Vulnerability Mapping Report

Climate Resilient Road Standards (CRRS) Project Phase 2

For: Department of Environment (Australia)

Adaptation and International Climate Change Policy Branch

Climate Change and Renewable Energy Division

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Acronyms

ARI	Annual Return Intervals
CRRS	Climate Resilience Road Standards
DEM	Digital Elevation Model
DFAT	Department of Foreign Affairs and Trade
EIRR	Economic Internal Rate of Return
GIS	Geographic Information System
GPS	Global Positioning System
HQ	Head Office or Head Quarters
LAT	Lowest Astronomical Tide
LiDAR	Light Detection and Ranging
MGHD	Metereology and Geo-Hazards Department
PVUDP	Port Vila Urban Development Project
PWD	Public Works Department
RAMP	Road Asset Management Program
RCP	Representative Concentration Pathways
R4D	Roads for Development (formerly VTSSP)
RME	Roads Maintenance Engineer
VRRM	Vanuatu Resilient Roads Manual
VTSSP	Vanuatu Transport Support Sector Program

Purpose of Report

This report has been prepared to document the Vulnerability Mapping undertaken as part of the second phase of the Climate Resilient Road Standards (CRRS) Project. It outlines both the methodology adopted and provides a summary of key outputs from this process to date. It should be noted, that Vulnerability Mapping will be a continuous process for Public Works Department. Vulnerability Mapping, together with Climate Screening Tools developed as part of CRRS project Phase 1 have been significant achievements of the CRRS Project and critical components towards climate change mainstreaming throughout PWD, as they have been developed in parallel to capacity building activities.

1. Methodology

1.1 Introduction

Vulnerability Maps have been produced as part of the Climate Resilient Screening Methodology. These should be used to advise where potential problems may be encountered and where extra Due Diligence is required.

The Vulnerability Maps produced in Phase 1 cover Ambae, Malekula, Pentecost and Tanna. They are available as PDF files set to print in A3 size. They are also available as PDF files set to print in A1 size if large hard copies are needed. The maps can also be accessed in "Manifold" GIS on the PWD GIS section computer (contact Jason Andrews, Public Works Department (PWD)) so that one may zoom in on a selected area to obtain greater detail.

2. Road Performance Expectations

2.1 Connectivity

The performance of a road can be defined in terms of its connectivity. Ideally a road should be an all-weather road, passable in all weathers, including extreme weather events. This is sometimes known as "Trafficability". Roads are a form of connecting communities with reources and welfare utilties such as hospitals and schools and these factors based on community priorities should be considered when deciding what level of effort is justified in keeping a road open.

2.2 Rural Access Index

Given budget constraints it must be accepted that roads may be closed at times. If this closure time is limited to a few hours, this should be acceptable to the community. This is consistent with the definition given by the World Bank in their publication "Rural Access Index: A Key Development Indicator", 2006 which states an "all-season road" is a road that is motorable all year round by the prevailing means of rural transport (typically a pick-up or a truck which does not have four-wheel-drive). Occasional interruptions of short duration during inclement weather (e.g. heavy rainfall) are accepted, particularly on lightly trafficked roads."

2.3 Climate Resilience

If a road is permitted to be closed for a short period of time due to flooding, it must be structurally sound when the floodwaters recede. This is "Climate Resilience".

2.4 Fit for Purpose

The road design and construction must be fit for purpose. This is directly related to the number and type of vehicles using the road. Economic considerations normally prevent and discourage overdesign. Given the low number of vehicles using roads in developing countries, and the low axle weights of vehicles usng the roads, in many cases roads will be unsealed.

2.5 Extreme weather events and over design

Notwithstanding the points made above, roads should be designed to withstand extreme weather events. This may require some overdesign (and increased costs) now but this is offset against potentially higher costs avoided later.

2.6 Do Nothing - Allowed to Fail

One scenario is to allow a road to fail structurally if there is confidence that it can be repaired quickly. This requires skilled labour and materials to be available locally. This is an option but is contrary to Resilience and is not encouraged as a design basis.

2.7 Existence Value

In many cases it is hard to justify expenditure on roads based on present and future traffic flows. Conventional economic appraisal would return a negative EIRR value. However roads perform many functions other than direct the vehicular access. There are social and economic spin-off benefits in having communities interconnected: access to schools, hospitals, markets, jobs; emergency response to accidents; disaster response to major incidents; provision of utilities such as electricity, telephone, internet connections, gas; job opportunities for the workforce and generation of a local revenue from tourism.

It is often not relevant to consider economic justification for road rehabilitation. If a road exists it should be passable. The existence of a road is sufficient self-justification in its own right.

2.8 Vulnerability Identification

In order to make the roads passable and to deal with urgent issues in a prioritised manner it is essential to determine the locations where road are most vulnerable. Efforts can then be directed to these locations.

There are many types of vulnerabilities to which a road can be exposed but for the purposes of this exercise three main categories were identified. They were :

- Roads close to a coastline and already suffering coastal erosion
- Roads passing up a steep slope
- Roads crossing a stream which is prone to flooding

Other vulnerabilties include issues such as overhanging slopes which may collapse onto a road.

3. Natural Hazards and Vulnerabilities

3.1 Natural Hazards and Climate Change

Vanuatu has been described as the South Pacific country most vulnerable to climate change but it is also exposed to many natural hazards.

3.2 Ring of Fire

The Pacific region is home to extremes in elevation and the world's most active seismic and volcanic activity. The Pacific Ring of Fire is a belt of oceanic trenches, island arcs, volcanic mountain ranges and plate movements that encircles the basin of the Pacific Ocean.

The ring is home to 90% of the world's earthquakes and is a direct consequence of plate tectonics and the movement and collisions of crustal plates, with the northwestward moving Pacific plate subducted beneath the Aleutian Islands arc in the north, along the Kamchatka peninsula and Japan in the west. To the south a number of smaller tectonic plates are in collision with the Pacific plate from the Mariana Islands, the Philippines, Bougainville, Tonga, and New Zealand. Like volcanic activity, earthquakes in the region occur largely in the countries which lie within "The Pacific Rim of Fire", associated with the plate boundary zone between the Pacific and Tonga. Vanuatu is located on the Ring of Fire.

3.3 Earthquakes

Large earthquakes are not uncommon in Vanuatu but a large part of the seismically active area of the region is rural and therefore effects are often minimal.

3.4 Tsunamis

Earthquakes often trigger other events like tsunamis which are evident in historical records of Port Vila.

The islands of the Pacific are particularly vulnerable. About 85% of the world's tsunamis strike in the Pacific Ocean, due to the active tectonics. Tsunamis are waves triggered when earthquakes, landslides or volcanic eruptions displace a section of water. Ringed by subduction zones, the places where one of the Earth's plates slides beneath the other, the Pacific suffers the world's most powerful earthquakes, and it holds the highest concentration of active volcanoes.

An earthquake on January 24th 1927 with a recorded magnitude greater than 7.1 centered in South Malekula produced the worst ever recorded tsunami.

In 1985, the seiche effect produced by a tsunami entering the almost enclosed harbour of Ifira Island resulted in flooding of the coastline to several meters above normal tide.

Since installation in 1993, dynamic tide gauges at Vanuatu have detected 29 separate tsunami events. The tsunamis detected include local, regional and transoceanic tsunamis.

Five local tsunamigenic earthquakes have occurred in the Vanuatu region since 1993. One was a magnitude Mw7.5 earthquake on 26 November 1999 that occurred 140 km to the northwest of Port Vila. A tsunami was generated which caused destruction on Pentecost Island where maximum tsunami heights reached 6m. The tsunami claimed 3 lives, although many were saved when some residents recognised an impending tsunami as the sea began to recede and managed to warn people to seek higher ground. The tsunami arrival coincided with low tide, which resulted in dangerously low sea levels 23 cm below the lowest astronomical tide. (LAT)

Another event was an earthquake of magnitude Mw7.2 on the 2nd of January 2002 that occurred 100 km west of Port Vila, Vanuatu. Several people were injured and there was widespread damage on the island of Efate. Access to the wharf was blocked by rockslides. The tide gauge at Port Vila recorded the tsunami wave that followed, whose peak to trough height reached 80 cm. More recent events are described below.

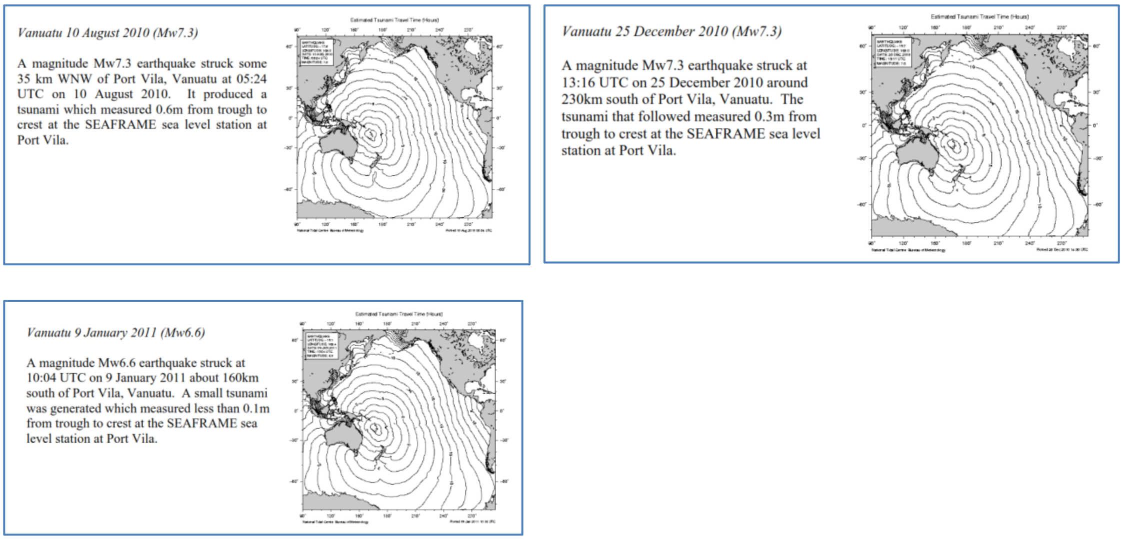


Figure 1 Earthquakes and Tsunamis in Vanuatu

Very recently such events are still occurring. An earthquake with a preliminary magnitude of 6.9 occurred at a depth of 200kms beneath Vanuatu on Friday January 23, 2015. There was no tsunami threat from this earthquake.

On February 19, 2015 an earthquake occurred under the ocean 92 kilometers north of Port Vila. It had a magnitude of 6.5 and an epicentre 10 kms below sealevel. No injuries or damage were immediately reported.

3.5 Subsidence

Vanuatu is particularly susceptible to seal level changes given the location of islands near to tectonic activity. One example is the island of Akam in South Malekula which subsided approximately 1 meter following an earthquake in 1996. Since then, the island has been subject to severe erosion on its eastward portion with recent accretion on the western side of the island. This situation will be exacerbated by sea-level rise as indicated by recent regional climate change projections. Residents are making voluntary decisions to leave the island citing climate change and increasing sea levels as a key factor in this decision.

3.6 Volcanoes

Vanuatu has several active volcanoes. As recently as February 21, 2015 volcanic eruptions occurred on Ambryn and Vanuatu. The Government of Vanuatu Metereology and Geo-Hazards Departmnet (MGHD) issued warnings to residents and aircraft.

4. *Vulnerability Mapping Exercise*

4.1 Assessment Methodology using Blackvue Technology

The Vulnerability Mapping Exercise was started in February 2015. This exercise combines data capture on climate vulnerable locations together with installation of software, on-the-job training of the Provincial Divisional staff on the use of hardware and software.

The methodology is based on a dashboard camera which is mounted inside a vehicle. This uses “Blackvue” software. It records a High Definition video of the road whilst reading directly satellite data to give GPS coordinates. It does not require a mobile phone network. It also contains a triaxial accelerometer recording “G” forces in 3 dimensions. This gives an indication of surface roughness. Time, date and location are all recorded on a SD card 16GB memory chip. This is removable and can be played back on any laptop. Alternatively the data can be uploaded onto the PWD network in any province and downloaded in PWD Head Office (HQ) Port Vila. Another parameter recorded is speed and this is being used as a proxy for road surface condition.

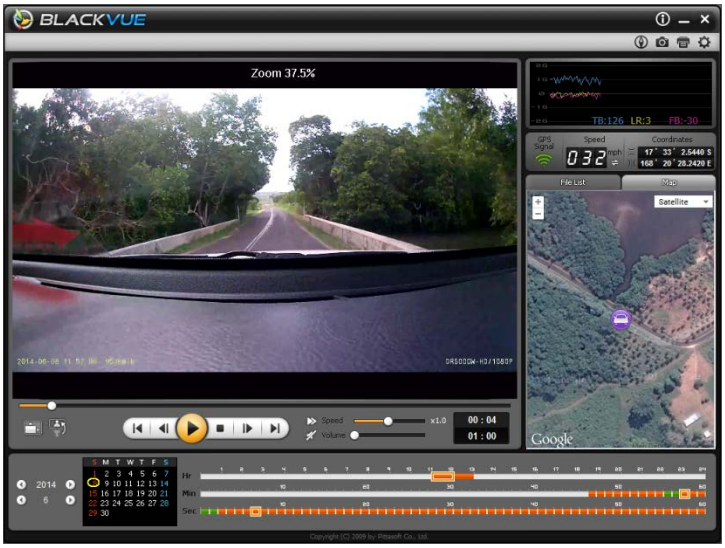


Figure 2 Example of Black Vue Screen

4.2 Extent of Vulnerability Mapping

It is intended that all the roads under the jurisdiction of PWD in Vanuatu will be recorded by driving down them. Installation and use of the camera will be demonstrated to the Provincial PWD staff in the field. Downloading and interrogation of the data will be demonstrated to them back in their office. This will constitute the on-the-job training (capacity building) aspect of this component of CRRS Project.

PWD have purchased 6 Blackvue cameras and software. These were delivered to the Provinces during the training exercise.

Whilst visiting each Province attempts will be made to meet with the Secretary Generals and Local Area Councils to elicit their opinions on local climate change vulnerabilities.

The data captured will be used to :

- Identify climate change vulnerabilities on each island
- Feed into the Road Inventory through an Excel file
- Support the establishment of a Road Asset Management Program.

The surveying will be undertaken by Team Leader CRRS Team Leader (Dr David Lees) , and Jason Andrews of PWD with support from Provincial PWD staff in terms of vehicles and manpower.

This survey and mapping exercise has started a process that will continue indefinitely. These surveys are not “One Off” exercises. As roads deteriorate further, or as repairs are completed, staff will return to the road section and repeat the survey to show the “before and after” situation. The aim of this mapping is to allow a rapid visualisation of road conditions to be quickly shown to decision makers.

4.3 Condition Inventory

As part of the survey staff are also required to note down significant features as they drive down the road. These are used as a cross reference when interpreting the Blackvue records. The template is given below. Vehicle odometer readings are used as a cross check on “distance run” as calculated from GPS values noted at the Start Locatin and End Location.

