VANUATU RESILIENT ROADS MANUAL

A Succinct Practical Guide

November 2014

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1 Main Climate Resilience Considerations

The main considerations for climate resilient infrastructure are vulnerability to the following :

- Sea Level Rise (SLR) is currently measured to be 6 mm per year throughout Vanuatu. It may rise faster than this if Global Warming continues.
- Wharves / jetties have a life of 50 years. Allow 0.5 meters SLR for 50 years into the future
- Storm surges cause wave overtopping of coastal roads. Any locations currently experiencing flooding during storms will experience more severe events in the future. Move roads 50 -100m away from coastlines.
- Extreme weather events will increase. Rainfall will become more intense, of shorter duration but may happen more often. Allow for more drainage.
- Steep slopes will become more difficult to climb. Use concrete. Add drainage.
- Roads may become impassable from flooding. Lift road on embankment. Add cross drainage
- Roads may be impassable from stream crossings in flood. Use concrete drifts. Indicate safe depths for pedestrians or vehicles.
- Temperatures will increase. Longer periods of drought can be expected. Anticipate less water availability.

2 A Climate Resilient Road

"A climate resilient road correctly designed now is no different to a climate resilient road in 2050."[1]

A good road is climate resilient. A ***climate resilient road*** will withstand heavy rainfall and if flooded, although it may be impassable for a time, when the waters recede the road will remain undamaged. The figure below shows a "good" design for a climate resilient road.

3 Road Performance

3.1 Connectivity

The performance of a road can be defined in terms of *Connectivity* or *Trafficability*. Ideally a road should be an all-weather road, passable in all weathers, including extreme weather events. In Vanuatu, at present, this is an unrealistic expectation. Given the present 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.

3.2 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".

[1] World Bank "Making Transport Climate Resilient" Country Report: Ethiopia, August 2010

3.3 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. Given the low number of vehicles using roads in Vanuatu, and the low axle weights, in most cases roads unsealed roads will be sufficient.

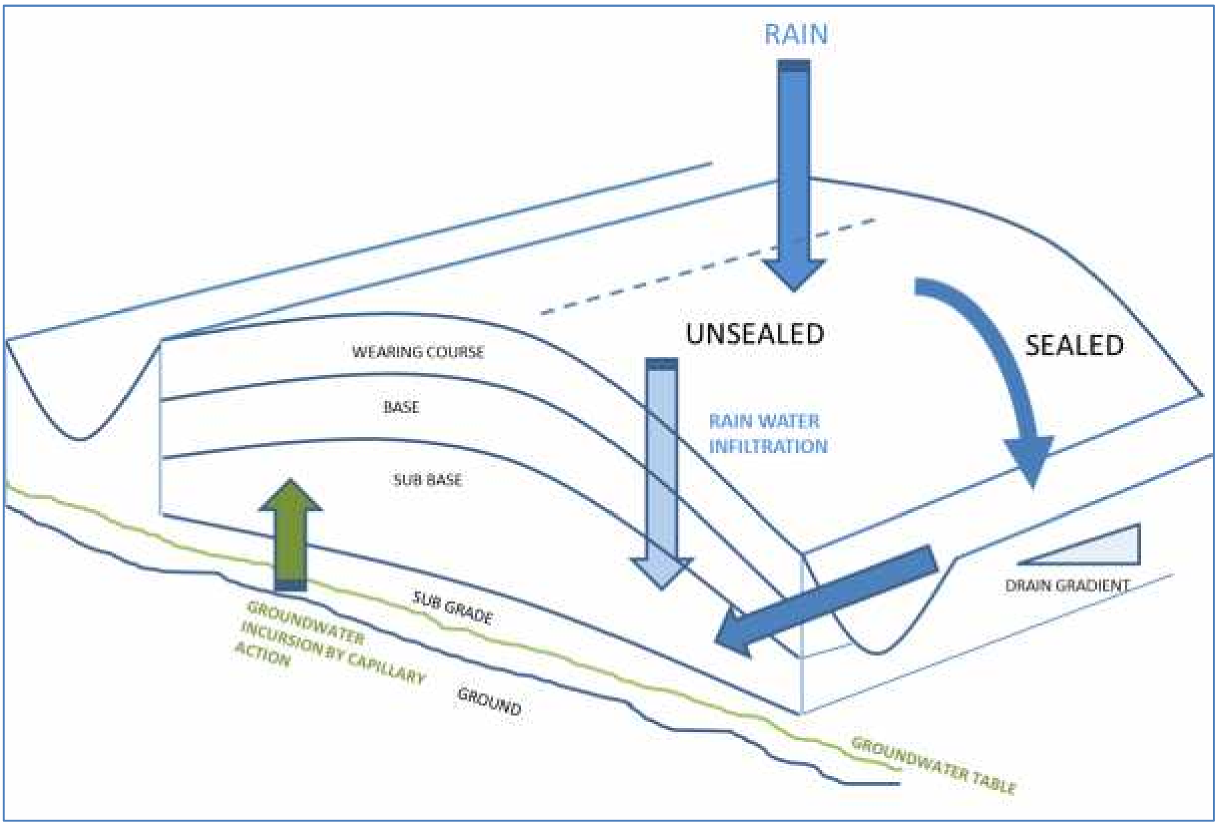


Figure 1 Conventional Design of Climate Resilient Road

3.4 Extreme weather events and over design

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.

3.5 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.

3.6 Existence value

If a road exists it should be passable. The existence of a road is sufficient justification.

3.7 Use of Roads for Emergency Services

A key usage of roads is to provide access routes for emergency service first responders. It should be passable even in extreme circumstances.

3.8 Alternative Alignments

As referred to above if road closure cannot be avoided then an alternative route should be identified, if it exists. Even if it involves longer travel time it will still provide an alternative route in a medical emergency or for disaster relief.

3.9 Pedestrian Bridges

Provision for emergency response is a key consideration. If temporary road closure for vehicles is anticipated due to flooding a combination of a pedestrian bridge in the vicinity of a stream crossing may be viable.

4 Climate Change Screening

4.1 Vulnerable Roads

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

- Close proximity to shoreline where 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.
- If inland on steep gradient > 10%.
- Road below steep slopes which are prone to landslides.
- Roads crossing water courses.
-

4.2 Priority Locations

To identify priority areas one should check if :

- Road close to hospitals, clinics.
- Road links centres of population.
- Road close to Airport.
- Road close to port, shipping wharf, jetty.
- Road close to schools.

5 Water and Drainage

In extreme weather events, drainage is the single most important factor in Climate Resilient Roads.

5.1 Water Entering a Road

Water can enter a road structure from three directions: above, the side or below. Drainage provision should always account for three components:

- Water falling onto the road from above
- Water flowing to the road from the high side
- Water rising from below from high watertable

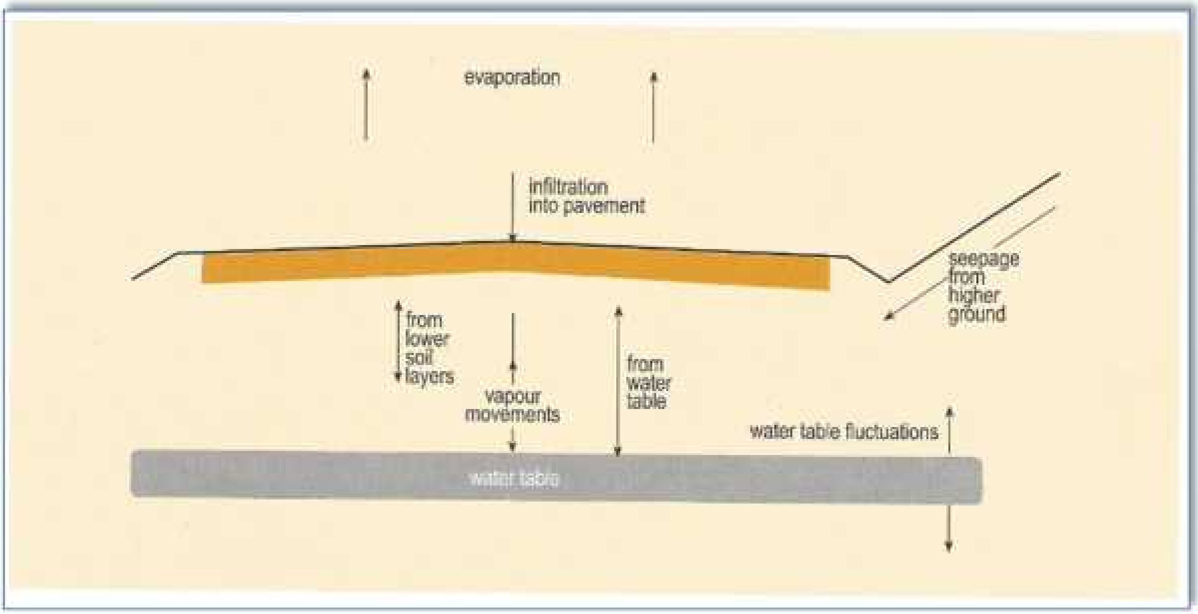


Figure 2 Three Components of road drainage

The three key drainage components are:

- Water that falls as rain onto the road surface must be shed off as quickly as possible by the use of a crowned crossfall of 4-6% on straight sections.
- Water flowing from the higher countryside must be intercepted and prevented from flowing toward the road by catch drains, diverted into natural watercourses
- Water collected alongside the road must be drained away from the road as soon as possible by the use of lateral side drains (table drains).
- If necessary water can be directed across the road by angled cross culverts.

5.2 Crossfall

Lack of adequate crossfall is the most common defect in unsealed roads as this does not provide adequate drainage of the road surface. Flat roads are most prone to potholes forming, if the shoulder has adequate crossfall there should be no evidence of potholes on the road surface. Crossfall should be sufficient to allow run off of water. If too steep, the surface material will be prone to scouring and erosion.

The crossfall used depends on local conditions and material properties. Crossfalls in the range of 4-6% are appropriate. In practice it is recommended that the road crossfall be initially constructed at 6% as over time it will flatten to around 4%. In terms of fall from the crown to the edge of the roadway the values for different crossfalls and road widths are given below in Table 12. For single-lane carriageways, it may be best to have a single crossfall for ease of grading during regular maintenance. The base and subbase layers should be extended outwards to form the shoulders, which should preferably be sealed if the road is sealed.

Crossfall	Road width			
	4 m	5 m	6 m	8 m
4%	80 mm	100 mm	120 mm	160 mm
5%	100 mm	125 mm	150 mm	200 mm
6%	120 mm	150 mm	180 mm	240 mm

Table 34. Crossfalls and road widths

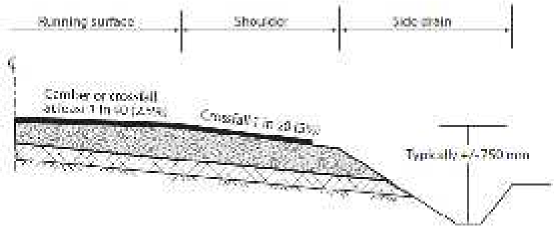


Figure 19. Ideal shoulder construction / drainage arrangements

Crossfall = > 2.5% if sealed = 4-6% if unsealed

5.3 Lateral or Side Drains

Side drains run parallel to the road and are used to drain water from the road surface and adjoining slopes. Side drains can have flat bottoms and may be lined or unlined unless there is a potential scouring problem. Such drains may be used only on one side of a road eliminating the need for the opposite drain, by either in-sloping or out-sloping the road. (Figure 21 and Figure 22).

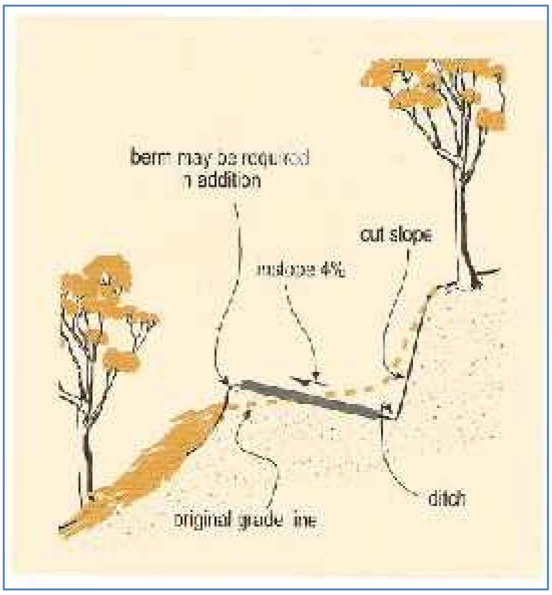


Figure 21. In-sloping

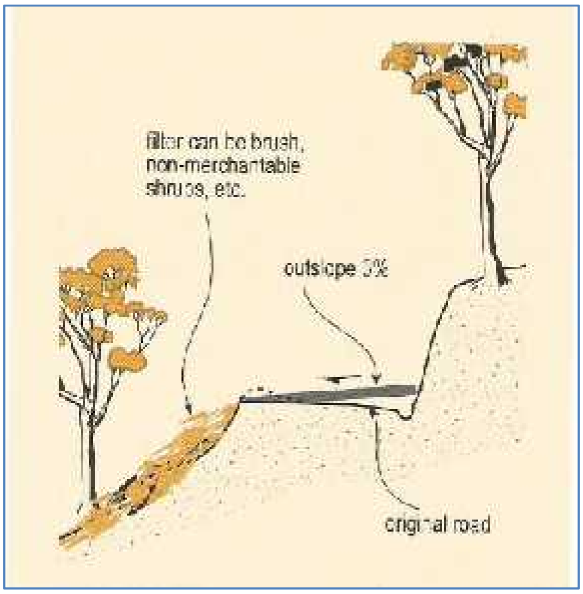


Figure 22. Outsloping

5.4 V-shaped and Trapezoidal Drains

V-shaped drains will be sufficient for normal rainfall. For prolonged heavy rainfall larger volume side drains are usually trapezoidal in shape and have a lower flow velocity. Trapezoidal or wide V shaped drains are better as they provide a greater flow capacity, reduce the flow velocity and thereby minimise scour. They should be vegetated with grass where possible and maintained by mowing. The longitudinal slope of the drain should be sufficient to avoid silting, but below the value at which scouring and erosion can occur. To avoid silting a minimum longitudinal slope is recommended of 0.5% (1:200) for an unlined ditch, and 0.33% (1:300) for a ditch lined with concrete or asphalt. Also recommended is a maximum slope of 5% (1:20) for an unlined ditch.

Provisions to prevent erosion are recommended for ditches which will carry a fast flow and which due to topography cannot be restricted to less than 5% longitudinal slope. Check walls and drop walls can be used at intervals on steep slopes, as can stepping the ditches down. However, attention must then be paid to localised erosion damage (e.g. at the steps). Grassing of the drain may also be used to reduce erosion and catch silt. However, during maintenance operations there is a risk that the grass cover may be removed as table drains are cleaned out and re-established. As a rule of thumb the spacing of cross drains used to reduce erosion along drains, is Spacing of cross drains (m) = 300 / % grade of longitudinal drain.

