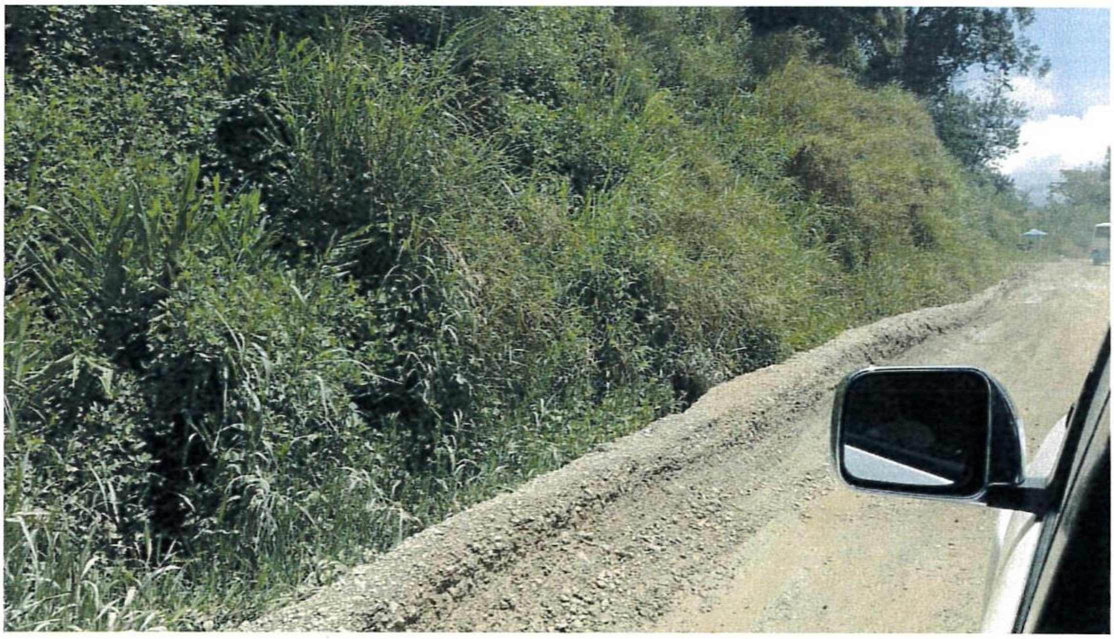

Photo 2 Illustrating how, typically, even the steep slopes near the Highway are covered in vegetation. However, does this vegetation contribute to slope stability?

Photo 3 In some areas the Highway travels through thick forest. Although it mostly passes through populated agricultural areas