<table>
<tr><th colspan="5">Road Inventory</th></tr>
<tr><td>Province</td><td></td><td colspan="2">Surveyor</td><td></td></tr>
<tr><td>Island</td><td></td><td colspan="2">Date</td><td></td></tr>
<tr><td>Start Location</td><td></td><td colspan="2">Start time</td><td></td></tr>
<tr><td>End Location</td><td></td><td colspan="2">End time</td><td></td></tr>
<tr><td>Road ID</td><td></td><td colspan="2">Road Category</td><td></td></tr>
<tr><td>Length of Road km</td><td></td><td colspan="2">Width of Road m</td><td></td></tr>
<tr><td colspan="5">Abbreviations</td></tr>
<tr><td colspan="5">Stream crossings</td></tr>
<tr><td colspan="5">Br Bridge BC Box Culvert PC Pipe Culvert LLDr Low Level Drift FDR Flumed rift</td></tr>
<tr><td colspan="5">Schools</td></tr>
<tr><td colspan="5">Pr Sch Primary Schools JSch Junior Schools, SSch Senior / High Schools</td></tr>
<tr><td colspan="5">Vill Village / Tn Town / Mkt Market / CC Community Center(CC)</td></tr>
<tr><td colspan="5">Medical Facilities</td></tr>
<tr><td colspan="5">CC Clinic/Health Center / H Hospital</td></tr>
<tr><td colspan="5">EL Electricity Cables MT Mobile Tower</td></tr>
<tr><td colspan="5">F Forest / Orc Orchard</td></tr>
<tr><td colspan="5">R River L Lake S Sea B Beach</td></tr>
<tr><td rowspan="2">Chainage from car trip meter</td><td rowspan="2">Inventory Abbreviation</td><td colspan="2">Direction</td><td rowspan="2">Remarks</td></tr>
<tr><td>LHS</td><td>RHS</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Figure 3 Example of Condition Survey Form used in Survey

5. Manifold GIS Software

At the same time as the site visits are made Manifold GIS Software is being installed in three of the PWD Provincal Offices. Five licences have been purchased and two installed in PWD HQ. The remaining three will be installed in Santo, Malekula and Tanna. Training will be given in the use of Manifold to calculate catchment areas, slopes and gradients. This information is needed for flood calculations and drainage sizing.

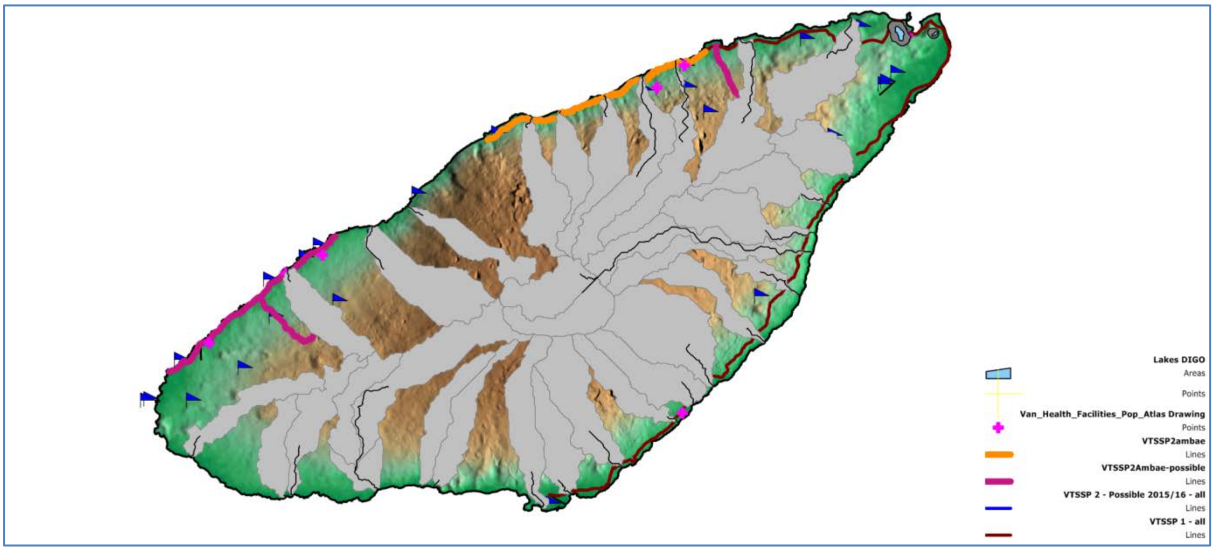


Figure 4 Example of Manifold Software Printout

6. Road Inventory

PWD have established a Road Inventory which is kept in a very rudimentary format on Excel. An example is given below. The data content is very basic.

Road Link Name	Road Length (Km)	Road Surface Type
White Grass Bangalows - Tafea Co-op Junction	10.5	Gravel
Tafea Co-op junction - Tanna Lodge	3.0	Gravel
Tanna Lodge - Green Point	14.2	Gravel
Green Point - Manuapen Junction	29.2	Earth

Figure 5 Example of Current PWD Road Inventory 2013 for Tanna

It is intended to use the output data from the Vulnerability Mapping as an input to the Road Inventory. The data entry columns of the Road Inventory will be expanded from 3 columns to 14 columns as shown in the figure below.

Road Link Name	SP	LAT	LONG	EP	LAT	LONG	Road Length (Km)	Road Surface Type	S1	S2	S3	S4	S5
Efate Ring Road to Mangaliliu Village	Efate Ring Road	-17.74299	168.31392	Mangaliliu Village	-17.74299	168.3139	1.442	Gravel	LAT LONG	Photo	video mangaliliu	Slope Profile	RRI
Manples Junction	Port Vila	-17.74299	168.31392	Airport Roundabout	-17.74299	168.3139	1.75	Sealed	LAT LONG	Photo	Video	Slope Profile	RRI

Figure 6 Example of Future PWD Road Inventory

This contains data cells which are hyperlinked to other data stored in the PWD network. This extra data includes still photographs, Blackvue video records and profile calculations. These can then be accessed by anybody within PWD through the existing network. This gives a quick and simple means of carrying out a quick preliminary screening for vulnerabilities on any road sections. This will be an essential and useful “Screening Tool” for PWD in the future.

!"Filename"	Date	Time	Latitude	Longitude	Altitude
C:\WORK\Vanuatu\MPWT Roads\Roads Inventory\DSCN0015.JPG	2014:06:04	06:25:43	-17.74299	168.313917	1

Road Link Name	SP	LAT	LONG	EP	LAT	LONG	Road Length (Km)	Road Surface Type	S1	S2	S3	S4	S5
Efate Ring Road to Mangaliliu Village	Efate Ring Road	-17.74299	168.31392	Mangaliliu Village	-17.74299	168.3139	1.442	Gravel	LAT LONG	Photo	video mangaliliu	Slope Profile	RRI
Manples Junction	Port Vila	-17.74299	168.31392	Airport Roundabout	-17.74299	168.3139	1.75	Sealed	LAT LONG	Photo	Video	Slope Profile	RRI

Figure 7 Example of New Road Inventory Accessing Photos, Videos and Gradients

The output of the Improved Road Inventory will be an input to the new Road Asset Management Program.

7. Road Asset Management Program (RAMP)

PWD are commencing the setting up of a Road Asset Mangement Program (RAMP). A fundamental need of such a program is a comprehensive data base of all road sections and conditions. The Improved Road Inventory will form the basis of the RAMP.

8. Vanuatu Roads for Development Program (formerly Transport Sector Support Program VTSSP2)

Australia is working with Vanuatu's Public Works Department to provide an increasingly well-maintained and reliable transport network. This program supports the Government of Vanuatu to effectively plan, build and maintain its road transport infrastructure.

In 2009, assistance for road rehabilitation commenced. A new phase of the program, which started in 2013, is streamlining public works administration and providing economic benefits to communities. The program directly involves community members in managing, maintaining and ultimately using improved roads, which will stimulate investment and reduce household impacts of high transport costs. The VTSSP2 program was renamed – Roads for Development (R4D) in 2014. CRRS and R4D staff are now working closely together in plementing the vulnerability mapping. R4D engineers have surveyed roads on Ambae, Tanna, Malekula and Pentecost using BlackVue cameras.

9. PWD Staff Surveying

Three Blackvue cameras have been purchased by PWD. They have been assigned to the Province PWD Departments in Santo, Malekua and Tanna. They will be used by their staff in their day to day activities.

One Blackvue camera is being held by Jason Andrews in the GIS Section. One camera is being held by the Director PWD and Deputy Director PWD for their use when inspecting sites.

This means there are 6 cameras in constant action. All data collected is handed over to the GIS section for systematic storage and retrieval.

10. Vulnerability Interpretation

10.1 Degree of Vulnerability

Vulnerability is linked to the expected performance of the road. A priority road may be more vulnerable because, if severed, the loss of access is more serious. For example a main road to an important location that is cut, even temporarily, may mean that in an emergency, rescue services cannot get in. One must consider several aspects of vulnerability :

1) Impacts of the environment on the road, for example, steep slopes that may become impassable in heavy rain **or** roads close to the sea shoreline that may be flooded in a storm surge. Roads which are exposed in this way are "Vulnerable Roads."
2) Connectivity. Roads which are priority roads, providing an essential service, can render the "community vulnerable", if the road is cut.

The relationship between the terrain and the communities is "connectivity". The importance of connectivity must be established. This obviously means that similar climatic conditions could have a lower level effect at one location (low vulnerability) yet a severe effect elsewhere (high vulnerability). Therefore one must look at :

- The Environmental terrain: geography, geo-morphology gradients, over hanging slopes under scouring rivers etc, that is aspects or roads which are "vulnerable" to Extreme Weather Events
- Communities and Facilities: villages, towns, airports, hospitals, schools, clinics which are of high priority and so "vulnerable.

10.2 Hazard, Risk and Consequences

Hazard and Risk are different. A hazard poses a threat to health or welfare. The risk is the probability of it happening plus the the consequences of an event occurring.

This could be expressed as road closure (in hours) or persons affected (numbers) or damage to property ($$). Damage to infrastructure such as roads or a wharf could be a combination of all of these.

Damages may be short-term such as structural failure needing repairs, or long term, such as permanent loss of the road alignment due to coastal erosion. All of these factors need to be considered when assessing vulnerabilities.

10.3 Ground Truthing

Although information from a GIS system is useful it should not be relied upon.

- Things may have changed since the GIS remote sensing imagery was obtained.
- Site visits with visual inspections, known as "*ground truthing*" are absolutely essential.

Regular site inspections help in compiling ground truth data and these are being entered in the Road Inventory.

11. Preliminary Screening

11.1 Priority Locations

To identify priority locations one should check if :

- Road close to hospitals, clinics.
- Road close to Airport.
- Road close to port, shipping wharf, jetty.
- Road close to Schools.

To identify vulnerable areas one should check if roads are in areas of :

- Close proximity to shoreline where wave erosion is self-evident.
- Close proximity to shoreline where overtopping by storm waves is known to occur.
- Flat areas prone to flooding which take long time to dry out.
- Steep gradient > 10%.
- Road below steep slopes prone to landslides.
- Road above streams prone to scouring.
- Roads crossing water courses.

These can be simplified into three main categories :

- Roads close to a coastline and already suffering coastal erosion
- Roads passing up a steep slope
- Roads crossing a stream which is prone to flooding

These are shown in the figure below :

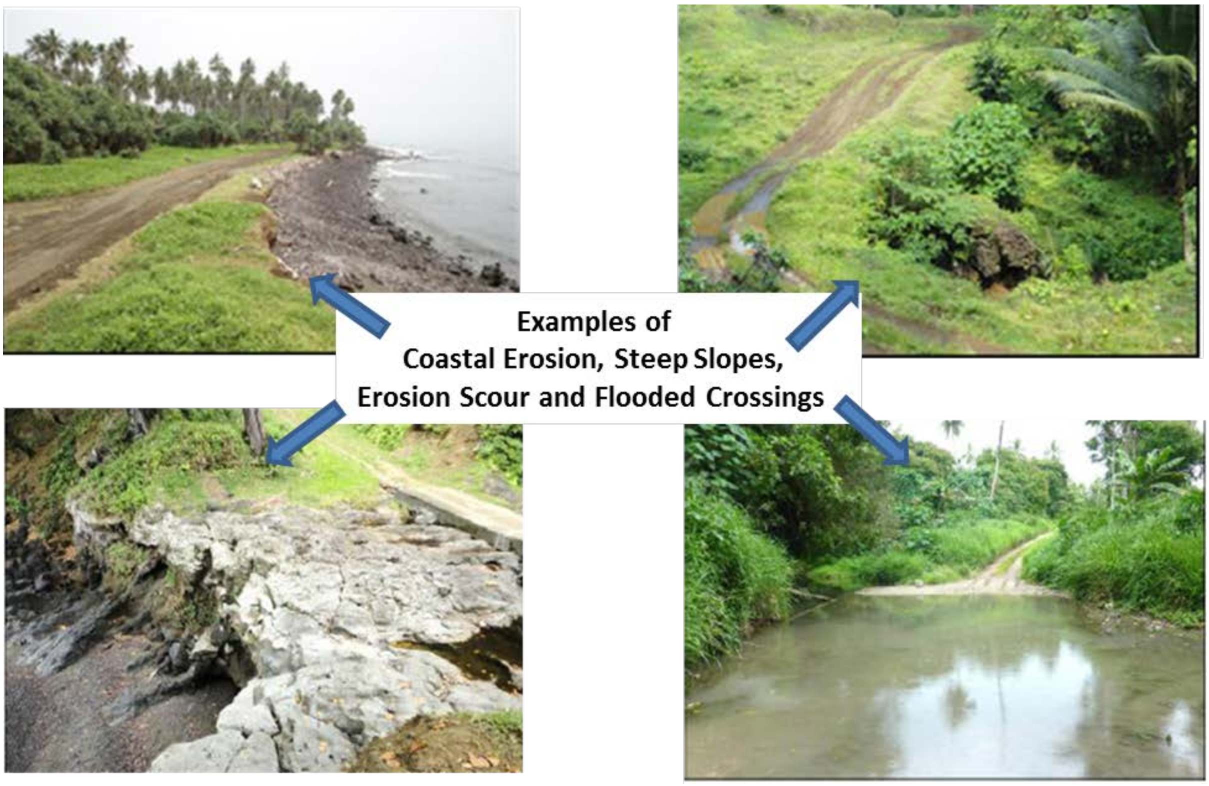


Figure 8 Vulnerable Areas

11.2 Establishing Slopes

The track of a road can be established using Google Earth "Pathway" command. From this the gradient can be determined. Digital Elevation Model (DEM) data can be used to establish contours and from that the gradient of the roads sections.

Where road gradients exceed 8-10% concrete slabs are recommended.

Examination of the contours can aid in the design of the drainage system.