5.5 Culverts

The minimum diameter of culvert pipes should be 600 mm to minimise frequent blockage. Go for a larger size where possible. Flow velocities should maintain self-cleaning. Provision of a silt trap on the inlet minimises potential silting in a pipe. Bar screens should be fitted on the upstream side of cross drains to catch debris. These will require regular cleaning.

5.6 Catch drains/banks

Catch drains/banks are used to drain water flowing towards the road from the higher surrounding area. These drains are often used at the top of deep cuts. The longitudinal slope of the catch drain should be greater than 1 % to prevent pooling of water above catch batters and the potential of creating landslips. To prevent scouring, the slope should be less than 5%, depending on the likelihood of the soil to erode. Vegetating the drain is an environmentally sound way to minimise erosion, even on difficult soils. This can be carried out by covering the surface of the drain with hessian or plant slashings, and applying grass seed.

6 Cross Drainage

6.1 Culverts

Culverts can be pipe culverts or box culverts. Culverts are constructed on roads using a variety of methods and materials. Pipe culverts include corrugated plastic pipes, steel pipes or arches, pre-cast or fresh concrete pipes, boxes, arches or half arches. Box culverts can be precast or cast in situ, and road crossings can be reinforced concrete slabs resting on a box culvert. Culverts should be provided with sufficient cover to protect them from traffic loads in accordance with manufacturers guidelines e. g. minimum 600 mm for reinforced concrete pipe.

6.2 Location

Wherever possible, culverts should be located in the original stream bed with the invert following the grade of the natural channel. Stream bed realignment may be undertaken in exceptional cases.

Figure 26. Box culvert from concrete and pipe culvert from corrugated metal sheeting

6.3 Grade

The ideal grade line for a culvert is one that produces neither silting, excessive velocities or scour. To avoid silting, culvert inverts should be placed at a grade of not less than 1.25 % for pipes, and 0.5 % for box culverts.

6.4 Foundations

Ideally, culverts should be located on sound foundations such as rock. Soft, saturated and expansive clayey soils may cause settlements or seasonal movements of the culvert. Removal of poor soils or stabilisation of the foundation should be considered.

6.5 Inlets

Culvert inlets should be eased to a smooth entry without abrupt changes in direction or drops which can cause turbulence. Where these are unavoidable they should be adequately protected by concrete, gabion mattresses or rip rap. Geotextile material should be placed under gabions or riprap and a cut-off wall to prevent undermining. Invert gradients should be increased by 1 % in the case of culverts provided with drop inlets.

6.6 Outlets

The invert level at the outlet of a culvert should coincide with ground level. Where culverts are unavoidably constructed on a steep slope, the energy generated must be dissipated to avoid serious erosion at the discharge end of the culvert. A stilling box and widening at the outlet are effective methods of reducing the velocity of the water. Rock dissipaters or gabions can be used in channels as shown in Figure 27. These also assist natural channel restoration by trapping silt and preventing it from reaching downstream waterways. Other means to trap sediment can consist of logs, rocks, straw bales etc. These can also be used in places where high flows of water are expected on high erodible soils or other sensitive areas. extension of the protection or energy dissipaters to prevent downstream scour should be considered

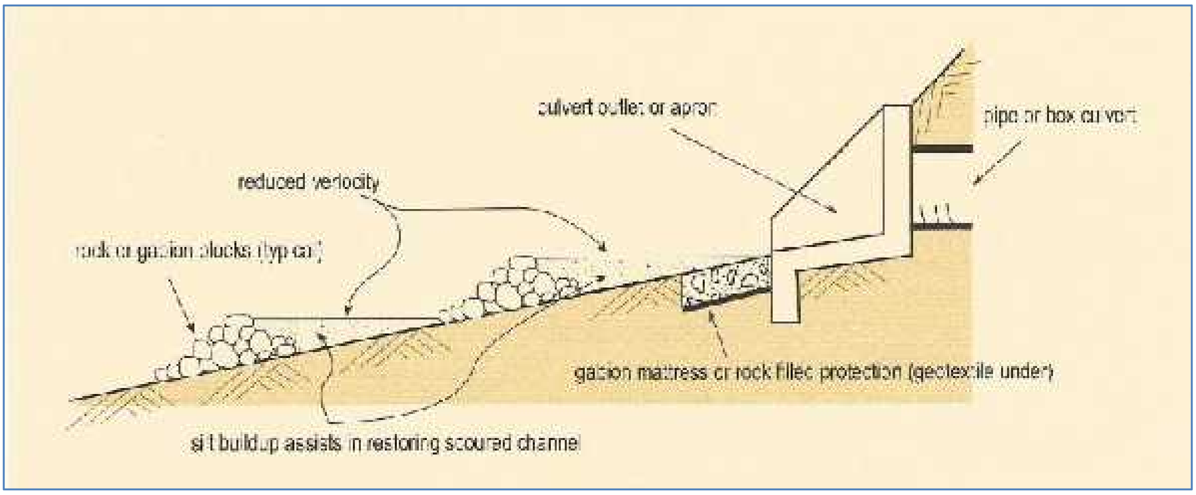


Figure 27. Culvert Outlet and Energy Dissipation

6.7 Allowing Water Flow over Road

Where traffic delays can be tolerated, a lower rainfall intensity is adopted based on lower storm frequencies (e.g. 1, 2 or 5 years events). Consequently, in the design of culverts for unsealed roads, it is acceptable that water be allowed from time to time to pass over the road or be temporarily ponded upstream, when the discharge from the catchment is greater than the capacity of the culvert. In so doing, care must be exercised to minimise possible damage to the road embankment. Inspections should be conducted after heavy rain to assess the extent of damage and works required to restore the road.

7 Calculating Size of Culverts

7.1 Calculation Methods

The size of a culvert to be provided under a road is mainly a function of the catchment size, the rainfall intensity and the nature of the vegetative cover of the area.

Inadequate culvert capacity can result in severe damage and expensive remedial works. At all natural watercourses an appropriate culvert or water crossing must be provided to take the estimated design flow.

The estimation of storm discharge for the detail design of a drainage structure should make use of the ***Rational Method***. A simplified method of calculating the size of a culvert required is to use ***Talbot's Formula*** below.

Although the accepted method of estimating peak discharge and designing culverts should be used whenever time permits, there may be occasions when such a degree of accuracy is unwarranted. In these situations, the Talbot's Formula method could be used (*Australian Army 1985*).

7.2 Simple Culvert Sizing Method

Talbot's Formula method provides a convenient way of determining the cross-sectional area of waterways required for small catchment areas. Talbot's Formula should be used with caution where seasonal rainfall is extreme. If in doubt err on the high side.

Talbot's Formula gives the area of waterway required if the rainfall, catchment area, and run-off coefficient are known. relating to the type of country being drained.

If one knows the rainfall in mm for 1 hour, use this figure.

Where maximum rainfall intensity in 1 hour is not known, then any of the following will give acceptable values:

- If the hourly rainfall is not known but the daily rainfall is known, assume 40% could fall in any 1 hour period.
- If the hourly rainfall is not known but average annual rainfall is known, use:

  - for areas having less than 2,500 mm of rain per year assume 8% could fall in any 1 hour period
  - for areas having greater than 2,500mm rain per year assume 4% could fall in any 1 hour period of the value.

When in doubt use the ***higher*** figure.

The ***Catchment Coefficient (C)*** should be selected. This varies with type of vegetation cover. Use the mm/ hour rainfall figure and vegetation type to calculate C.

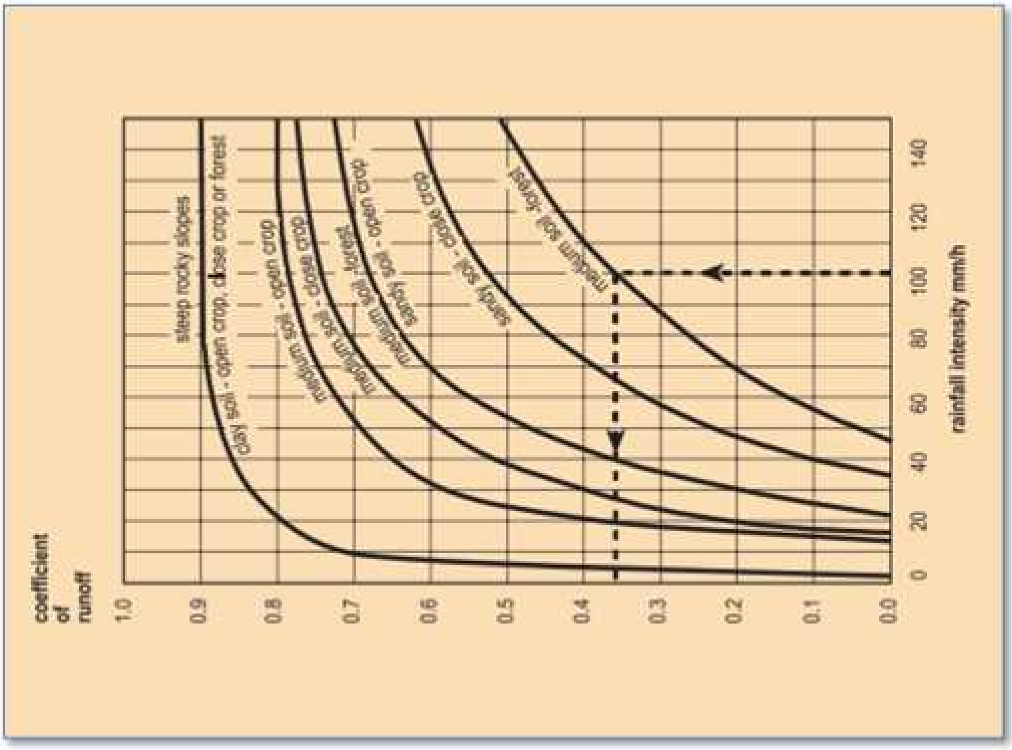


Figure 31. Run-off co-efficient for rural catchments

One then needs to know the area of the catchment. This can be obtained from topographical maps by looking at contours. Or the PWD GIS Section can calculate this for you if the GPS coordinates of the stream crossing are known. Use a handheld GPS unit to obtain these.

Using the value of C and the catchment area, calculate the required area of the culvert using the chart below.

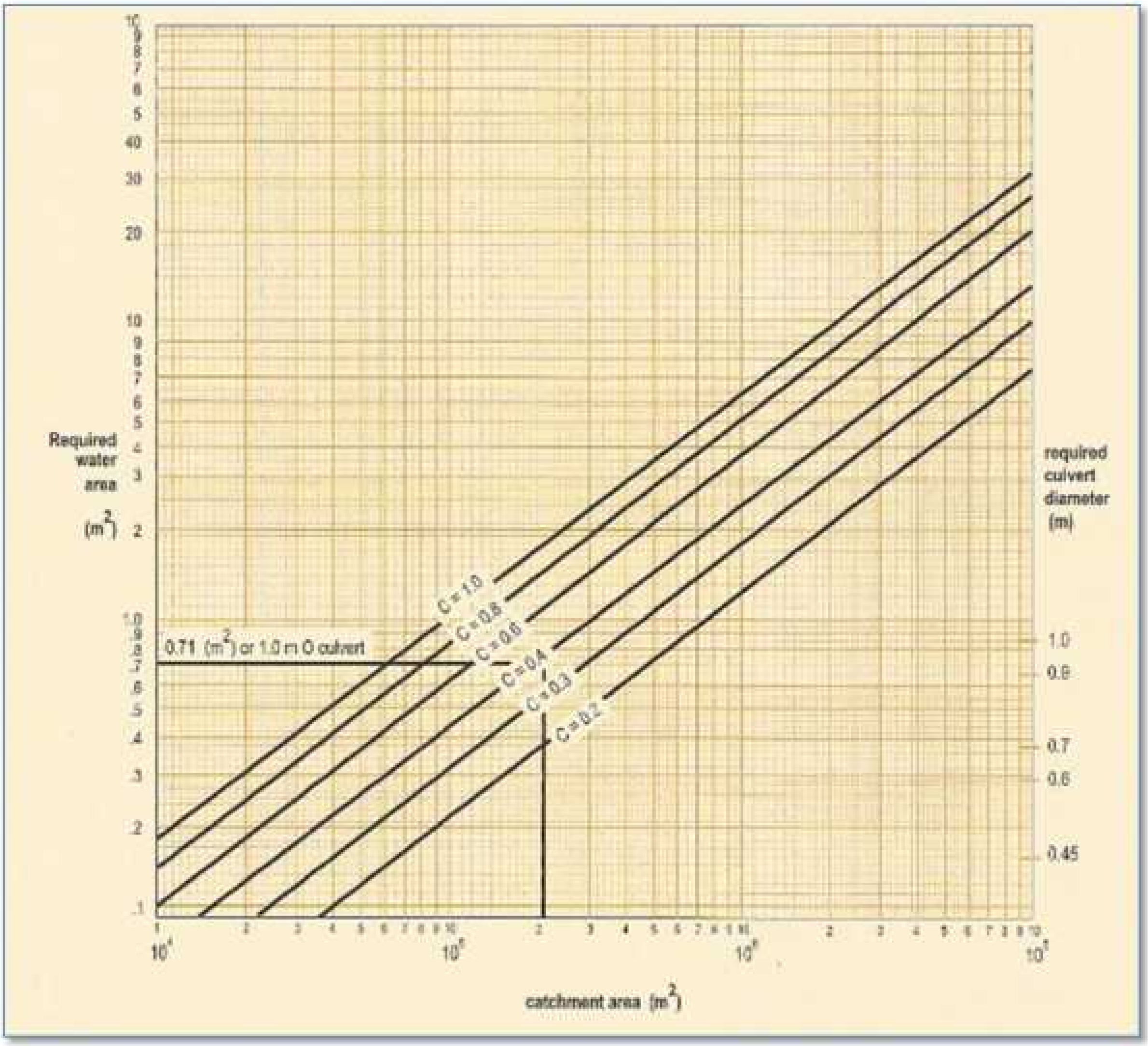


Figure 30. Talbot's Formula

The above figure shows required waterway area using Talbot's Formula based on rainfall of 100 mm in one hour.

This relationship was derived for a catchment area having an anticipated rainfall intensity of 100 mm in 1 hour. For areas having a different rainfall, the result should be divided by 100 and multiplied by the anticipated rainfall.

Do not forget this give the required AREA. This has to be converted into diameter of a pipe or square cross section of a box culvert.

Example

The following are examples of the use of Talbot's Formula:

1. Select a suitable culvert size for a catchment area measured at 210,000 m^2. The rainfall is 100 mm in 1 hour and the catchment area is predominantly medium soil in a forest area.

By referring to Figure 30 for a rainfall intensity of 100 mm the run-off coefficient is estimated at 0.36.

For a catchment area of 2.1×10^5 m^2 and referring to Figure 31 the area of waterway is estimated at 0.7 m^2.

2. What size of pipe is this ? The area is pi r squared.
Pi=22/7
Area = 0.7
$0.7 = 22/7 * r^2$
$\frac{0.7}{22} * 7 = r^2$

r = square root of [0.7 * 7/22] = SQRT [4.9/22] = SQRT [0.22] = 0.47m

Remember this is the **RADIUS**. So the **DIAMETER** is 2 x 0.47 = 0.94m

This is close to a pipe with a **diameter** of 1 m.