Photo 4 Agricultural practices at some points appear to facilitate erosion

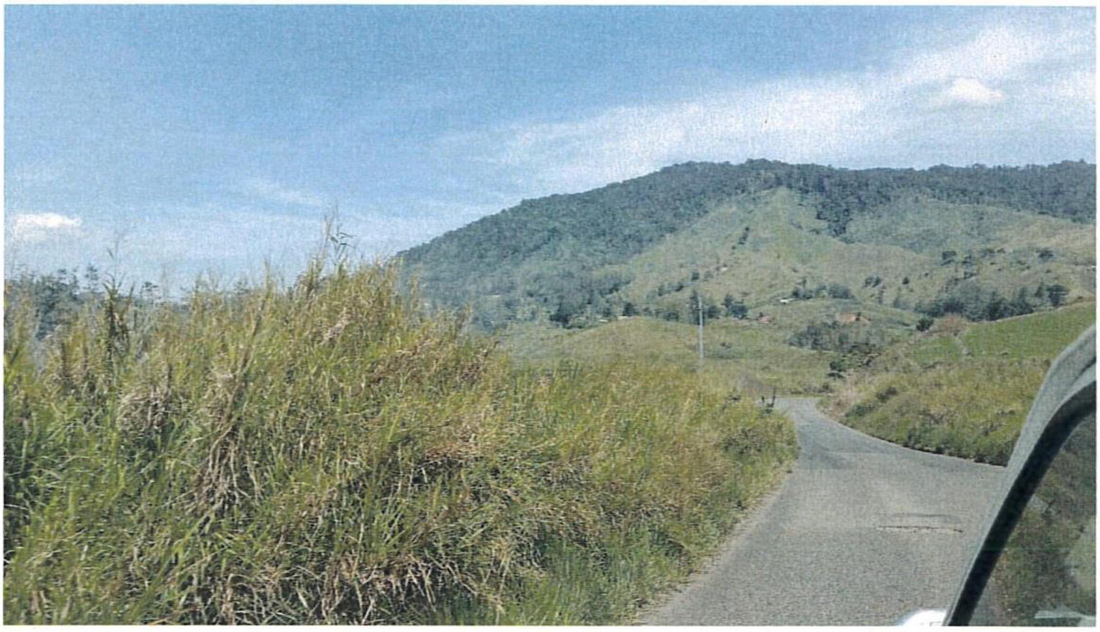

Photo 5 illustrating how, at some points, the land surrounding the road is thinly vegetated or almost barren

Photo 6 (Zone 1) showing a stream flowing down temporary drains by the Highway. This is possibly due to a recent shift in a tributary, leading to part of the tributary now following the Highway's course

Photo 7 (Zone 1) showing a typical stretch of the Highway, without failures

Photo 8 showing a crossing the main river in Zone 1. The river here is characterised by shifting sediment and braiding