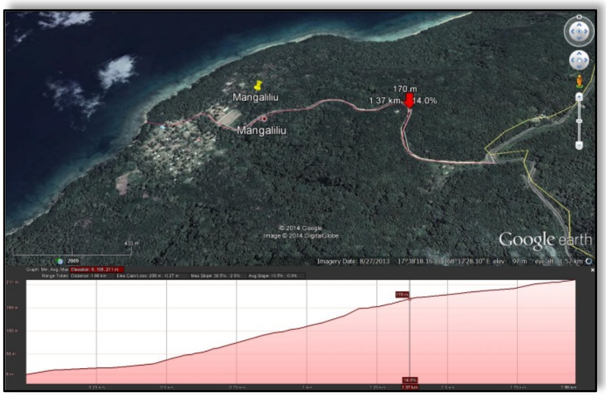


Figure 9 Gradient Profile

11.3 Road and Stream Crossings

In the event of a road which connects priority locations being intersected by a major stream then the situation should be examined in more detail.

These crossing points may be subject to flash floods with rising flood waters making the roads impassable. It is helpful to know the height of a flood that is likely to occur both now and in the future under different climate change scenarios. This requires complex hydrological calculations but this has been simplifed so that PWD staff can make assessments that are rapid yet based on good science and robust assumptions. This is a form of Screening for Climate Change Impacts.

Using PWD in house “Manifold” GIS software the topographical map is divided into catchments and the areas of these catchments calculated. This allows major streams to be identified (shown by thick black lines on the map) and the exact point where they intersect the road to be specified in terms of GPS coordinates..

Rainfall data for future climate change scenarios (RCPs) and projected years (2030 and 2055) has been calculated with ARIs (Annual Return Intervals) of 1 to 100 year events.

This data can be used to calculate the volume and height of a flood.

[*At this point refer to the Manifold GIS files and the EXCEL Spreadsheet in the VRRM*]

12. Decision Trees

The Decision Trees given below should be used in the Screening Procedure in conjunction with the Vulnerability Maps to ascertain potential hazards. Appropriate mitigating actions can then be determined.

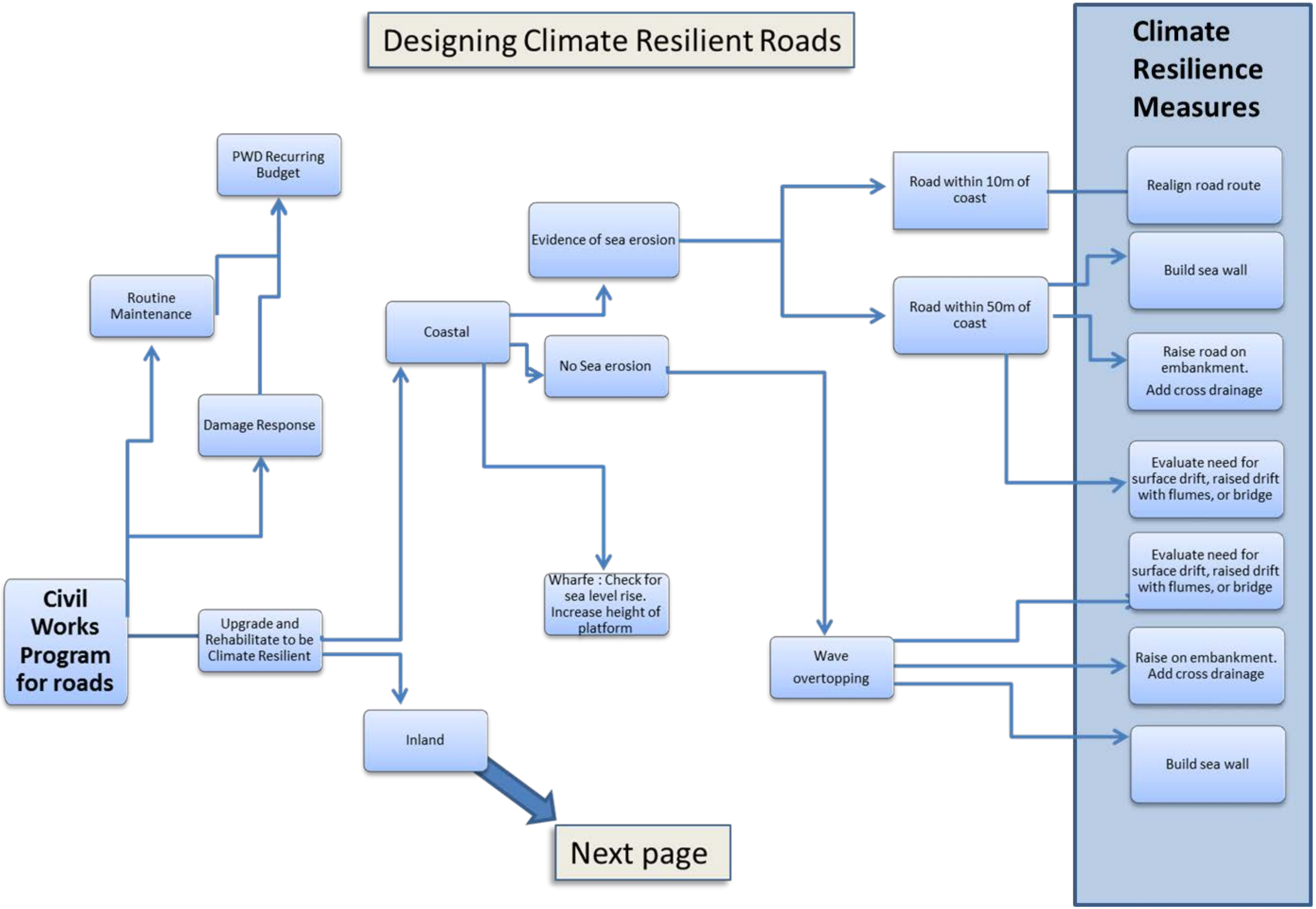


Figure 10 Designing Climate Resilient Roads

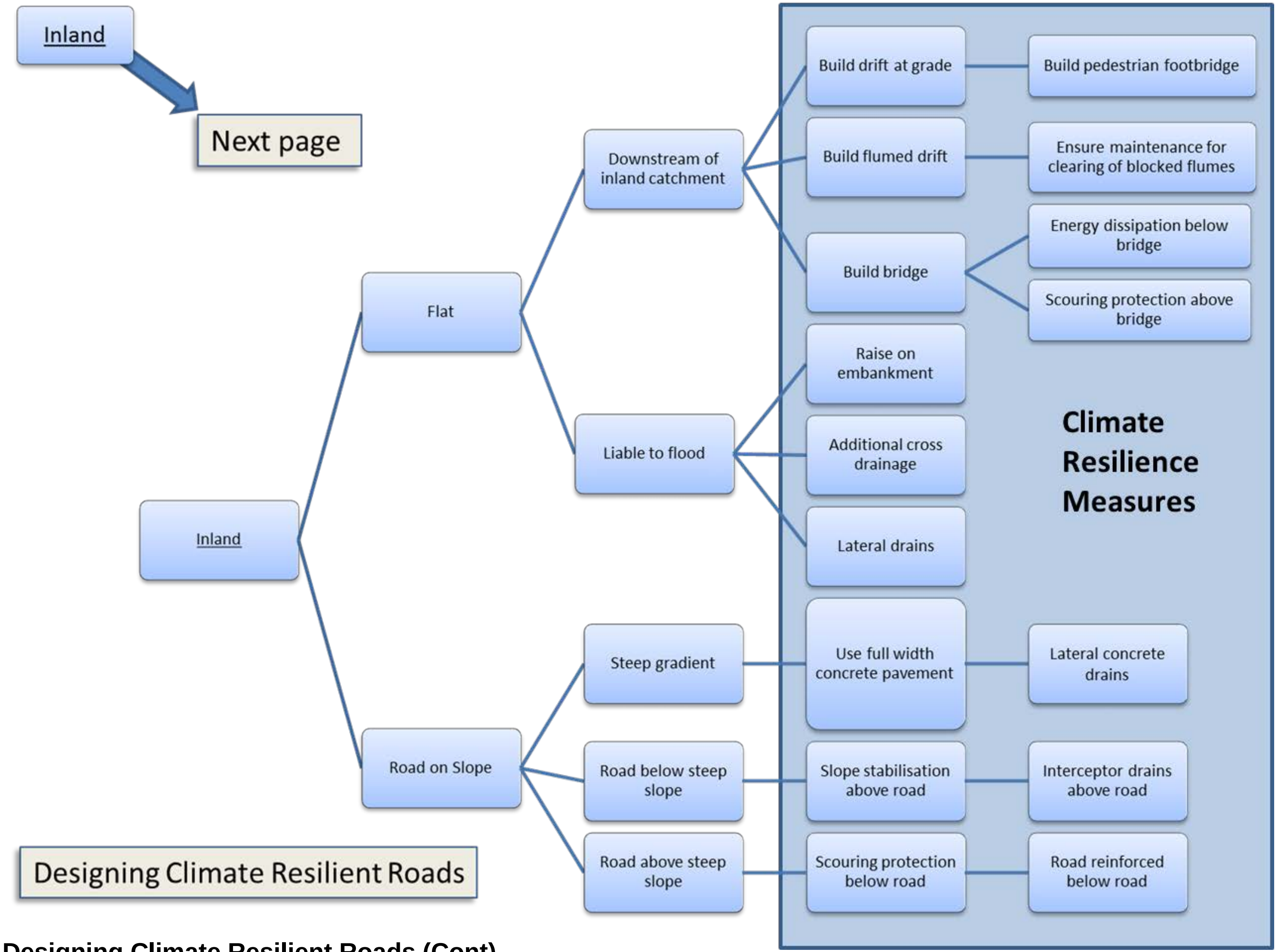


Figure 11 Designing Climate Resilient Roads (Cont)

13. Vulnerability Maps Phase 1

13.1 Vulnerability of Roads

The Vulnerability Maps produced in Phase 1 are color coded in the following way :

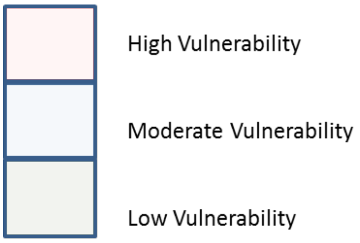


Figure 12 Vulnerability Maps Color Code

Reference should be made to the vulnerability maps given for :

- Ambae
- Malekula
- Pentecost
- Tanna

These are shown in Annex 1.

13.2 Vulnerabilities due to Connectivity Demands

The following maps show the vulnerabilties due to connectivity demands.

Roads, health facilties, schools, cacthments and major river crossings are shown. Schools are represented by blue flags, hospitals by red crosses.

Where a road crosses a major stream (indicated by a thick black line) major flooding can be expected due to an Extreme Weather Event. Attempts to cross whilst the road is in flood must be discouraged.

The legend is as given below.

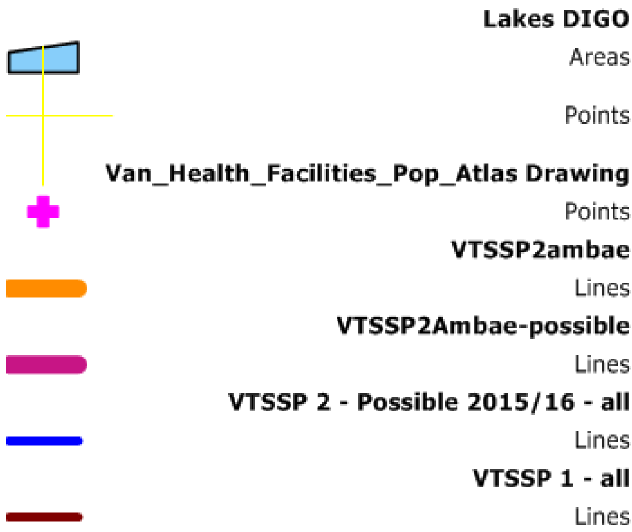


Figure 13 Legend

These are shown in Annex 2.

14. Vulnerability Maps Phase 2

In CRRS Phase 1 the emphasis was on producing hard copy maps for use in planning purposes. In CRRS Phase 2 the emphasis changed in response to the needs of PWD, that is the updating of the Road Inventory and the development of the RAMP.

Sections of roads were surveyed, GPS coordinates recorded and visual records both in video and still photos stored in the data base. This is a large amount of information and cannot be reproduced in a report such as this. However examples are given here to illustrate the types of situations encountered.

The survey itself should be objective not subjective. That is to say, the decision as to what is a hazard and what is not, should not be made by the surveyor but he should travel along all the roads in his division and record them all. Then afterwards he can analyse the information and prioritise. If this is not done then obviously vulnerable roads may be surveyed and some roads missed. Also some roads maybe deemed vulnerable by others for personal rather than technical reasons.

Eventually a visual record of all roads in Vanuatu will be established. This will allow a rapid response to inquiries as to whether any section of road is exposed to climate change vulnerabilities and what are the nature of those vulnerabilities.

Given below are survey results obtained so far. The vulnerability assessment is carried out in two stages. Firstly the recorded data is presented below. Then it is followed by comments, observations and recommendations. It is presented by province.

15. SHEFA Province

15.1 Efate Ring Road

Efate Ring road was constructed by USAID under the Millenium Challenge project at a cost of approximately US$750,000 per kilometre. It is constructed to a high standard being sealed with shoulders and drains. It crosses many streams, passes up and down steep gradients and in places has overhanging slopes. Examples are given below.

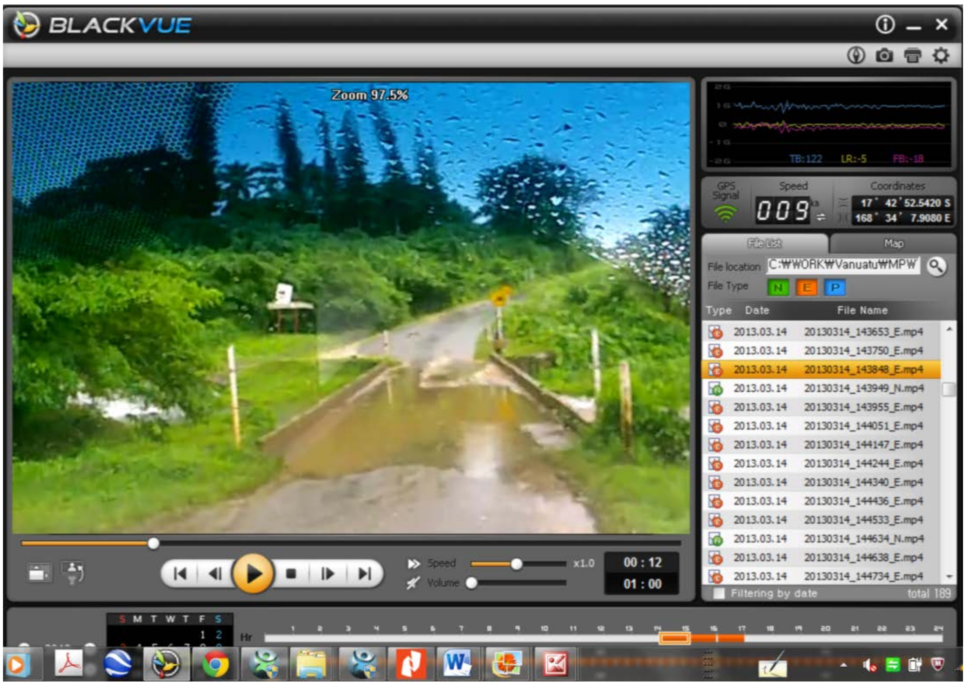


Figure 14 Screenshot of Waterfall Bridge North of Eton

Figure 15 Eton North Bridge

Figure 16 Upstream View

Figure 17 Downsteam View

Figure 18 Very Small Culverts

Figure 19 Height of Floodwaters

The figure above shows that the culverts in the bridge are of small diameter. These impede the water flow and are prone to rapid silting.