3. What area of waterway is required for the same catchment area if the anticipated rainfall is 160mm/h?

$$\text{Area of waterway required} = 0.7 \times \frac{160}{100} = 1.12\ m^2$$

4) Assume the rain fall doubled. Say it went from 100mm/hr to 200mm/hr. So the area goes from 0.7 m^2 to 1.4 m^2. So the area of the culvert doubles when the rainfall doubles.
BUT
Doing the same calculation as above
Pi=22/7
Area = 1.4
$1.4 = 22/7 * r^2$
$\frac{1.4}{22} * 7 = r^2$

r = square root of [1.4 * 7/22] = SQRT [9.8/22] = SQRT [0.45] = 0.667m

Remember this is the **RADIUS**. So the **DIAMETER** is 2 x 0.667 = 1.33m

So the rain fall has doubled (gone up 100%) but the pipe **diameter** has gone from 0.94 m to 1.33m. An increase of 4**0%**. **Doubling the rainfall does not double the pipe size.**

5) Of course pipe culverts come in standard sizes so having calculated the diameter you then select the size of one pipe, or the number of pipes of a certain size, needed.

The drainage methods used for unsealed roads are the same as those used for sealed roads. The capacity of drainage structures should be based on local experience. In all cases combine calculations with observations on site. Increase the size of drainage structures to minimum 600 mm for easy maintainence although 900 mm is preferable.

8 Erosion

8.1 Scour Checks

Protect drainage channels and side drains by the use of scour checks. These can be easily constructed by labour-based methods from wooden sticks, rocks, concrete or other materials. The frequency of scour checks needs to be properly adjusted according to slope gradient in order to prevent erosion between the checks causing damage to the system. The following can be used as a guide:

Gradient of the ditch	Scour check spacing (m)
4% or less	(not required)
5%	20 m
8%	10 m
10%	5 m

Scour checks can also be placed across pavements to prevent loose materials being carried away. (Figure 37)

Figure 37. Horizontal scour checks

Figure 38. Cross road

scour checks

8.2 Slope Protection

If required, placing of topsoil and planting of vegetation on the slopes of embankments should take place in order to minimise erosion before indigenous vegetation can establish roots. Where grass or other vegetation is planted for protection of slopes, advice should be obtained from local residents or farmers.

Figure 39.Need for protection of slopes against erosion

8.3 Erosion of Culverts

Short culverts requiring high headwalls and wingwalls are prone to erosion around both inlets and outlets, especially along the wingwalls. Constructing culverts that are sufficiently long to reach the toe of the embankment will minimise necessary protection measures, future maintenance and the risk of damage to the embankment around the openings. It is necessary to carefully assess the additional cost of lengthening culverts against these benefits, especially in the case of rural roads that are often located in remote areas where regular maintenance is a challenge.

9 Bridges

Bridges and other forms of stream crossings are key elements in any road network and represent a major investment. Because of the cost and importance of road structures, main water crossings require careful selection of site, structure type and design. Design of large bridges is a specialist subject and is not included in this guide.

10 Return Period

The return period for a given flow of water is related to the estimated statistical risk of overtopping of drainage structures. The return period is a critical parameter in the design of rural roads because it controls the level of risk in relation to cost of construction and the type of structure that is appropriate. As a broad guide, the following return periods can be considered for rural roads:

Structure	Minimum ARI	Desired ARI
Major Bridges	50 years	100 years
Lesser Bridges	10 years	50 years
Culverts: 5 - 10 years	5 years	10 years
Low Level Drifts	2 years.	5 years.
Flumed Drifts	5 years	10 years
Lateral Drainage	5 years	10 years
Cut off Drains	2 years.	5 years.
Cross Drainage	2 years.	20 years.

Table 15. Return periods for structures

If a lower ARI is chosen the the ***Consequences*** of overtopping such as temporary road closure should be considered and clearly highlighted in the design.

11 Stream Crossings

11.1 Low-water crossings

Low-water crossing structures are generally designed to allow flooding during periods of high annual run-off. The design flow is something that should be evaluated in the design process. Low-water crossings come in two basic forms, as illustrated in Figure 33.

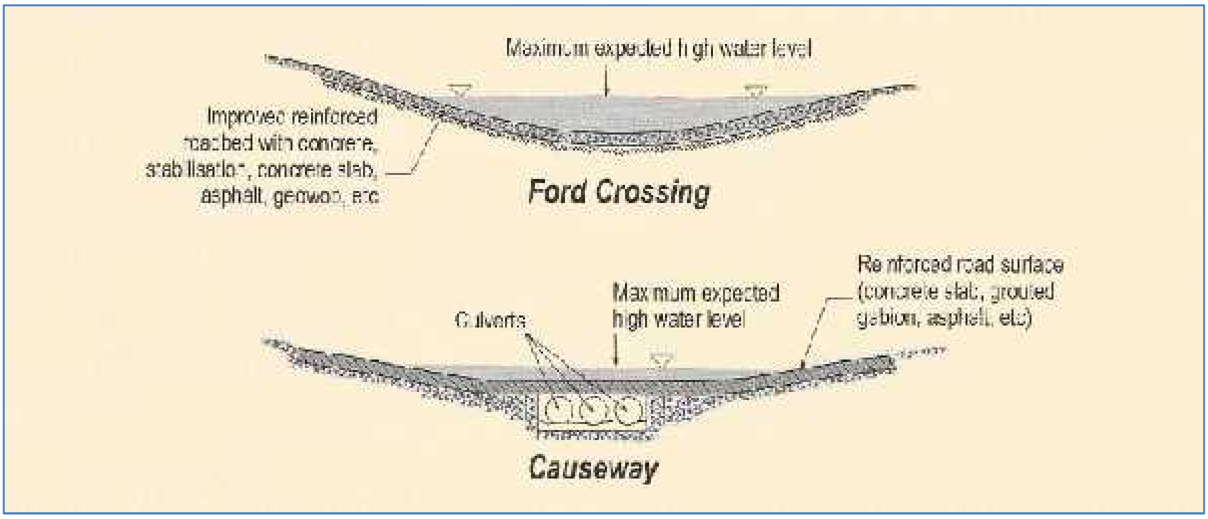


Figure 33. Types of Low Water Crossings

Selecting the best structure for a low-water crossing depends on a number of factors listed in Table 14 below.

Considerations	Most desirable	Least desirable
Access priority	Low	High
Alternative route available	Available (within a 2 hour trip)	Not available (or > 2 hour trip)
Traffic speed	Low	High
Average daily traffic	Low (< 100 vpd)	High (> 200 vpd)
Flow variability	High	Low
High flow duration	Short (< 24 hours)	Long (3 days)
High flow frequency	Seldom (rare closure < 10 times per year)	Often (frequent closure > 10 times per year)
Debris loading	High	Low
Channel entrenchment	Shallow	Deep

A low-water crossing can substantially reduce costs. Typical design standards that can be adopted for low-cost crossings are a 1 in 2 year flood allowing traffic to pass, with greater floods overtopping a low bridge structure.

11.2 Drifts

In Vanuatu a low-level structure designed to accept overtopping without damage is ideally suited for rural roads in locations where full all-weather passability is not necessary and delays are acceptable to the community. Various alternative names are sometimes used to describe these structures. Drifts are designed to provide a firm driving surface in the riverbed, where traffic can pass when water levels are moderate. Road safety must be considered and guideposts should be provided. Erect guide posts and flood indicators so that the edges of the causeway are defined and water depth can be determined.

Figure 35. Low Level Crossing with flow and drift with guideposts

Vented drifts, sometimes named fords, causeways or Irish bridges, (larger structures are called low level bridges) allow water to pass through openings, but can withstand overtopping without damage. Openings in vented drifts should, like culverts, be made large enough, preferably not less than 600mm diameter, although 900mm is preferable, so that cleaning during maintenance is made easier and the risk of blockage is minimised.

12 Safety in Low-water crossings

12.1 Safety Criteria

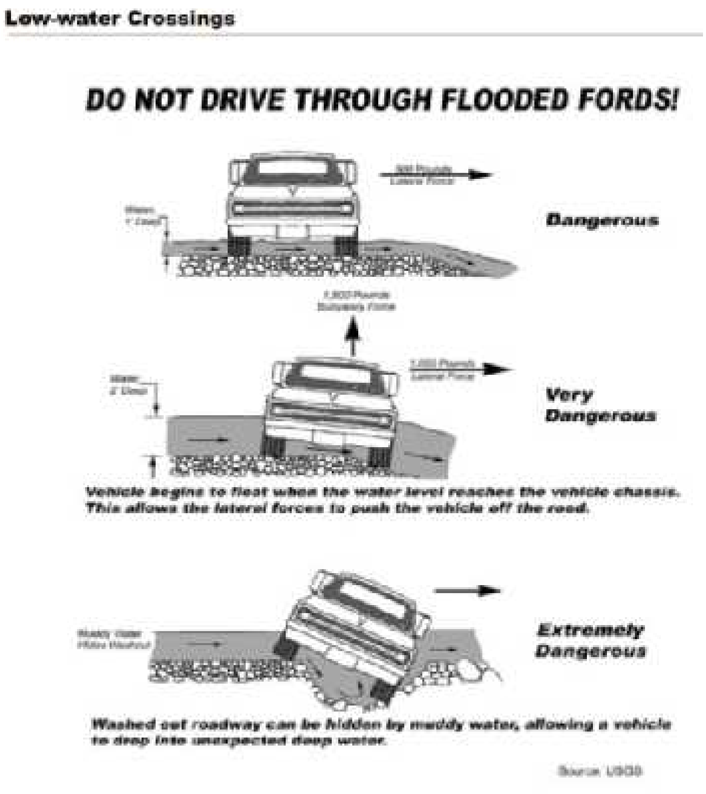
The use of drifts for flood management introduces the risk that pedestrians and vehicles could be swept away. Whilst the aim of climate resilience is to produce all-weather roads which remain open 24/365 this is unlikely to be attained at present. Indeed experience shows that even in highly developed economies this level is never actually reached. If it is accepted that the road may be blocked by flooding for a certain period then it must also be accepted that person will attempt to cross. Safety considerations should be taken into account and if necessary pedestrian footbridges should be provided.

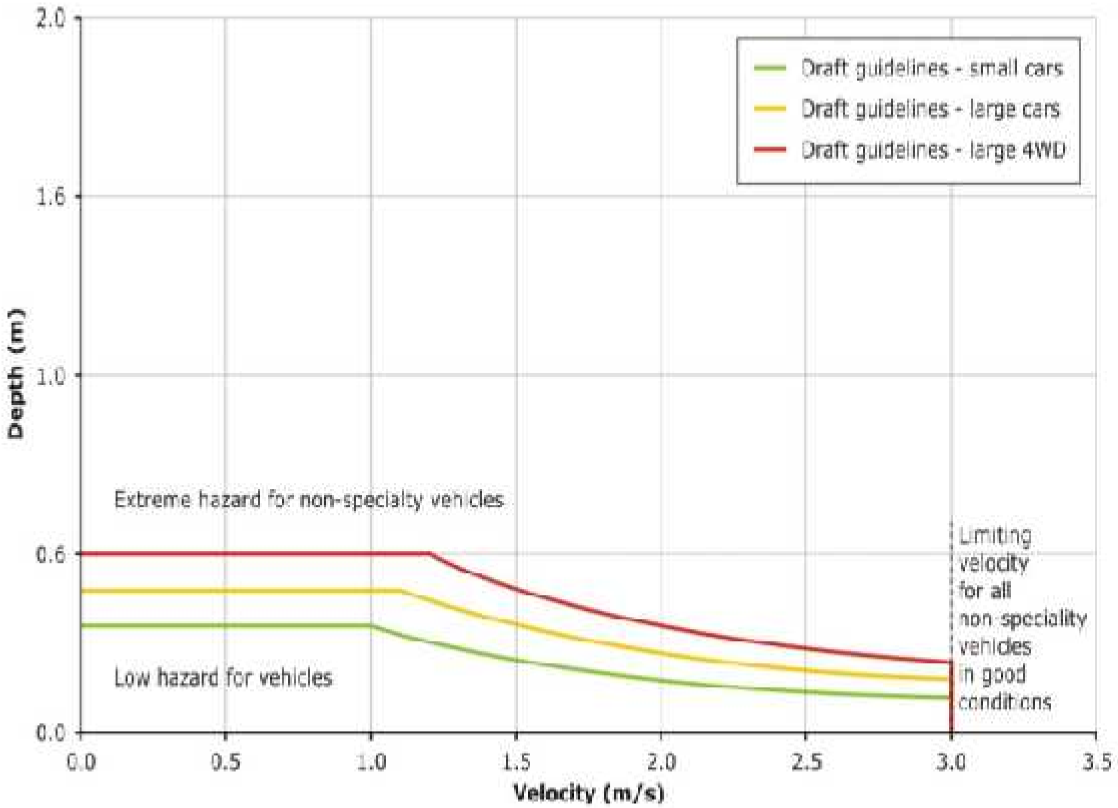
Safety is of primary concern and it is reported that 10 deaths per year occur in Vanuatu when people attempt to cross flooded crossings. Drivers may underestimate how fast small streams can rise in some parts of the country during a flood. Even 300 mm of water can float a car or truck causing it to lose control and 600mm can cause it to overturn (Figure 32).

12.2 Safety for Vehicles

The following table gives figures for safe water heights, velocities and the cross product in still and flowing waters. In still water modern vehicles, which are more water-tight and buoyant than older vehicles, are more prone to buoyancy and flotation. In fast moving waters the risk is higher and so the safe depth is lower. In extreme weather events the risks associated with attempting to cross flowing streams will increase.

The Automobile Association UK guidance says a flood of 0.3m could move a car and 0.6 m could float a car.





12.3 Pedestrian users

On many roads numbers of pedestrians is higher than the number of vehicles. This highlights the need to consider pedestrian requirements and road safety design for non motorised users. An increase in the shoulder width of the road addresses this situation in most instances.

A figure of 0.15 m is the safe limit for pedestrians. It is not realistic to expect pedestrians or drivers to estimate the flow velocity and depth and act accordingly. Some countries use painted marker posts. For example, if you can see the lower white part it is safe to cross but if you can only see the red upper part it is not safe. A public awareness campaign helps travellers understand the significance of the signage.On some drifts concrete blocks are used on the downstream side of drifts to prevent vehicles being washed downstream. If made to appropriate height they could be used for warning – if one can see them it is safe to cross – if one cannot, it dangerous.