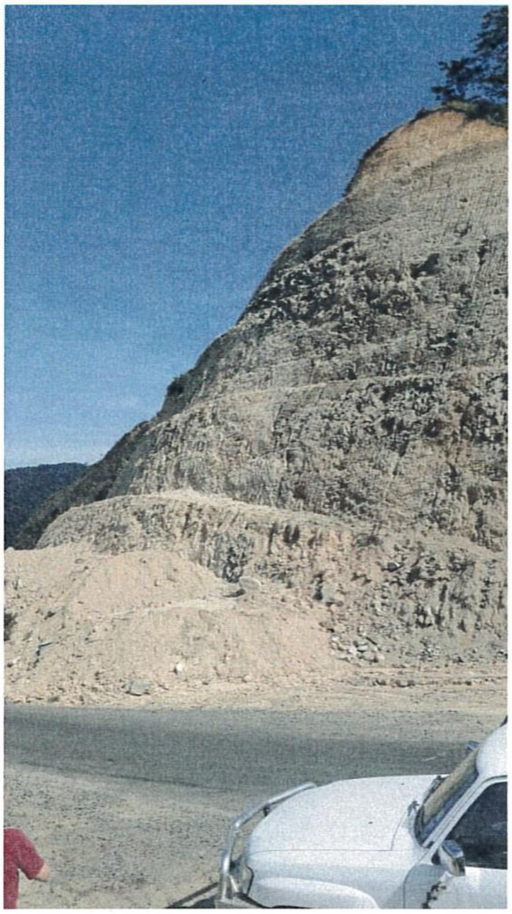

Photo 9 showing the major landslide at Kasim pass, Zone 2

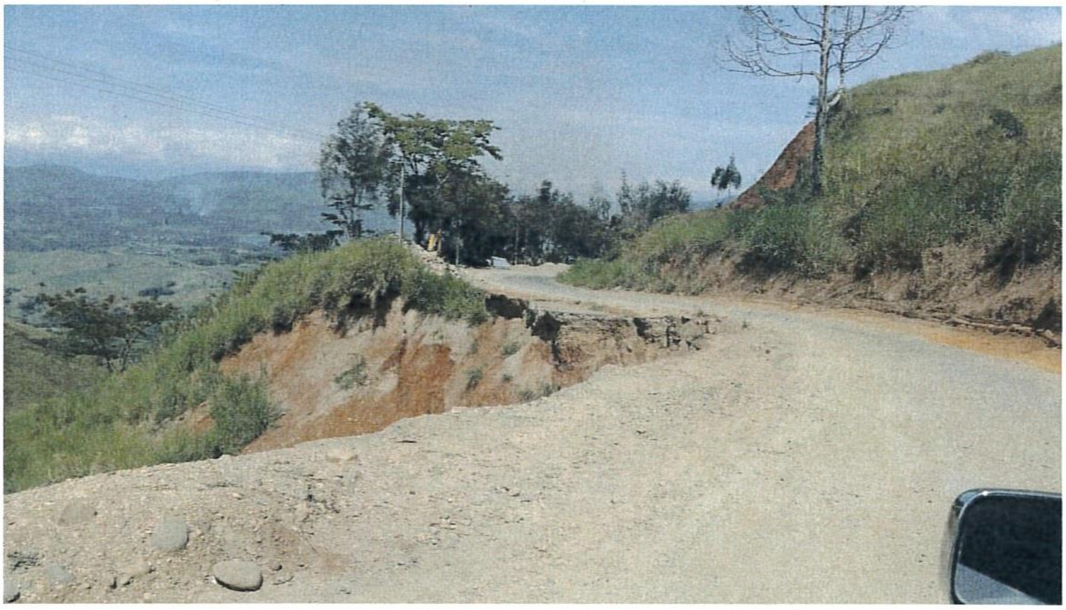

Photo 10 showing the effects of major regressive erosion by water coming out of a culvert, in Zone 2

Photo 11 showing an example of severely degraded pavement, in Zone 3

Photo 12 showing water lying on the road surface in Zone 3 – this is evidence that the water table lies close to or above the road surface

Photo 13 showing one of many recent minor landslides, this one in Zone 3

Photo 14 showing severely degraded pavement and effects of regressive erosion, in Zone 3

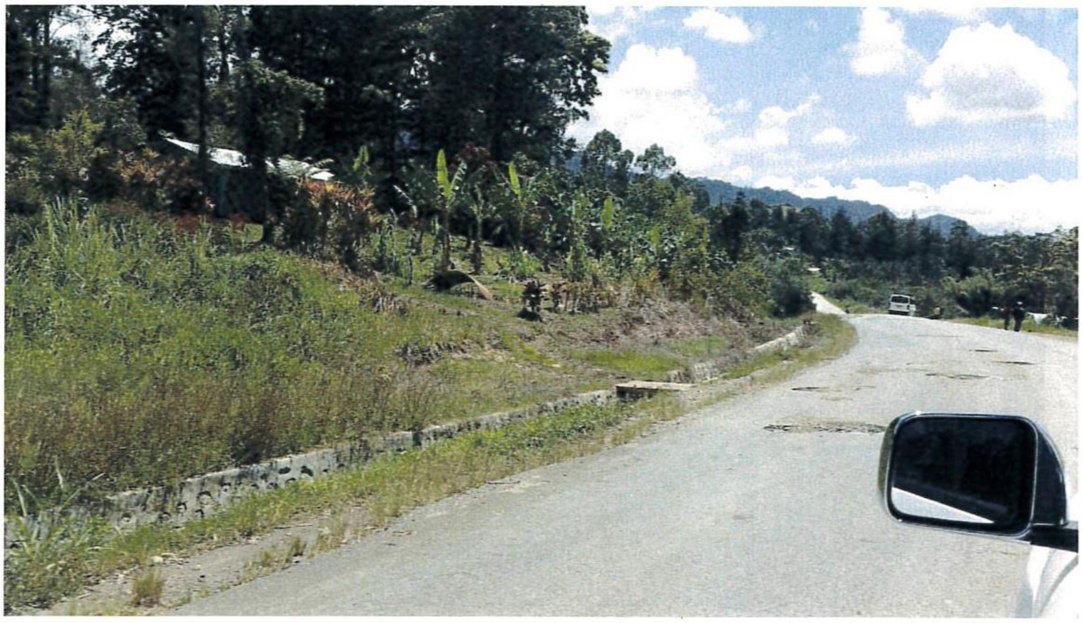

Photo 15 showing a section typical to zones 2 - 5, with frequent potholes

Photo 16 showing a severely degraded section, with deformation and potholes (Zone 3)

Photo 17 showing the damaged wing outlet to the culvert near Leron Bridge. This culvert had been recently constructed with support from TSSP. Several meters of the wing on the far side have been washed away by recent floods

Photo 18 this is the stream that caused the damage to the culvert in the previous photo. The catchment area is clearly visible