Sediment deposits can be seen on the invert of the culvert decreasing its effective size.

This local resident is showing the height of flood waters. He is indicating that waters rise to the marker level 0.6 on the staff gauge. (He is holding out 6 fingers)

Larger pipe culverts or larger box culverts allow a faster water flow and so are self cleaning.

This bridge cannot be changed but the lesson learned should be used in future designs. More regular maintenance cleaning is required.

Figure 20 Vented Road crossing with concrete safety blocks

This is a vented drift. Note the difference in height between upstream (right hand side) and downstream (left hand side) flows. The vents are impeding the flows.

Figure 21 Side view showing vented drift

The figures above show two shots of another bridge on the Ring Road. The bridge has vents as the stream is perpetually flowing. The sea is short distance (200m) downstream so this is the exit point of a large catchment. The culverts are of small diameter and are not capable of dealing with heavy flows. There is evidence of overtopping of the road, as scouring is occurring on the road embankment as shown in the figure above.

The concrete blocks are installed to stop vehicles driving off the bridge if attempting to cross when the pavement is under water. Guide posts showing flood heights are provided but no indication is given as to what is a safe height to cross. Warning signs should be provided.

Figure 22 Slope instability above Ring Road

This slope above the road has been deforested and is in danger of collapse. Heavy rains will exacerbate this situation.

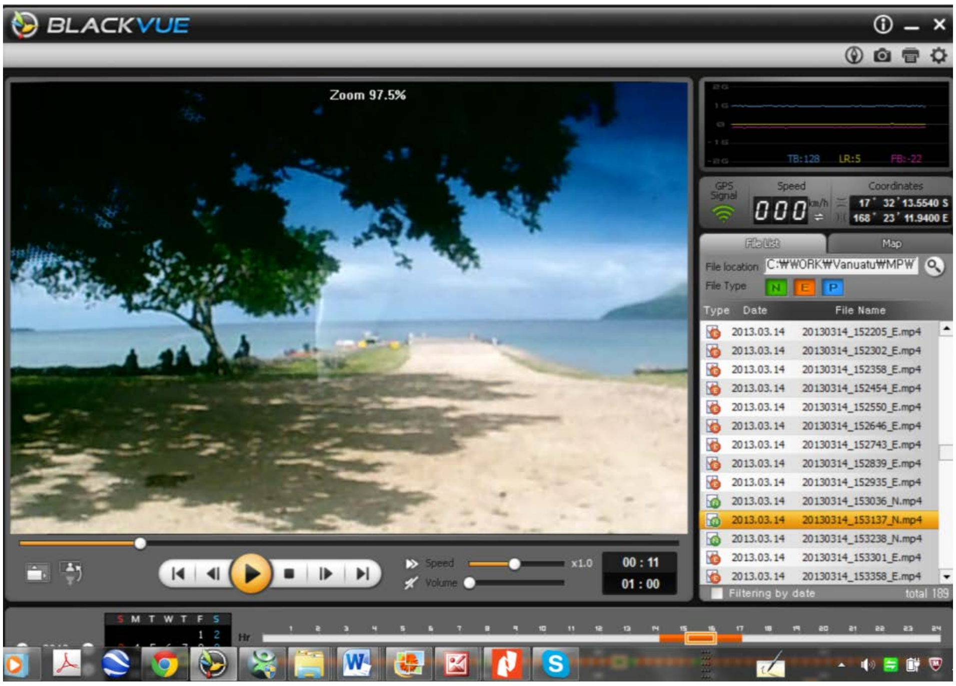


Figure 23 Emua Wharfe Ring Road

Figure 24 Emua Wharfe Ring Road

Figure 25 Emua Wharfe Ring Road

This wharfe is a popular jumping off point for tourists visiting the islands to the north of Efate. It is also a supply point for small boats serving the islands such as Emao. It is constructed of wire box gabions filled with stones.

As shown below the gabions are collapsing due to the sharp rocks cutting through the wire.

This is due to a lack of geotextile material being placed in the boxes before filling with stones. This is a design and construction error. The gabions can be repaired.

Figure 26 Gabions deteriorating due to lack of Geotextile membrane

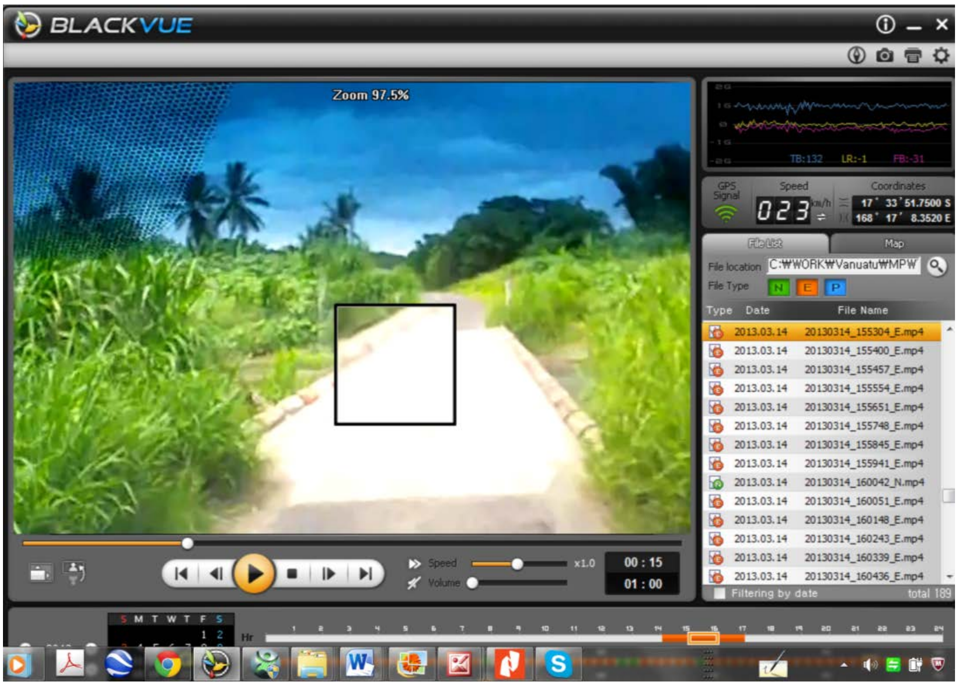


Figure 27 Vented Culvert Drift crossing

Vented drift crossings are very common on the Ring Road. One can see that vegetation is overgrowing the roads blocking site lines. Maintenance cleaning of the culverts is infrequent.

Figure 28 Lakenasua Unvented Drift Crossing

Lakenasua is probably the most vulnerable crossing on the Ring Road. It is the subject of a separate case study under CRRS. The outlet to the sea is about 300 metres to the right of the photo. To the left is a catchment area which has been identified under Manifold and using LiDAR files. It extends several kilometers into the hills and is a very large catchment. Flows across this drift are severe and cars have been washed away. The black and white warning signs give no indication as to what is a safe height to cross.

As can be seen in the photo scouring of the river bank is occurring on the right hand side of the drift. Reinforcement and river training is urgently required.

15.2 Manples Junction Port Vila

Manples Junction is part of the ring road in that it connects Port Vila with the airport.

Figure 29 Manples Junction Flooding

It floods on a regular basis being impassable on a monthly basis. It was the subject of a separate case study under CRRS. It is included for improvement under the Port Vila Urban Development Project. CRRS have provided rainfall data for project climate change scenarios to the PVUDP team.

15.3 River Flooding and Seven Stars

Seven Stars lies above Manples Junction and flows from here contribute to flooding in Maples. The MGHD reported that this rainfall was the heaviest in Port Vila for the first two months of 2015. Bauerfield International Airport recorded 85.2mm of rain in a 24 hour period.

Figure 30 Seven Stars Flooding

15.4 Ongoing Surveys

Other surveys in SHEFA are still ongoing. This includes Managaliliu spur road in Efate and Epi Island.

16. Santo – Sanma Province

16.1 Survey Summary

A road condition survey was carried out on main roads on Santo Island and Malo Island, Sanma Province. A drive recorder with GPS (Blackvue) was utilized in this survey; this recorded the windshield view of each road as well as its location, road roughness, and the speed of the survey vehicle.

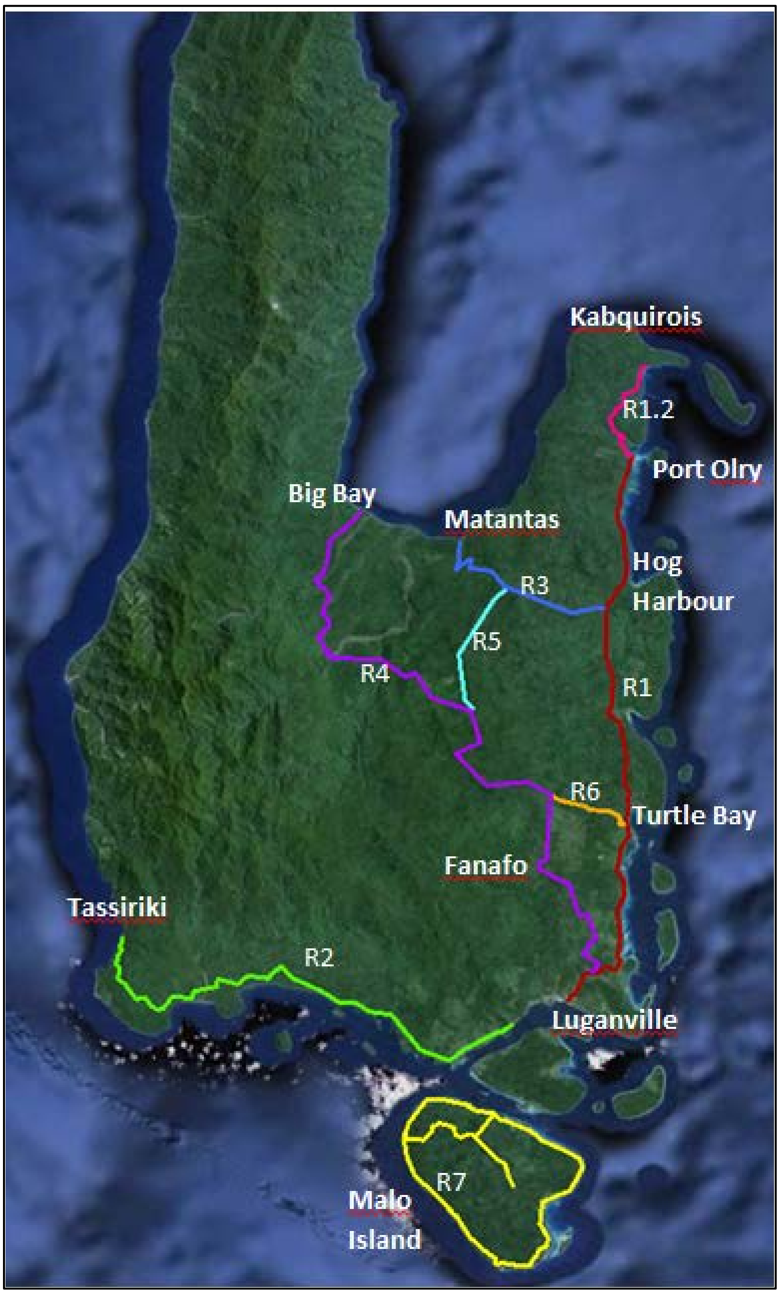
This report focuses primarily on the vulnerability of each road to climate impact; such as coastal erosion and heavy rain fall.

Most roads in Sanma province are unsealed and are in poor to extreme condition. Full sealing of each road would be ideal; however, securing the basic access (bridge, paved hills) would be the priority.

16.2 Survey Location & Dates

For Road ID and Locations, please refer to the map beloe

- Day 1 16 Feb, 2015 R2 (South Santo Rd)
- Day 2 17 Feb, 2015 R1 & R1.2 (East Coast Rd) , R3 (Matantas Rd), R5 (Connection Rd for R3 &R4)
- Day 3 18 Feb, 2015 R4 (Big Bay Rd), R6 (Big Bay Bypass Route)
- Day 4 19 Feb, 2015 R7 (Malo Island)



16.3 Survey Vehicle

- Santo Island G958 Mazda Pickup Truck 4x4, PWD Sanma Division
- Malo Island 8440 Toyota Hilux Pickup Truck 4x4, Private Truck

16.4 Santo & Malo Road Network

N.B. The road ID was assigned by this survey staff for convenience. PWD has not established such an official road ID.

R1 (East Coast Road)

Luganville – Port Olry

R1.2 (Bush Rd extending North)

Port Olry - Kabquirois

R2 (South Santo Road)

Luganville - Tassiriki

R3 (Matantas Road)

R1 Near Hog Harbor - Matantas

R4 (Big Bay Road)

Luganville – Big Bay via Fanafo

R5 (Connecting Route for R3 & R4)

R3 to R4

R6 (Bypass for R4)

R4 to Turtle Bay on R1

R7 (Malo Road)

Malo Ring Road and Inland Rds

16.5 Survey Direct Results

For simplicity in the survey the roads were designated :

- R1 East Coast Road
- R2 South Santo Road
- R3 Matantas Road
- R4 Big Bay Road
- R5 Road connecting R3 & R4

The location of Screenshots of Blackvue data are shown in the table and in the map below.