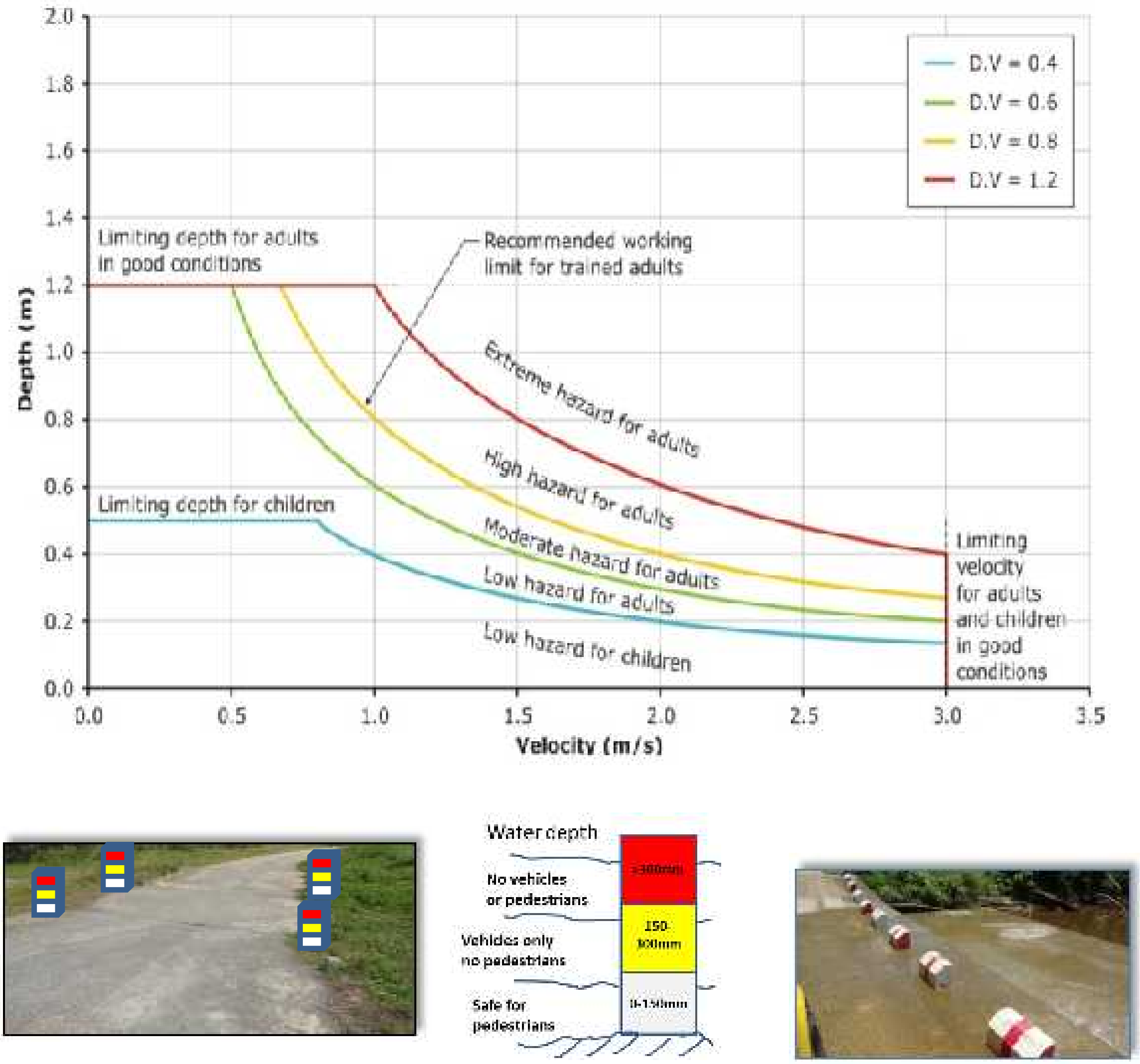


Figure 63 - Thresholds for Vehicle and People Stability in Floods

13 Slopes

13.1 Terrain and Slopes

The major effect on steep slopes is erosion, particularly due to heavy rain. Average annual rainfall in Vanuatu is around 2500 mm per year, with peaks of up to 4000 mm per year. Deterioration of slopes will affect security when slippery and/or cause the occurrence of deep ravelling. A simple classification of 'flat', 'rolling', "hilly" and "steep" terrain descriptions has been adopted as a basis for specifying appropriate geometric standards. The definition of each can be described in general terms as follows:

Terrain	Class	Description	Gradient	
Steep	S4	Roads in rugged with substantial restrictions to both horizontal and vertical alignments	> 1:7	> 15%

Hilly	S3	Roads can have substantial cuts and fills	1:10 to 1:7	10-15%
Rolling	S2	Roads can have substantial cuts and fills	1:20 to 1:10	5-10%
Flat	S1	Roads generally follow the ground contours	Up to 1: 0	< 5%

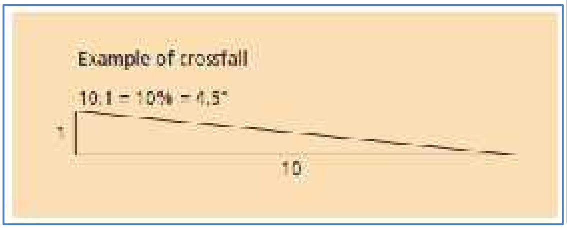
Table 4. Terrain / slope class

13.2 Measuring Slopes and Gradients

Gradient measurement can be expressed in various ways as listed below:

- By **ratio** (**slope** or **gradient**) such as 10:1 (10 refers to the horizontal H and 1 refers to vertical V distance m/m)
- By **percentage** such as 10% (vertical divided by horizontal distance and multiplied by 100%)
- By **degrees**.

It is important not to mix up units. For example, slopes can be stated as 10:1 = 10% = 4.5°

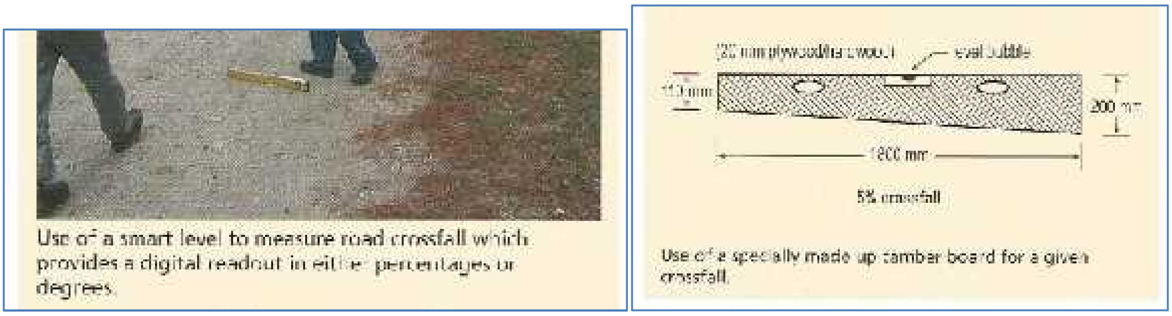


Ratio values m/m (H:V)*	Percentage values	Degrees values
100:3	3%	1.35°
100:4	4%	1.80°
100:5	5%	2.25°
100:6	6%	2.70°
100:7	7%	3.15°
100:8	8%	3.60°
100:9	9%	4.05°
100:10	10%	4.50°

Figure 56. Ways to specifying Crossfall

Crossfalls in the field can be measured in various ways. Some graders have levelling devices that provide the crossfall of the road. A 'smart level' can be used which provides a digital readout, in either percentage values or degrees, of the actual crossfall of the road being measured.

An alternative is to use a camber board which is cut to the required crossfall and has a spirit level on top to show when the desired crossfall is achieved (Figure 57).



Use of a smart level to measure road crossfall which provides a digital readout in either percentages or degrees.

Use of a specially made up camber board for a given crossfall.

Figure 57. Ways of Measuring Crossfall

Figure above shows use of a smart level to measure road crossfall which provides a digital readout in either percentages or degrees. Smartphones can be loaded with Apps to measure inclination. These can be placed on a straight edge on the road. Hand held inclinometers can be used to measure longitudinal road gradients, crossfall and stream gradient which occur at right angles to a stream flow.

13.3 Roads on steep gradient.

Check for :

- Steep inclines
- Soil and muddy surface
- Lack of drainage
- Not passable in wet weather
- Concrete strips

Mitigation :

- Use concrete across full width of road.
- Ensure longitudinal side drains.
- Direct the drainage flow to watercourse.
- Do not allow to discharge to non-draining area.
- Concrete strips save money but can lead to rutting.
- If strips used continue up full incline, do not stop halfway up.
- Continue concrete up full height of road.

Figure 54. Vulnerable steep muddy road, concrete strips and Climate Resilient road

14 Maintenance

14.1 Common drainage problems

- Blocking of drains by debris or vegetation
- Silt deposition in the bottom of drains and culverts, reducing the gradient
- Erosion of the bottom of side drains in erodible soils or on steep gradients
- Erosion at culvert outfalls, resulting from high discharge velocities
- Erosion of shoulders and side slopes.

Drainage should not interfere with the natural flow of water. Culverts on natural watercourses should follow the existing alignment. Sharp changes in direction should be avoided. Use frequent small culverts rather than occasional large ones. Maintenance must be regular. Minimum size for access for maintenance is 600mm diameter for a pipe drain or 600mm x 600mm for a box drain. Drift culverts should be sized at a minimmum of 600mm and preferably 900 mm for ease of maintenance.

The importance of maintenance cannot be overemphasized. Inadequate maintenance, or total absence of maintenance, will lead to blockages, particularly of small diameter pipes. This will lead to structural failure of the drainage system and eventually the road.

Figure 32. Cross drainage poorly maintained

<u>If necessary drainage systems in remote areas should be adopted which do not rely on regular maintenance, such as providing crossing drifts at grade and allowing stream water to flow over them.</u>

If road crosses a flowing stream create a flumed drift ONLY if confident maintenance will be adequate. Road crossings in remote areas cannot be expected to receive regular maintenance. If projected calculated flood indicates crossing will be hazardous, and road priority is HIGH provide a bridge. Single span bridge or double span with central pillar requires minimal maintenance. If maintenance is NOT adequate construct drift at grade and anticipate road closure. Provide alternate crossing such as footbridge and identify alternate route.

Roads can be constructed at grade with no culverts. If the drift is strengthened then at a later date a box culvert can be added with decking laid on top to form a bridge. A drift with no culverts has no maintenance requirements yet the opportunity to install a boxculvert based causeway at a late date has not been lost. This would be a **no regrets** decision.

15 Coastal Effects

Check for wave overtopping:

- Road located within 50 m of coastline - slightly vulnerable.
- Road within 20 m of coastline - moderately vulnerable.
- Road within 10 m of coastline - highly vulnerable.

Check for coastal erosion: visual evidence of beach retreat / sea advance

- Loss of trees.
- Tree stumps in sea.
- Interview local residents. Ask about situation 10, 20 years ago.

Figure 49. Evidence of Coastal Erosion

Although coastal erosion is not necessarily attributable to climate change its makes coast lines more vulnerable to sea level rise and wave overtopping.

Mitigation:

- Realign inshore. Do not make minor re-alignments for example 10 m. Make major move, 100 - 200m inland.
- Raise road height above level of inundation by at least 0.5 m.
- If road raised on embankment, incorporate pipe culverts for cross drainage to allow water drainage back to sea.
- Provide Beach protection. Place boulders, wire mesh gabions, or textile mesh gabions to form seawall on beach side of road. Provide concrete vertical seawall if funds allow.
- Select alignment to exploit natural protection such as mangroves
- Check local residents are not removing mangroves for other purposes
- Determine highest astronomical tide (HAT) from hydrographic charts, tide tables for nearest port or highest high tide recorded. Check with MGHD.
- Check for tide gauge on wharf
- for projections 50 years into future; assume SLR = 0.5m

- Set freeboard (height above sea level) at 0.5 m.
- Take HAT + SLR + 0.5 as height of upper surface of platform.

Figure 51. Wharf with low freeboard at high tide. Tide Gauge

Figure 50. Wave Run Up and Over topping

16 No Regrets Decisions.

All decisions made on the level of intervention must be based on the principle of no regrets. Whatever decision is made should allow for further modifications to be made in the future without excess cost or difficulty. The climate change design interventions should be reviewed every 5 to 10 years.[2]

17 Decision Tree Analysis

The steps described above are given in the Decision Trees below. These should be followed by PWD engineers and decision makers as a guide and checklist when designing new roads, or rehabilitating existing roads, to be climate resilient.

[2] Wharfs: Increasing sea levels are causing engineers to rethink the design parameters required to design wharf and port structures. However, to design a port that will work in 20 - 30 years time means that it will not work now. In Vanuatu, on an ADB ports project, the solution was to reinforce the pilings which supported the wharf so that as the sea level rose the height of the platform could be raised using additional concrete. The added weight of the concrete could be supported by the existing pilings. "Infrastructure and Climate Change in the Pacific", GHD Report for Ausaid, 2012.

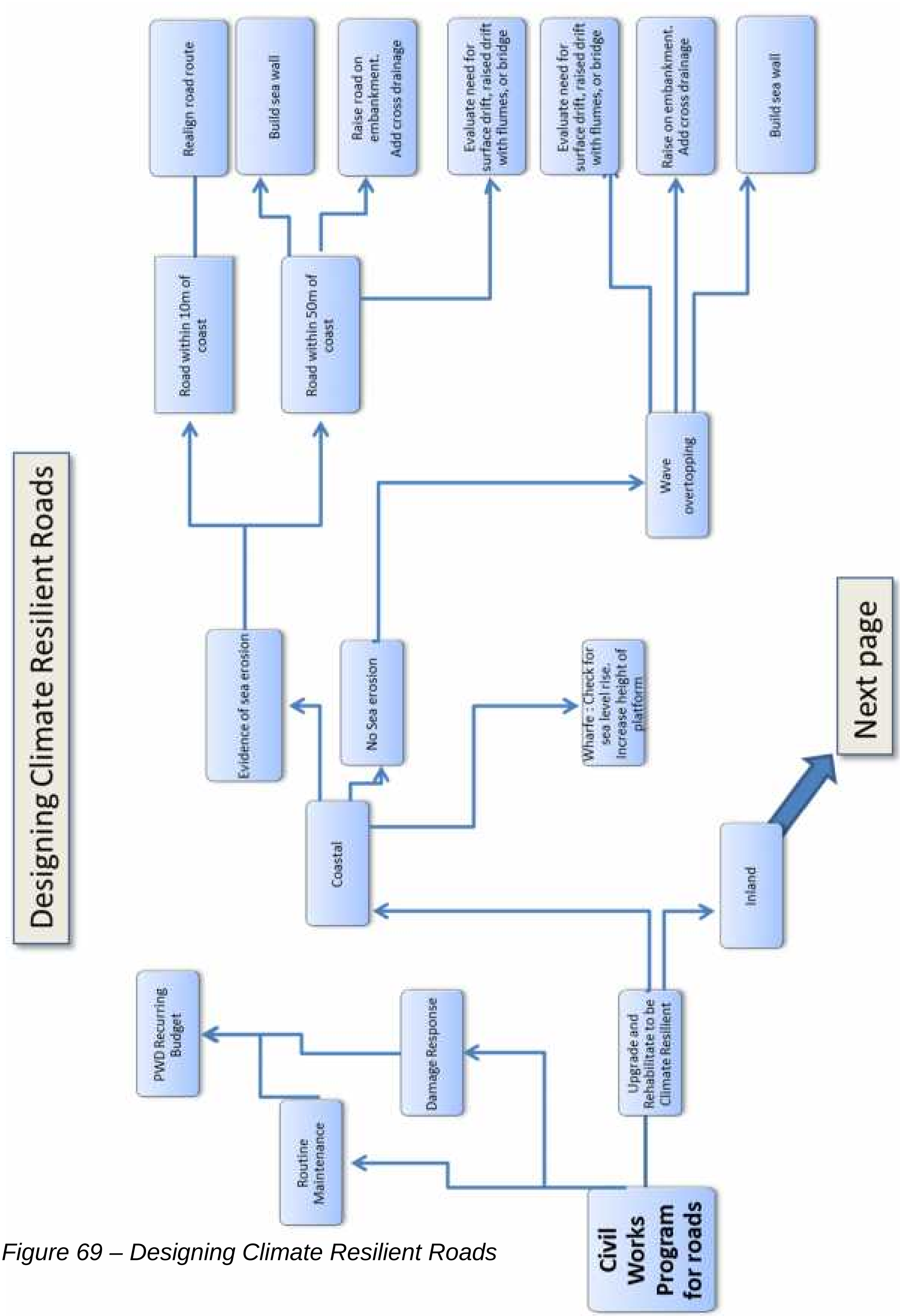


Figure 69 – Designing Climate Resilient Roads

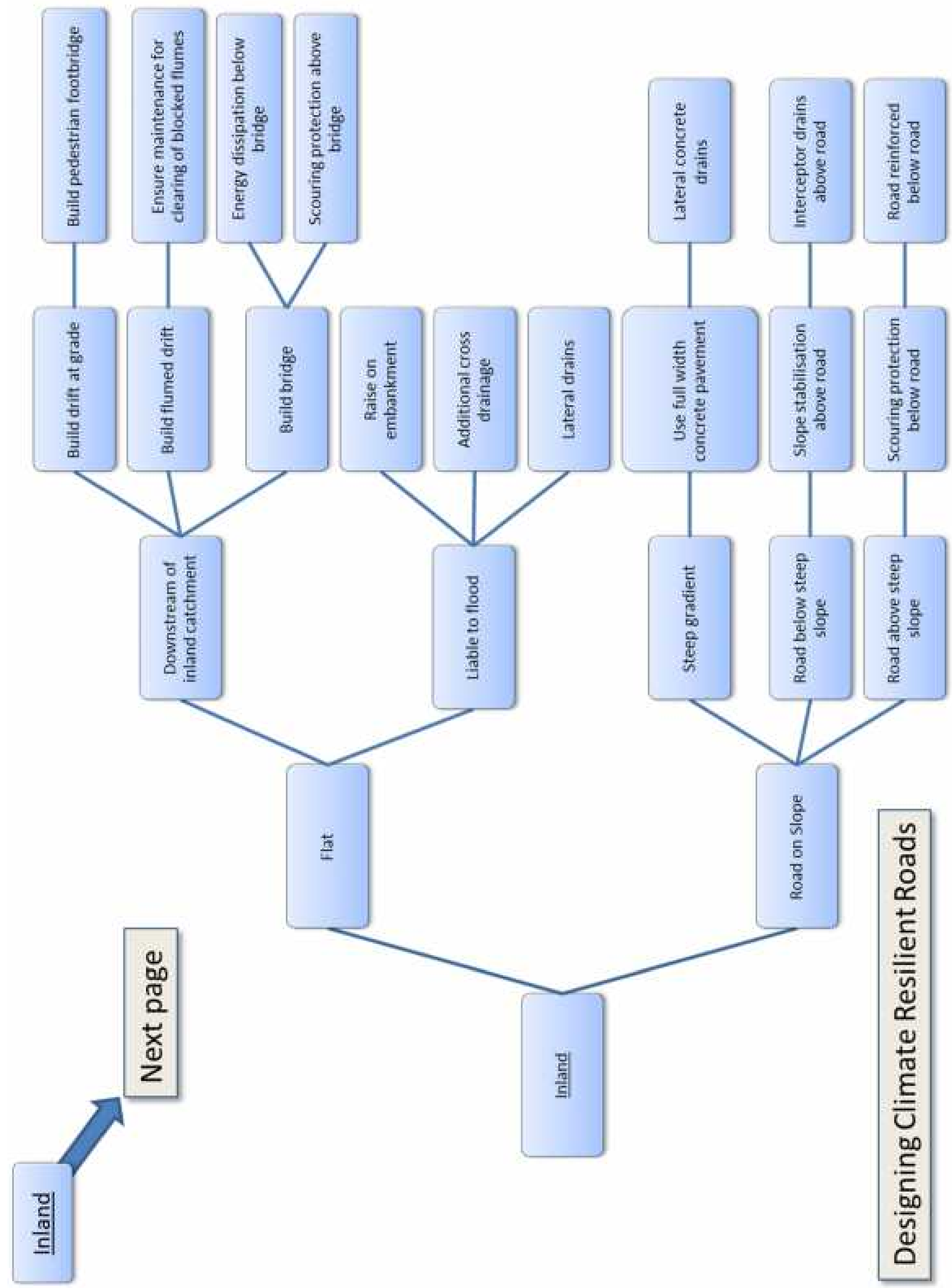


Figure 70 – Designing Climate Resilient Roads (Continued)

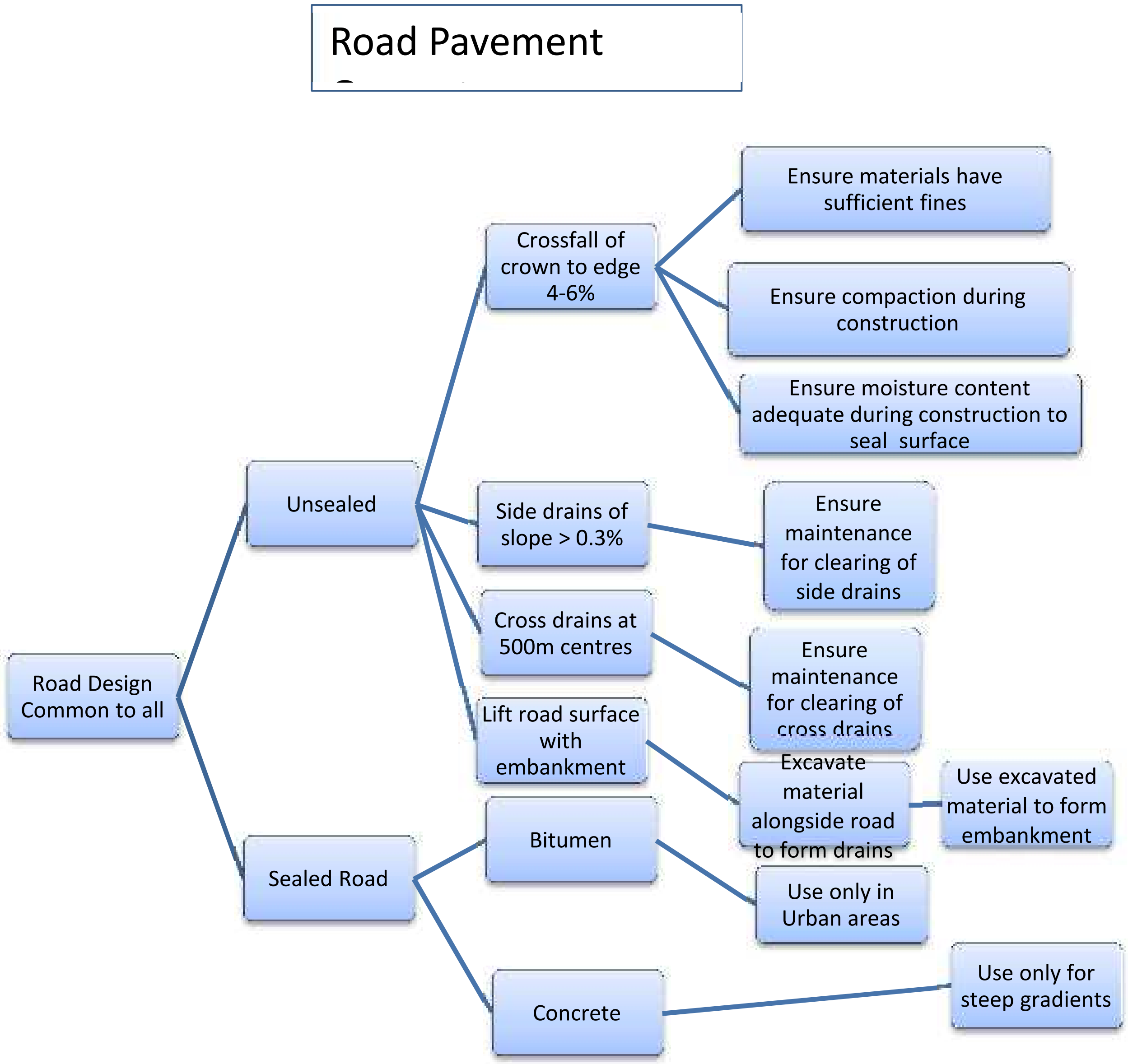


Figure 71 – Geometry of Climate Resilient Roads

Annexes

18 Annex 1 Standards Drawings

PWD Standard Drawings are available in soft copy in PWD HQ Port Vila. They are also in the Vanuatu Resilient Roads Manual (Full Version)

19 Annex 2 Technical Specifications for Road Construction

Technical Specifications for Road Construction are available in soft copy in PWD HQ Port Vila. They are also in the Vanuatu Resilient Roads Manual (Full Version)

20 Annex 3 Standards Proposed For Road Design

20.1 Geometry

a) Cross section	UNPAVED				PAVED		
Road Function	**Arterial**				**Arterial**		
			Feeder				**Feeder**
Road Class	**T4**	**T3**	**T2**	**T1**	**T4**	**T3**	**T2**
Average Annual Daily Traffic (AADT)	> 500	200 - 500	50 - 200	< 50	> 500	500 - 200	200 - 50
Number of lane	2	2	2	1	2	2	2
Min. traffic lane width (m)	3 m	2.5 m	2.5 m	3 m	3 m	3 m	3 m
Min shoulders width (m) [1]	0.5 m	0.5 m	0.5 m	0.5 m [2]	1 m	1 m	1 m
Min carriageway width (lanes + shoulders)	7 m	6 m	6 m	4 m	9 m	9 m	8 m
Target speed (km/h) (Flat - Rolling terrain)	60 – 40	40 – 20	40 - 20	30 - 10	60 – 40	40 - 20	40 - 20
Desirable maximum grade [3]	12 %				12 %		

[1] Increase shoulder width of 0,5 m if there are more than 100 pedestrians per day (on arterial roads), especially if it is in the vicinity (500-1000 m) of a school, hospital, town, church, airport, etc.

[2] If natural gravel is suitable and passing lane (3 m wide) is provided min every 300m or when condition facilitate, shoulder may not be necessary.

[3] It is suggested to keep the minimum following slope: 12% for a maximum distance of 600 m; 15% for a maximum distance of 200 m and 18% for a maximum segment of 50 m

b) Camber (cross fall) after compaction

- Minimum 5% for Coronous wearing course (could be increase to 8% when issues are found or expected like steep slopes)
- 3% (flat camber) for free draining cohesion less volcanic scoria and scoria.

- Minimum 3 % for bituminous / concrete surfaced roads and

c) **Horizontal / vertical alignment (desirable)**	**T4**	**T3**	**T2**	**T1**
Minimum radius curve	100 m	60 m	60 m	10 m
Maximum superelevation	8 %			
Minimum stopping sight distance (m) for 2 lanes roads	85 (60 km/h)	65 m (50 km/h)	50 m (40 km/h)	35 (30 km/h)
Minimum meeting sight distance (m) for 1 lane roads	Not applicable	130 (50 km/h)	100 (40 km/h)	70 (30 km/h)

NOTE: Guide need to be validated with every provincial engineer

20.2 Pavement

a) Unsealed / sealed	**T4**	**T3**	**T2**	**T1**
Total pavement thickness (mm)[1.]	250	200	150	100 [2]

[1] If CBR ≤ 5%, improvement of subgrade needed.

[2] For Feeder roads Traffic level 1 (F-T1), pavement material may not be provided if not necessary

b) Rigid pavement		**T4**	**T3**	**T2**	**T1**
Min. subbase for rigid pavement		150 mm			Not applicable
Mountainous	> 15 %				
Hilly	10 – 15 %				
Rolling	5 – 10 %			Not needed	
Flat	< 5 %				

Rigid pavement is to ensure accessibility and increase security. It is suggested on arterial roads only.

Strongly recommended to build rigid pavement. Width of 4 m (150 mm thick) (25 MPa reinforced concrete)

Tracks could be suitable in given case: 2 x 0.75 m with or without grouted stone

c) Material properties

Grading

Sieve	Envelope
53	100
37,5	90-100
19	70-100
2,36	35-65
0,425	15-50
0,075	10-30

Note on grading specification
This envelope is assuming that some of the largest particle (37,4-53mm) will break down during compaction. It is also assuming that the spread-water-compact operation is performed adequately. Some quarries may also have harder particles, which wouldn't break down. This could make the wearing surface to become fairly rough after few months of heavy traffic and rain. In that case, it is advised to revise the grading specifications in order to reduce (or eliminate) the coarser content (37,5-53mm), at least for the wearing course. A smaller nominal size would ease spreading and compaction and smoother ride.

Other characteristics that can be relevant to verify are PI, LS and CBR but not yet to become requirements.

Characteristics	Specification	
Grading Coefficient	16 – 34	(%passing 26.5 mm - %passing 2 mm) x %passing 4.75 mm / 100
Grading Modulus	1.5 – 2.5	(200 – (%passing 2 mm + %passing 0.425 + %passing 0.075)) / 100
Fine to sand ratio	0.25 – 0.24	5 passing 0.075 / % passing 2.36
Plasticity Index (PI)	Max 15	If CBR in unknown or < 8 %
Plasticity product	300 - 400	PI x % passing 0.425 mm
Shrinkage Product (Sp)	100 - 365[1]	LS x % passing 0.425 mm
Soaked CBR	Min 30%	

[1] 240 Preferable

20.3 Drainage and Structures Design

Design return period	
Peak discharge for Culverts	1:5 years
Peak discharge for Low Level Structure	1:2 years
Peak discharge for High Level Structure	1:50 years
Pipes and culverts	
Minimum gradient	2 %
Minimum diameter	750 mm
Minimum cover (reinforced concrete)	2/3 of pipe diameter
Minimum cover (galvanized iron ARMCO)	1/2 of pipe diameter
Maximum desirable velocities in un-lined channels	0,5 m\s

No vegetation, sandy material Bunch grasses, exposed soil Well established grass Beyond 1.8 m/s line drains and / or scour checks are recommended.	1,2 m\s 1,8 m\s
Table drains [1] Trapezoidal drains V-drains	 1 x 0.5 bottom x 0.5 x 0.4 m deep 1 x 1 x 0.4 m deep
Spacing of scour checks Gradient of side drain < 4 % 4 – 6 % 6 – 10 % > 10 %	 30 m (only if eroded) 20 m 10 m 5 m
Spacing of mitre drains and relief culverts Gradient of side drain < 1 % 1 - 4 % 5 – 6 % 7 – 8 % 9 – 10 % > 10 %	 50 m (avoid sedimentation) 200 m (avoid erosion) 160 m (avoid erosion) 120 m (avoid erosion) 80 m (avoid erosion) 40 m (avoid erosion)
Maximum slope proposed on embankments and channels Soil with stone pitching or large earth channel Firm Clay, Coronous or small earth channel Sandy or silty soil, scoria, grassed channel	 1:1 1:1,5 1:3
Concrete drift Minimum thickness [2] Minimum width (when full width)	 200 mm 4 m

[1] A minimum crown height of 0.75 m above the invert level of the side drain is recommended.