#	Item	Type	Condition	Photo/ Blackvue Reference
	R1 (East Coast Road)			
	Good			
	R2 (South Santo)			
1	Nakere Bridge	Slab w/ Culvert	Severely Damaged	1. Nakere River
2	Manniao Bridge	Bridge	Destroyed	2. Manniao Bridge
3	Wailo Bridge	River	No Bridge	3. Wailo Bridge
4	Navaka River	River	No Bridge	4. Navaka River
5	Buvo Bridge	Bridge	Destroyed	5. Buvo Bridge
	R4 (Big Bay Rd)			
6	Glass Hill	Hill	Rugged	6. Glass Hill
7	Lape River Hill	Hill	Rugged	7. Lape River Hill
8	Lape River	River	Concrete Slab	8. Lape River
9	Jordan River	River	No Bridge	9. Jordan River
10	Jordan River Hill	Hill	Slippry and impossible to climb	10. Jordan River Hill
	Luganville			
11	Road to South	Coastal Erosion	Erosion to the side of the road	11.1 Erosion near Coral Quays (1) 11.2 Erosion near Coral Quays (2)
12	CBD	Coastal Erosion	Erosion to the side of the road	12.1 Near Unity Park 12.2 Near Pacific Petroleum
	Malo Island			
13	Seawater backflow to road	River	No Bridge, seawater backflows to road	13. Near PWD
14	Bridge	Bridge		14. Malo Bridge
15	Culvert Carried by water	Culvert	Culvert Carried away by water	15. Box Culvert