[2] Considering the base is well compacted and built properly

20.4 Pavement thickness

Pavement thickness in Vanuatu based on traffic volume should have a thickness of 100 mm to 300 mm, with 100 mm being the minimum. Most pavement thickness in Vanautu is specified at 150 mm. If the subgrade CBR (when wet) is higher than 5 %, this thickness should be suitable for most traffic purposes. Even 100 mm should be fine if the subgrade CBR is higher than 15%. However, if the subgrade is weaker than 5%, thickness should be increased. It is therefore important to be able to evaluate the real subgrade CBR when weakness is suspected. Some examples are illustrated in Table 10 below.

ADT[1]	% HV[2]	Lanes	ECAs	CBR values			
				3	5	9	15
50	1	1	4×10^2	100	100	100	100
150	2	2	1×10^3	210	160	100	100
250	3	2	3×10^3	220	165	100	100
250	10	2	9×10^3	245	180	130	100
400	4	2	6×10^3	240	155	110	100
600	5	2	1×10^4	250	180	130	100
800	20	2	6×10^4	290	210	150	115

[1] Average daily traffic [2] Percentage Heavy Vehicles

Table 10. Estimated Pavement thickness required (mm)

21 Annex 4 Design Guide For Best Use Of Local Materials

Vanuatu is particularly unique in its archipelago is formed by 80 relatively small islands and therefore, not linked with a "main" road to each other. They are rather isolated from each other. This context makes the use of imported material and/or equipment very expensive.

Fortunately, there are satisfactory materials for construction purposes in abundance on most islands. Sometimes, the materials may not be "ideal" or "perfect" but it is affordable and acceptable for low volume roads.

Care and sensible actions can result in the properties of the local material suiting the purposes. As most islands are relatively small, it could be very costly to have heavy equipment available and to keep them in a working state on each isalnd. Therefore, compromise and adaptive actions are necessary.

Immediate actions and further actions are proposed to improve local materials. Those proposed actions were mainly based on the overall knowledge of the material type in general. As the knowledge of the specific properties of the local materials is known, the actions to improve the possibilities and requirements may be refined or revised.

Coronous is a good material for base and a wearing course as long as some care is taken in grading and compacting adequately. It can also be a good concrete aggregate but would require heavy processing (crushing, washing and sieving). Test results will be used to assess the potential of the material. Further, an economical study will be needed to evaluate the options and suitability for small-scale processing operation.

Scoria has a good bearing capacity but it is an "average" material for a pavement wearing course as it lacks plastic fines. However, it can be suitable as a base course if the road is sealed (bitumen, chip or concrete). It is hoped that stabilizing scoria with plastic fines to improve its stability, its compaction and its water resistance (less wear, less dust, less corrugate) will improve its use. The behaviour of scoria in concrete in unknown but if the gravel size has enough strength (which could be the case as VTSSP1 used on the Otta Seal trial), it is hoped for good results.

There is little improvement to suggest this for the other local materials. Care would be needed with sand and coral/gravel from beach/stream for concrete to use the correct size in sieving and ensure salt is removed by washing when used in reinforced concrete. Together, they have the ability to make very good concrete.

For more details refer to full VRR Manual

22 Annex 5 Summary of Material Suitability

22.1 Knowledge and Local Experience on the use of various material

Unconsolidated natural deposits where available, has been historically used on the islands for various purposes. Most of these natural material are designated as: Coronous (or raised reef), scoria (or cinder gravel), basalt cobble, beach coral, volcanogenic and coral sand. They were and/or can be used for

	Coronous	Scoria	Cobble	Beach coral	Sand
Embankment	Green	Green	Dark blue	Dark blue	Dark blue
Subgrade	Green	Green	Dark blue	Dark blue	Dark blue
Subcase	Green	Green	Dark blue	Dark blue	Dark blue
Base (if sealed)	Green	Green	Dark blue	Dark blue	Dark blue
Wearing course	Green	Yellow	Dark blue	Dark blue	Dark blue
Surfacing (Otta seal)	Yellow	Yellow	Orange	Orange	Dark blue
Surfacing (other)	Orange	Orange	Orange	Orange	Yellow
Concrete aggregates	Green	Yellow	Orange	Green	Green
Masonry	Orange	Yellow	Dark blue	Dark blue	Green
Gabion	Green	Yellow	Green	Dark blue	Dark blue
Stone pitching / grouted stone	Yellow	Yellow	Green	Dark blue	Green

Green	Successfully used in the past
Yellow	Good potential with some processing but need further study
Orange	Would need major process (crushing, etc) or extensive research
Dark blue	Not suitable

22.2 Use of Coronous

Coronous material or raised coral reef deposit is found on all islands having public roads except on Ambae and Ambrym. It can be described as a poorly consolidated rippable rock producing - moderately to well graded, irregular to angular carbonate GRAVEL with some to many cobbles of sandy plastic 'putty' CLAY or sandy SILT. The status of the knowledge on its use is mapped in the table below.

<table>
<tr><th></th><th></th><th>General comment on usage</th><th>Issues or precaution needed – Material selection</th><th>Issues or precaution needed – Construction</th><th>Proposed study</th></tr>
<tr><td>Embankment</td><td></td><td>Make suitable and stable fill.</td><td>Larger size of gravel not more than 2/3 of the thickness of the compacted layer.</td><td>Need to be shaped and compacted properly to refusal.[1]</td><td>No</td></tr>
<tr><td>Subgrade</td><td></td><td>Make a good and stable subgrade.</td><td>Not applicable</td><td>Need to be shaped and compacted properly to refusal.[2]</td><td>No</td></tr>
<tr><td>Sub base</td><td></td><td>Make a good and stable sub base (as long as the subgrade is stable).</td><td rowspan="3">Material with high fine content may not be stable and have low CBR. Need less than 30% fines. If too plastic, stability may decrease. Need to remove gravel larger than 53 mm and keep not more than 10% larger than 37,5 mm. May be improved by processing in the quarry.
Almost all deposits suitable for “as dug” or screened sub base material.</td><td rowspan="3">Good construction procedure is a MUST. Cross fall of 5% to drain water, spread, shape and compact properly to refusal [2].</td><td>No</td></tr>
<tr><td>Base [1]</td><td></td><td>Can make a good and stable base</td><td>No</td></tr>
<tr><td>Base/ Wearing</td><td></td><td>Can make a good base/wearing course for low volume roads. Stable, “waterproof” and traffic resistant. Proper proportion of plastic fines will “bind” the material.
“As dug” and screened materials typically compact well to form a dense interlocking structure. Some breakdown of particles.</td><td>Need to monitor the performance and to relate it with the particle characteristics.
Search for option of processing in the quarry and the possible use of a small crusher</td></tr>
<tr><td>Surfacing (Otta seal)</td><td></td><td>Has been used successfully in Tonga.</td><td>Would need some processing.</td><td>Knowledge, experience and</td><td>Yes</td></tr>
</table>

			Screening and perhaps crushing.	equipment also needed	
Surfacing (other sealing)		Never been tried	Particles strength could be an issue		If need arise
Concrete / coarse aggregate		Currently used in batch plant in Port Vila. Also used in many islands to build houses	Need processing: screening and perhaps crushing for large volume. Need to care for fines that could stick on aggregates		Cost of processing options
Masonry		Not recommended. Need non plastic sand and fine gravel < 5mm..	Would need too much processing.		No
Gabion		Suitable but need processing	Important screening need to be done 100-200 mm needed	Some particles could be week and break down with interlocking	Cost of processing options
Stone Pitching or grouted stone		Suitable but need processing	Important screening need to be done 150-200 mm needed	Some piece could be week and break down	Cost of processing options

[1] Base course for seal roads

[2] Layers not exceeding 150 mm, respect OMC (± 2%), compact with heavy roller with 8 to 12 passes depending on the weight of the roller. Refusal is when an extra pass leaves no print.

22.3 Use of Scoria

Scoria or cinder gravel or volcanic cinder is found on few islands, but on Ambae and Ambrym it is the only "gravelly" material available. It can be described as a loose natural gravel – typically comprising variably graded silty sandy to very sandy angular to subangular vesicular GRAVEL with some to many cobbles (volcanic bombs) and with a lack of plastic fine.

The status of the knowledge on its use is mapped in the table below.

		General comment on usage	Issues or precaution needed – Material selection	Issues or precaution needed – Construction	Proposed study
Embankment		Make suitable and stable fill but slope should be reduce as	Size of gravel larger than 2/3 of the compacted layer has	Need to be shaped and compacted	No

	the cohesion is low	to be removed	properly	
Subgrade	Make a good and stable subgrade.	Not applicable	Need to be shaped and compacted properly	No
Sub base	Make a good and stable sub base (as long as the subgrade is stable).	The grading and particle strength properties of coarse deposits may be significantly improved by crushing. The more uniformly graded fine to medium gravel deposits are typically unsuitable for use in base construction but will represent useful sources of selected subgrade fill and sub base.	Good construction procedure is a MUST. Spread, shape and compact properly to refusal [2]. Mechanical stabilization with plastic fines can greatly help.	No
Base [1]	Can make a good and stable base in lightly trafficked roads			Monitor the performance and to relate it with the particle characteristics. Processing in the quarry and the possible use of a small crusher. Perform trial in adding plastic fines
Base/ Wearing	Gives a suitable support but corrugate and wears very quickly. Considering its poor "as dug" grading, relatively low particle strength and lack of plastic fines, these materials can rate poorly when used for base/wearing course and need higher maintenance.			
Surfacing (Otta seal)	Trial performed in Ambae in 2012. Results were promising. .	Would need some processing. Screening and perhaps crushing.	Knowledge, experience and equipment also needed	Continue trial in building on experience
Surfacing (other sealing)	Never been tried			Need to know the particles strength
Concrete / coarse aggregate	No known use on Vanuatu. Used overseas in light weight concrete	Would need processing (screening and perhaps crushing)		Cost of processing options
Masonry	No known use on Vanuatu			Need to investigate the grading of fine content
Gabion	No known use on Vanuatu. Where there is scoria,	Important screening need to be done (100-200 or 150-200)	Some piece could be week and crumble	Particles strength would need to be
Stone Pitching or				

grouted stone		there is basalt cobble which are preferred			investigate

[1] Base course for seal roads

[2] Layers not exceeding 150 mm, respect OMC (± 2%), compact with heavy roller with 8 to 12 passes depending on the weight of the roller. Refusal is when an extra pass leaves no print.

22.4 Use of Basalt cobbles

		General comment on usage	**Issues or precaution needed – Material selection**	**Issues or precaution needed – Construction**	**Proposed study**
Embankment		Not applicable			
Subgrade		Not applicable			
Sub base		Not applicable			
Base [1]		Not applicable			
Base/ Wearing		Not applicable			
Surfacing (Otta seal)		Not applicable			
Surfacing (Other sealing)		Never been tried	Would need crushing. Usually good strength. Crushed basalt is known to make elongated shape.		If need arise. Would need to crush and perform various testing
Concrete / coarse aggregate		Never been tried	Would need crushing. Usually good strength. Crushed basalt is known to make elongated shape.		If need arise. Would need investigate for crushing
Masonry		No known use on Vanuatu			Need to investigate the grading of fine content
Gabion		No known use on Vanuatu. Where there is scoria, there is basalt cobble which are preferred	Important screening need to be done (100-200 or 150-200)	Some piece could be week and crumble	Particles strength would need to be investigate
Stone Pitching or grouted stone					

[1] Base course for seal roads

22.5 Use of Beach Coral and gravel

		General comment on usage	Issues or precaution needed – Material selection	Issues or precaution needed – Construction	Proposed study
Embankment		Not applicable			
Subgrade		Not applicable			
Sub base		Not applicable			
Base [2]		Not applicable			
Base/ Wearing		Not applicable			
Surfacing (Otta seal)		May be possible, but never tried.			If need arise
Surfacing (other sealing)		Never been tried	Would need crushing. Could have a valuable strength.		If need arise. Would need to crush and perform various testing
Concrete / coarse aggregate		It is the primary source of concrete coarse aggregates on the islands. Make suitable results.	Need to be sieved and washed.		No
Masonry		Not applicable			
Gabion		Not applicable			
Stone Pitching or grouted stone					

[2] Base course for seal roads

22.6 Use of Sand (Beach and volcanogenic)

		General comment on usage	Issues or precaution needed – Material selection	Issues or precaution needed – Construction	Proposed study
Embankment		Not applicable			
Subgrade		Not applicable			

Sub base		Not applicable			
Base [2]		Not applicable			
Base/ Wearing		Not applicable			
Surfacing (Otta seal)		Not applicable			
Surfacing (other sealing)		Never been tried. Could maybe be use in sand seal.			If need arise.
Concrete / coarse aggregate		It is the primary source of concrete fine aggregate. Make suitable results.	Need to avoid fine sand. Need to be sieved and washed.		No
Masonry		Suitable for use in masonry	Need to avoid fine sand.		No
Gabion		Not applicable			
Stone Pitching or grouted stone		Suitable for use in mortar or grout	Need to avoid fine sand. Need to be sieved and washed.		No

[2] Base course for seal roads

23 Annex 6 -Better Control of Compaction

To be used whenever pavement material is to be imported, spread, water and compact (for all roadwork including IBC, NCB and force account)

23.1 Work Specification

(If applicable, ensure to include the following requirement in the existing Work Specification)

- Gravel and gravel source to be approved by the supervisor prior to spreading.
- Gravel must be free of particles larger than 50 mm (remove or crushed oversize)
- Spread uniformly at the required thickness (+10% before compaction) and ensure there is no segregation
- Evaluate the initial moisture content of the material and select the amount of water to add per square meter (m^2)
- Water the material to its Optimum Moisture Content (OMC) before compacting
- Compact with at least 8 passes of approved compactor equipment or until no roller imprint on the surface can be recognised.