Figure 31 Climate Vulnerable Areas on each Road Network

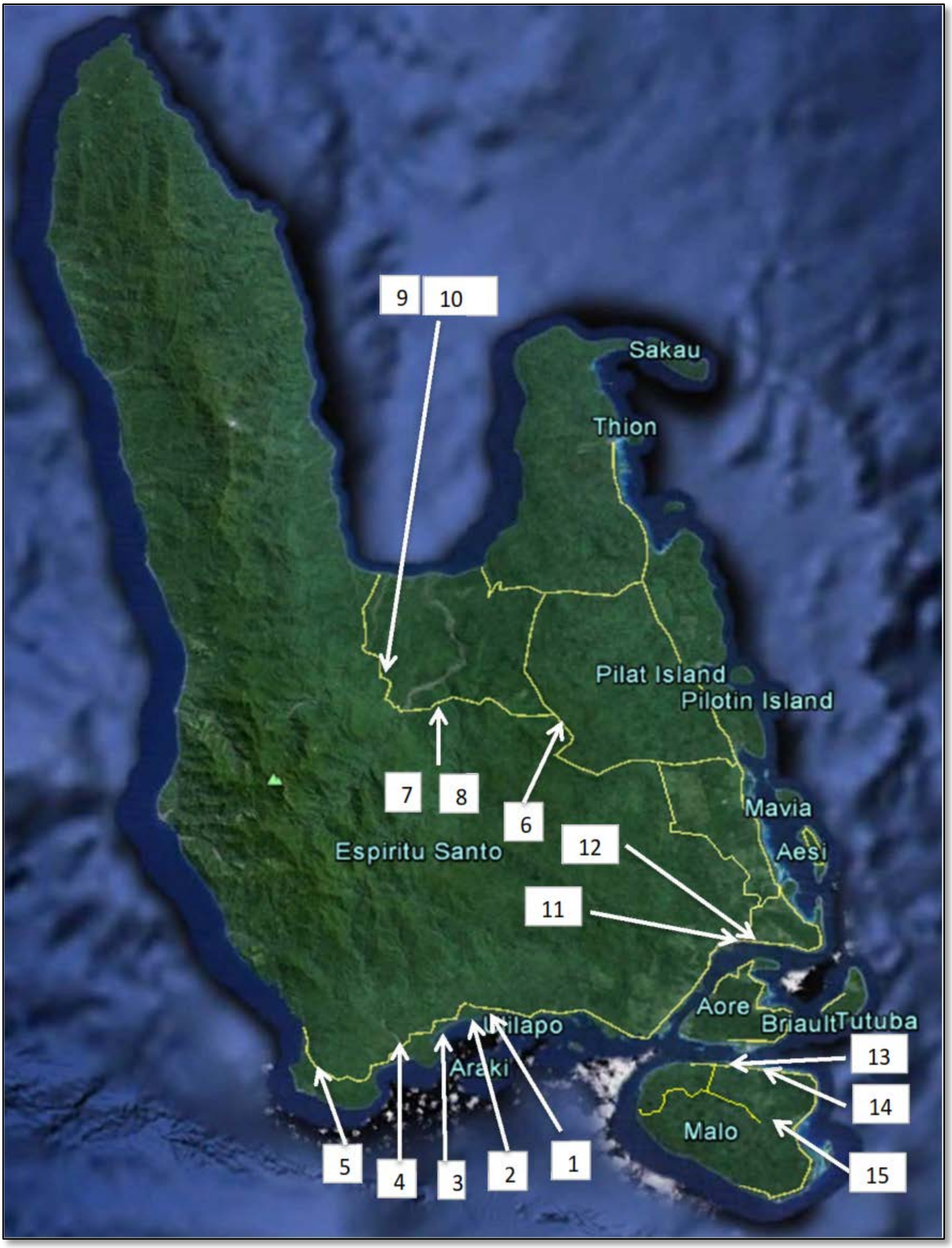


Figure 32 Location Map of Screen shots - Santo and Malo

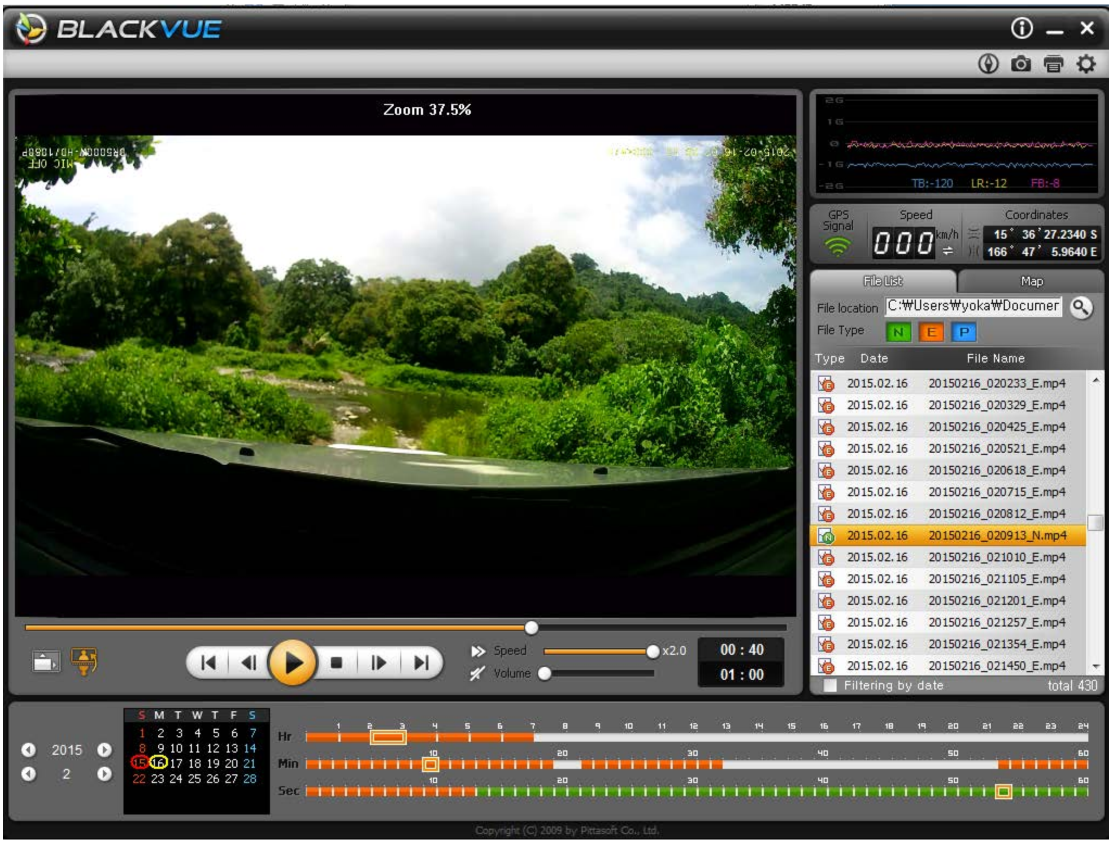


Figure 33 Screenshop of Nakere River

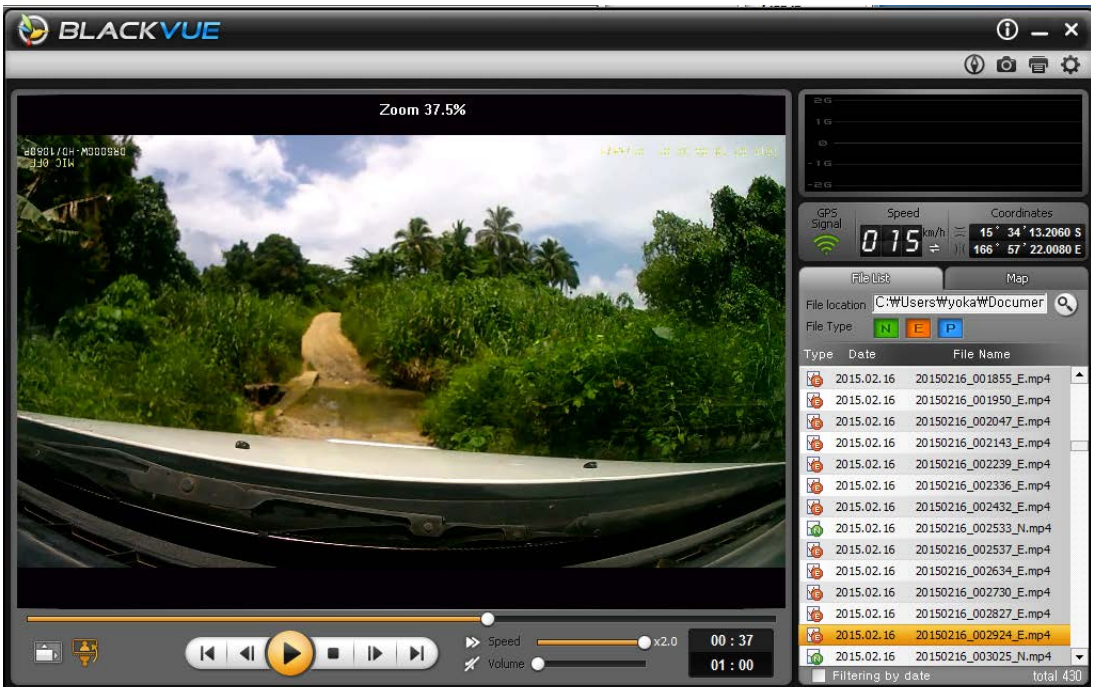


Figure 34 Screenshot of Manniao Bridge

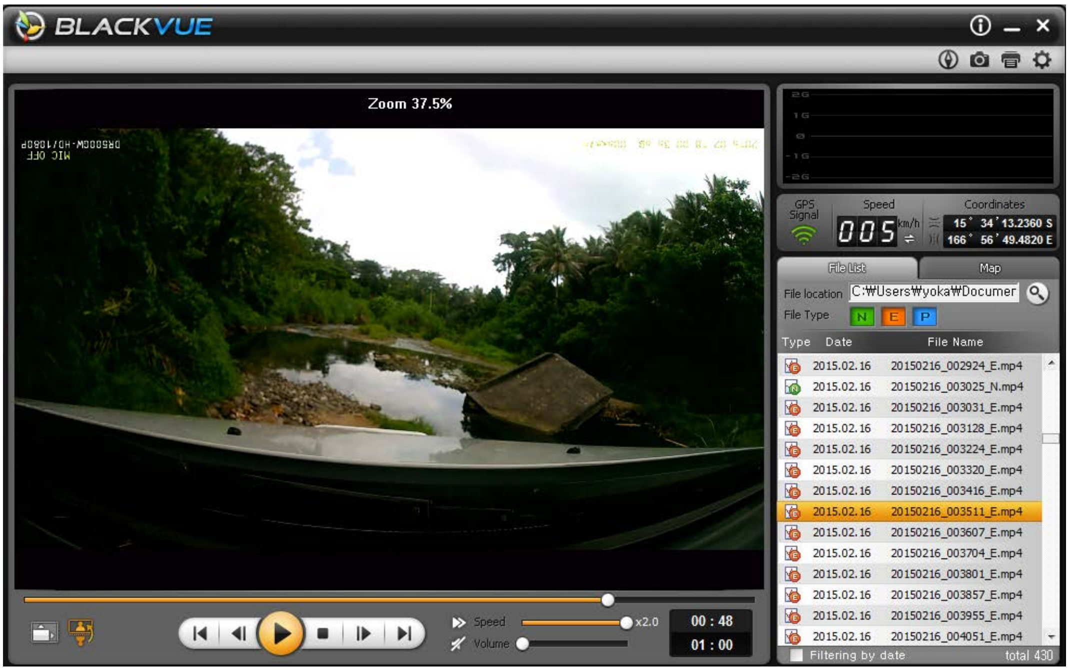


Figure 35 Screenshot of Wailo Bridge

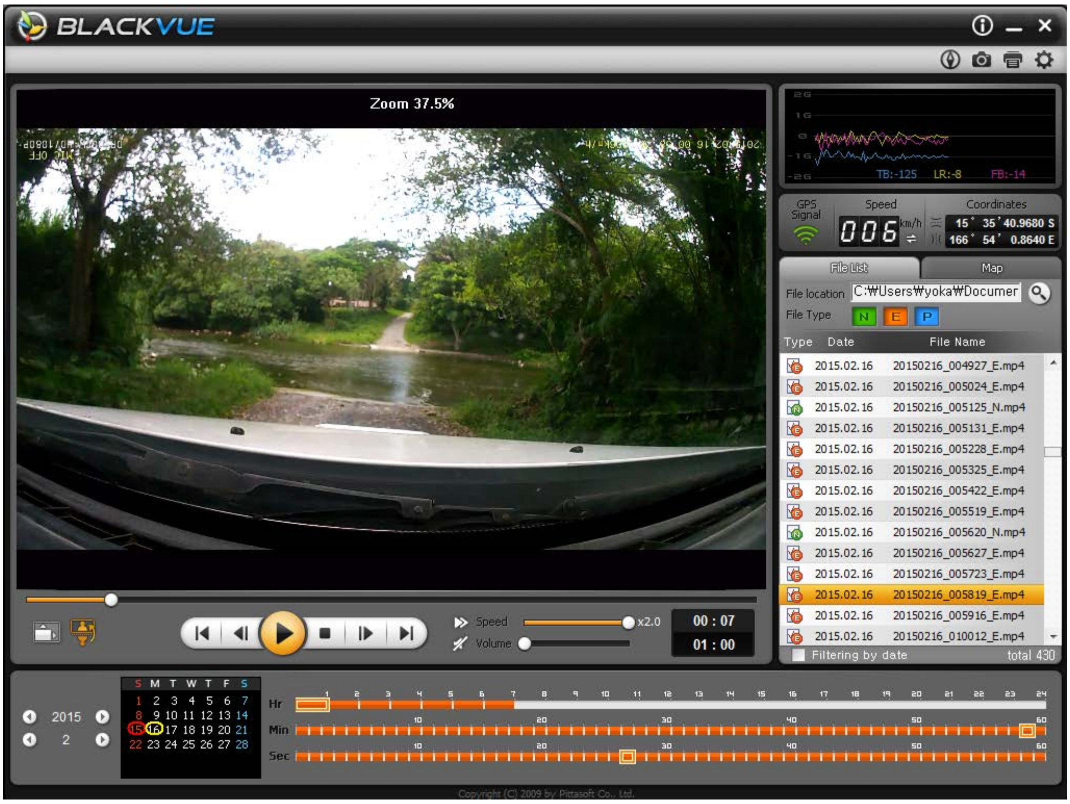


Figure 36 Screenshot of Navaka Riverr

Figure 37 Screenshot of Buvo Bridge

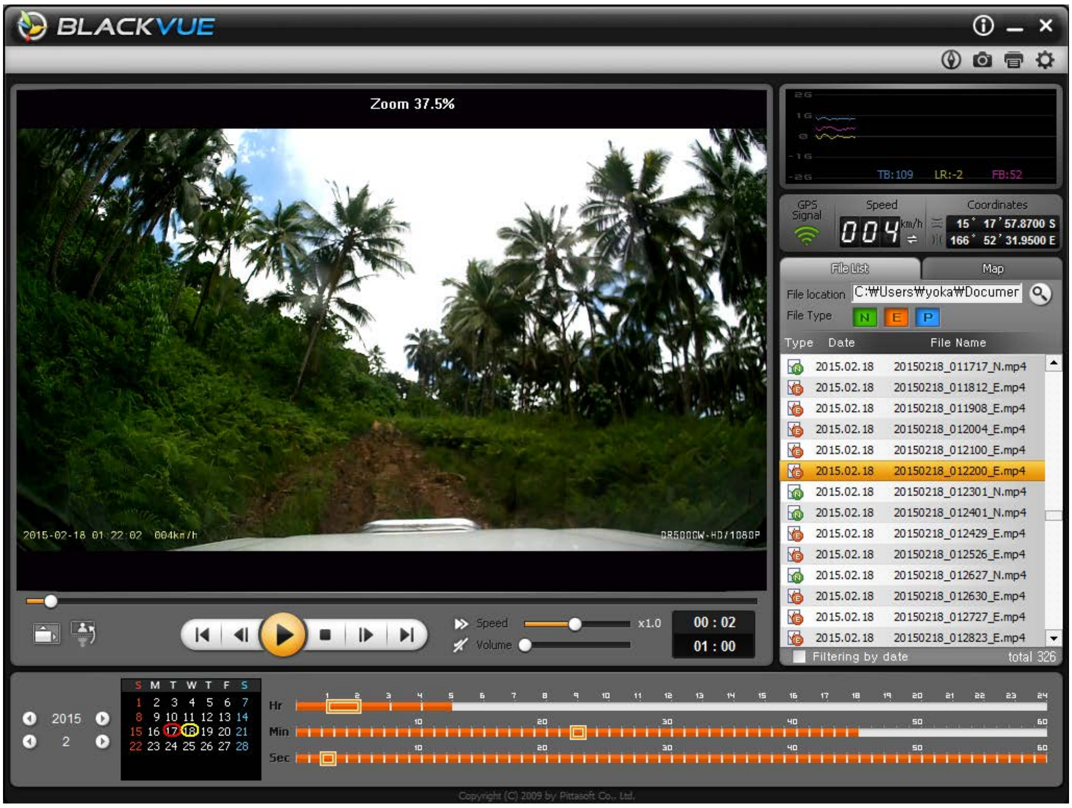


Figure 38 Screenshot of Glass Hill

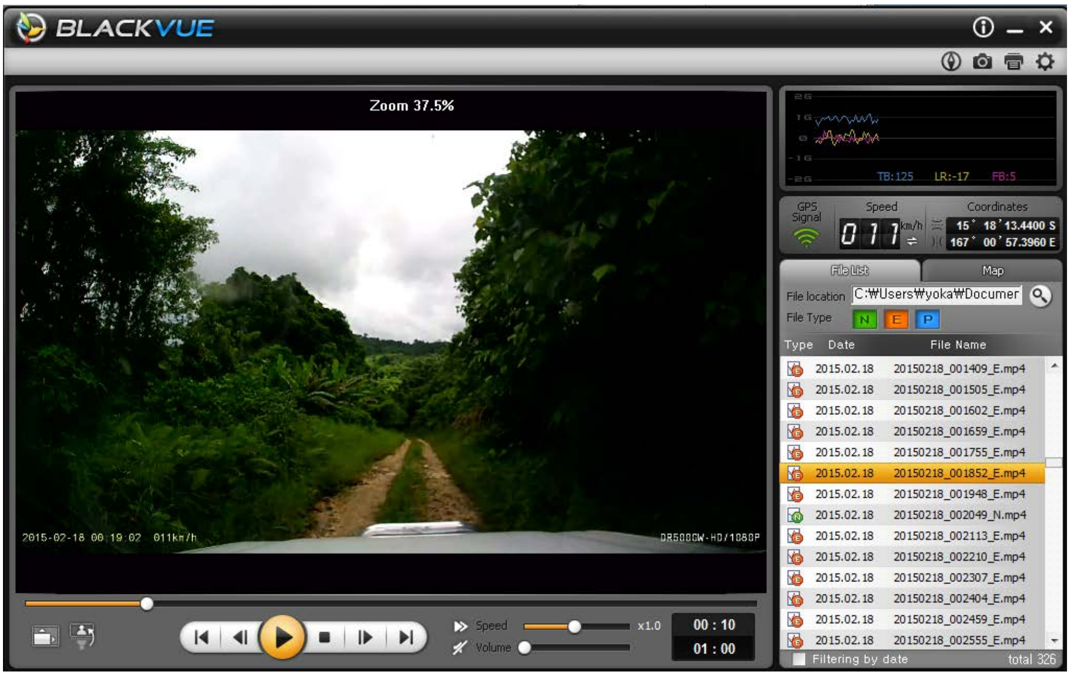


Figure 39 Screenshot of Lape River Hill

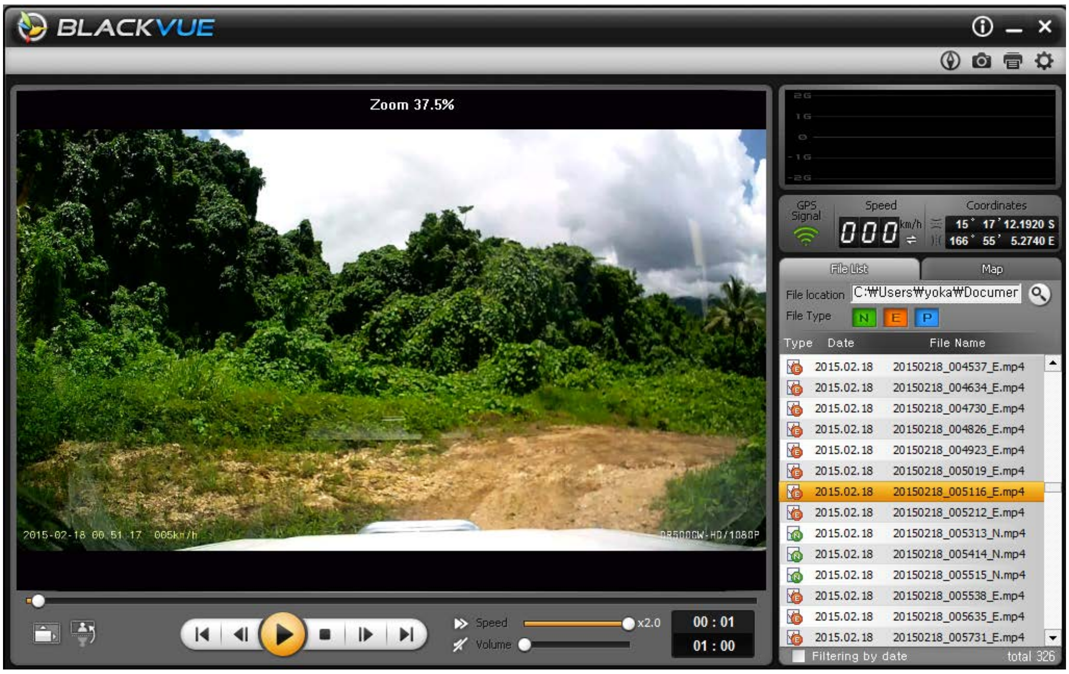


Figure 40 Screenshot of Jordan River Hill

Figure 41 Screenshot of Jordan River

Figure 42 Screenshot of river approach

Figure 43 Erosion near Coral Quay

Figure 44 Erosion near Coral Quay

Figure 45 Unity Park

Figure 46 Pacific Petroleum

Figure 47 Road near PWD

Figure 48 Malo Bridge

Figure 49 Culvert Carried away by water

Figure 50 Bridge near PWD

16.6 Road Condition and Priorities

R2, South Santo serves a large population alongside the road, as well as the population that resides in the North West Santo. North West Santo does not have roads; therefore the residents travelling to Luganville normally take boats to Tassiriki, and from there they take land transportation.

This R2 road has a number of rivers crossing the road. The lack of proper bridges makes these rivers impassable at times of heavy rain.

R4 road provides an access to the community in Big Bay and others in central area. This road consists of a few large hills and large river crossings. The survey team was in fact unable to cross one of the rivers, Jordan River. The team attempted to continue the travel by climbing a hill; however the steep slope and the deep mud made a 4WD truck impossible to make the climb.

The details of each road are to be shown at the next section.

16.7 Road Condition Details

R1 (Santo East Coast Road) Luganville – Port Olry

This road has been built by the U.S.A. recently, the condition is excellent. Typical travel speed is 80-100km/h, indicating the road condition is very well.

No significant area vulnerable to climate.

Typical view of R1 Road

R1.2 Port Olry - Kabquirois

This is an unsealed road connecting the North Eastern communities to Port Olry.

Condition is rough to fair, but is not significantly vulnerable to climate change.

Typical view of R1.2 Road

R2 (South Santo Road)
Luganville – Tassiriki

This is the main route for communities in South Santo. A great number of population utilizes this road for traveling and transporting commercial goods such as copra.

This road is highly vulnerable to climate impact mostly due to lack of bridges. There are a number of rivers and creeks crossing the road, and many of them are impassable at the times of heavy rain.

Typical view of R2 Road

16.8 Highly Vulnerable Areas

Below are the major areas **highly vulnerable** to climate.

1. Nakere Bridge

Type: Concrete Slab with culverts
Condition: Damaged.
Not passable when the water level rises due to heavy rain.
Coordinates: 15 34’13.2060 S
166 57’22.0080 E
Blackvue File: 20150216_002924_E.mp4

2. Manniao Bridge

Type: Bridge
Condition: Destroyed
Coordinates: 15 34’13.2360 S
166 56’49.4820 E
Blackvue File: 20150216_003511_E.mp4

River width: 20m

The destroyed bridge indicates the strength of the river at the times of flash flooding. Only experienced 4WD truck drivers can pass this river.

Manniao Bridge (Continued)

3. Wailo River

Type: River
Condition: No Bridge
Coordinates: 15 35’40.9680 S
166 54’0.8640 E
Blackvue File: 20150216_005819.mp4

25m wide river only passable by experienced 4WD truck drivers.

4. Navaka River

Type: River
Condition: No Bridge
Coordinates: 15 36’42.6420 S
166 52’8.9220 E
Blackvue File: 20150216_010935_E.mp4

A very large river. On normal days, the stream is 15m wide, but the it can be 200m wide at the times of cyclone.

5. Buvo Bridge

Type: Bridge
Condition: Destroyed
Coordinates: 15 36' 27.2340 S
166 47' 5.9640 E
Blackvue File: 20150216_020913_N.mp4
River Width: 25m

A large river only passable by 4WD truck

R3 (Matantas Rd)
Near Hog Harbour – Matantas

This road connects Matantas Village to R1.
The condition is overall poor; however there are no places significantly vulnerable to climate, and the basic access is maintained.

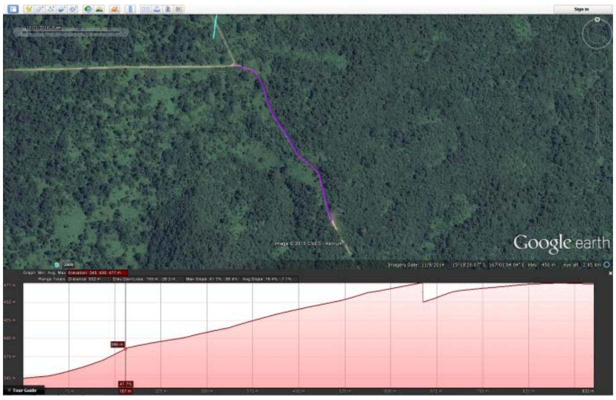
Typical view of R3 Road

R4 (Big Bay Rd)
Luganville – Big Bay via Fanafo

This road connects Big Bay and other small communities to Luganville. The hilly terrain makes the traveling difficult, and the second of the three large rivers was impassable for the survey team.

Typical view of R4 Road

1. Glass Hill



Type: Hill
Condition: Very Rugged
Coordinates: 15 18’13.4400 S
167 00’57.3960 E
Blackvue File: 20150218_001852_E.mp4
Max Slope: 41.7 %? (Google Earth)
Elevaton Difference:
132m?

This is a very high and steep hill near the junction to R5. It is very rugged and dangerous for driving.

Many drivers now choose to drive on R5 and avoid this hill.

**Accuracy of slope and elevation info. From Google Earth is questionable*

2. Lape Hill

Type: Hill
Condition: Very Rugged
Coordinates: 15 17’12.1920 S
166 55’5.2740 E
Blackvue File: 20150218_005116_E.mp4
Max Slope: 36.8 %? (Google Earth)
Elevaton Difference:
45m?

This hill too is very rugged and dangerous. Rutting by wheels and water is deep, and 4WD is required.

**Accuracy of slope and elevation info. From Google Earth is questionable*

3. Lape River

Type: River, Concrete Slab
Condition: Large River
Coordinates: 15 17’10.9860 S
166 55’ 1.4340 E
Blackvue File:
20150218_005414_N.mp4

There is a concrete slab built by European Union. The river is large and the speed of water is rapid. Not passable at the times of heavy rain.

4. Jordan River

Type: River
Condition: No Bridge
Coordinates: 15 17’46.2960 S
166 52’21.6840 E
Blackvue File: 20150218_011512_E.mp4

The river is large and only experience 4WD driver can cross the river. The survey team was unable to cross this river.

5. Jordan River Hill

Type: River
Condition: No Bridge
Coordinates: 15 17’57.8700 S
166 52’31.9500 E
Blackvue File: 20150218_012200_E.mp4

The hill was very slippery as the roadbase has been dug out. The rutting was very deep, and the survey vehicle did not have high enough clearance.

This hill is **highly vulnerable** to climate change impact.

R5 (Road connecting R3 and R4)

This road connects R3 and R4. This is an important route for R4 users as it serves as a bypass for the rugged R4 road. Drivers can connect R1, R3, and R5 in order to reach communities on R4 road.

Condition is rough, but basic access is maintained.

Typical view of R5 Road

R6 (Bypass for R4)

This road is a shortcut for R4, as it connects R4 to R1 at Turtle Bay area. There are no rivers or extremely steep hills. The basic access is maintained; however, the condition is very poor and repair work is recommended.

Typical view of R6 Road

R7 Malo Road

Overall Malo roads are in the fair condition. There are two creeks that crosses the road, and when the tide is high, the sea water backs into the road.

There is a bridge on a creek; however it is very old and replacement is recommended.

Typical view of R7 Road

1. **Seawater backs into the road**

Type: Creek
Condition: Seawater backs into the road
Coordinates: 15 37'33.78 S
167 09'36.08 E

The road is approximately 45m from the sea. Crossing salt water can spoil the vehicles.

2. **Bridge**

Type: Bridge
Condition: Deteriorated
Coordinates: 15 37'49.66 S
167 11'03.40"E

Very old and deteriorated. Currently it is passable for light trucks; however it may collapse in the near future.

3. **Box Culvert**

Type: Culvert
Condition: Been displaced by the water
Coordinates: data error

A large box culvert has been displaced by the water, indicating the extreme strength of flash flooding.

Luganville Urban Roads

Roads in Luganville city are a mix of sealed and unsealed roads.

Typical view of Luganville

1. **Near Coral Quays**

   Type: Coastal Erosion
   Condition: The sea has eroded the shore, and currently the shore is less than 10m from the road at the worst areas.
   Coordinates: 15 32’39.57” S
   167 08’56.10 E

2. **Near Unity Park**

   Type: Coastal Erosion
   Condition: The sea has eroded the shore, and it is about to reach the road.
   Coordinates: 15 30’54.24 S
   167 10’43.11 E
   Erosion at the shore is visible throughout the city. Ruins of the structures from the WW II era can be seen everywhere.
   This is a back road, and not a primary route.

3. Near Pacific Petroleum

Type: Coastal Erosion
Condition: The sea has eroded the shore. The worst area is about 10m to the road.
Coordinates: 15 30’55.21 S
167 11’50.67 E

This is a main road connecting Luganville city to the airport.

16.9 Conclusion

All roads except R1 and Luganville urban roads are unsealed, and their condition ranges from poor to extremely severe.

This survey concluded R2 and R4 are the roads highly vulnerable to climate change.

17. Malekula

Malekula is currently being surveyed by Fred Siba, PWD Divisional Engineer in charge of the Road Inventory. He is being assisted by Jason Andrews.

A major issue is Assen Point Road on South east Malekula. This road is suffering severe coastal erosion. It is the subject of a separate case study under CRRS.

Figure 51 Assen Point Road

Use has been made of LiDAR files supplied by Australian Aid / DFAT and views of the road demonstrating the severe erosion conditions are given below.

Figure 52 Assen Point Road

Figure 53 Assen Point Road

This allows a very rapid visual presentationto be made to decision makers. The conclusion is that remedial works will be exposed to severe weather conditions in the future and that relocation of the road to another alignment 1 km inland is the most cost effective solution.

18. Pentecost

Pentecost is currently being surveyed by James Hakwa, PWD engineer in charge of the Road Inventory. He is being assisted by Jason Andrews.

19. Tanna

Tanna is currently being surveyed by Richard Farrell, Senior Maintenance Engineer in charge of R4D Road Inventory. He is being assisted by Road Maintenance Engineer, Marko Vrkjlan, from the Roads for Development Program.

20. Conclusions

Two types of vulnerability have been identified :

- Roads and infrastructure which are vulnerable to extreme weather events.
- Priority locations which are connected by roads which if cut place stress on the locations

The locations of these are indicated in the maps given in the annexes.

The Decision Trees should be used as part of the Screening Methodology to identify vulnerable locations.

In all cases conclusions inferred from GIS data should be confirmed by ground truthing during site visits.

In response to a request from PWD to upgrade the Road Inventory System a survey has been imlemented based on Blackvue software. This uses dashboard cameras to record videos, GPS coordinates, rouad roughness and speed.

Speed has been adopted by CRRS and R4D as a proxy for road roughness.

Eventually a visual record of all roads in Vanuatu will be established. This will allow a rapid response to inquiries as to whether any section of road is exposed to climate change vulnerabilities and what are the nature of those vulnerabilities.

21. Annex 1 Vulnerabilities due to Terrain

These maps show the vulnerabilties due to terrain and environmental conditions.