23.2 Quality Control

Test / Check	Measure	Method	Frequency	Tolerance
Gravel source approved	Quarry Permit required	Check document	Each source	Na
Gravel material approved	Max. 50 mm	Visual (or sieve or tape)	Each day	± 5 mm
Spread uniformly, no segregation	Na	Visual	All	Na
Thickness of the layer	As required	Tape / gauge	Each 20 m or each spot	± 10 mm
Evaluate initial moisture content	Na	Hand test, hydrometer, speedy	Every 10 -15 m or at least 3 location	± 2 %
Add water to OMC [1]	Amount of water needed per m^2	Tape, volume of water	Each section	Na
Compact gently with NO vibration	Na	Visual	All	Na
Leave it for 2-3 h	2 - 3 h	Time	Each section	_
Ensure material at OMC	Target OMC 8-11 %	Hand test, hydrometer, speedy	Every 10 -15 m or at least 3 locations	± 2 %
Compact with roller vibrating	8-10 passes or to refusal [2]	Visual count, check imprints of roller	All	Na

[1] Check initial moisture and add amount needed to reach 12% if dry and sunny weather (10% if wet and cloudy weather)

[2] Compaction to refusal is when the compactor leaves no more imprint on the material.

Table 27. Quality Control checks

Water to add to the granular material to bring the moisture at its optimum for compaction (addition in litre of water per square meter – L / m^2)

Target Moisture: 12% (Dry and sunny weather)

Initial state	Increase in MC	Thickness of the layer to compact (mm)				
		50	75	100	125	150
Dry (± 2 %)	+ 10	10	15	20	25	30
Slightly Moist (± 5 %)	+ 7	7	10.5	14	17.5	21
Moist (± 8 %)	+ 4	4	6	8	10	12

Target Moisture : 10% (Wet and cloudy weather)

Initial state	Increase in MC	Thickness of the layer to compact (mm)				
		50	75	100	125	150
Dry (± 2 %)	+ 8	8	12	16	20	24
Slightly Moist (± 5 %)	+ 5	5	7.5	10	12.5	15
Moist (± 8 %)	+ 2	2	3	4	5	6

Table 28. Moisture Test Targets

24 Annex 7 - Possible Methods To Evaluate Moisture Content Of Materials On Site

It is very important to ensure that the material is close to its Optimum Moisture Content (OMC) when compacting on site. Therefore, simple methods are proposed below.

Method	Pros	Cons	Note
Sampling and lab test	Accurate	Takes too long. No facilities on outer island	
Moisture Roll Meter (Speedy)	Accuracy ± 1% ; fast on-site result (10 min) ; Fairly easy to use (1 h training)	Need to manage equipment and supply of reagent powder. Some cost.	1
Agricultural Moisture meter	Easy and fast. Direct reading	Accuracy and durability unknown. Cost unknown.	2
Hand squeeze test	Fast and no cost	Not accurate. Very subjective.	3

Table 29. Evaluate Moisture content

1. Four Moisture Roll Meters were bought during VTSP1. Reagent lost. Need to be supplied.
2. More research should be done regarding this method. Could be promising.

3. Experience and much "calibration" with known moisture content to ensure reasonable estimates. Also depend greatly on the fines content.

25 Appendix 8 - Better Control of Concrete Work Specification

To be used whenever for all roadwork including IBC, NCB and force account

(Ensure to include the following requirement in the existing Work Specification)

- Sand for concrete mixing shall be clean river/beach sand free from dust, salt, lumps, soft or flaky particles or organic
- Aggregates shall be well graded and free from organic material and salt
- Water shall be clean, free of oil, free of salt and shall not contain any impurity that may affect concrete durability
- The water / cement ratio shall not be more than 0.5
- Compact of vibrate concrete (care must be taken regarding segregation)
- Cast element shall be protected from direct sunshine for 14 days
- Concrete slabs and walls crowns shall be kept wet for 7 days
- No concrete shall be cast unless the formwork, reinforcement and hardcore bed have been checked and approved by the supervisor

Table 30. Requirement for concrete mix

Test / Check	Measure	Method	Frequency	Tolerance
Sand and Gravel/Coral source approved	Quarry Permits required	Check document	Each source	Na
Sand material approved	5 mm	Visual (or sieve)	Each day	Na
Gravel/Coral material approved	5 – 20 mm (unless instructed)	Visual (or sieve or tape)	Each day	+ 5 mm
Compliance with mix design[1]	Quantity	Visual	Each batch	Na
Water/cement ratio	Max 0.5	Check	Each batch	
Time of mixing	2 min	Watch	Each batch	
Time for pouring	45 min	Watch	Each batch	+10 min
Workability (if required)	Normally 80-100 mm	Slump cone	As required	-
No segregation	Na	Visual	All	Na
Time for wet curing	7 days	Visual	Daily	Na
Quality of cast concrete	No honey combs / No cracks	Visual	All	Na

Concrete strength evaluation	As specified, 15, 20 or 25MPa	Schmidt Hammer	When needed	

[1] Unless otherwise specified, Concrete Mix by volume should be as follow

- Class 10 MPa: 1:4:4
- Class 15 MPa: 1:3:6
- Class 20 MPa: 1:2:4
- Class 25 MPa: 1:1.5:2.5

26 Annex 9 - Quarry Material Process Options

Pavement material is actually the principal material extracted from quarries on outer islands. It has to be processed as the material should be free from particles bigger than 50 mm. This is addressed in options 1 and 2.

Concrete aggregates and cobbles come naturally from sources like beaches and streambeds. This type of extraction is not well accepted from an environmental point of view and therefore, opportunity to extract them from a Coronous/scoria quarry need to be evaluated. In addition, from an environmental point of view, some islands may not agree to remove beach/stream material.

Therefore, technical options are given below. However, all islands would need a small-scale operation, which can be itinerant between islands. An economical evaluation will be essential to complete the study.

Size definition

MM 0.005 0.075 4.75 76 300

CLAY	SILT	SAND	GRAVEL	COBBLE	BOULDER

Range of Material Size Needed

Pavement materials: Max. 50 mm

Concrete aggregates: min 5 / max 20 mm . 5-20

Cobbles for gabion / grouted stone : min 100 mm / max 200 mm . 100-200

Table 31. Size definition of material

Option	Process	Local work	Machinery	Issues
1	- Try to remove > 50 mm as much as possible with the excavator	Give work to 2 MD/100m3	Use of excavator or loader.	Unused material > 50 mm

	- Remove more > 50 mm with people when stockpiling - When reloading, remove bigger pieces - On site, have site workers remove big gravel before compacting	Removing big part on 50 m3 / d Pavement material only, Ø < 50 mm	Move only once	(waste)
2	- Try to remove > 50 mm as much as possible with the excavator - Pass material through a grizzly (wire screen used to separate larger from smaller) (50 mm) - Stockpile	No manual workers Pavement material only, Ø < 50 mm	Use of excavator or loader. Move twice	Unused material > 50 mm (waste)

3	- Try to remove > 50 mm as much as possible with the excavator - Pass material unto a double grizzly if possible (200 and 50) - Stockpile < 50 mm - Have workers manually crush gravel 50-100 to incorporate onto pavement material < 50 mm - Stockpile the rest 100-200 for gabion/grouted stone, etc.	Give work to 75 MD/100m3 Crushing 0,75 m3/d - Pavement material, Ø < 50 mm + - Cobble 100-200	Use of excavator or loader. Move twice for pavement/cobbles	Unused material > 200 mm (waste)
4	- Could sieve natural material to get the pavement material - The oversize material can be crushed manually of with crusher to make concrete aggregates.	- Pavement material < 50 mm +		
5	- Use of big sieve or grizzly	- Coarse concrete aggregates 5 -20 +		

Grizzly can be bought for a few thousands dollars or can be homemade. Small crusher on tracks can worth around 80,000$ (less if not on tracks)

Table 32. Process of gravel selection

Further technical and economical research needs to be done of various options available.

Figure 46. Pictures from a worksite. 1. Grizzly bar; 2. Sorting gravel; 3. Shifting gravel with an Excavator; 4. Gravel Sieve

27 Annex 10 Hydraulic Calculations by the Rational Method

The 'rational method' is a standard approach to estimating floods for drainage of small catchments.

The basic formula is : $Q = 0.278\ C\ I\ A$
Where Q is peak flow rate in m^3/sec
C = runoff coefficient
I = rainfall intensity in mm/hr
A = Area in km^2

0.278 = Conversion factor for flow in m^3/s, rainfall in mm/hours and area in km^2.

To use the method one must first derive basic data on the drainage area (or catchment).

- Catchment area (A in km^2) ,
- distance from the further point to the outlet (L in km)
- "Fall" between the highest point and the outlet (H in metres).

Calculate the slope (S in m/km) which is given as the fall, H, divided by distance, L.

The duration of the critical storm is then calculated by the Bransby Williams formula :

Duration = $L / (A^{0.1} \times S^{0.2})$ where duration is in hours.

If the duration is given in minutes the formula is Duration = $58.5 \times L / (A^{0.1} \times S^{0.2})$

Given the duration, the intensity can be calculated from the IDF curve.

The final element to be estimated is the runoff coefficient, C. The runoff coefficient can be calculated by the method of partial runoff coefficients. [3]

The four elements are:

- 0.30: Hilly with average slopes of 10 % to 30 %,
- 0.20 Negligible surface depression. Drainage paths with steep banks and small storage capacity. No ponds or marshes.
- 0.10: Normal , deep loam
- 0.05: Good to excellent; about 50 % of area in good grassland; woodland or equivalent cover

The methodology is applicable in small rural catchments.

[3] "California Department of Transportation, Highway Design Manual, 1995, pp. 810-816". And other older references.

28 Annex 11 - Methodology for calculating flood height across a drift

Where it is known that a drift will carry a flow the flood height can be calcuated. This requires use of the Manifold GIS files and the EXCEL Spreadsheet. Manifold will give the Catchment Area, and Fall across the catchment. EXCEL will give the flood height.

- Adopt a design standard now of 1 in 2 year event. This is a rainfall of 60mm /hour or 250mm per day.
- Assume rainfall is same all over Vanuatu.
- Calculate for a 1 in 10 year event now. This is a rainfall of 100 mm/hour or 400 mm / day.
- Check there is no apparent deforestation on the slope above the road surface. The model assumes heavy vegetation everywhere.
- The model is based on a simplified (by the consultants) version of the rational method. Heavy vegetation and steep slopes are assumed throughout Vanuatu.
- Identify the location of a stream crossing.
- Determine the GPS coordinates of the intersection of the stream and the road. Use latitude and longitude. Not UTM. If you use UTM draw attention to this.(as the "*page number*" must be stated.)
- Measure the length of the drift along the centre line of the road.
- Access the Manifold GIS "Map '*island-name'*" and enter GPS coordinates.
- Identify the catchment
- Measure the catchment length, fall and area.
- Enter these data into EXCEL spreadsheet.
- For selected return period calculate flows.
- Enter length of drift and set flows for differing return periods (2 years, 5, 10, 20, 50, 100) to obtain likely height of the Flood (H_F)
- Compare with standard
- H_F less than 150mm = non-hazardous for pedestrians.
- 150mm < H_F < 300 mm = hazardous for pedestrians - nonhazardous for vehicles.
- H_F > 300mm = hazardous for vehicles - all forms of crossing prohibited.

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

A screen shot of the EXCEL file is shown below. Varying the length of the drift will alter the flood height and this, combined with the selection of various Return Periods, will allow "What-if" Scenarios to be simulated.

Figure 59. Drift under flowing water

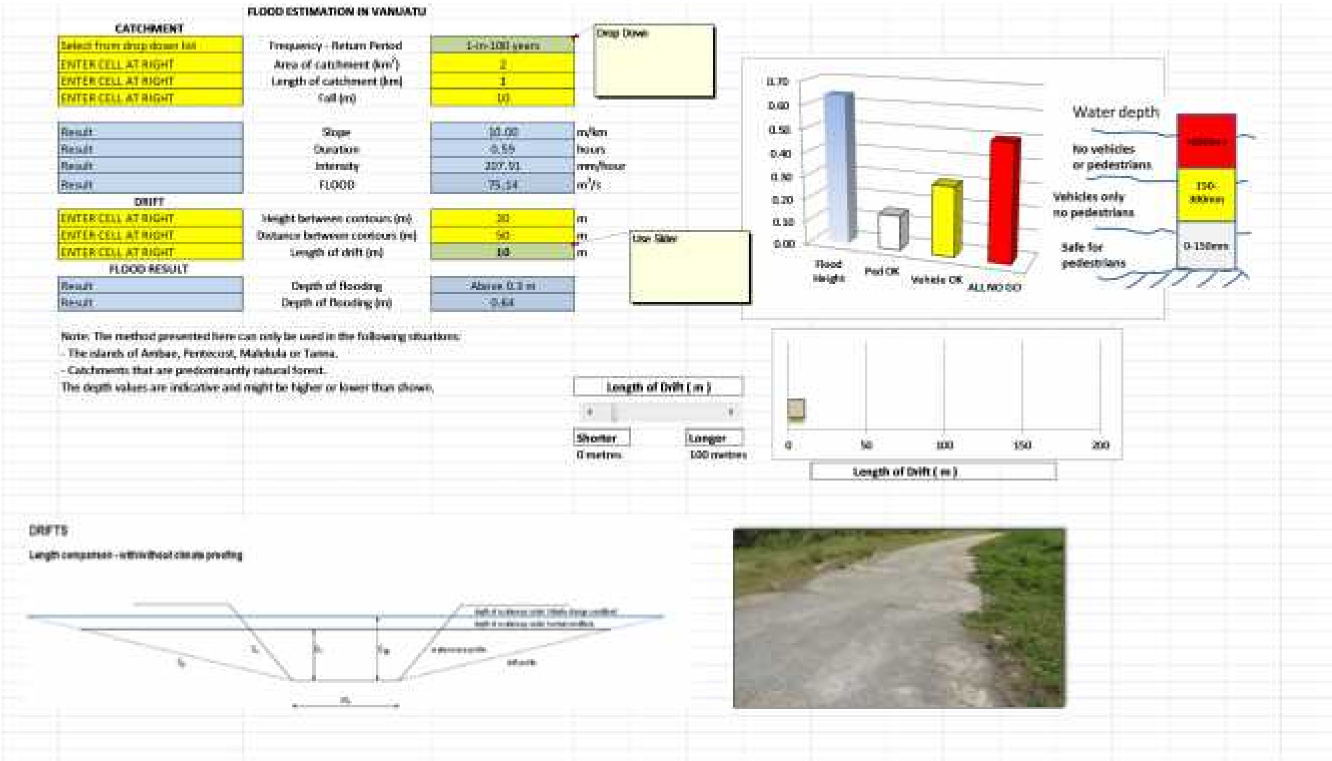
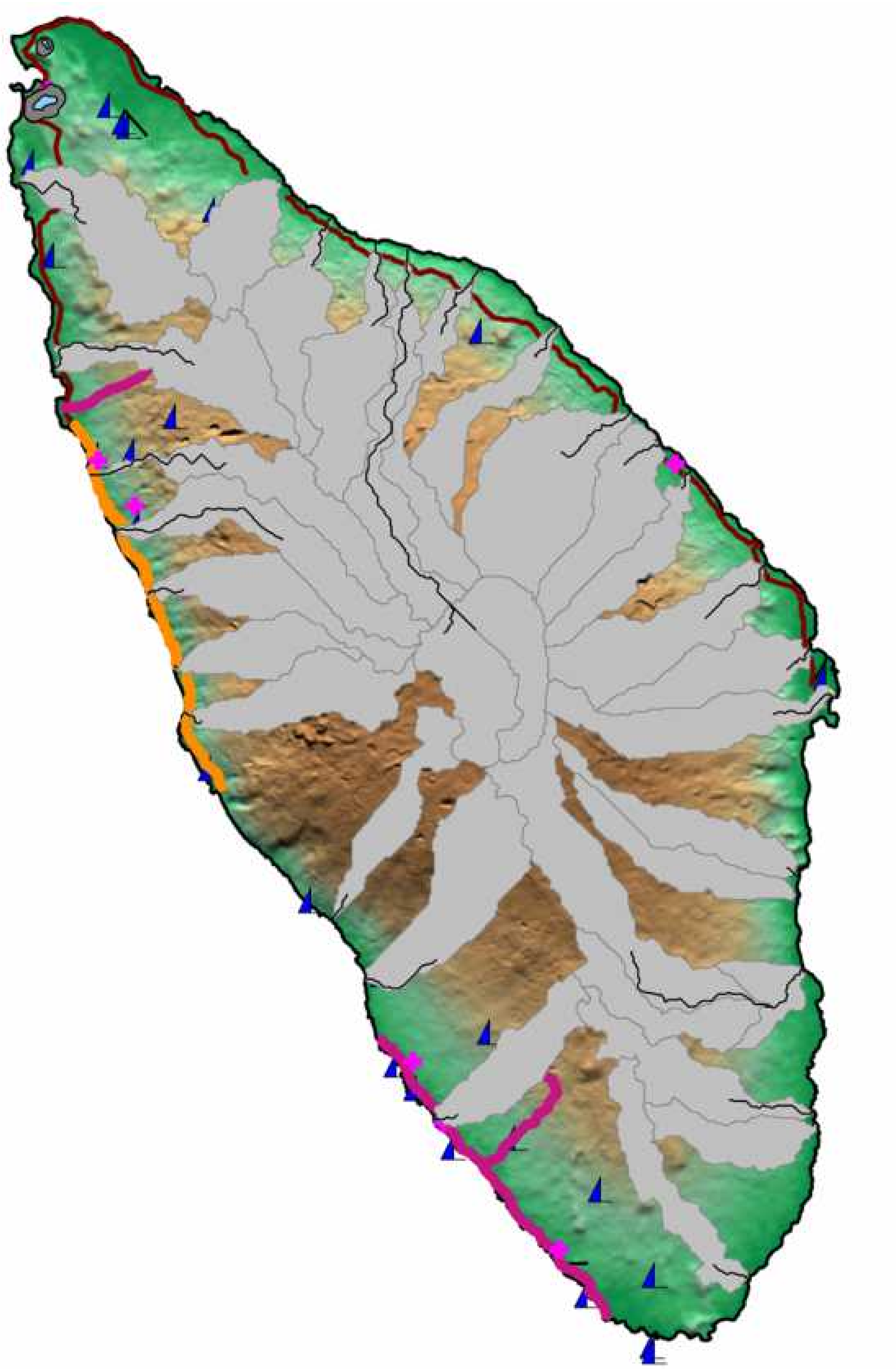