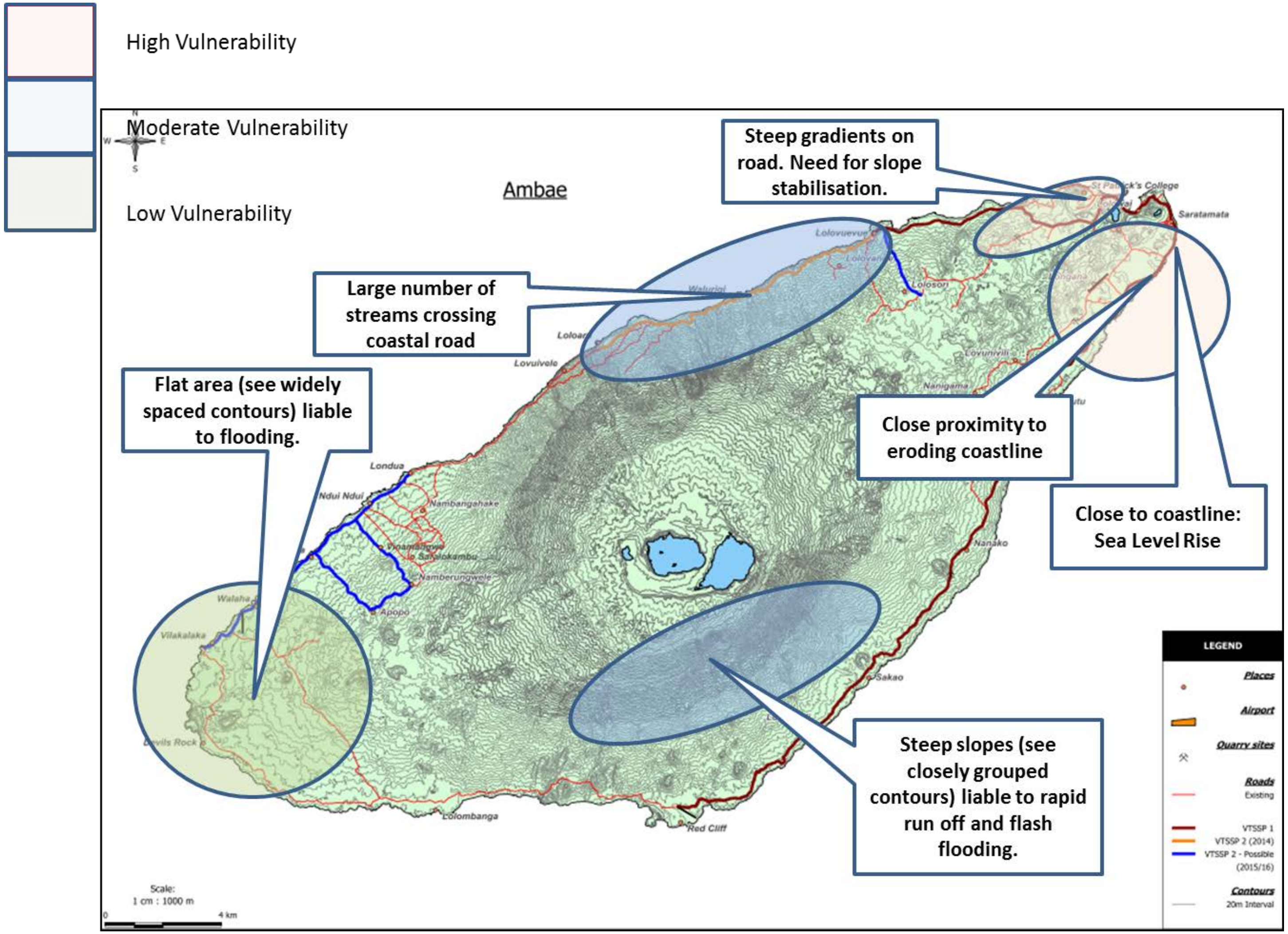


Figure 54 Ambae

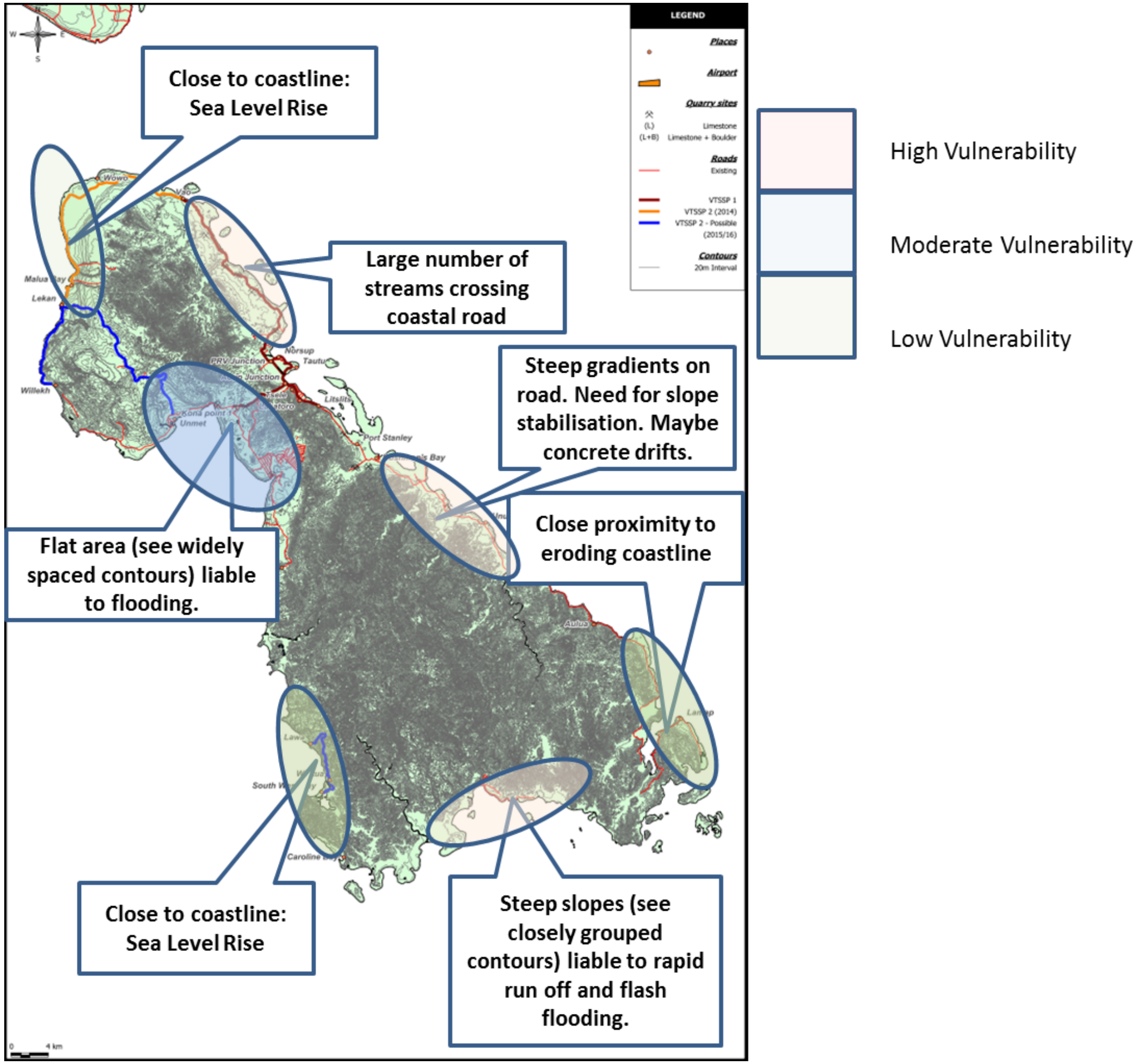


Figure 55 Malekula

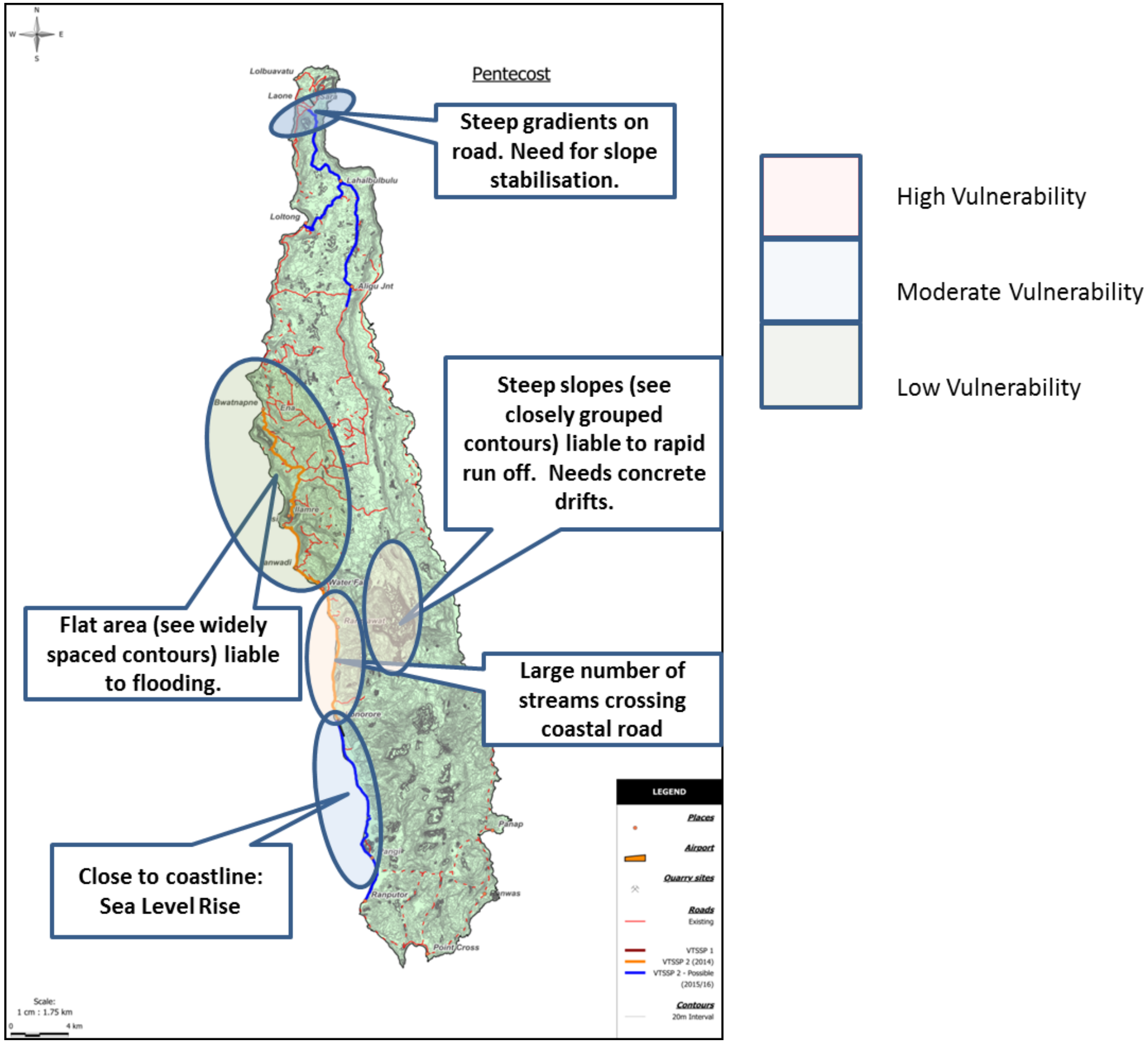


Figure 56 Pentecost

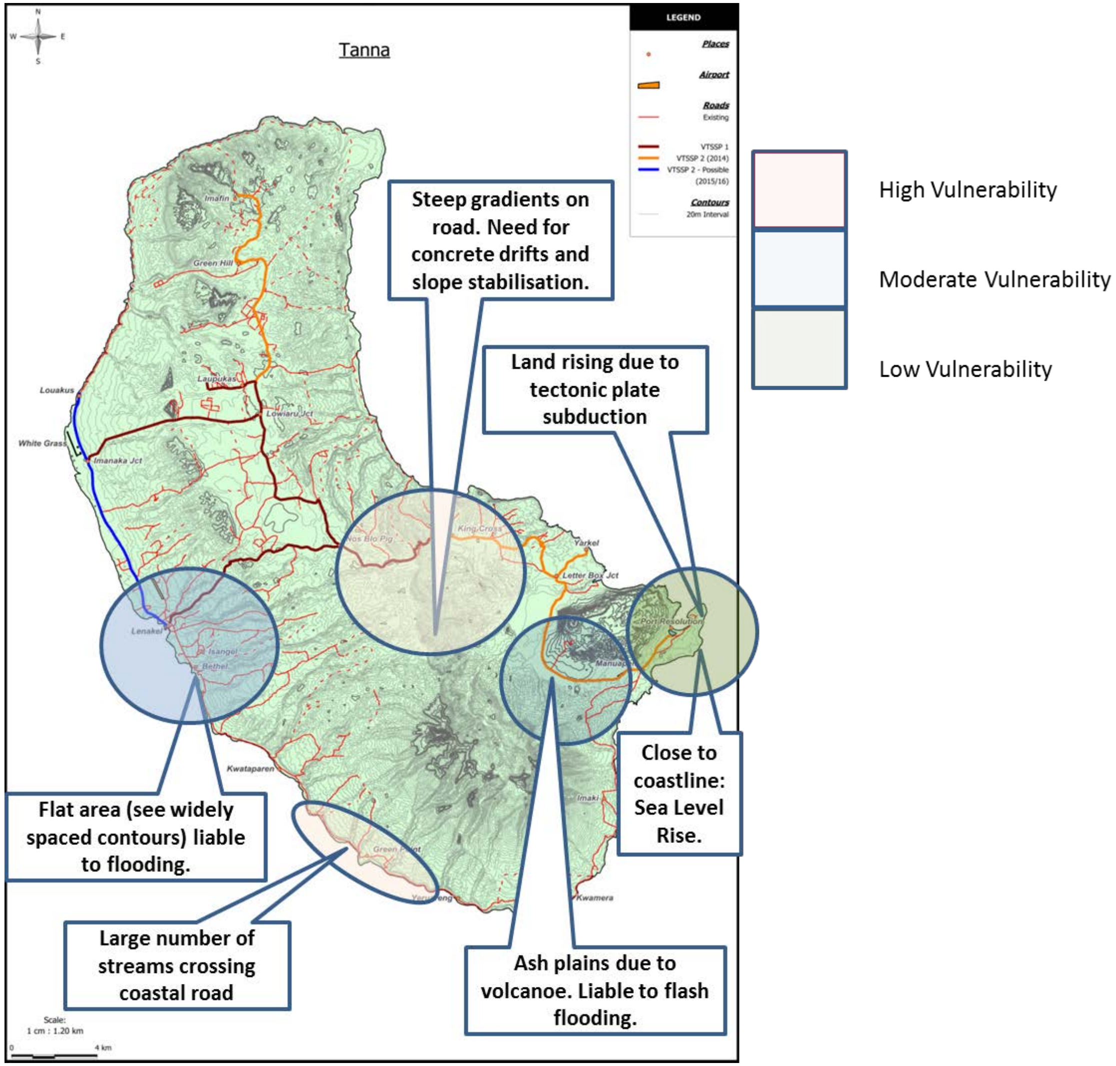


Figure 57 Tanna

22. Annex 2 Vulnerabilities due to Connectivity Demands

The following maps show the vulnerabilties due to connectivity demands.

Roads, health facilties, schools, cacthments and major river crossings are shown. Schools are represented by blue flags, hospitals by red crosses.

Where a road crosses a major stream (indicated by a thick black line) major flooding can be expected due to an Extreme Weather Event. Attempts to cross whilst the road is in flood must be discouraged.

The legend is as given below.

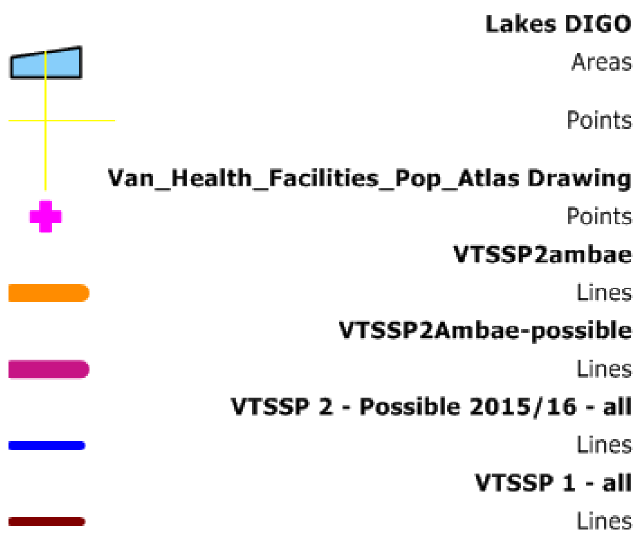


Figure 58 Legend

Figure 59 Ambae

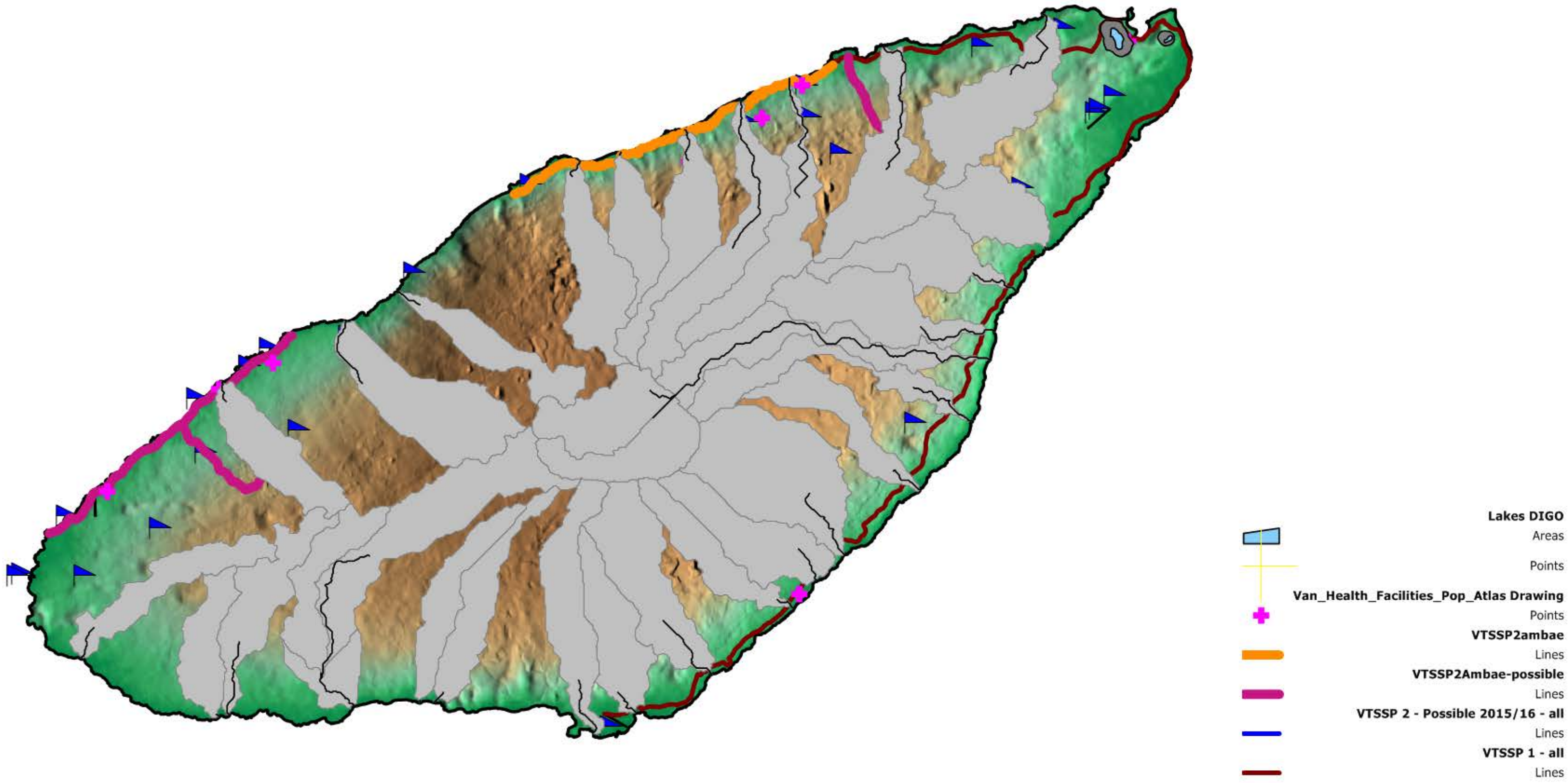


Figure 60 Malekula

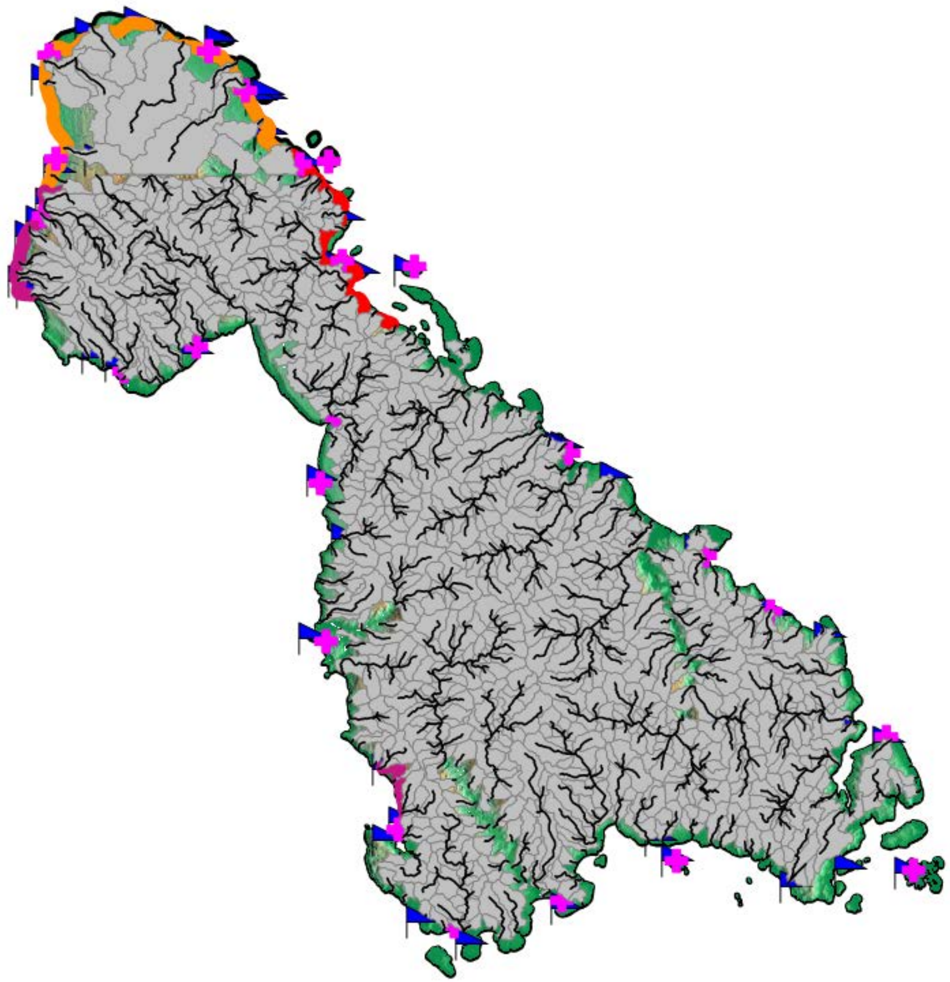


Figure 61 Pentecost

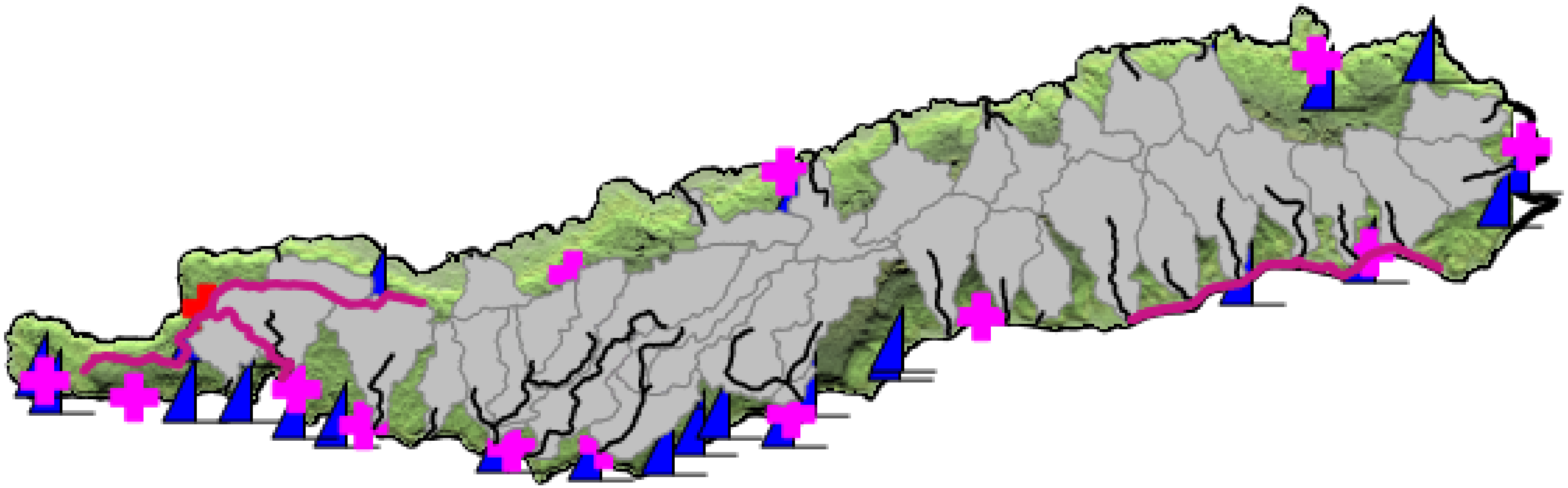


Figure 62 Tanna