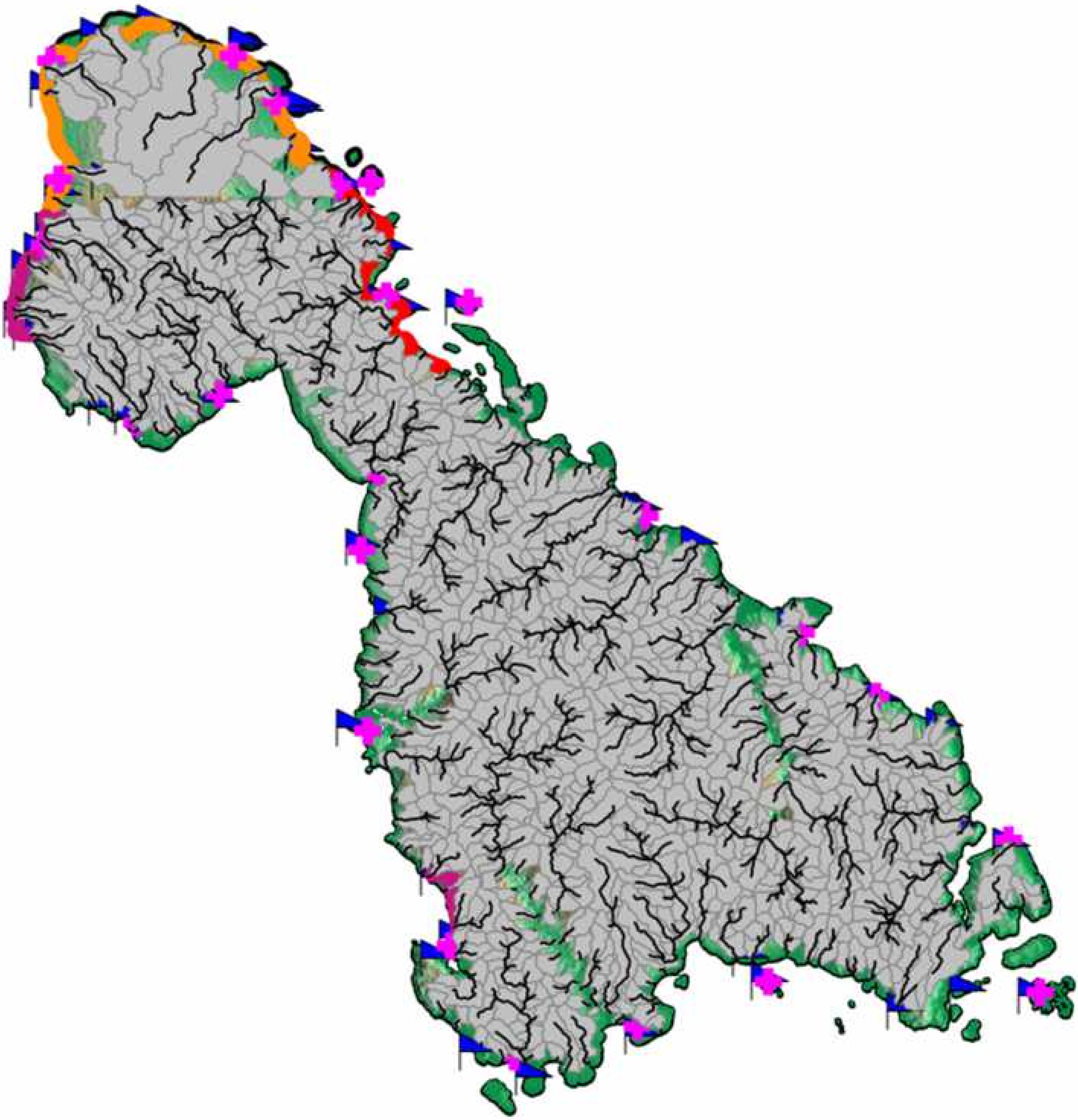
Figure 62. Screen shot of the EXCEL file

Having determined the flood height one can assess possibility of an extreme weather event rendering the crossing not passable. For this, one should refer to the safe crossing heights desribed below.   If the road is designated a priority road, but a vehicular bridge crossing cannot be justified, then then the provision of a pedestrian footbridge can be considered. This methodology will permit calculation of the needed height of a bridge crossing allowing a safety factor for extreme weather events.

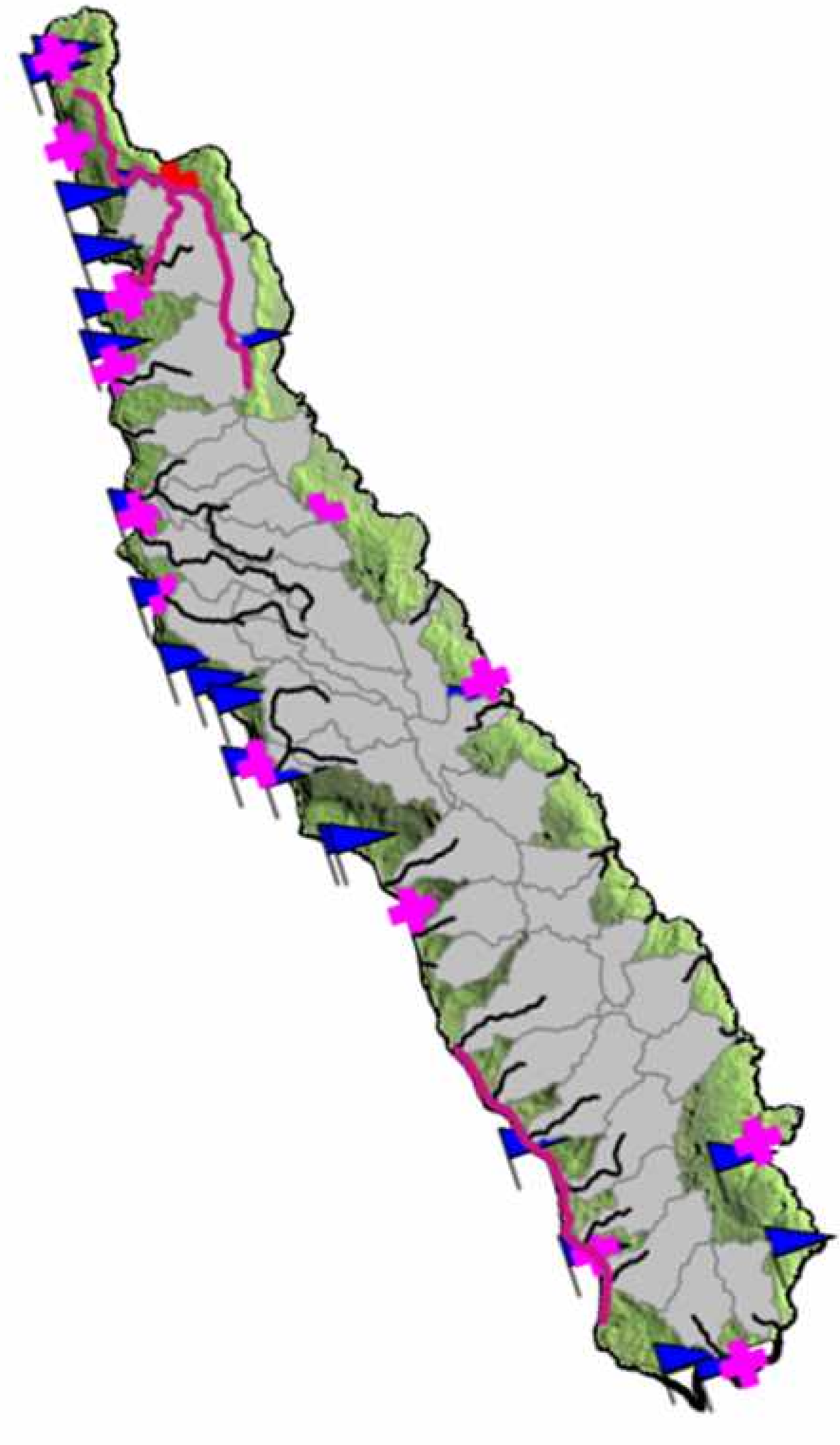
Vulnerability Maps - Black lines indicate major stream crossings



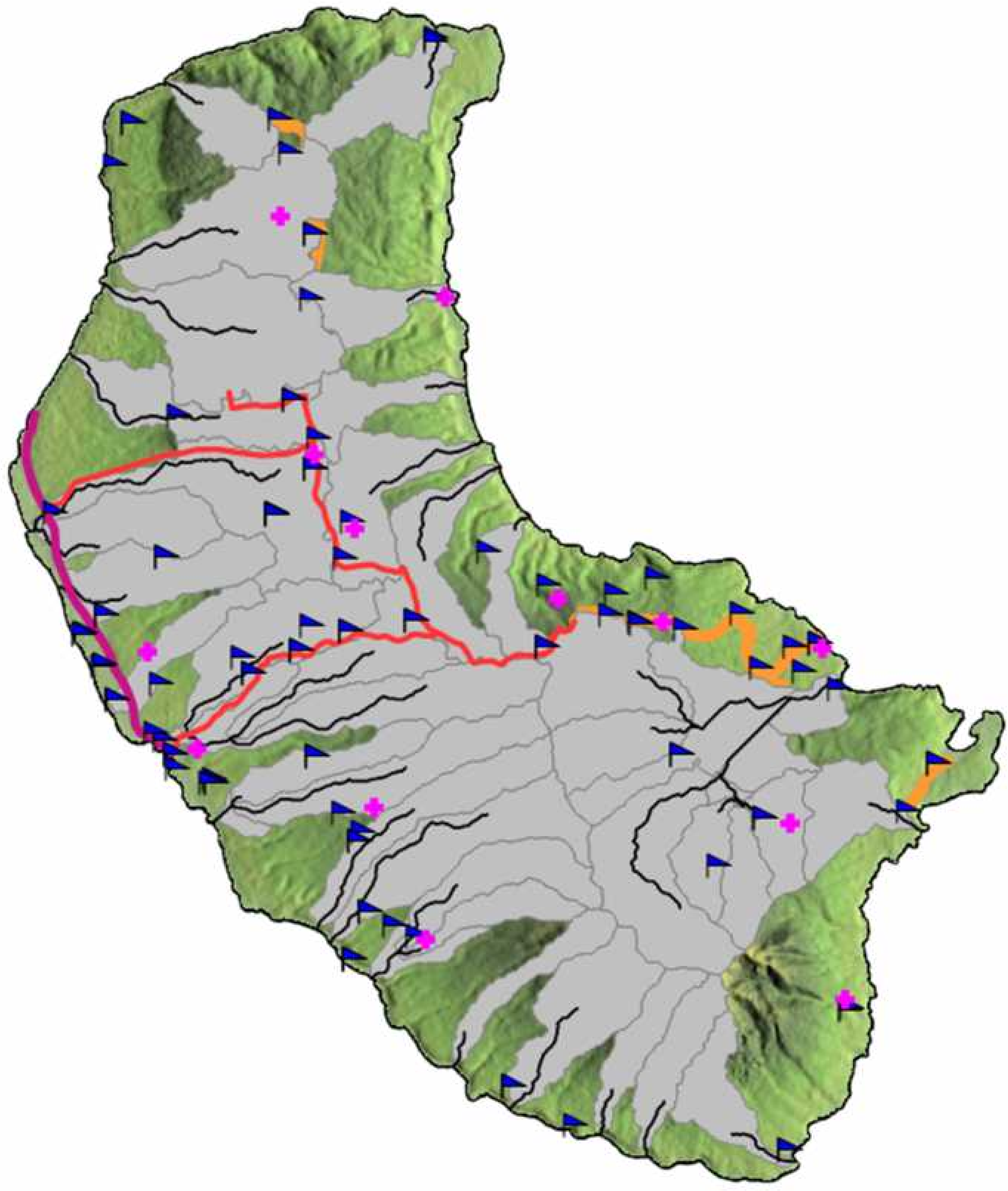
Ambae



Malekula



Pentecost



Tanna Island

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